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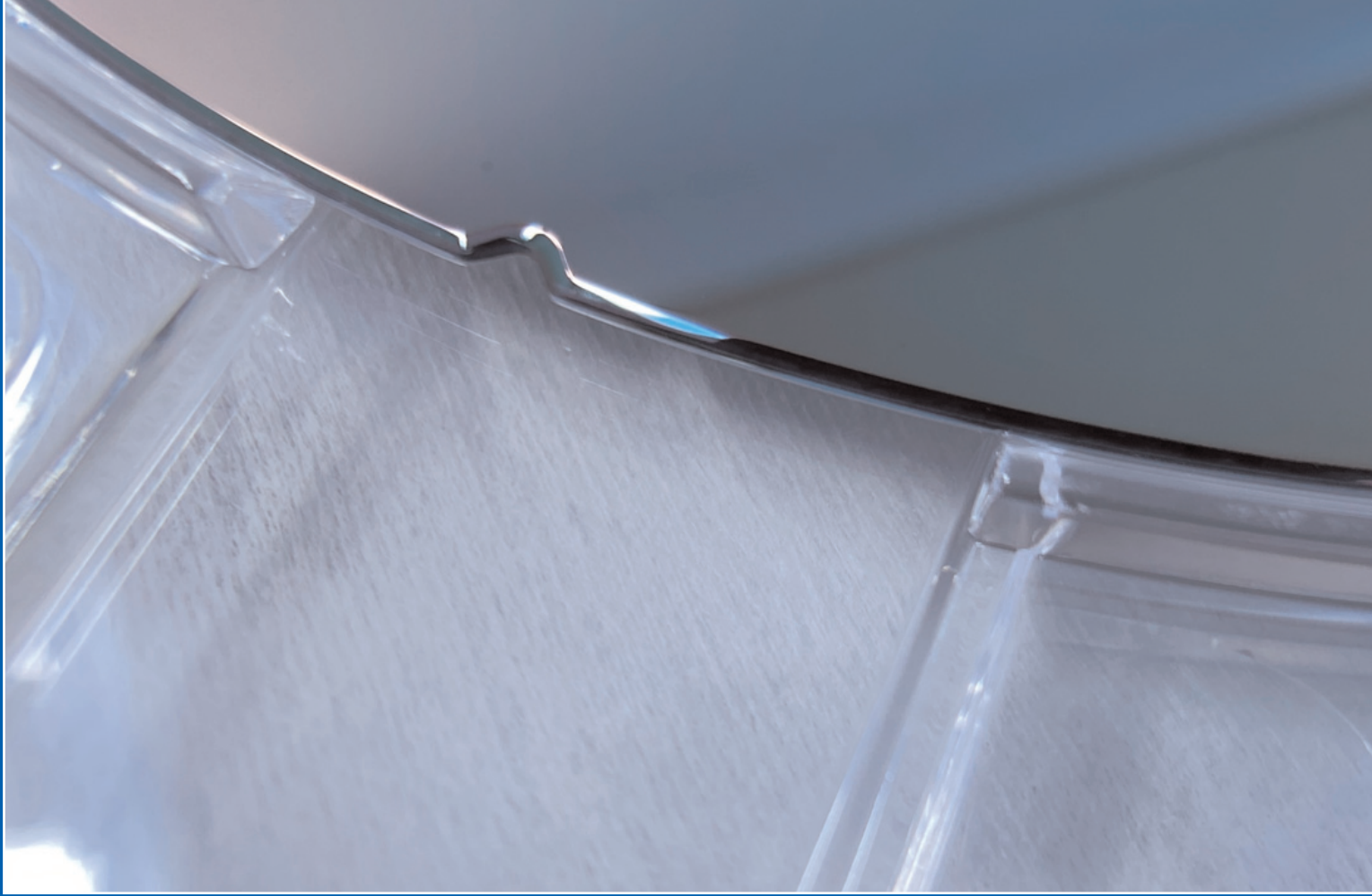
semiconductor **TODAY**

C O M P O U N D S & A D V A N C E D S I L I C O N

Vol. 15 • Issue 6 • July/August 2020

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GaN-on-silicon for RF & high-power electronics



II-VI buying Ascatron & INNOViON • SweGaN expands to larger HQ
ALLOS sells high-power electronics & RF business to AZUR



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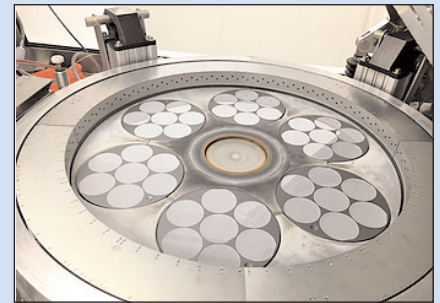
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contents

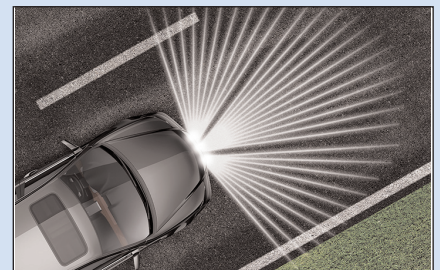
Editorial	4
Markets News	6
Compound semiconductor market to grow at 6.3% CAGR in 2025 • GaAs RF revenue to fall 3.8% in 2020 due to US-China trade war and COVID-19 • 5G handsets 18.9% of smartphone production in 2020	
Microelectronics News	12
Impact of COVID-19 on June-quarter revenues of Qorvo and Skyworks mitigated by 5G adoption	
Wide-bandgap electronics News	16
I-VI acquiring Ascatron and INNOViON • ROHM and LEADRIIVE open joint lab in Shanghai • OPPO adopts Navitas' GaNFast power ICs • SweGaN expands to larger headquarters • GaN-on-Si firm ALLOS sells high-power electronics and RF business to AZUR SPACE • Sino-American Silicon Products invests in AWSC	
Materials and processing equipment News	31
IVWorks & IntelliEPI partner on MBE-grown GaN epi • Aixtron's revenue rebounds by 37% in Q2 • BluGlass commissions largest RPCVD system • AMEC launches HiT3 MOCVD system for DUV LED mass production	
LED News	45
ALLOS and KAUST co-developing nitride-based red LEDs on silicon • BluGlass wins grant to develop large-scale plasma deposition source	
Optoelectronics News	52
EKOLAS project yields high-efficiency, high-performance laser bars	
Optical communications News	56
CompoundTek & STAR collaborating on silicon photonics wafer test	
Photovoltaics News	70
Fraunhofer ISE raises efficiency record for III-V/silicon tandem cell grown directly on silicon from 24.3% to 25.9%	
Technology focus: Deep-UV LEDs	74
Carrier-localization engineering for DUV LEDs	
Technology focus: Deep-UV LEDs	77
Effectively releasing tensile stress in AlN thick film for low-defect-density AlN/sapphire template	
Technology focus: LEDs	80
Phosphor-free white LEDs for efficient displays & communications	
Technology focus: GaN epitaxy	82
Baking and plasma-enhanced low-temperature GaN ALD	
Technology focus: GaN-on-Si transistors	84
Boosting mobility in InAlGaN-barrier heterostructure	
Technology focus: GaN-on-silicon	86
GaN complementary logic on silicon using normally-off transistors	
Technology focus: Nitride electronics	88
ALLOS transferring RF & power electronics patents & know-how to new GaN-on-Si entrant Azur Space	
Market focus: Smartphones	92
Smartphone shipments fall 15.7% year-on-year to 279.7 million in Q2	
Suppliers' Directory	94
Event Calendar and Advertisers' Index	100



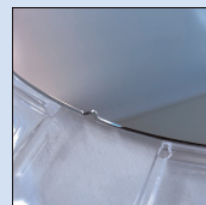
p40 EVG has completed construction of its new Cleanroom V building, nearly doubling cleanroom capacity at its HQ .



p41 BluGlass has commissioned its largest RPCVD system, accommodating 6 x 6" wafers or 42 x 2" wafers.



p52 ams' VCSEL technology is a core component of the ibeoNEXT solid-state LiDAR sensor system, to be on production vehicles at Great Wall Motor Company starting in 2022.



Cover: South Korea's IVWorks — which manufactures 100–200mm GaN epiwafers for RF & power electronics applications — and US-based epiwafer foundry IntelliEPI have announced a joint partnership on technology and business development for GaN epi materials based on MBE technology. **p31**

GaN-on-Si RF & high-power electronics

While the COVID-19 pandemic is still spreading widely — in a second wave in some regions, as social interaction and economic activity is opened back up — the counterpoint is that industrial production has revived after the initial widespread shutdowns.

Second-quarter 2020 revenue for wireless chip makers Skyworks and Qorvo was better than expected (see pages 12–15). Both firms attributed this to the initial launch of 5G, which is “really kicking off in China”, says Skyworks. Smartphone shipments were down by a record 16% year-on-year in Q2/2020 according to both IDC and Informa (see pages 10 and 52), but this is accelerating smartphone makers’ introductions of their 5G handsets. The penetration rate of 5G into the global smartphone market will reach 18.9% this year then 39.5% in 2021 and well over 50% in 2022, forecasts TrendForce (see page 11). Due to the higher frequencies, the addition of new band combinations and the adoption of dual transmit architectures to support 5G, the increased RF content of \$5–7 in each 5G handset mitigates the impact of fewer shipments, says Qorvo. “There is a big step-up in content in those 5G phones compared to the 4G phones,” adds Skyworks. “Our revenue with the Chinese players is up on a year-over-year basis.”

Likewise, in infrastructure, 5G is driving the adoption of gallium nitride for power amplifiers. “Our technology investments are aligned with long-term market drivers in 5G handsets and infrastructure, defense, Wi-Fi 6 and IoT,” notes Qorvo.

Correspondingly, Germany-based metal-organic chemical vapor deposition (MOCVD) system maker Aixtron has reported Q2/2020 revenue up 37% on Q1, with “the growing markets for gallium nitride (GaN) and silicon carbide (SiC) power electronics” being a major driver (see page 38). In particular, due to the demand for RF & power electronics as well as the economies of scale of using lower-cost, larger-diameter (up to 200mm) silicon substrates (compared with SiC), there is increasing interest in growing GaN-on-silicon.

For example, Germany-based silicon wafer maker Siltronic has ordered an additional Aixtron MOCVD system as it ramps production of GaN-on-Si epiwafers (page 36). Also ordering an AIX G5+ C system is Germany-based Azur Space, which is expanding from its core business – of making gallium arsenide (GaAs)-based multi-junction solar cells — into making GaN-on-Si RF & high-power electronics epiwafers (page 39). This ties in with Azur buying the RF & high-power electronics business & IP of Dresden-based ALLOS, as the latter focuses on micro-LED display applications of its GaN-on-Si technology (see page 30 and 88).

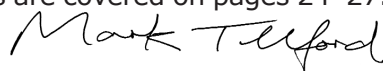
Likewise, US-based Veeco’s TurboDisc MOCVD platform has been selected by German research institute IHP Microelectronics for the development of high-performance, silicon-based microelectronic technologies (page 36).

Further, molecular beam epitaxy (MBE)-based GaAs and InP epiwafer foundry IntelliePI in the USA has partnered with South Korean GaN epi firm IVWorks to develop production of 200mm GaN-on-Si — see page 31.

In addition, Taiwanese GaAs IC foundry AWSC’s has gained investment from Hsinchu-based Sino-American Silicon Products, whose silicon wafer manufacturing subsidiary GlobalWafers in July established a joint research center with Taiwan’s National Chiao Tung University (covered on page 84) and will aid AWSC’s GaN process development (page 29).

The latest commercial GaN-on-Si product developments by the likes of EPC, Transphorm, GaN Systems and Navitas are covered on pages 24–27.

Mark Telford, Editor



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Semiconductor Today covers the R&D and manufacturing of compound semiconductor and advanced silicon materials and devices

(e.g. GaAs, InP and SiGe wafers, chips and modules for microelectronic and optoelectronic devices such as RFICs, lasers and LEDs in wireless and optical communications, etc).

Regular issues contain:

- news (funding, personnel, facilities, technology, applications and markets);
- feature articles (technology, markets, regional profiles);
- conference reports;
- event calendar and event previews;
- suppliers’ directory.

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Compound semiconductor market to grow at 6.3% CAGR from \$32bn to \$43.4bn in 2025

Gallium nitride to hold largest market share

The compound semiconductor market will rise at a compound annual growth rate (CAGR) of 6.3% from \$32bn in 2020 to \$43.4bn by 2025, according to the report 'Compound Semiconductor Market with COVID-19 Impact Analysis by Type (GaN, GaAs, SiC, InP), Product (LED, RF Devices, Power Electronics), Application (Telecommunication, General Lighting, Automotive, Power Supply), and Geography — Global Forecast to 2025' from MarketsandMarkets. The increasing use of compound semiconductors in LED applications has fueled the demand, notes the firm, while the growing demand and implementation of gallium nitride (GaN) and silicon carbide (SiC) in the semiconductor industry is expected to play a vital role.

The compound semiconductor market includes major tier-1 and tier-2 players like Nichia, Samsung Electronics, ams, Qorvo and Skyworks, which have manufacturing facilities spread across various countries throughout the Asia Pacific, Europe, North America and the rest of the world (RoW). Multiple facilities shut down due to the COVID-19 pandemic. The report expects that the semiconductor industry will decline significantly globally in 2020 due to COVID-19, and that this specifically translates into a snowballing effect on the compound semiconductor market. This could lead to lower research expenditure related to compound semiconductors, it notes.

GaN in LED and RF devices to hold largest market share

As it has been increasingly used in LEDs, power devices and radio-frequency (RF) devices, GaN is estimated to have the largest share of the compound semiconductor market by value. GaN LEDs are used in

general lighting, consumer devices, commercial and automotive applications. Due mostly to GaN's wide-bandgap properties (and its use to make white LEDs), LEDs comprise the largest share of the GaN market. Increasing demand for GaN LEDs in various applications (such as general lighting, signage and automobiles) is expected to drive the growth in the GaN market.

GaN is also finding importance in RF devices as they have the ability to combine high RF power output over broad bandwidths at high frequencies. As industry shifts towards the adoption of 5G networks for >6GHz frequencies, silicon will not be able to meet the various requirements of networks, as silicon devices operate well below 3GHz. At the higher frequencies used for 5G (such as 3.5GHz), GaN is more efficient than LDMOS/silicon devices. Hence GaN will gain traction for 5G applications, particularly for base-station power amplifiers, notes the report.

Telecoms the largest segment by application

Telecommunications is estimated to comprise the largest segment in the compound semiconductor market by application, with 5G providing a huge opportunity. Growth is driven mainly by increasing demand for RF devices.

Rapid advances in the telecom sector are being seen in both developed and emerging countries across the world. The technological shift from 3G to 4G/LTE and now 5G has increased network traf-

fic through mobile devices and resulted in increased network interference across the communication channels. As industry shifts towards adoption of 5G, RF content used per smartphones is expected to increase. To meet all the requirements for 4G and 5G (including saturated and linear efficiency), it is necessary to use a power amplifier manufactured with compound semiconductor technology, which is expected to drive market growth.

Asia-Pacific to emerge as largest region

By region, APAC is expected to be the largest market for compound semiconductors during the forecast period. The rapid market penetration of GaN and SiC in power devices (where they are increasingly replacing silicon counterparts) is predominant across several application segments in APAC. For power devices, the growing number of GaN and SiC power applications creates huge revenue potential in this region, it is reckoned. This is attracting several industry players to commercialize GaN and SiC power devices in mass production for several power applications which, in turn, are increasing the revenue potential of the compound semiconductor market in this region.

Major players in the compound semiconductor market are cited in the report as Nichia (Japan), Samsung Electronics (South Korea), ams (Austria), Qorvo (USA), Skyworks (USA), Cree (USA), GaN Systems (Canada), Infineon (Germany), Mitsubishi Electric (Japan), NXP (Netherlands), and ON Semiconductor (USA).

www.marketsandmarkets.com/Market-Reports/compound-semiconductor-market-178858112.html

The semiconductor industry will decline significantly globally in 2020 due to the COVID-19 pandemic

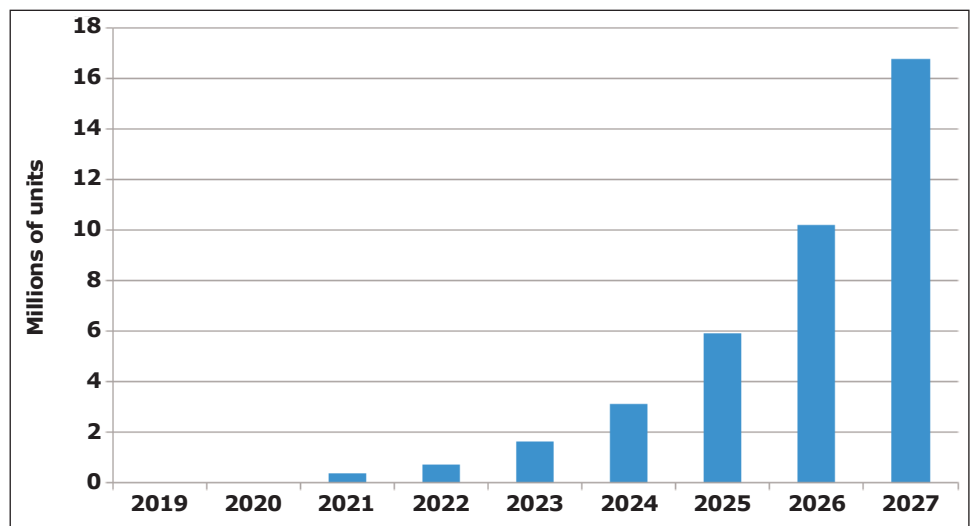
Global shipments of micro-LED displays to reach 16.7 million units in 2027

Smartwatches and TVs are driving growth

Driven by increasing demand for innovative, self-emissive displays, global shipments of micro light-emitting diode (μ LED) displays are expected to soar from negligible levels in 2020 to more than 16 million units by 2027. Growth is being led by demand from the smartwatch and television markets, according to the 'Micro-LED Display Technology and Market – 2020 report' from Omdia. It is expected that shipments of micro-LED displays to the smartwatch market will exceed 10 million units in 2027, while shipments to the TV industry grow to more than 3.3 million units.

"Because of their superior luminance efficiency compared to rival organic light-emitting diode (OLED) displays, micro-LED displays are expected to become the next self-emissive display technology," says associate director Jerry Kang. "Numerous startups, display manufacturers and consumer brands now are developing their own micro-LED displays, devices and process in various sizes, ranging from medium-to-large sizes to ultra-small dimensions," he adds.

Micro-LEDs represent an emerging flat-panel display technology that employs arrays of microscopic LEDs to comprise the individual pixel elements. Compared with conventional LCD displays, micro-LED displays can deliver superior contrast, faster response times and reduced energy consumption. As mentioned, micro-LEDs also



offer superior luminance efficiency compared with OLEDs. As a result, micro-LED technology is expected to emerge as a competitor to LCDs and OLED displays in applications ranging from wearable devices to televisions.

Several major technology players are taking steps to improve micro-LED technology and manufacturing.

Taiwanese firm AU Optronics recently introduced a prototype 9.4-inch flexible display using blue micro-LED pixels under red and green color-conversion filters on low-temperature polysilicon (LTPS) plastic substrate.

Plessey Semiconductors announced it will help Facebook to prototype and develop new technologies for potential usage in the augmented reality/virtual reality (AR/VR) space.

Samsung Electronics in 2018 introduced a prototype TV with a

chip-on-board (COB) processed RGB micro-LED display. The firm plans to launch the product in 2020.

Samsung Display has also started the development of quantum dot nanorod LED (QNED) technology, which applies nanotube LEDs onto an oxide TFT glass substrate. Furthermore, many consumer brands are expected to release their own micro-LED displays or devices in the near future.

"The micro-LED market is poised for much more rapid growth once the technologies for manufacturing micro-LED chips — including mass transfer — gain more maturity," Kang says. "The growing use of micro-LED display technology will push display makers to evolve away from current LCD and OLED display technologies."

<https://technology.informa.com/607848/microled-display-technology-market-report-2019>

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Mini/micro-LED market to reach US\$4.2bn in 2024

China mini/micro-LED project investment US\$5.59bn in 2019

By 2024, the global mini/micro-LED market will reach US\$4.2bn in revenue, forecasts TrendForce's latest 'LED Industry Demand and Supply Data Base'.

The positive outlook of the mini/micro-LED industry has attracted many investors. Since 2019, total investment in mini/micro-LED-related projects in China has reached RMB39.1bn (US\$5.59bn), with more than 14 newly added projects. This massive influx of capital is expected to accelerate the overall pace of mini/micro-LED commercialization.

Given the recent delays in mini-LED commercialization this year, some manufacturers are likely to push back their original plans of ramping up mass production of mini-LED TVs and monitors in mid-2020, notes analyst Allen Yu. On the other hand, since micro-LEDs

are still in the R&D stage for most manufacturers, the technology has a long way to go before it is ready for commercial use. Nevertheless, investors are still relatively hopeful about the future of mini/micro-LEDs. For instance, LED chip and packaging suppliers, such as San'an Optoelectronics, Epistar, HC Semitek, Nationstar and Refond, as well as video wall and panel manufacturers such as Leyard, Unilumin, TCL CSOT and BOE, have all launched mini/micro-LED-related projects in an effort to drive the industry forward.

In July 2019, San'an commenced its mini/micro-LED wafer and chip development and production project in Ezhou, Hubei, which aims mostly to develop new mini/micro-LED displays and is projected to involve RMB12bn worth of investment capital. In December 2019,

Leyard and Epistar jointly invested RMB1bn to set up a mini/micro-LED production center in Wuxi, Jiangsu. Also, in May, MTC established its headquarters and its LED packaging facilities in the Qingshanhu District of Nanchang, Jiangxi. MTC is expected to build 5000 production lines for LED packaging operations (including mini/micro-LED packaging), with an investment totaling RMB7bn.

TrendForce believes that participation of the above companies in mini/micro-LED R&D will inject a corresponding influx of capital in all aspects of mini/micro-LED technology development, including new equipment, materials and manufacturing technologies, with these investment efforts also resulting in the maturation of the related supply chain.

www.ledinside.com

Project	Start Date	Location	Amount Invested (Unit: Billion RMB)
San'an Optoelectronics Mini/Micro LED Project	2019.7	Ezhou	12
China Overseas Holding Group Semiconductor Micro Display Project	2019.4	Chengdu	10
MTC Nanchang LED Packaging Project	2020.5	Nanchang	7
Unilumin Zhongshan Smart Manufacturing Project	2019.1	Zhongshan	2.2
Konka Chongqing Micro LED Project	2019.9	Chongqing	2
HC Semitek Mini/Micro LED Project	2020.4	Yiwu	1.5
Leyard-Epistar Micro LED Project	2019.12	Wuxi	1
Zhejiang Bright Semiconductor Mini/Micro LED Sapphire Project	2019.12	Jinhua	1
Shenzhen MTC Mini/Micro LED Project	2019.12	Nanchang	1
Nationstar Second LED Packaging Facility Expansion Project	2020.4	Foshan	0.5

Partial list of newly added mini/micro-LED-related projects in China since 2019.

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GaAs RF revenue to fall 3.8% in 2020 due to US–China trade war and COVID-19

5G to drive recovery in 2021

RF front-end component integrated device manufacturer (IDM) and foundry revenues will be affected under the dual influences of the COVID-19 pandemic and the Chinese government's policy of decoupling from the USA, driven by the ever-intensifying US–China trade war that began in 2019, according to TrendForce. Reduced demand for telecoms end-devices in 2020 is also expected to lead to a bearish market for gallium arsenide (GaAs) RF front end as well. GaAs RF front end revenue is therefore projected to fall by 3.8% year-on-year to US\$5.793bn for 2020.

RF front-end components can be classified according to their applications in various telecom devices, including power amplifiers (PAs), low-noise amplifiers (LNAs) and filters, notes analyst John Wang. Of the above applications, GaAs is particularly suitable for use in PA components because of its high temperature resistance, high usable frequency range, and low noise operating at high frequencies. Furthermore, the number of PA components used in smartphones has increased along with the jump in cellular frequencies. For instance, 4G smartphones contain on

average of 5–7 PA parts per unit, while 5G smartphones contain 10–14 parts.

Despite continued US-China trade war, 5G to drive RF recovery in 2021

Given the ever-intensifying US–China trade war (in which the US government increased tariffs on Chinese goods imported into the USA), the Chinese government has attempted to respond by instituting a policy of decoupling from the USA and by importing goods and services from other countries instead. Nonetheless, China still depends on US-based IDMs for PA components and RF modules due to its insufficient R&D competencies for RF front-end components. Although the trade war has reduced the revenues of US-based IDMs earned from Chinese clients, the fact that Chinese smartphone makers must import some products from these IDMs means that US-based IDMs were able to maintain their bottom lines to a certain extent. In first-quarter 2020, Qorvo's revenue grew by 15.7% year-on-year to \$788m, while Skyworks' revenue fell by only 5.5% year-on-year to \$766m.

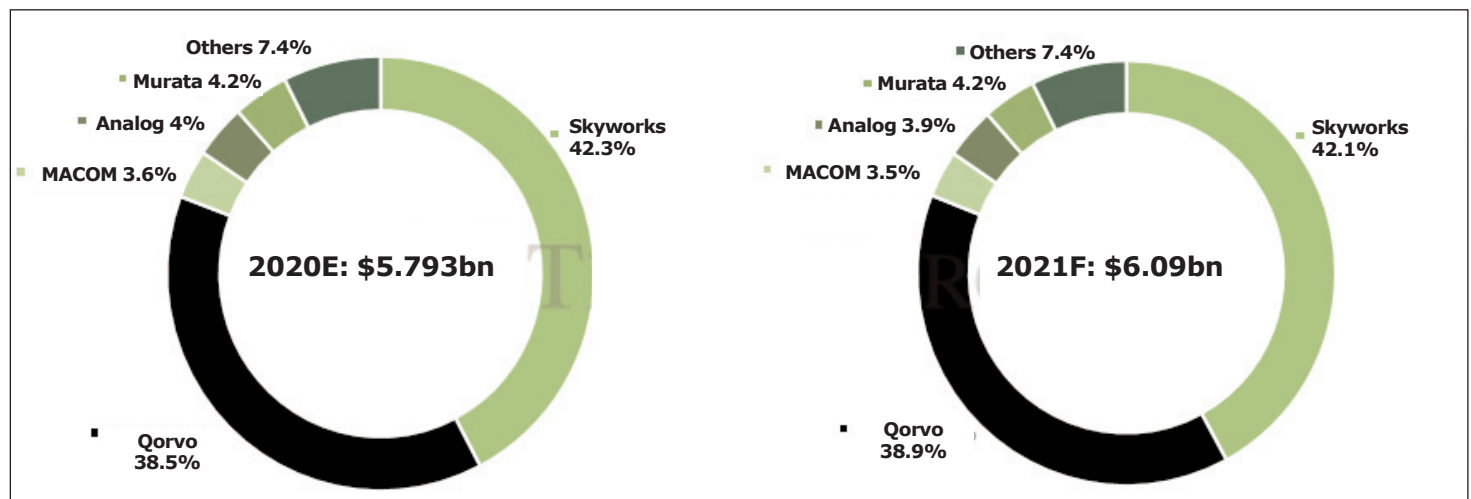
Overall GaAs foundry revenue was likewise disrupted by the US–China

trade war in first-half 2019.

In second-half 2019 however, under the influence of China's decoupling from US goods and services, Chinese IC design companies decided to purchase directly from Taiwan's WIN Semiconductor Corp and Advanced Wireless Semiconductor Company (AWSC). In first-quarter 2020, WIN's revenue grew by 67.8% year-on-year to \$201m, while AWSC's revenue also rose by 162.6% to \$27m. On the other hand, the performance of Global Communication Semiconductors (GCS) was relatively mediocre, with revenue falling by 2.8% year-on-year to \$12m in Q1/2020, since operations at its primary fab, in California, were affected by the pandemic.

TrendForce expects the revenues of major RF front-end IDMs to potentially rebound from rock bottom in 2021, as the global build-out of 5G base stations accelerates, and 5G handsets account for an increasing share of smartphone makers' annual production. At the same time, some foundries are also likely to benefit from these circumstances, with overall GaAs foundry revenue expected to rebound too.

www.trendforce.com



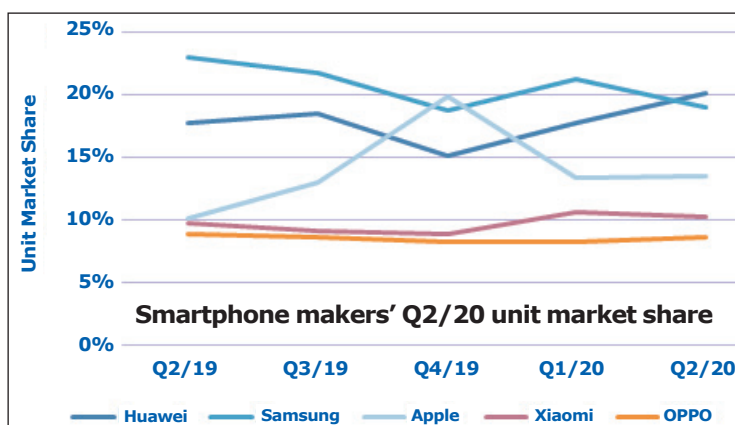
Forecasted revenue for GaAs RF front-end IDMs, 2020–2021.

Smartphone shipments fall a record 16% year-on-year in second-quarter 2019 to 278.4 million

Global smartphone shipments fell 16% year-on-year to 278.4 million in second-quarter 2020, according to preliminary data from the International Data Corp (IDC) Worldwide Quarterly Mobile Phone Tracker. Although this a larger decline than in first-quarter 2020, it was expected, as major economies around the globe were in lockdown for the majority of Q2 due to the pandemic.

"Smartphones shipments suffered a huge decline in Q2 as they directly correlate to consumer spending, which had a massive reduction due to the global economic crisis and rising unemployment brought on by the widespread lockdowns," says Nabila Popal, research director with IDC's Worldwide Mobile Device Trackers. "This, combined with the closure of retail stores, especially in regions where online shopping is less common, compounded the negative effect on smartphone sales. In addition, consumers spent significantly on other technologies, such as PCs, monitors and tablets, to facilitate mandatory work from home and distance learning, leaving an even smaller share in the shrinking consumer wallet for smartphones."

From a regional perspective, Asia/Pacific (excluding China and Japan), Western Europe and the USA declined 31.9%, 14.8% and 12.6%, respectively. China fared slightly better, with a decline of 10.3%, and arguably shows some early signs of market recovery. "The smartphone supply chain ground to a halt when the pandemic hit. However recovery, specifically in China, has been strong," notes Ryan Reith, vice president, Worldwide Mobile Device Trackers. "The question now becomes what does demand look like with so much uncertainty around the world. We have already seen OEMs moving more aggressively with their 5G portfolios both



iPhone shipments managed to climb 11.2% year-on-year due to the continued success of the iPhone 11 series and the timely launch of the new SE (2020), which managed to effectively

in terms of production and price points. However, we still see consumer demand for 5G being low, so the supply-side push is likely to produce very high-priced competition."

Smartphone company highlights Huawei for the first time reached the number 1 position, with 55.8 million smartphones shipped in Q2, despite a small decline of 5.1% year-on-year. With the overall market declining even faster, the firm also achieved its highest-ever share (20%) of the global smartphone market. This was driven by Huawei's tremendous growth in China — almost 10% year on year — which offset the large declines that it faced in every other region. Looking forward, the impact of the US technology ban will continue to create uncertainty for Huawei in foreign markets.

Samsung shipped 54.2 million smartphones, finishing a close second with 19.5% share. However, the South Korean firm suffered a 28.9% year-on-year decline, the most significant among the top five vendors. While the A series continues to perform well, contributing to the majority of its volume, premium devices such as the Galaxy S20 and the Galaxy Z Flip, unfortunately launched in the peak of the pandemic, are facing sales challenges despite price reductions.

Apple shipped 37.6 million iPhones, which placed it in third with 13.5% share of the market.

target the lower-priced segment (boding well for the vendor in this time of crisis where consumers are shifting towards more budget-friendly devices). Looking ahead, the launch of four new potential models will signal Apple's entry into 5G and challenge Android 5G devices that have been out for more than a year.

Xiaomi shipped 28.5 million devices, maintaining its number-four position and achieving a 10.2% market share despite shipments falling 11.8% year-on-year. Although Xiaomi faced a large drop in both China and India, the lockdown and anti-China sentiment in India had a larger impact on the vendor, with a 50% year-on-year drop despite maintaining its number one position.

OPPO returned to the top 5 in Q2, with 8.6% market share, despite shipments falling 18.8% year-on-year to 24 million units. Roughly 60% of shipments were to its domestic market of China, which was a key factor in getting the vendor back into the top 5 globally. In China, the A series was again the volume driver while the new Reno 4 series performed much better than expected due to very competitive pricing. Meanwhile, in OPPO's second-largest market India, the vendor faced challenges in both supply and demand, with factory shutdowns and consumers facing the anti-China sentiment.

www.idc.com

5G handsets 18.9% of smartphone production in 2020

Chinese brands took 75% share of 5G smartphone market in first-half

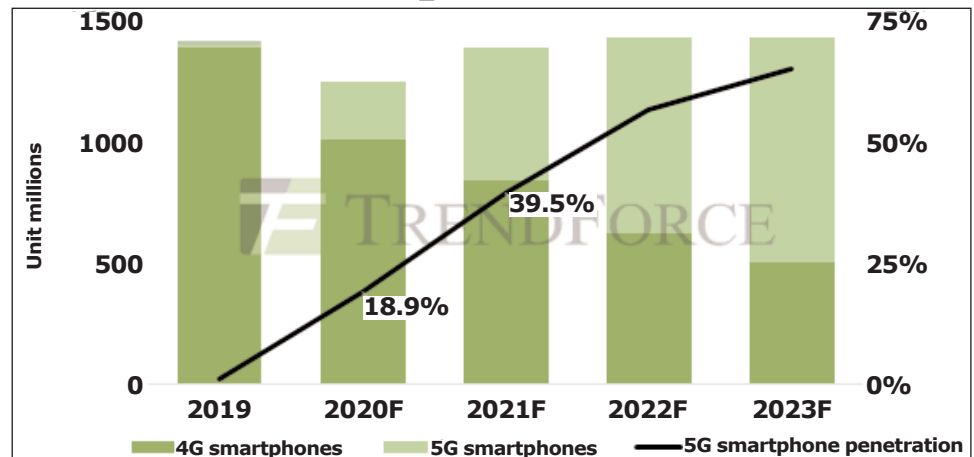
5G remains a hot topic in the smartphone market this year, as smartphone brands and mobile processor manufacturers, such as Qualcomm and MediaTek, strive to expand their shares in the 5G market. According to market research firm TrendForce, the Chinese government's 5G commercialization efforts have been particularly aggressive, leading the country's 5G base-station deployment and network coverage to each score first place in the global 5G industry. As such, Chinese brands, which were ahead of their competitors in 5G strategies, took a 75% share of the global 5G smartphone market in first-half 2020.

Aside from the various Android-based smartphone brands, Apple's new models will also join the ranks of 5G smartphones. Given the total smartphone production forecast of 1.24 billion units in 2020, 5G handset production will reach 235 million units, an 18.9% penetration rate, reckons TrendForce.

Chinese brands to occupy four of top six 5G smartphone brands by production volume

Analysis of the projected top six smartphone brands ranked by 5G smartphone production volume shows Huawei firmly in first place. Under the impact of US sanctions and in preparation for China's active 5G commercialization efforts, Huawei has shifted its focus to the domestic Chinese market. The firm is expected to produce about 74 million 5G smartphones this year.

Apple's annual 5G smartphone production is expected to total about 70 million units in 2020, taking second place. However, 5G functions will increase the production cost of smartphones accordingly. If Apple decides to directly reflect this added cost on the retail prices of the iPhone 12 series, it may lower consumers' willingness to purchase, in turn affecting the sales performances of the new



Global smartphone production forecast, 2019-2023.

Rank	Brand	Market Share
1	Huawei	31%
2	Apple	30%
3	Samsung	12%
4	Vivo	9%
4	OPPO	8%
4	Xiaomi	8%
5	Others	2%
Total		100%

Top-6 smartphone brands' 5G production and market share in 2020.

iPhones, reckons TrendForce.

Samsung has been experiencing setbacks in the Chinese market in recent years. Although these have not seriously affected its global market share and revenue, they have considerably slowed Samsung's growth in the 5G smartphone market. Its 5G smartphone production this year is forecasted to be 29 million units, placing it third globally.

Vivo, OPPO (including OnePlus, OPPO, and Realme) and Xiaomi are tied for fourth place. As Huawei's aggressive domestic expansion in the past few years has compressed the market shares of the three brands in the Chinese market, they have been actively focusing on increasing overseas market shares to maintain their annual production performances. Vivo, OPPO and Xiaomi's annual 5G smartphone production volumes are projected

to reach about 21 million, 20 million and 19 million units, respectively.

Mid-to-low-end 5G chipsets from AP suppliers to boost 5G smartphone penetration in 2021

An aggressive push by mobile processor manufacturers will lead to the rapidly increasing presence of 5G chipsets in the mid-to-low end market, driving 5G smartphone production above 500 million units in 2021, potentially to about 40% of the total smartphone market, reckons TrendForce.

Once 5G chip prices reach a stable level this year, smartphone brands may look to gain additional shares in the 5G market by sacrificing gross margins. In doing so, they are likely to accelerate the drop of 5G smartphones' retail prices, and the market may see the arrival of 5G smartphones around the RMB1000 price level by the end of this year.

Incidentally, the penetration rate of 5G smartphones does not equal the usage rate of the 5G network, which depends on the progress of base-station construction. Since the current 5G infrastructure build-out is pushed back as a result of the pandemic, global 5G network coverage is unlikely to surpass 50% before 2025 at the earliest, with complete coverage taking even longer, notes TrendForce.

www.trendforce.com

Qorvo's COVID-19 impact mitigated by 5G adoption

For fiscal first-quarter 2021 (ended 27 June 2020), Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has reported revenue of \$787.5m, roughly level with last quarter but up 1.5% on \$775.6m a year ago.

This marked the first full quarter after completing the acquisitions (in February) of both Custom MMIC of Westford, MA, USA (expanding its portfolio of GaAs and GaN monolithic microwave integrated circuits for defense & aerospace) and Decawave Ltd of Dublin, Ireland (a supplier of ultra-wideband solutions for mobile, automotive and Internet of Things applications).

Revenue exceeds the midpoint of the \$710–750m guidance by \$57.5m due to stronger-than-expected demand in both the Mobile Products and Infrastructure & Defense Product (IDP) segments.

Despite being down 15.8% from \$556m both a year ago and last quarter (when it comprised 70.6% of total revenue), Mobile Products yielded a still more-than-expected \$468m (59.5% of total revenue), as handset demand was more resilient and global supply-chain disruption (due to the COVID-19 pandemic) was less impactful than anticipated, and 5G smartphones comprised an increasing percentage of total units. Qorvo supported multiple production ramps, and benefited broadly from integration trends at multiple customers. Revenue was diversified across categories, including modules integrating power amplifiers (PAs), switches, bulk acoustic wave (BAW) install filters, as well as antenna-plexers, antenna tuners, and specialized RF power management. "Across our customers, we are engaged on the most critical 5G challenges and enabling them to introduce innovative new designs, enhance performance and bring products to market faster," says president & CEO Bob Bruggeworth.

In particular, Qorvo says that it:

- was selected by a leading Korea-based smartphone maker to supply a highly integrated high-band solution for this year's flagship model;
- ramped an antenna-plexer addressing antenna network complexity and optimizing system efficiency for upcoming foldable smartphones;
- captured the complete main path (highly integrated low-band, mid/high-band and ultra-high-band modules) at leading Android smartphone makers for upcoming 5G products;
- supported customers across all major chipset providers, and began production shipments for leading firms using Mediatek's 5G baseband;
- began high-volume shipments of ultra-wideband (UWB) solutions enabling accuracy and reliability in spatial awareness applications (including contact tracing/social distancing) for many customers globally;
- increased mobile power management shipments, driven by adoption of 4G/5G dual transmit.

Infrastructure & Defense Products yielded a record \$319m (40.5% of total revenue), up 37.5% on \$232m last quarter and up 45.7% on \$219m (just 28.2% of revenue) a year ago.

Driven by the ongoing build out of 5G network base-stations, Infrastructure was a record, as Qorvo increased its support for 5G, specifically sub-6GHz massive MIMO deployments. In particular, Qorvo:

- ramped shipments of programmable power management and motor control solutions (after buying Active-Semi International Inc of Dallas, TX, USA over a year ago), improving the efficiency of solid-state drives in places like data centers and enabling brushless motors used in consumer products;
- ramped the programmable power management solution, along with a Wi-Fi 6 front-end module (FEM) for a leading drone manufacturer, enabling longer flight time, greater range and larger payload;
- began sampling GaN power amplifiers for upcoming C-band spectrum allocations in the USA.

In Connectivity, Qorvo:

- experienced continued strong demand for Wi-Fi 6 products, including FEMs and BAW filters, driven by work-from-home trends;
- began shipping integrated ultra-low-power, multi-protocol Zigbee, BLE and Thread IoT solutions supporting a large provider of smart-home infrastructure solutions.

In Defense, gallium nitride (GaN) product revenue was also a record (doubling year-on-year), with multi-year radar programs boosted by the continued ramp of Wi-Fi 6. Also, Qorvo saw design wins for an integrated GaN multi-chip broadband transmit–receive (Tx/Rx) module and a 50W GaN power amplifier for defense radar programs.

"The rollout of 5G and Qorvo's operational performance helped drive a June quarter well above our expectations," summarizes chief financial officer Mark Murphy.

Non-GAAP gross margin was 48.6%, down from 49.6% last quarter but up from 46.2% a year ago, and exceeding the 47.5% guidance due to lower-than-expected manufacturing costs and favorable mix effects.

Despite being up on \$167.9m a year ago, operating expenses have been cut from \$181m last quarter to \$178.7m (well below the expected \$187m, due partly to discipline in spending on discretionary activities): selling, general & administrative expenses were cut from \$60.7m to \$56.2m; R&D spending was actually raised from \$85.1m to \$86.6m.

Net income has fallen from \$185.3m (\$1.57 per diluted share) last quarter to \$175.1m (\$1.50 per share) but this is up on \$165.3m (\$1.36 per share) a year ago (and well above the guidance of \$1.13 per share).

"Qorvo delivered an exceptional June quarter, with revenue and EPS well above guidance," notes Bruggeworth. "Our technology investments are aligned with long-term market drivers in 5G handsets and infrastructure, defense, Wi-Fi 6 and IoT."

Cash flow from operations was \$214m (level with last quarter).

Capital expenditure (CapEx) was \$29.9m (cut further, from \$35.1m last quarter and \$50.3m a year ago). Free cash flow was hence \$184m (up from \$179.2m last quarter).

During the quarter, Qorvo repurchased \$75m of shares. "We continue to invest ahead of customer and market needs while sustaining responsible capital return," says Murphy.

On 11 June, Qorvo raised \$300m via an add-on to its 2029 unsecured notes, augmenting liquidity and extending the weighted average maturity of its outstanding debt to October of 2027. "Our leverage remains low and we have no near-term maturities," notes Murphy.

Cash and cash equivalents hence rose from \$715m to \$1136m. The firm has an untapped \$300m unsecured revolving credit facility.

"With this financial flexibility, we can focus on advancing technology supporting customers and making prudent organic and inorganic investments that support long-term earnings and free cash flow growth," says Murphy. "Acquisitions have been integrated quickly and are performing well. On ultra-wideband [Decawave], we see a wide array of applications emerging with this wireless technology, and have significant customer engagement on the design of new products and solutions. We expect this business and our MEMS technology acquisition [RF MEMS antenna tuning technology firm Cavendish Kinetics Inc of San Jose, CA, USA, acquired last October] to contribute meaningfully to Qorvo over time. Our other recent acquisitions are already accretive."

"Custom MMIC, a bolt-on to our IDP segment, exceeded plan in its first full quarter and further strengthens our defense & aerospace franchise," says Murphy. "Programmable power management [Active-Semi] is serving customers advanced power management needs, is delivering in line with our expectations, and is on track to grow revenues strongly by double-digits this quarter versus the same period last year," he adds.

For fiscal Q2/2021 (to end-September 2020), Qorvo expects rev-

enue to rise by 19% sequentially to \$925–955m, reflecting strong growth in Mobile (to \$640m, as the launch of new 5G handsets is adding more complex parts and driving higher content) and over 50% year-on-year growth in IDP (to \$300m, from the timing of base-station deployments). IDP should see strong year-on-year growth through the year, as infrastructure demand remains robust (boosted by 5G) and defense, Wi-Fi and power management strengthen.

N.B. Fiscal Q2 is a 14-week quarter (to make 2021 a 53-week fiscal year). The effect of the extra week is \$65m, so adjusting to a typical 13-week quarter equates to \$873m revenue. This is still up by 10% both sequentially and year-on-year, like for like.

"Our efforts to improve the portfolio and drive productivity are yielding favorable results. And we expect this progress to continue as we're forecasting approximately 50% gross margin in the September quarter," says Murphy. This reflects "volume growth and ongoing efforts to improve the quality and efficiency of our business. Specifically, we've invested early and adequately in the technologies that markets need, focused our product portfolio on where we can best serve customers, gained productivity across our operations and reduced our capital intensity, recognizing that a potential impact to our demand and supply chain remains," he adds. "Given the uncertainty due to the pandemic, we believe our work to minimize inventories and reduce our cost structure will help us sustain about 50% gross margin through the balance of the [fiscal] year."

Operating expenses should rise to \$207m due to higher personnel costs, increased product development activities, and resumption of some discretionary spend. Excluding the extra week, OpEx would be nearer

\$196m, and should remain below that for the balance of the year. Diluted earnings per share are expected to rise to \$1.90.

"We expect end-market demand to support full fiscal year revenue growth [albeit by less than 5%]," says Murphy. "We're in the early stages of a multi-year [5G] upgrade cycle supporting growth across both businesses," notes Bruggeworth.

"In Mobile Products, we're benefiting from the need for more and better RF fueled by higher front-end integration and increased complexity. This includes the move to higher frequencies, the addition of new band combinations and the adoption of dual transmit architectures to support 5G. Content expansion and increased complexity supporting 5G architectures favor our design expertise and technology at scale. We're securing broad-based design wins. We're seeing increased demand for a broad-based multiplexing solutions across a range of baseband, across a range of band combinations," Bruggeworth says. "Smartphone units are forecasted to be down over 10% year-over-year. RF content expansion in 5G devices of \$5–7 is mitigating the impact of fewer units. For the year, we continue to expect approximately 250 million 5G smartphones globally," he adds.

In Infrastructure, our opportunities in small-signal devices like LNAs are growing in line with the increase in massive MIMO antenna elements, while revenue related to GaN PAs is added content. Globally, we expect 5G base-station deployments to outpace the initial deployments of 4G, with over three quarters of a million deployments this calendar year growing to more than a million in 2021. In the USA and Europe, we see deployments picking-up next year, adding to this multi-year investment cycle by the carriers. This will drive strength in IDP, given our technologies, design capabilities, and operational excellence."

Despite rising from \$164m in fiscal 2020, CapEx should remain below \$200m in fiscal 2021.

www.qorvo.com

Skyworks' June-quarter revenue falls a less than expected 4% to \$736.8m, aided by 5G launch in China

Double-digit revenue growth expected in September quarter

For fiscal third-quarter 2020 (ended 26 June), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of \$736.8m, down about 4% on \$766.1m last quarter and \$767m a year ago.

However, despite the negative impact from the COVID-19 pandemic, revenue was up 2.5% year-on-year if you exclude revenue from China-based smartphone and telecom network infrastructure maker Huawei Technologies Co Ltd, which on 15 May 2019 was added to the 'Entity List' of the US Department of Commerce's Bureau of Industry and Securities (BIS), prohibiting the sale to Huawei of products covered by the Export Administration Regulations (EAR) without obtaining an appropriate license. (Huawei was previously Skyworks' second largest customer, contributing 12% of total revenue in fiscal first-half 2019.)

Also, the revenue of \$736.8m was \$46.8m above the midpoint of the \$670–710m guidance given on 4 May, boosted by a number of opportunities that Skyworks was able to execute on, largely the initial launch of 5G products in China with partners including Samsung, Oppo and Vivo.

China comprised 23% of total revenue. "Most of that is Oppo, Vivo, Xiaomi. There's very little Huawei left. And then, of course, some other smaller Chinese customers," says senior VP & chief financial officer Kris Sennesael. "5G is really kicking off in China... There is a big step-up in content in those 5G phones compared to the 4G phones. And, as a result of that, our revenues with the Chinese players is up on a year-over-year basis," he adds.

"We also had some nice penetration in our Wi-Fi portfolio," says president & CEO Liam K. Griffin.

"Our Wi-Fi 6 launches, they were beneficial to us. But there was still a great opportunity in core mobile to grow."

By sector, Mobile (Integrated Mobile Systems and Power Amplifiers) comprised 69% of total revenue and Broad Markets comprised 31%, roughly equal to last quarter.

On a non-GAAP basis, gross margin has fallen further, from 50.4% a year ago and 50.2% last quarter then slightly again to 50.1%, hampered by COVID-19-related disruption in the supply chain as well as logistic costs in Skyworks' own factories. However, the 50.1% gross margin was slightly above the 50% guidance, driven partly by a richer mix with more 5G products.

Operating expenses have risen from \$135m (17.6% of revenue) last quarter to \$139m (18.9% of revenue), above the forecasted \$135.5m, as the firm makes the necessary investments in R&D to accelerate future growth.

Net income has fallen further, from \$233.6m (\$1.35 per diluted share) a year ago and \$229.5m (\$1.34 per diluted share) to \$210.8m (\$1.25 per diluted share), but this exceeded the guidance of \$1.13 per diluted share.

Operating cash flow was \$259m (down from \$280.4m last quarter).

Capital expenditure (CapEx) was \$71.6m (almost 10% of revenue), up from \$60.7m (just 7.9% of revenue) last quarter. Free cash flow has hence fallen further, from \$220m (free cash flow margin of 29% of revenue) to \$187m (25.4% margin). Nevertheless, on a trailing 12-month basis, free cash flow margin is 32%.

During the quarter, Skyworks paid \$73m in dividends and repurchased about 670,000 shares of common stock at an average price of \$87.42 for a total of \$59m. (During the first three quarters of fiscal 2020, the firm repurchased 4.6 million shares. During the last 12 months, it has returned 84% of free cash flow back to shareholders via dividends and share buybacks.) Cash and investments still rose during the quarter from \$1108m to \$1162m. The firm has no debt.

"Skyworks delivered results well above expectations in the June quarter, as our Sky5 platform gains traction, powering innovation in 5G applications at the leading mobile phone OEMs worldwide, and increasingly across our IoT customers," says Griffin.

During the quarter, Skyworks secured key design wins across numerous applications from the mobile phone to industrial, IoT, automotive, cognitive audio, aerospace and defense.

"Specifically, in mobile, we are expanding our Sky5 platform across multiple flagship 5G models at Samsung, Motorola, Oppo, Vivo and Xiaomi," notes Griffin. "In addition, we are populating some of the highest-performing 5G platforms that we'll be launching later this year. In IoT, we're enabling AT&T's tri-band home gateways with our Wi-Fi 6 solutions; ramping indoor and outdoor access points at Aruba, Juniper and Linksys; powering integrated connectivity in Amazon and Ring security systems;

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launching voice assistant solutions and mesh routers at Google; and we're leveraging our 4x4 MIMO and Wi-Fi engines and premium sound bars at Sonos. In addition, we delivered new cognitive wireless audio solutions powering the leading gaming headsets," he adds.

"In the industrial space, we are supporting IoT platforms at Bosch and Gemalto and leveraging our GPS, circulator and advanced filter solutions at leading aerospace & defense companies. And in automotive, we're capturing new designs with Sky5 at BMW, Ford and other leading manufacturers," says Griffin. "These wins demonstrate our market leadership, underpinned by a diverse and growing set of critical technologies, resolving increasingly complex architectures and preparing our customers for the performance gains demanded in 5G."

"With 5G gaining traction, we are now at the cusp of a multi-year upgrade cycle, one in which Skyworks is uniquely positioned to outperform," reckons Griffin. "Our Sky5 platform provides tremendous flexibility to our customers, purpose-built to be baseband agnostic, while powering the most

innovative 5G handsets," he adds. "In addition, these same 5G solutions are now expanding across industrial and automotive applications. And, as complexity intensifies, we are aggressively adding to our enabling technologies, with ongoing investments in both TC-SAW and bulk acoustic wave (BAW) filtering." Skyworks has just surpassed 150 million shipments of BAW-enabled modules. "We see strong momentum for this technology in both Mobile and Broad Markets," notes Griffin. "Our proven ability to advance key connectivity protocols, delivering higher speeds and lower latency, across 3G, 4G and now 5G, positions us well to capitalize on rapidly evolving market opportunities," he reckons.

For fiscal-quarter fourth 2020 (to end-September), Skyworks expects double-digit sequential revenue growth to \$830–850m, with Broad Markets up double-digits as business accelerates, and revenue with Chinese 5G players accelerating strongly in Mobile. Gross margin should be 50–50.5% (the longer-term target is still 53%). Despite operating expenses growing to \$142.5m, diluted earnings per share should rise to \$1.51.

"We expect further strong sequential growth into the December quarter," says Sennesael. "We have been loading our factories in order to drive maximum usage of our capital equipment and then trying to minimize our capital expenditures, and so most of the inventory that we have [which has more than doubled year-on-year, from \$22.8m a year ago to \$46.4m in the March quarter] is based on backlog and firm orders that we have on the books. So, there is very little risk for E&O [excess and obsolete]," he adds.

"Given our confidence in Skyworks' strategic outlook and strong cash flow generation, we are announcing another substantial raise to our quarterly dividend," says Sennesael. The board of directors has declared a cash dividend of \$0.50 per share of common stock (a 14% increase on the prior quarterly dividend of \$0.44 per share), payable on 1 September, to stockholders of record at the close of business on 11 August.

"Our efforts are underpinned by years of investment in next-generation technologies, uniquely positioning Skyworks to deliver long-term profitable growth," says Griffin.

www.skyworksinc.com

Skyworks ships 150 millionth BAW filter-enabled modules Focus on in-house BAW to prepare for transition to 5G mobile

Skyworks has reached a milestone with the shipment of over 150 million bulk acoustic wave (BAW) filter-enabled modules for 5G mobile solutions.

To prepare for the transition to 5G, Skyworks has focused efforts on the development of in-house BAW technology that is supported through its design teams, fabs and proprietary IP.

As noted by a recent GSM Arena article and according to market research firm Strategy Analytics, 5G smartphones will comprise a much larger portion of global shipments this year, growing more than tenfold to an estimated 15% of all smartphone shipments, up

from just 1% in 2019.

Skyworks says that its BAW technology expands the reach across its product portfolio and represents the culmination of years-long investment from which it has secured multiple design wins with market-leading customers. In addition, Skyworks will leverage BAW technology across its broad portfolio.

"This key achievement marks the success of our long-term investment, commitment and strategy as a company – driving towards world-class BAW technology and performance," says Joel King, senior VP & general manager of Mobile Solutions. "Coupled with

our industry-leading TC-SAW [temperature-compensated surface acoustic wave] capabilities, the addition of high-performance BAW delivers to our customers a truly differentiated RF front-end solution, with an architecture that aggressively scales across other platforms."

Skyworks says that its high-reliability, field-proven 8-inch BAW filter production line supports the challenging needs driven by the growth in 5G, adoption of Wi-Fi 6E and the expansion of filters required in next-generation smartphones, Internet of Things (IoT) devices and automotive applications.

II–VI acquiring Ascatron and INNOViON to form vertically integrated SiC power electronics platform

SiC epi and implant technology complement GE device license

Engineered materials and optoelectronic component maker II–VI Inc of Saxonburg, PA, USA — which manufactures silicon carbide (SiC) substrates — has entered into a definitive agreement to acquire the outstanding shares of Ascatron AB of Kista, Stockholm, Sweden (which was spun out of research institute Acreo in 2011).

II–VI will also acquire all the outstanding interests of the owners of the parent firm of INNOViON Corp of Colorado Springs, CO, USA, which provides ion implantation technology for silicon and compound semiconductor devices.

Both transactions are scheduled to close by the end of 2020.

Led by a team of experts in wide-bandgap materials with more than 200 person-years in the SiC and semiconductor industry, Ascatron produces SiC epitaxial wafers and devices that enable a wide range of high-voltage power electronics applications.

INNOViON is said to be the world's largest provider of ion implantation services, with 30 implanters across a global footprint supporting capabilities in semiconductor materials processing for up to 300mm wafers. The firm's processes enable doping in a wide range of semiconductors, including silicon carbide, gallium arsenide, indium phosphide and silicon.

The technology platforms of Ascatron and INNOViON complement to II–VI's SiC substrates, global large-scale wafer fabrication footprint, and the SiC device technology licensed from GE in June, says II–VI's CEO Dr Vincent D. Matterna Jr. "While we continue to serve our existing customers with our advanced materials and components, we will combine these capabilities to achieve one of the world's most advanced, in-house, vertically integrated 150mm SiC technology platforms," he adds. "This builds upon our deep expertise in SiC sub-

strates and adds advanced SiC epitaxy, device fabrication and module design to meet the rapidly growing demand for SiC power electronics."

SiC represents a disruptive technology in power electronics through advantages that are pivotal to electric vehicles (EVs), renewable energy, micro-grids and power supplies for data storage and communications. SiC achieves superior efficiency, higher energy density and lower total system-level cost of ownership compared with silicon-based devices.

II–VI says that, as a part of its vertical integration strategy, it is leveraging its broad engineered materials and optoelectronic device technology platforms, as well as its manufacturing capabilities around the globe, to drive scale and innovation through the development of high-performance compound semiconductor devices.

www.ascatron.com

www.ii-vi.com

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Infineon's MOSFETs used in Ingeteam's 400kW converter

Power conversion group Ingeteam S.A. of Bilbao, Spain and Infineon Technologies AG of Munich, Germany have teamed up to target ultra-fast electric vehicle (EV) charging.

Rated at 400kW, Ingeteam's INGEREV RAPID ST400 converter is based on Infineon's CoolSiC silicon carbide metal-oxide-semiconductor field-effect transistors (MOSFETs) in an EasyDUAL 2B housing. A single charging point implements eight of Infineon's FF6MR12W1M1_B11 modules. Depending on the charging capabilities of the respective car, an EV now only needs to stop for a minimum of 10 minutes for an 80% battery charge (comparable to refueling a conventional car with internal combustion engine).

The design of the INGEREV RAPID ST400 converter has proven to operate successfully under real-world conditions. Already last year, the first project integrating this tech-



EasyDUAL 2B housing,

nology was developed, implemented and commissioned by IBIL (the leading recharge technology services company in Spain) for Repsol, the multi-energy provider and leading Spanish petrol station operator. Located at Ugaldebieta in the Bay of Biscay region, it was commissioned in October 2019 as a lighthouse project in the field of electro-mobility. The facility on the heavily frequented A-8 motorway features four ultra-fast charging points. These units guarantee opti-

mal distribution of the available power between the four vehicles that can be connected simultaneously. More importantly, the technology has operated without any major downtime from the start.

"SiC enables high switching speeds with lower switching losses. This results in shorter charging times and charging stations that are about one-third smaller, since considerably fewer components are required for cooling," notes Dr Peter Wawer, president of Infineon's Industrial Power Control division. "With its physical properties, SiC can make an important contribution to electric mobility," he adds. "As various consumer studies show, the acceptance of electro-mobility very much depends on the availability of an efficient fast-charging infrastructure. We have proven that we can provide the underlying technology."

www.ingeteam.com

www.infineon.com/coolpic

PV inverter using ON Semi's full-SiC power modules

ON Semiconductor of Phoenix, AZ, USA — which supplies power management, analog, sensors, logic, timing, connectivity, discrete, system-on-chip (SoC) and custom devices — has introduced a full-SiC (silicon carbide) power module for solar inverter applications, which has been selected by power and thermal management solutions provider Delta to support its M70A three-phase photovoltaic (PV) string inverter portfolio.

The NXH40B120MNQ family of full-SiC power modules integrates a 1200V, 40mΩ SiC MOSFET and 1200V, 40A SiC boost diode with dual boost stage. The use of SiC technology delivers the low reverse recovery and fast-switching characteristics needed to achieve the high levels of power efficiency required in applications such as solar inverters.

"Silicon carbide technology has the potential to revolutionize the energy market," believes Asif Jakwani,

senior VP of the Advanced Power Division at ON Semiconductor. "The full-SiC integrated power modules developed by ON Semiconductor address the need for higher system efficiency at elevated power levels in solar inverters, and demonstrate the maturity of SiC technology," he adds.

"We are always looking to engage with suppliers that can help us achieve highest efficiency, reduce product volume and weight, and meet the needs of the global solar PV market," says Raymond Lee, head of Delta's PV Inverter business unit. "The full-SiC power modules from ON Semiconductor were selected for our M70A 70kW three-phase PV string inverter because they provide best-in-class performance which, combined with our unique expertise in high-efficiency power electronics, allow our products to achieve peak energy conversion efficiency as high as 98.8%."

As part of ON Semi's growing portfolio of Power Integrated Modules (PIMs) based on wide-bandgap (WBG) technology, the NXH40B120MNQ offers a high level of integration with pin assignment optimized for inverter design. By using SiC components, the power module delivers low conduction and switching losses, enabling the use of higher switching frequencies, which contributes to higher inversion efficiency. The modules are designed for ease of use, with solderless press-fit connections and customer-defined thermal interface options, depending on customer preferences.

The NXH40B120MNQ full-SiC power module is available in 2- and 3-channel variants, and is complemented by the NXH80B120MNQ0, a 2-channel module that integrates a 1200V, 80mΩ SiC MOSFET with a 1200V, 20A SiC diode.

www.onsemi.com/products/power-modules/sic-modules

ROHM and LEADRIVE open joint lab in Shanghai

SiC-based EV power modules and inverters to be co-developed

Power semiconductor maker ROHM Semiconductor of Kyoto, Japan and Leadrive Technology (LEADRIVE) of Shanghai, China, which manufactures automotive powertrains for new energy vehicles, have opened their joint laboratory for silicon carbide (SiC) technology in the China (Shanghai) Pilot Free Trade Zone (Lingang New Area).

Adopted increasingly in onboard vehicle chargers and DC/DC converters, SiC power devices provide several advantages compared with silicon-based power devices such as insulated-gate bipolar transistors (IGBTs). One key benefit is significantly lower losses during both switching and conduction along with being able to operate at higher temperature.

Since 2017, ROHM and LEADRIVE have been collaborating and carrying out detailed technical exchanges on automotive applications utilizing SiC power devices. Establishing a joint research lab centered on vehicle power modules and inverters utilizing ROHM's SiC MOSFET bare chips and isolated gate drivers will give both firms the opportunity to further accelerate the development of innovative power solutions, it is reckoned.



LEADRIVE's chairman & general manager Dr Jie Shen (right) shaking hands with Shinya Kubota, managing director (at that time) of ROHM Semiconductor (Shanghai) Co Ltd (left) at the opening ceremony.

"The adoption of power modules that integrate SiC chips for new energy vehicles will become an industry trend over the next couple of years. Commercializing mature SiC-equipped devices by collecting resources from around the world and carrying out R&D gives us a competitive edge as an automotive tier-1 manufacturer," believes Dr Jie Shen, chairman & general manager at Leadrive Technology (Shanghai) Co Ltd. "ROHM has been a strong partner since LEADRIVE was

important when developing SiC power device technology," he adds. "LEADRIVE plays an important role in the applied research of SiC as a manufacturer of automotive power modules and inverters. Through this joint research lab, we can strengthen our partnership and contribute to the technical innovation of automotive power solutions centered on SiC," he concludes.

www.leadrive.com

www.rohm.com/web/global/sic-mosfet

founded. This joint research laboratory will allow us to deepen our collaboration," he adds.

"We are committed to promoting the use of SiC for xEV applications," says Dr Kazuhide Ino, board member, corporate officer, chief scientific officer & senior director of Power Device Business at ROHM Co Ltd.

"Understanding customer needs and market trends is extremely

Macnica to distribute UnitedSiC's products in Japan

Sales and support for silicon carbide power semiconductors

Silicon carbide (SiC) power semiconductor maker United Silicon Carbide Inc (USCi) of Monmouth Junction, NJ, USA has entered into an agreement for Yokohama-based Macnica Inc, a major distributor of semiconductor products in Japan, to distribute its product portfolio to Japanese customers in high-growth applications such as electric vehicles (EVs), battery charging, IT infrastructure, renewable energy and circuit protection.

"This partnership focuses on selling and supporting the UnitedSiC product line to a wider group of Japanese power designers by leveraging Macnica's highly regarded technical design-in expertise," says Yalcin Bulut, UnitedSiC's vice president of global sales & marketing. "This agreement will assure our customers will receive the best support as we grow our business in Japan," he adds.

"With continued pressure from the power engineers to deliver improved efficiency, performance and cost-effectiveness, we are confident we can deliver a value-add solution to the Japanese customers with the UnitedSiC products," comments Yusuke Kobayashi, president of Altima Company (a division of Macnica).

www.macnica.co.jp/business/semiconductor/manufacturers/uni
www.unitedsic.com

Improving home storage system efficiency

Low-loss hybrid inverters use GaN and SiC power transistors

To meet the evolving needs of climate change and the German energy transition, as well as combat the rising energy costs for end consumers, more and more households are adding home storage systems to their photovoltaic (PV) systems. A major challenge of PV home storage is that the batteries are charged within a few hours in intense sunlight and then discharged at very low power, or partial load, over a long time period during the night. Because of this, battery inverters in home storage systems should have high conversion efficiency over the largest power range possible. In the HyBaG project, which started in 2017, the Fraunhofer Institute for Solar Energy Systems ISE in collaboration with Siemens-owned inverter manufacturer Kaco New Energy and STS — Spezial-Transformatoren Stockach has developed a low-loss hybrid inverter that functions efficiently even at partial load. With the new inverter, private households can save up to €250 annually.

Energy storage systems can make an important contribution to renewable energy storage, grid stability and reducing CO₂ emissions. For this, the systems must be optimized in terms of efficiency, costs and use of resources on a continual basis, notes Fraunhofer ISE. The HyBaG project partners have therefore developed a demonstrator of a photovoltaic home storage system meeting the highest requirements.

In this project, Fraunhofer ISE developed highly efficient compact battery chargers including innovative control technology. A central component of its work in the project was to develop compact and modular battery controllers. This could be achieved by using gallium nitride (GaN) and silicon carbide (SiC) power components. These transistor bridge circuits are the core of modern battery chargers and



Optimized battery charger for high-voltage battery with 6kW nominal power (photo courtesy of Fraunhofer ISE).

enable increasingly faster switching with lower losses.

Optimization of partial load efficiency

In the project, various approaches to optimize the partial load efficiency were examined by simulation. Prototypes were then constructed using the best resulting concepts. Both the hardware as well as the control software for the power electronics were optimized. Different circuitry topologies were investigated and their partial load efficiencies were evaluated at low power levels.

Considering various parameters, an interleaved converter for the high-voltage battery controller was selected and constructed. This makes it possible to specifically adjust the power range to one-third, two-thirds or full nominal power by activating or deactivating individual converter bridges.

For very low power levels, an additional operating mode (gap limit mode) with variable switching frequency and minimum possible losses and a pulsating mode (burst mode) with one phase in which the converter is active only 10% of the time. "This can significantly increase the partial load efficiency, as it reduces the control and no-load losses that strongly influence the efficiency in the partial load

range," says Cornelius Armbruster, project manager at Fraunhofer ISE.

If not all phases are operated at the same time, it is recommended that the individual phases be operated alternately in order to achieve a uniform thermal load. The modulation method showing the best efficiency differs depending on the power range. Within the project, operation management, whose efficiency was optimized for the different power ranges, was developed

and implemented.

Savings potential through optimization of partial load efficiency

In series production, home storage systems based on silicon carbide components can be put on the market today at nearly no additional cost. At present, the optimization of efficiency during partial load operation is seldom carried out. A rough comparison of the available home storage systems on the market shows that considerable differences between the systems still exist.

"A major factor behind these differences is the losses in the partial load range," says Leonhard Probst, who is responsible for optimization of the battery charger in the project. Very good home storage systems have fewer losses. Simulations performed in the HyBaG project estimated that annual electricity savings of €150–250 can be expected.

The battery team at Fraunhofer ISE remains in close contact with manufacturers of battery storage systems with the aim of demonstrating the potential for optimization and accompany developments in this field of technology.

www.elektronikforschung.de/projekte/hybag
www.ise.fraunhofer.de

Cree's revenue fall less-than-expected 5% in June quarter COVID-19 contributes to Wolfspeed gross margin falling further, from 40% to 35.3%

For full-year fiscal 2020 (to 28 June), Cree Inc of Durham, NC, USA has reported revenue of \$903.9m, down 16% on fiscal 2019's \$1080m.

By segment, revenue for Cree's Wolfspeed silicon carbide materials and silicon carbide (SiC) power device & gallium nitride (GaN) RF device business fell 13% from \$538.2m to \$470.7m (52% of total revenue), as a result of softness in customer demand as well as a significant impact from the COVID-19 pandemic and associated disruptions. Revenue for LED Products (chips and components) fell 20% from \$541.8m to \$433.2m (shrinking from 50% to 48% of total revenue), due to market softness, trade and tariff concerns with China, and lower utilization due to COVID-19.

Fiscal fourth-quarter 2020 revenue was \$205.7m, down 5% on \$215.5m last quarter and 18% on \$251.2m a year ago. However, this was \$5.7m above the mid-point of the \$185–215m guidance.

Wolfspeed revenue was \$108.4m (52.7% of total revenue), down 19% on \$134.2m a year ago (due to continued softness in sales of electric vehicles in China, plus supply & demand challenges tied to the pandemic) and down 5% on \$113.9m last quarter (as improved performance in RF and, in particular, power devices was more than offset by lower shipments to one non-semiconductor customer in the SiC materials business that was not designated as an essential business during the pandemic plus the deferral of shipments to a few SiC wafer customers, as permitted under their long-term agreements with Cree).

LED Product revenue was \$97.3m (47.3% of total revenue), down 4% on \$101.6m last quarter (reflecting supply constraints) and down 17% on \$117m a year ago (driven largely by global trade events and the pandemic), but near the top of the \$85–100m guidance range.

On a non-GAAP basis, full-year gross margin has fallen from 37.3% in fiscal 2019 to 28.7% for fiscal 2020, including Wolfspeed falling from 48% to 39% and LED Products from 28% to 21%.

Quarterly gross margin declined further, from 37% a year ago and 29.8% last quarter to 26.4% in fiscal Q4/2020.

Wolfspeed gross margin has declined further, from 50% a year ago and 40% last quarter to 35.3%, due mainly to decreased factory efficiency resulting from the safety measures to protect staff during the pandemic, as well as the challenges of continuing low yields (related to the 150mm SiC MOSFET product ramp-up in the Durham fab) plus factory transitions that will continue to be a headwind until production is shifted to Cree's new Mohawk Valley Fab. However, Wolfspeed gross margin is above the expected 33–35%.

LED Product gross margin was 22.8%, down from 24% a year ago, but up from 20% last quarter (and above the forecasted 19–21%) due primarily to favorable product and customer mix.

Operating expenditure (OpEx) for Q4/2020 was \$83m, cut from \$86m last quarter. "This reflects our efforts to continue to execute disciplined cost control by prudently balancing our operating expenses with the necessary investments for our long-term growth and the decision not to pay management bonuses and some other incentives for fiscal 2020," says chief financial officer Neill Reynolds.

Nevertheless, net loss for fiscal Q4/2020 was \$20m (\$0.18 per diluted share), up from \$15.5m (\$0.14 per diluted share) last quarter and compared with net income of \$11.6m (\$0.11 per diluted share) a year ago. Full-year net loss was \$49.1m (\$0.45 per diluted share) for fiscal 2020, compared with net

income of \$76.9m (\$0.74 per diluted share) in fiscal 2019.

For fiscal Q4/2020, cash generated from operations was \$10.5m (an improvement on cash used of \$27.7m last quarter). Capital expenditure (CapEx) was \$70.2m (roughly level with last quarter, taking full-year CapEx to \$244.3m — above the target of \$240m, which had been increased from \$200m in November then \$230m in February — as capital allocation priorities remain focused on expanding Wolfspeed's capacity). Free cash outflow was hence –\$59.7m (cut from –\$97.5m last quarter).

In mid-April, Cree issued \$575m of convertible notes (due 2026) and used part of the net proceeds from the offering to repurchase \$150m of the \$575m of convertible notes (due 2023) issued in August 2018. The repurchase resulted in a gain on extinguishment of convertible notes.

During the quarter, cash and short-term investments hence rose from \$853m to \$1251.7m. Cree has zero balance on its line of credit, and convertible debt with a total face value of \$1bn.

"Our performance in the fourth quarter demonstrates solid execution despite the unprecedented challenges presented by the ongoing pandemic and geopolitical concerns," says CEO Gregg Lowe.

"Fiscal 2020 marked a transition year in our journey to become a global semiconductor powerhouse," says Lowe. In May 2019, Cree began a multi-year factory optimization plan, anchored by an automated 200mm SiC wafer fabrication facility (a \$1bn project over five-plus years), which in September it said would be built in Marcy, NY (Mohawk Valley) to complement the 'mega materials' factory expansion underway at its US campus headquarters in Durham (forming a 'silicon carbide corridor' on the East Coast of the USA). "We also

have a fab expansion going on down in Durham," notes Reynolds. "We're outsourcing the LED silicon carbide and fab operations and upgrading that, replacing it with Wolfspeed capacity. This is going to support some of the capacity ramp at the end of this year [fiscal 2021] and as we see some opportunity into fiscal year 2022. So we expect that expansion to be complete towards the end of this fiscal year." Cree will incur restructuring costs associated with the movement of equipment as well as disposals on certain long-lived assets.

"The COVID-19 situation remains very fluid, making it difficult to assess its impact on our near-term operations and overall demand environment. To account for this, we are again providing a wider-than-usual guidance range for the first quarter of fiscal 2021, along with our underlying assumptions based on what we know today," says Reynolds. "In addition, while we continued to make progress on our 150mm [SiC] MOSFET yields, they are still below expected levels," he adds. "The pandemic certainly has not helped. Access to labs, volumes in the factory: these types of things have been a challenge for us in terms of driving that improvement."

For fiscal first-quarter 2021 (to end-September 2020), Cree targets revenue of \$203–217m, including LED Product revenue of \$96–100m (due mainly to improving supply dynamics) and Wolfspeed revenue of \$107–117m.

"We've largely hit the bottom as it relates to materials [SiC wafers]," Reynolds believes. "As these long-term agreement (LTA) contracts are structured, we maybe expect to see some pickup as you start to move outside of December maybe into the March or June quarter," he adds.

"We are encouraged by the early signs of strengthening demand of the device business [particularly power products] and our ability to improve fulfilment out of our factories while maintaining additional COVID-19 safety protocols we have

in place," says Reynolds.

"Having vertical integration is another key factor and that's certainly helping us from a design-win perspective," notes Lowe.

Device design-ins amounted to \$400m in fiscal Q3 and \$600m in fiscal Q4/2020, respectively. The latter includes an 800V SiC inverter, co-developed with Delphi Technologies plc of London, UK, for battery electric vehicles (BEVs) for vehicle propulsion systems in the Chinese market (adding to the initial design win with a "a premium global automaker" announced with the Delphi partnership in September 2019). This cumulative \$1bn of design-ins in fiscal second-half 2020, despite COVID-19, boosts Cree's SiC device pipeline to about \$10bn (including \$1.6bn via distributor Arrow).

Fiscal Q1/2021 gross margin should be 25–27%, which includes the impact of \$4m of unallocated costs relating to transitioning LED factory operations to Wolfspeed. Wolfspeed gross margin is expected to rise to 35.5–37.5% due to better factory efficiency driven by higher staff attendance, but still below the normal 40%+ as the firm continues to maintain COVID-19 safety procedures. LED gross margin is expected to fall back to 19.5–21%.

Net loss should rise to \$22–26m (\$0.20–0.24 per diluted share).

"While we maintained tight cost controls during fiscal Q4 and did not pay management bonuses or institute merit increases, we will

Fiscal 2021 will be the peak investment year to fund our long-term growth ambitions. We anticipate CapEx of about \$400m to support our capacity investments, most notably the construction of our Mohawk Valley fab and the expansion of our Durham fab and materials factory

increase OpEx in fiscal Q1/2021 [to \$88–89m]," says Reynolds. "This reflects higher spending on R&D projects, including our Mohawk Valley fab process development and resumption of accruing for management incentives. Our operating expenses will gradually increase throughout the year, as our revenue normalizes," he expects.

"We remain firmly committed to our capacity expansion plans to capitalize on what we believe to be a multi-decade growth opportunity for silicon carbide," says Lowe.

"Fiscal 2021 will be the peak investment year to fund our long-term growth ambitions. We anticipate CapEx of about \$400m to support our capacity investments, most notably the construction of our Mohawk Valley fab and the expansion of our Durham fab and materials factory," Reynolds continues.

"There will be some variability in our CapEx and cash flow during fiscal 2021 as it is tied to the percentage of completion of Mohawk Valley [for which vertical construction is now underway, with steel girders installed and walls being installed] and the timing of roughly \$500m of reimbursements we expect to receive in conjunction with our partnership in the State of New York [which involves a SiC prototype line at the State University of New York (SUNY) Albany, to de-risk the Mohawk Valley fab start-up]," he adds. "This level of investment reflects the slightly steeper customer ramp that we have discussed previously and keeps us on track to begin ramping production in the new fab beginning in calendar year 2022 [supporting Wolfspeed's growth, and driving its gross margin towards the targeted 50%]."

Nevertheless, during the period of significant CapEx investment (beyond the end of fiscal 2021), Cree expects free cash flow to still be negative, before an inflection point in the business happening in fiscal 2022 (aided by some of the \$500m reimbursements from the State of New York).

www.cree.com

Mitsubishi develops GaN PA module for 5G base-stations Surface-mount matching circuit shrinks size and boosts power efficiency

Tokyo-based Mitsubishi Electric Corp has developed new technology to realize a gallium nitride (GaN) power amplifier (PA) module for 5G base-stations that offers a combination of a compact footprint (6mm by 10mm) and extra-high-power efficiency exceeding 43% (at the 5G frequency range of 3.4–3.8GHz).

The module, which uses a minimum number of chips in the matching circuit to control high-quality signal output, is expected to help realize 5G base-stations that are widely deployable and highly power efficient. Technical details of the new module were presented at the IEEE International Microwave Symposium (IMS 2020) in August. **High-density mounting technology to realize compact PA module for more widely deployable 5G base-stations**

In 4G base-stations, which do not use massive multiple-input and multiple-output (mMIMO) antennas, power amplifiers use metal-foil transmission lines for the matching circuit. While this lowers power loss

(resulting in high-efficiency operation), transmission lines take up space and make it difficult to realize base stations that are both extra small and extra power efficient. Mitsubishi Electric's new technology eliminates the need for transmission lines in 5G power amplifiers.

The new amplifier module's matching circuit is integrated with surface-mount devices (SMDs), such as capacitors and inductors. By introducing a highly accurate electro-magnetic field analysis method and applying a unique technology for the dense arrangement of SMDs, Mitsubishi Electric was able to reduce the amplifier's size to just one-ninetieth that of conventional power amplifiers (6mm x 10mm rather than 60mm x 78mm).

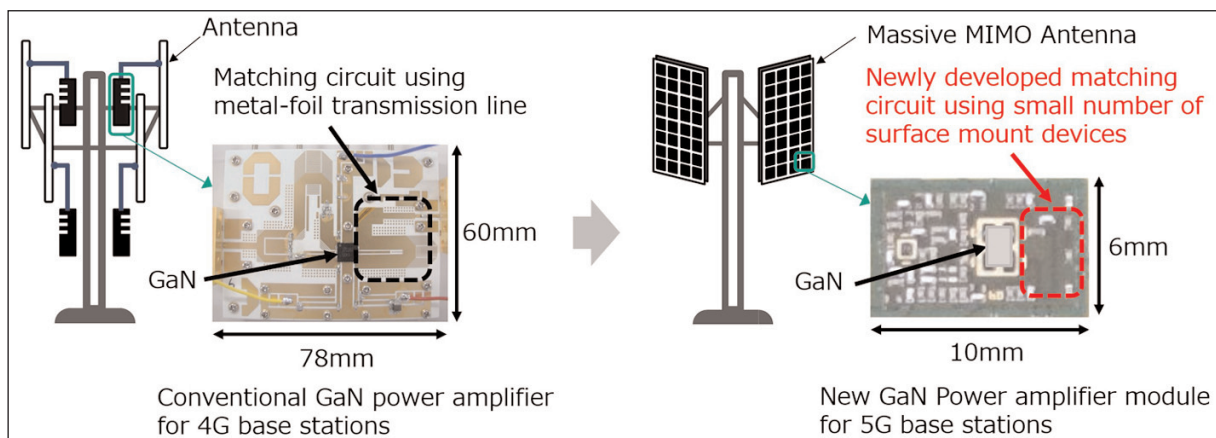
Power efficiency reduces 5G base-station power consumption

Using SMDs for the matching circuit can not only reduce the amplifier's size but also decrease power efficiency because SMDs tend to have high power loss. Mitsubishi Electric's new technology, however, creates a matching circuit using a small number of SMDs. Furthermore, the SMDs offer the same electrical characteristics as those of metal-foil transmission lines. The resulting power amplifier module achieves record power efficiency of 43–48% in the 3.4–3.8GHz bands used for 5G communications (rather than the 39–43% of the conventional power amplifier module).

www.ims-ieee.org

www.merl.com

www.MitsubishiElectric.com/semiconductors



Mitsubishi unveils SiC MOSFET circuit simulation model Model to enable more efficient circuit design for power converters

On 8 July, at the online International Conference on Power Conversion and Intelligent Motion (PCIM Europe 2020), Tokyo-based Mitsubishi Electric Corp presented a new, highly accurate SPICE (Simulation Program with Integrated Circuit Emphasis) model for analyzing the electronic circuitry of discrete power semiconductors (T. Masuhara, T. Horiguchi, Y. Mukunoki, T. Terashima,

N. Hanano and E. Suekawa, 'Development of an Accurate SPICE Model for a New 1.2-kV SiC-MOSFET Device'). The technology is deployed in the N-series 1200V silicon carbide (SiC) metal-oxide-semiconductor field-effect transistor (MOSFET), samples of which begin shipping in July.

The firm says the model simulates high-speed-switching

waveforms almost as well as actual measurements, on a level of accuracy currently believed to be unmatched in the industry, which is expected to lead to more efficient circuit designs for power converters.

Going forward, Mitsubishi Electric expects to add several temperature-dependent parameters to enable its SPICE model to work at high temperature.

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Transphorm's second 900V GaN FET enters high-volume production

Transphorm says that its second 900V GaN FET is now in production.

The TP90H050WS offers a typical on-resistance of 50mΩ with a 1kV transient spike rating and is now JEDEC qualified. The primary target markets are broad industrial and renewable energy, including applications such as photovoltaic inverters, battery charging, uninterruptible power supplies (UPS), lighting and energy storage. Additionally, with the 900V portfolio, Transphorm is working its way up the voltage range to include three-phase applications.

Introduced last year, the TP90H050WS is the firm's second 900V device following the TP90H180PS. The two-chip normally-off power transistor delivers a ±20V gate robustness in a standard TO-247 package, increasing its reliability and designability for power systems. The combination of Transphorm's high-speed GaN and the thermally robust TO-247 package enables systems to reach greater than 99% efficiency while generating up to 10kW of power in

typical half-bridge configurations with bridgeless totem-pole power factor correction (PFC).

"Transphorm's work on its 900V platform illustrates the capability of high-voltage gallium nitride power transistors," says Philip Zuk, VP of technical marketing & NA sales.

"This device gives us the ability to support applications that were not previously accessible to us," he adds. "We have received strong interest when sampling these 50mΩ FETs... Their availability status has shifted now to high-volume production to meet customer demand."

900V GaN in application

Illinois Institute of Technology (IIT) is currently working with the TP90H050WS in an ARPA-E Circuits program that uniquely brought together Transphorm's product with IIT's solid-state switching topologies. The project aims to generate reliable solid-state circuit breaker (SSCBs) for renewable energy microgrids. It includes developing an autonomously operated, programmable and intelligent bi-directional SSCB using the 900V GaN devices.

"Our SSCB project required a non-traditional power conversion solution that not only outperformed mechanical circuit breakers speed-wise, but also helped us reduce power loss," says Dr John Shen, IIT. "Transphorm's GaN technology surpassed our expectations. It delivered the full package. High power density, reliable bi-directionality, and, as the only 900V GaN device on the market, unprecedented power output in a small package," he adds.

900V evaluation board

Transphorm continues to simplify development efforts with its DC-to-AC inverter evaluation board. Designed using four TP90H180PS 170mΩ FETs, the TDINV3500P100-KIT uses a full-bridge topology to support single-phase inverter systems operating at or above 100kHz.

The evaluation board, along with both in-production 900V transistors, are available through distributors Digi-Key and Mouser.

www.transphormusa.com/en/product/tp90h050ws-2

Transphorm trading on OTC market under symbol TGAN

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and makes JEDEC- and AEC-Q101-qualified 650V and 900V gallium nitride (GaN) field-effect transistors (FETs) — has received approval from FINRA (Financial Industry Regulatory Authority Inc) for its common stock to be listed and quoted on the Over-the-Counter (OTC) market. Transphorm is now trading on the OTCQB under the symbol 'TGAN'.

Transphorm's public listing marks "an important milestone in the company's evolution," say co-founders Umesh Mishra Ph.D. (chief technology officer) and Primit Parikh Ph.D. (chief operating officer). "The listing of our common

stock provides both existing and prospective investors with direct access to invest in Transphorm and participate in our future anticipated growth as we continue to scale Transphorm's high-voltage GaN products for power conversion applications across our growing base of customers," they add.

Transphorm's product portfolio consists of both 650V and 900V GaN FETs for high-voltage power conversion applications ranging from 30W to over 10kW, including the industry's first JEDEC (commercial/industrial)- and AEC-Q101 (automotive)-qualified 650V devices and the only 900V GaN device on the market, it is claimed. With an IP portfolio that exceeds

1000 patents, the firm's products offer the quality and reliability (Q+R) backed by field performance of less than 1 failure per billion hours of operation spanning 65W (adapters/fast chargers) products to 4kW (power supplies/UPS) products. The AEC-qualified devices are currently being evaluated by electric vehicle (EV) power conversion suppliers and design partners for design-in on future automotive applications. Transphorm is actively ramping volume production in support of the growing adoption of its GaN power FETs, targeting power adapter, computing, uninterruptible power supply (UPS), data-center and communications infrastructure applications.

EPC doubles performance of 200V eGaN FET family

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA — which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications — says that it is advancing the performance capability while lowering the cost of off-the-shelf gallium nitride transistors with the introduction of its EPC2215 and EPC2207 200V eGaN FETs. Applications include class D audio, synchronous rectification, solar MPPTs (maximum power point trackers), DC-DC converters (hard-switched and resonant), and multi-level high-voltage converters.

The EPC2215 ($8\text{m}\Omega$, $162\text{A}_{\text{pulsed}}$) and the EPC2207 ($22\text{m}\Omega$, $54\text{A}_{\text{pulsed}}$) are about half the size of the prior-generation 200V eGaN devices and double the performance. The per-

formance advantage over a benchmark silicon device is hence even higher. The EPC2215 has 33% lower on-resistance, yet is 15 times smaller in size. Gate charge (Q_G) is ten times smaller than the silicon MOSFET benchmark with the new technology and, like all eGaN FETs, there is no reverse recovery charge (Q_{RR}), enabling lower-distortion class D audio amplifiers as well as more efficient synchronous rectifiers and motor drives.

“This latest generation of eGaN FETs achieve higher performance in a smaller, more thermally efficient size, and at a comparable cost to traditional MOSFETs,” says co-founder & CEO Alex Lidow. “The inevitable displacement of the aging power MOSFET with GaN devices is becoming clearer every day.”

EPC worked in collaboration with Semiconductor Power Electronics Center (SPEC) at University of Texas at Austin to develop a 400V, 2.5kW-capable eGaN FET-based four-level flying capacitor multi-level bridgeless totem-pole rectifier that is suitable for data-center applications using the new EPC2215 200V device. “The advantageous characteristics of eGaN FETs allowed this converter to achieve high power density, ultra-high efficiency, and low harmonic distortion,” comments professor Alex Huang.

The EPC2215 FET is priced at \$2.84 each and the EPC2207 at \$1.49 each (in 2.5k reels), with half-bridge development boards EPC9099 and EPC90124, respectively, both priced at \$118.75.

www.epc-co.com

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GaN Systems & BrightLoop to develop power converters 650V GaN transistors to be used in electric motorsport and aerospace

GaN Systems Inc of Ottawa, Ontario, Canada (a fabless developer of gallium nitride-based power switching semiconductors for power conversion and control applications) and BrightLoop Converters of Paris, France (which manufactures power converters for harsh environments) have announced a strategic partnership to develop AC/DC and DC/DC converter products for electric motorsport and aerospace applications. Leveraging GaN Systems' 650V GaN transistors, BrightLoop is producing a range of converters that are smaller, lighter and more efficient than those currently available in the market, it is claimed.

BrightLoop's most recent family of DC/DC converters, including the 1.9kW, 4.8kW and 9.6kW DC/DC converters designed for hybrid and electric racing, incorporates GaN Systems' transistors and are around half the size and weight of

the firm's first-generation DC/DC converter developed without GaN. BrightLoop says that it continues to make advances using GaN to produce lighter and more compact converters.

BrightLoop's DC/DC converters are now used in many of the Formula E teams and the winning team from 2019. The converter's function is to power all the low-voltage electronics including pumps, lighting and radio. Most recently, the World Sporting Consulting (WSC) Group, the motorsport event and racing promotion organization overseeing the Touring Car Racing (TCR) and ETCR (Electric Touring Car Racing) brands, announced BrightLoop as the sole supplier of DC/DC converters for cars in ETCR (the world's first electric touring car championship, beginning this summer).

Additionally, later next year for aerospace applications BrightLoop

will unveil a high-performance 5kW AC/DC power factor correction (PFC) product, which also incorporates GaN Systems transistors. It operates from an input voltage of 60–180V_{AC} and achieves 96% efficiency.

"The industries which we service require high reliability and performance and GaN is an important piece in helping us achieve that," says BrightLoop's CEO Florent Liffiran. "GaN Systems offers one of the best lines of 650V GaN transistors and, coupled with its unique packaging, allows unprecedented integration," he adds.

"Teaming up with a leader like BrightLoop to demonstrate GaN Systems' products in these very demanding applications proves the value and ruggedness of our GaN in high-reliability power applications," says GaN Systems' CEO Jim Witham.

www.brightloop.fr/en/motorsport

GaN Systems issues 12V Class-D audio amplifier reference designs

Technical manual follows May's launch of evaluation kit

GaN Systems has issued its latest technical manual '12V High-Efficiency Audio Reference Designs using GaN Power Transistors'.

The technical manual was developed in response to the launch of its Class-D audio amplifier evaluation kit in May and from growing customer interest for designs in the 12V market for automotive, marine, powersports and other applications from power system design engineers.

High-quality audio is now a 'must have' across all segments from pro-audio, home-audio and portable audio, says the firm. Class-D audio systems using GaN are not only smaller and lighter but provide better sound quality, it adds.

The new technical manual provides several amplifier designs for 12V input systems using GaN Systems' Class-D audio amplifier evaluation kit, which includes a 2-channel, 200W-per-channel (8_) Class-D audio amplifier and companion 400W continuous power audio-grade switch-mode power supply (SMPS), including:

- Single-Phase and Dual-Phase 12V Boost Converter design supports both a 'direct' +12V to +18V single-rail power supply and a 'boosted' +12V to +18V single-rail power supply configuration;
- Direct +12V to +18V VIN Supply to +/-32V VOUT Boost Converter design supports a 'direct' +12V to +18V VIN supply and allows for the best cost versus

power output trade-off, while maintaining the desired audio performance.

In audio systems, delivering more power and more channels has typically meant driving up size and weight and sacrificing sound quality. With GaN, designers can provide more power, more channels and better sound quality in small, lightweight solutions, says GaN Systems.

The technical manual, as well as the Class D amplifier and power supply kit and white paper 'See, Feel, and Hear the Difference with GaN Class-D Amplifier and Companion SMPS', are available at:

www.gansystems.com/class-d
www.gansystems.com/evaluation-boards/gs-evb-aud-amp12v-gs

OPPO adopts Navitas' GaNFast power ICs

50W Mini is smallest, thinnest, lightest universal fast charger

Navitas Semiconductor Inc of El Segundo, CA, USA says that phone maker OPPO has adopted its gallium nitride (GaNFast) power ICs to enable what's claimed to be the world's smallest, thinnest and lightest 50W fast charger. Measuring only 82mm x 39mm x 10.5mm (34cc) and as light as 60g, it is the first fast charger that is as thin as the phone itself.

The Mini provides the full 50W via OPPO's SuperVOOC fast-charging protocol, or the USB-C Programmable Power Supply (PPS) specification. The device has the flexibility to charge smartphones, tablets and many types of laptop. It's also the same size as the popular Asian 'Wang Wang' brand rice cookie — which has led many to refer to it as the 'cookie' charger.

The 50W Mini SuperVOOC charger was launched on 15 July by OPPO's chief charging technology scientist Jialiang (Jeff) Zhang. "Using gallium nitride devices to drive transformers to very high frequen-

cies has been the dream of all technical workers for many years," he says. "GaN devices will trigger a technological revolution in the field of power supplies."

GaN runs up to 20x faster than silicon and enables 3x more power, which translates to up to 3x faster charging in half the size and weight. GaNFast power ICs monolithically integrate GaN power, GaN analog and GaN logic circuits on the same chip, to enable faster, reliable, efficient operation, says Navitas.

For the 50W Mini, the high-speed performance of GaNFast power ICs opened the door to a new circuit topology — the 'pulsed' active-clamp flyback (ACF), which can tolerate a very wide input voltage range while maintaining a steady output to charge the phone battery. This allows the designer to remove the electrolytic 'bulk capacitor' from the system, which can take up 40% of the total volume. In addition, running 16x faster than traditional

chargers meant that a traditional 50kHz 'wire-wound' transformer with over 20mm height can be replaced with a new high-speed 800kHz, 8mm planar transformer for an extremely low-profile and lightweight form-factor.

The new topology also allows OPPO's proprietary 'direct-charge' approach to reduce wear-out mechanisms and extend phone battery life.

"The 50W Mini is a great example of a next-generation fast charger, where new materials, new architectures and new component technology combine to create a revolution in power electronics," says Stephen Oliver, Navitas' VP marketing & investor relations. "We're at the point where GaN fast chargers have stepped far beyond boutique accessories and are now addressing high-volume, cost-effective and extremely high-performance markets."

www.GaNFast.com

www.navitassemi.com

Navitas and Lenovo partner on first GaNFast 90W fast charger for e-sports mobile phones

Navitas Semiconductor Inc of El Segundo, CA, USA says that the fastest, most powerful charger for Legion e-sports, using GaNFast power ICs, has been launched into mass production and supplied 'in-box' with every Lenovo Legion phone.

Founded in 2014, Navitas introduced what it claimed to be the first commercial gallium nitride (GaN) power ICs. The firm says that its proprietary 'AllGaN' process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with GaN analog and logic circuits, enabling faster charging, higher power density and greater energy savings for mobile, consumer, enterprise, eMobility and new energy markets.

GaN technology enables the 90W dual USB-C output charger to deliver 40% more power and charge 25% faster than previous best-in-class hardware, it is claimed.

Measuring only 66mm x 62mm x 28mm (115cc), the 90W Legion fast charger can charge a 5000mAh battery to 100% in only 30 minutes, enabled by GaNFast technology. Running 20 times faster than the traditional silicon, it improves the power by three times, making the charging speed three times faster, in half the size and weight of silicon chargers.

"It is a great pleasure for us to establish long-term cooperation and explore more new possibilities with Navitas Semiconductor," says

Jin Chen, general manager of Lenovo China's Cellphone Business Department.

"The cooperation with Lenovo is a great milestone because Lenovo is not only a top phone manufacturer but also a top PC device manufacturer," says Yingying (Charles) Zha, VP & general manager of Navitas China. "GaNFast power ICs are a single chip integrating GaN field-effect transistor (FET), GaN digital and GaN analog circuits. It rapidly promotes the commercialization of the new generation of high-frequency, high-efficiency and high-power-density power converters," he adds.

www.GaNFast.com

www.navitassemi.com

SweGaN expands to larger headquarters

150mm GaN-on-SiC epi added for RF & high-power switching devices

SweGaN AB of Linköping, Sweden, which manufactures custom gallium nitride on silicon carbide (GaN-on-SiC) epitaxial wafers (based on a unique growth technology) for telecom, satellite, defense and power applications, has relocated its corporate headquarters to a new facility in Linköping that combines a lab housing several production tools and an administration and office area. Concurrently, SweGaN has added 150mm (6-inch) QuanFINE GaN-on-SiC epiwafers to its product portfolio for RF and high-power switching devices.

The new HQ is just 200m from Linköping University and 10km from Linköping's international airport, enabling easy access for visits by customers and partners. Constructed with meter-thick concrete walls and formerly used by the Swedish Défense Research Agency (FOI), the new facility was opened in first-quarter 2020.

"The facility is a huge contrast

from our previous cramped quarters" says CEO Olof Kordina. "The lab area has incredibly robust 1m-thick walls... [it] houses SweGaN's main operational offices and a lab for production and R&D," he adds.

Also, responding to significant customer demand for larger QuanFINE products, SweGaN has developed the 150mm epi growth process and delivered the new 150mm QuanFINE epiwafers to customers, starting already in Q1/2020. The 150mm epiwafers will boost the manufacturing capacity of GaN-on-SiC RF devices for various applications. "The new QuanFINE 150mm epiwafers are mass-produced in our new high-capacity reactor," notes Kordina.

"Our new product signals that SweGaN is aligning its production capacity and capability closely with our customers' needs for the rapidly expanding 5G networks, defense radars and satellite communication," states chief technol-

ogy officer Jr-Tai Chen. "The 150mm QuanFINE product will also facilitate the development of high-end GaN power devices, where price-performance ratio and reliability are critical elements for our customers."

Highlighting that device manufacturers typically execute over 100 steps during the fabrication of a device, a larger epiwafer — in simple terms — means that manufacturers can produce more devices in the same cycle time, creating clear benefits for return-on-investment.

SweGaN claims that the unique, simplified QuanFINE heterostructure provides superior electrical and thermal properties, including low current dispersion, excellent heat dissipation and high breakdown performance, to ensure the best long-term return-on-investment for customer product development for RF and power applications.

www.swegan.se/technology.html

MACOM launches GaN-on-SiC power amplifier product line MACOM PURE CARBIDE

First two products in range unveiled

At the IEEE International Microwave Symposium (IMS 2020) virtual event (4–6 August), MACOM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and sub-assemblies for analog RF, microwave, millimeter-wave and photonic applications) introduced its new gallium nitride on silicon carbide (GaN-on-SiC) power amplifier product line, branded MACOM PURE CARBIDE. The firm also launched the first two new products in the product line, the MAPC-A1000 and the MAPC-A1100.

"This new product line significantly enhances the capability of our existing RF Power product portfolio,"

says president & CEO Stephen G. Daly. "GaN-on-SiC is a compelling technology and we are excited to begin offering our customers both standard and custom MACOM PURE CARBIDE power amplifier solutions," he adds.

The MAPC-A1000 is a high-power GaN-on-SiC amplifier designed to operate between 30MHz and 2.7GHz and is housed in a surface-mount plastic package. The easy-to-use general-purpose amplifier integrates an input match that simplifies the customer's design-in effort. The amplifier can deliver output power of more than 25W (44dBm) at greater than 50% efficiency from 500MHz to 2.7GHz

when tested in a circuit designed for operation over 2.2GHz simultaneous bandwidth.

The MAPC-A1100 is a high-power GaN-on-SiC amplifier designed to operate up to 3.5GHz. The device is capable of supporting both continuous-wave (CW) and pulsed operations with output power levels of at least 65W (48.1dBm) in an air-cavity ceramic package.

The two new general-purpose amplifier products are suitable for use in avionics, high-power mobile radios, wireless systems and test instrumentation.

www.ims-ieee.org
www.macom.com/products/product-detail/MAPC-A1000

Sino-American Silicon Products partners with AWSC in private placement

SAS subsidiary GlobalWafers to help expedite AWSC's gallium nitride process development

Gallium arsenide (GaAs) IC foundry Advanced Wireless Semiconductor Company (AWSC) of Tainan Science-based Industrial Park, Taiwan has approved a private placement raising a total of NTD\$3496.5m through the issuance of 45,000,000 common shares at a price of NTD\$77.7 per share.

In a board meeting on the same day, Sino-American Silicon Products Inc (SAS) of Hsinchu, Taiwan passed a resolution to participate in the cash capital increase. SAS will subsequently own a 22.53% stake in AWSC, becoming its largest shareholder.

In recent years AWSC has been developing a gallium nitride (GaN) manufacturing process and considers that the quality and stable supply of the upstream wafers are the key factors, leading to the private placement and involvement of SAS as the subscriber. SAS' Hsinchu-based subsidiary GlobalWafers Co Ltd (GWC) is ranked as Taiwan's largest and the world's third-largest silicon wafer manufacturer. In July, GWC jointly established a compound semiconductor research center with Taiwan's National Chiao Tung University to expedite the develop-

ment of the third-generation compound semiconductor material through academic-industrial collaboration.

By forming a vertical strategic alliance, AWSC and SAS expect to collaborate on developing GaN products to supply the key components of 5G, electric vehicles (EVs) and other high-frequency and high-power products and to construct a competitive compound semiconductor industry chain in Taiwan, as well as expanding operational scale and improving operational performance.

AWSC's client base is diversified, covering the world's main design houses and integrated device manufacturers (IDMs) in the radio-frequency (RF) components industry. To capture the business opportunities in 5G, WiFi and 3D sensing vertical-cavity surface-emitting laser (VCSEL) chips, AWSC has con-

AWSC has been developing a GaN manufacturing process and considers that the quality and stable supply of the upstream wafers are the key factors

structed a second plant and will purchase and install equipment. It is estimated that total production capacity will reach 15,000 wafers per month by the end of 2020, while the new plant is scalable and can be expanded to an additional capacity of 20,000 wafers per month, according to market demand. With the introduction of a strategic investor to the private placement, AWSC expects the proceeds of NTD\$3496.5m to fund future capital expenditure.

SAS says that there are two main reasons for it to subscribe to all of the shares in AWSC's NTD\$3496.5m private placement. First, AWSC's expertise in GaAs foundry and focus on developing new products with novel manufacturing processes, as well as recently expanding its client base of IC design houses, has translated into growing sales and profits. Second, AWSC has been exploring GaN, while GWC has been developing gallium nitride on silicon carbide (GaN on SiC), demonstrating synergy by complementing upstream and downstream materials.

www.awsc.com.tw
www.gw-semi.com

Qorvo boosts 2.9–3.5GHz GaN PA by 50% to 150W

Improved range, performance and multi-target tracking in S-band phased-array radars

Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications) has introduced a gallium nitride (GaN) power amplifier (PA) that delivers a 50% increase in power for improved range, performance and multi-target tracking in S-band (2–4GHz) phased-array radars.

The QPA3070 is said to leapfrog

existing industry offerings, providing a first-ever 150W of power for the 2.9–3.5GHz frequency range, 58% power-added efficiency (PAE) and 28dB power gain. Qorvo says that this is possible through its ultra-reliable and highly efficient gallium nitride on silicon carbide (GaN-on-SiC) process technology, which offers superior efficiency, power density and affordability.

The PA delivers these features in a small (7mm x 7mm x 0.85mm) and cost-effective surface-mount package, which enables engineers to design higher-power radar solutions with significant size, weight, power and cost (SWAP-C) improvements, and bring them to market faster.

The QPA3070 PA is available now to qualified customers.

www.qorvo.com/products/p/QPA3070

GaN-on-Si firm ALLOS sells high-power electronics and RF business to AZUR SPACE

ALLOS focusing opto business on micro-LED display market

Azur Space Solar Power GmbH of Heilbronn, Germany has acquired the electronics business of IP licensing & technology engineering firm ALLOS Semiconductors GmbH of Dresden, Germany. AZUR SPACE will use the acquired technology to expand its III-V epitaxy business into the booming market for gallium nitride on silicon (GaN-on-Si) high-power electronics and RF epiwafers. ALLOS will continue its optoelectronics business, focusing on the emerging micro-LED display market.

Azur Space's entry into supplying III-V-epiwafers to the high-power electronics (HPE) market follows several years of working in stealth mode through preparation and investment. Beyond the supply of GaN-on-Si epiwafers, the firm is also engaged in gallium arsenide (GaAs) for the HPE market. "We are the leading provider of high-efficiency multi-junction space solar cells based on III-V epitaxy, with a capacity of 500,000 wafers/year and with multiple MOCVD reactors running 24/7," says Azur's CEO Juergen Heizmann. "Our skills and know-how are a perfect match to the requirements of the quickly emerging III-V HPE epiwafer market," he reckons.

Through investment of over €10m and leveraging its III-V manufacturing expertise and facilities, Azur aims to grow HPE into a second business line. A driving force behind its decision to enter the HPE epiwafer market is the strongly growth in demand for energy-efficient power systems in electric or hybrid vehicles (EV/HEVs), all kinds of charging solutions, renewable energy, server farms, electric motors and many other HPE applications. "With ever increasing electrification and novel applications, the HPE market continues to grow – and the climate challenge is



200mm GaN-on-Si epiwafer example for HPE application to be supplied by AZUR based on ALLOS' technology.

increasing the need for energy efficiency," says Heizmann. "With the two inherently high-efficient III-V technologies GaAs and GaN-on-Si, Azur is addressing the huge demand to contribute to the energy revolution, replacing less efficient technologies."

Since its formation, ALLOS developed its GaN-on-Si epi technology for both high-power electronics and micro-LED applications. "We attained leading positions in two very attrac-

Azur Space's entry into supplying III-V-epiwafers to the high-power electronics (HPE) market follows several years of working in stealth mode through preparation and investment

With the transaction, ALLOS has ceased to service the high-power electronics and RF markets but retains the technology and rights for the optoelectronics market

tive markets. However, customers' required technologies and business models are different in both markets," notes ALLOS' co-founder & CEO Burkhard Slischka. "Due to its skills and resources, Azur Space is the right company to bring the technology into mass produc-

tion and to serve a global customer base," he adds. "Thanks to the booming demand for GaN-on-Si HPE epiwafers, the timing is right as well and, through the deal, we will participate in the long-term market success."

With the transaction, ALLOS has ceased to service the high-power electronics and RF markets but retains the technology and rights for the optoelectronics market. In the latter, ALLOS sees its 200mm and 300mm epiwafer technology as being crucial in meeting the uniformity, crystal quality and manufacturability requirements for novel micro-LED display applications. "We can now fully focus on the rapidly evolving micro-LED market, where our technology provides huge yield and cost advantages throughout the entire value chain and where we have direct access to the companies driving the development," says Slischka.

Azur and ALLOS will complete the transfer of the HPE and RF business and technology by the end of September. In advance of the start of manufacturing, Azur is already open to customer enquiries.

www.azurspace.com

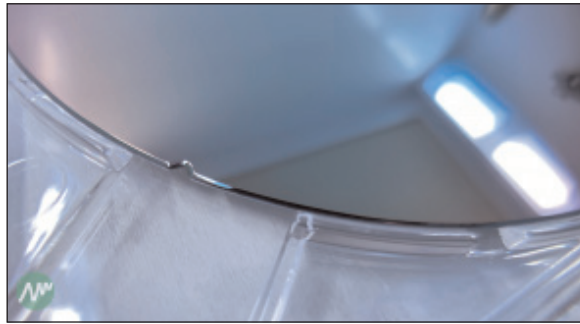
www.allos-semiconductors.com

IVWorks & IntelliEPI partner on MBE-grown GaN epi

AI-based GaN epi technology to combine with large-scale production

IVWorks Co Ltd of Daejeon, South Korea — which was founded in 2011 and manufactures 100–200mm gallium nitride (GaN) epitaxial wafers for RF & power electronics applications — and Intelligent Epitaxy Technology Inc (IntelliEPI) of Richardson, TX, USA — which was founded in 1999 and manufactures molecular beam epitaxy (MBE)-grown epitaxial wafers — have announced a joint partnership on technology and business development for GaN epitaxial materials based on MBE technology. The two firms have been collaborating closely since 2018 on developing production-scale manufacturing of GaN epiwafers by MBE. The framework of the technical and marketing alliances was formalized in 2019.

GaN/Si (up to 200mm) and GaN/SiC (up to 150mm) now available for evaluation
IVWorks, which uses hybrid-MBE technology to produce GaN epiwafers, has developed the Domm machine-learning-based artificial intelligence (AI) epitaxy system, which is said to dramatically improve productivity and scalability. Hybrid-MBE growth is performed with a hybrid nitrogen source of ammonia and plasma for optimal quality and high growth rate. In addition, IVWorks' Domm



IVWorks' 200mm GaN HFET-on-Si epiwafer.

AI technology uses a deep learning algorithm to detect and analyze reflection high-energy electron diffraction (RHEED) patterns, which can monitor crystal growth at the atomic level during MBE growth in real-time. Furthermore, a prediction model is created by learning the validity and correlation of the dataset that integrates classified RHEED patterns, growth conditions, and quality results of the epiwafers. This prediction model can be applied to epiwafer manufacturing to maximize productivity.

IntelliEPI specializes in arsenide (As)-, phosphide (P)- and antimonide (Sb)-based MBE epiwafer production as well as gallium antimonide (GaSb) substrate manufacturing, with products including a range of epiwafers for microelectronics and optoelectronics device applications. IntelliEPI says it will leverage its strength in high-volume

MBE production, equipment modification and component manufacturing to rapidly bring GaN to its product line.

"By partnering with MBE epiwafer production experts such as IntelliEPI, we will accelerate the role we play in supplying high-quality GaN epiwafers to the global semiconductor industry

through the revolutionary AI manufacturing system, while enhancing market penetration and response," reckons IVWorks' CEO Dr Young-kyun Noh. "Thanks to IntelliEPI's long experience of compound semiconductor epiwafer business and large-scale production, we will be able to significantly strengthen competitiveness for the GaN epi business," he adds.

"This partnership will advance MBE GaN growth by combining AI technology from IVWorks and IntelliEPI's large-scale production MBE growth capabilities and related equipment expertise," says IntelliEPI's president & CEO Dr Yung-Chung Kao. "IntelliEPI will work closely with IVWorks to develop a global business based on MBE GaN technology for RF and power device markets."

www.ivwkr.com
www.intelliepi.com

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AXT's Q2 sees stronger-than-expected growth in InP Strategic applications like 5G, data centers and PON strengthening

For second-quarter 2020, AXT Inc of Fremont, CA, USA – which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials – has reported revenue of \$22.1m, up 6.8% on \$20.7m last quarter but down 10.9% on \$24.8m a year ago.

Of total revenue, the proportion from the Asia Pacific was 70% (rebounding from 62% last quarter, which was impacted by Chinese New Year then the Coronavirus-related shutdowns in China, plus reduced operation of the firm's manufacturing facilities in China to limit staff exposure). Meanwhile, North America rose from 9% to 11% and Europe fell back from 30% to 19%. Only one customer reached 10% of revenue, and the top five generated about 30% of revenue (down from 49% last quarter).

Revenue from raw materials joint ventures was \$5.3m, up almost 40% on \$3.8m last quarter and 26% on \$4.2m a year ago.

Substrate revenue was \$16.9m, level with \$16.9m last quarter but down 18% on \$20.6m a year ago.

Germanium substrate revenue was down only slightly from last quarter (which had been the highest since Q3/2018).

"We are encouraged to see growth in strategic applications like 5G, which not only drives our growth but also functions as the catalysts for a number of related technologies. We saw this most clearly in our indium phosphide sales," says founder & CEO Dr Morris Young. "We had expected to take a step back following the strong quarter in Q1, instead demand for indium phosphide was again strong in Q2, allowing us to deliver the high end of our [\$20.5–22.5m] revenue range and outperform earnings. We believe that indium phosphide is being used in 10G and emerging 25G laser interconnects or 5G base

stations. Growth in 5G network construction presents a net new opportunity for AXT. It is beginning to drive both front-haul and back-haul applications and it is also likely to continue to fuel a healthy PON [passive optical network] market, as the two technologies are very closely linked. Further, AXT is well positioned to supply into all of the major supply chain for 5G and its related applications," he adds.

"Growth in 5G is also driving greater bandwidth requirement in the data center. In Q2, we also saw healthy demand for indium phosphide for data-center applications. Silicon photonics technology provides a number of advantages such as lower power consumption and increasing bandwidth and data-transfer capabilities. These, coupled with a surge in consumer demand for high-speed broadband services, are driving hyperscale cloud and large enterprise data centers to deploy optical modules that can support network speeds of 100G and 400G and beyond," says Young.

Regarding, gallium arsenide, as expected, LED applications – particularly automotive – were weak again. "This was offset by the strength in wireless applications, which had good growth," says Young. "Demand is driven by a variety of Internet of Things (IoT) applications, including WiFi devices, and a rebound in Q2 after work stoppages in Q1, and possibly cell-phone devices in China."

Gross margin was 30.6%, down from 34.3% a year ago but up from 26.6% last quarter (and well above the expected mid-20s) due to a combination of the higher revenue, improvements in manufacturing, and strong performance from one of the two consolidated raw material companies.

Operating expenses were \$6.3m, up slightly from \$6.2m both last quarter and a year ago.

Despite \$278,000 in charges from the 25% tariff on importing wafers from China into the USA, net income was \$0.36m (\$0.01 per share), down from \$1.45m (\$0.04 per share) a year ago but an improvement on a net loss of \$0.18m (\$0.01 per share) last quarter (and better than the expected net loss of \$0.01–0.03). However, this includes a grant of \$1.6m from a provincial government agency in China as an award for AXT relocating its GaAs manufacturing facilities from Beijing to its province.

Depreciation & amortization was \$976,000 and capital expenditure (CapEx) was \$4.3m (rebounding from \$2.1m last quarter).

During the quarter, cash, cash equivalents and investments rose by \$3.7m from \$28.8m to \$32.5m.

"Our accounts receivable is higher than it normally might be running, probably due to the Chinese New Year and also the Coronavirus. We worked on it in Q2 and brought the day sales outstanding number down into a more reasonable range and, as a result, the cash increased," says VP & chief financial officer Gary Fischer.

Net inventory rose modestly from \$48.3m to \$49.6m, consisting of 44% in raw materials, 51% work in progress (WiP) and only 5% in finished goods.

"Our net cash burn in 2020 will be similar to our cash burn in 2019, which was only \$3.2m," forecasts Fischer. "Depending on the anticipated growth in the second half, it could initially consume additional cash as we add capacity [more furnaces] driven by growth of course and increased raw materials going into WiP. So we feel we have a strong cash position, which is important in light of the uncertainties resulting from COVID-19," he adds. "We still have an untapped line of credit with Wells Fargo Bank, and a second bank in China is

arranging another line of credit for us... We do not anticipate tapping all of this, but it is a prudent in today's environment."

"The challenges presented by COVID are not behind us," says Young. "We're not experiencing any noticeable disruption in our supply chain of raw materials required to manufacture our substrates. We're able to obtain everything we need. The biggest challenge to productivity remains the limited travel between our teams in China as well as travel restriction to and from China. This has impeded our ability to address certain manufacturing efficiencies in the new facilities as aggressively as we otherwise would like to," he adds.

"The demand environment for our products seems to be improving, with a number of growth drivers intact," notes Fischer. For third-quarter 2020, AXT expects revenue to grow to \$23.5–24.5m, including continued growth in InP. Gross margin should continue to increase. Net profit should be about breakeven. "We won't have the

help in Q3 of a grant in China, but that is offset by increased revenue. Growth is good, so we can deal with that," he adds.

"We view 2020 as a turning point in our business," says Young. "There are clear signs in the marketplace that strategic applications like 5G, data centers and PON are strengthening. In addition, we believe new applications across our portfolio are creating exciting incremental opportunities beginning later this year. Further, with the relocation of our GaAs manufacturing largely completed and production ramping, we are now focusing on elevating our manufacturing and business processes to serve the needs of increasingly sophisticated applications and customer requirements," he adds.

"AXT is now engaged in multiple significant qualification efforts. The first in the area of indium phosphide for data-center applications is expected to begin contributing to our revenue results in Q4," notes Young.

"In addition, we are working

through several other qualifications that can meaningfully impact our business opportunities in 2021," he adds. "Since we announced the qualification of Dingxing by a major consumer in March a number of additional qualification customers have completed their certification and have given us approval to ramp production. These customers are also reporting an improvement in quality and consistency, a benefit of our new state-of-the-art lines. By Q4 we'll have approximately 75% of our gallium arsenide revenue coming out of the new facilities. It represents a significant increase in production volume throughout 2020. Relocation of our gallium arsenide manufacturing facility has evolved from being a risk factor in our business to becoming a significant competitive differentiator for 2020 and beyond."

"In total, we believe we are positioning ourselves for renewed revenue expansion and improving profitability," concludes Young.

www.axt.com

Riber's first-half revenue down 17% year-on-year 35% drop in Systems offset by 39% growth for Services & Accessories

Riber S.A. of Bezons, France – which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells – has reported revenue of €11.6m for first-half 2020, down 17% on first-half 2019's €13.9m. Business shows a good level of resilience despite an environment disrupted by the COVID-19 pandemic and the lockdown measures, which have delayed certain deliveries, says the firm.

System revenue fell 35% by from €8.6m (four production systems) to €5.6m (three systems, including just two production units) after delivery of one production machine was deferred to Q3/2020 following difficulties sourcing certain parts.

Evaporator revenue has fallen further, from €1m to €0.1m, as the

market remains sluggish due to the current lack of investment in the organic light-emitting diode (OLED) screen industry, notes the firm.

Services & Accessories revenue has risen by 39% from €4.3m to €6m, in line with the plan to develop this business.

The proportion of revenue from Asia has rebounded from just 22% to 43%, while the USA has fallen back from 22% to 5% and Europe from 56% to 52%.

The order book at end-June is down year-on-year by 36% from €28.4m to €18.2m. This is largely due to Systems orders have fallen by 42% from €21.5m to €12.5m (comprising seven systems to be delivered in 2020, including two production systems). However, the delay in taking new orders is attributed to

the pandemic and stronger restrictions in granting export licenses. Due to the slowdown in customer activity, Services & Accessories orders were down 18% from €6.9m to €5.7m. Evaporators orders were zero (the same as a year ago).

However, due to a strong portfolio of prospects, Riber expects to see a significant improvement in orders during second-half 2020.

Riber says that, faced with the cautious market environment seen during first-half 2020, it is taking particular care with its operational efficiency and its cost management. However, the firm has been awarded a €6m French government-backed loan, enabling it to continue investing in its R&D projects and production equipment.

www.riber.com

Veeco returns to positive operating cash flow as it completes restructuring

Revenue recovery expected to start in Q3

For second-quarter 2020, Veeco Instruments Inc has reported revenue of \$98.6m, down 5.6% on \$104.5m last quarter but up slightly on \$97.8m a year ago.

"We are seeing broad strength across our product lines, with notable activity in 5G-related RF filter applications with our wet etch and clean products," CEO Bill Miller Ph.D. "Our Scientific & Industrial market continues to perform well," he adds.

The Scientific & Industrial segment comprised 44% of total revenue, led by ion beam system shipments to data-storage customers.

The Advanced Packaging, MEMS & RF filter segment — including lithography and Precision Surface Processing (PSP) systems sold to integrated device manufacturers (IDMs) and outsourced assembly & test firms (OSATs) for Advanced Packaging in automotive, memory and other areas — comprised 22% of total revenue (rebounding from just 8% last quarter), driven by a recovery in sales of advanced packaging lithography systems and upgrades to OSATs and device manufacturers.

The Front-End Semiconductor segment (formerly part of the Scientific & Industrial segment, before the 2017 acquisition of lithography, laser-processing and inspection system maker Ultratech) contributed 18% of total revenue (down from 30% last quarter), resulting from shipments of laser spike annealing (LSA) systems as customers ramped their advanced technology nodes.

The LED Lighting, Display & Compound Semiconductor segment — which includes photonics, 5G RF, power devices and advanced display applications — comprised 16% of total revenue, with metal-organic chemical vapor deposition (MOCVD) and wet etch and clean products sold to a variety of customers.

By region, China has rebounded to 18% of revenue, mainly from MOCVD system and service revenue. Europe, the Middle East & Africa (EMEA) has rebounded further to 26% of revenue, driven by sales to data-storage customers. The rest of the world (including Japan, Taiwan, Korea and South-east Asia) has fallen back further to 26% of revenue (mainly sales of LSA, lithography, and wet etch and clean products). The USA has fallen back to 30% of revenue (including sales of several technologies to various customers).

"Despite the pandemic, we have been executing well thanks to our dedicated global team. All of our sites have been operating at or near normal capacity throughout the quarter," comments Miller.

On a non-GAAP basis, gross margin has fallen back from 44.9% last quarter to 43%. However, this is still up on 37.8% a year ago, aided by manufacturing efficiency improvements, plus a better product mix.

Operating expenditure (OpEx) was \$34.4m, roughly level with \$34.2m last quarter but cut from \$38.5m a year ago. Less travel and other variable expenses were reduced as a result of COVID-19-related restrictions. "We are ahead of schedule on our expense reduction target, and our restructuring activities are now complete," notes chief financial officer John Kiernan.

"Comparing to our financials from a year ago, we significantly improved operating results due to steps taken over the past several quarters such as de-layering the organization to improve accountability and reduce cost, right-sizing the manufacturing footprint, and divesting a non-core product line," says Miller.

Veeco finalized the sale of a non-core product line in April for \$11.4m (of which \$9.7m was paid on closing the transaction, with the

balance to be paid 18 months later). The divestment is part of Veeco's two-phase business transformation (begun last year) that aims to: (1) return the company to profitability (reducing costs and de-layering the company, involving eliminating over 30% of VP-level and above positions — including the chief operating officer role and promoting John Kiernan to chief financial officer at the beginning of this year — while trimming about 7% of staff); and (2) drive growth.

Net income was \$5.5m (\$0.11 per diluted share), halving from \$10.9m (\$0.22 per diluted share) last quarter but a big improvement on a loss of \$3m (\$0.06 per diluted share) a year ago.

"We again posted solid financials driving non-GAAP profitability and strong cashflow from operations, contributing to significant improvements in year-over-year profitability," notes Miller.

Cash flow from operations was \$20m, recovering from outflow of -\$2m last quarter and up on +\$14m a year ago. Capital expenditure (CapEx) has been cut further, from \$4m a year ago and \$1.1m last quarter to \$900,000.

From a working capital perspective, accounts receivable fell from \$84m (higher than normal, due to the timing of when some payments were due flowing just outside the quarter) to \$67m, reducing days sales outstanding (DSOs) from 73 to 61 days. This was partially offset by accounts payable falling from \$36m to \$26m, driving down days payable outstanding (DPO) from 57 to 42 days. Inventories rose from \$130m to \$137m — raising days of inventory (DOI) from 204 to 211 days — resulting from investments made in adding safety stock related to COVID-19 supply-chain actions and in preparation for higher shipments in second-half 2020.

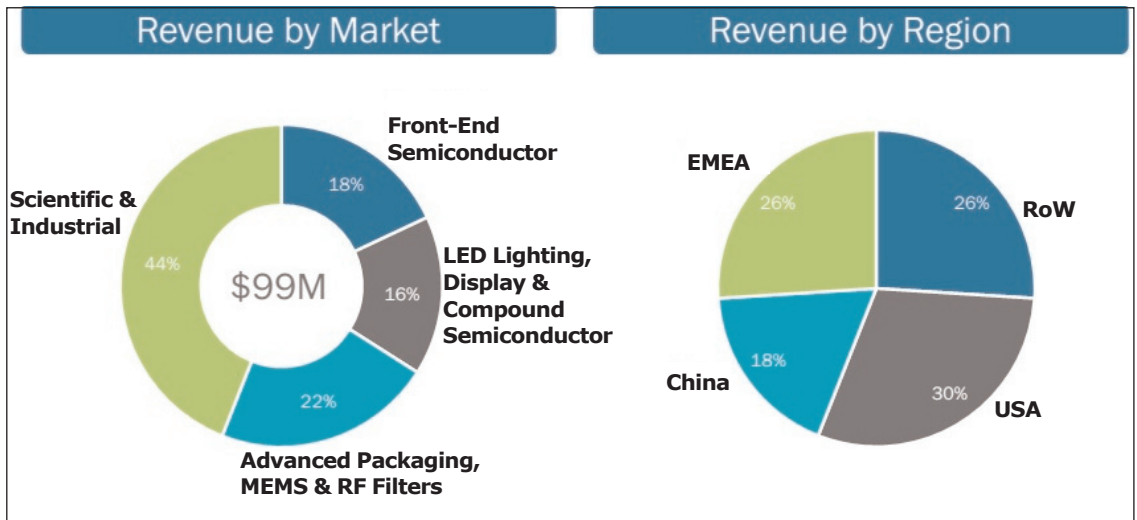
The firm's original convertible debt, issued in 2017, had a face value of \$345m, a coupon of 2.7% and is due in January 2023. In May 2020, Veeco issued \$125m of new convertible notes with a coupon of 3.75% due in June 2027. The firm hence retired \$88m of the January 2023 notes. After transaction fees and the cost of the cap call, Veeco added about \$30m of cash to its

balance sheet, improving liquidity. Convertible debt is now \$382m, comprising two tranches of notes with a weighted average coupon of 3% and a carrying value on the balance sheet of \$317m (up from \$303m last quarter). Annual cash expense on this debt is \$11.6m.

Overall, after raising \$10m from the sale of the non-core product line plus \$30m in net proceeds from the convertible debt offering, plus the \$20m operating cash flow minus the \$900,000 CapEx, Veeco's cash and short-term investments rose during the quarter by \$59m, from \$242m to \$301m.

"Despite the challenges facing the global economy, we are continuing along our transformation path to improve profitability and grow the company," says Miller. "Looking at our 2020 progress to date, we put appropriate actions in place and maintained our resiliency during the global pandemic."

"We executed Phase 1 of our company transformation, which included reducing our expenses, improving gross margin, optimizing R&D spending, and strengthening our foundational businesses which fund our opportunities for growth. We are continuing to work on growing the company, which is the second phase of our transformation," he adds. "We have new products, which are enabling us to grow market share in our existing markets, and we are also extending our core technologies into front-end semi, photonics, and RF applications."



"The market drivers where we participate — such as 5G RF, the cloud, and high-performance computing — are all trending positively," says Miller. "We have strong customer engagements across multiple product lines and have a healthy backlog. Q2 revenue appears to be a low point, and we are optimistic about the second half of the year," he adds.

For third-quarter 2020, Veeco expects revenue to grow to \$100–120m. "We are experiencing challenges closing new orders in China due to the current trade restriction environment, and have lost several orders that we were anticipating," notes Kiernan. "As a result, in the near-term we expect revenue from China customers to decrease as a percentage of our overall revenue."

Gross margin should be 42–44%. OpEx is expected to rise to \$35–37m. "On a go-forward basis, we expect to keep SG&A [sales, general & administrative expenses] as low as possible, but plan to strategically increase R&D in certain areas to support our growth initiatives," says Kiernan. Net income should be \$5–12m (\$0.10–0.26 per diluted share).

"Based on our backlog and strength we are experiencing in data storage and 5G RF filters, we see Q4 revenue trending slightly higher than Q3," forecasts Kiernan.

"In compound semiconductor markets, we continue to make investments in our MOCVD product

portfolio," says Miller. "Our latest product, the Lumina system, deposits arsenides and phosphides and is based on our TurboDisc technology, providing excellent film uniformity, yield and low defectivity over long campaigns. The Lumina system is designed for applications such as indium phosphide lasers for datacom and telecom, 3D sensors for facial recognition and world-facing applications, LiDAR for autonomous vehicles, and red LEDs for micro-LED displays. This system is performing well and we have received excellent feedback from our top tier-1 customer," he adds.

"Our Propel platform is a 300mm-capable, fully automated, single-wafer reactor also based on our TurboDisc technology for best-in-class film quality, and it can be clustered with multiple chambers for high-volume manufacturing. The Propel system deposits gallium nitride for applications such as 5G RF GaN power amplifiers, power electronic devices used in wireless charging, and micro-LED. We see opportunity in the compound semiconductor markets where our Lumina and Propel systems would be an ideal fit," Miller continues.

Despite this, near-term visibility remains limited, especially in China where the regulatory environment is providing headwinds. "Customers are weighing options between buying equipment from US suppliers like Veeco or alternative non-US suppliers when available," Miller notes.

www.veeco.com

Germany's IHP Microelectronics chooses Veeco TurboDisc MOCVD platform

Silicon-based microelectronics to be developed for wireless and broadband communications

Veeco Instruments Inc of Plainview, NY, USA says that its TurboDisc metal-organic chemical vapor deposition (MOCVD) platform has been selected by German government-funded research institute IHP Microelectronics of Frankfurt (Oder) for the development of high-performance, silicon-based microelectronic technologies. IHP has expertise in silicon-based systems, high-frequency integrated circuits, and technologies for wireless and broadband communication.

"Their selection of our TurboDisc platform is validation of its exceptional process capabilities and ability to help enable game-changing technologies," says Veeco's chief technology officer Ajit Paranjpe.



"We look forward to continuing to support IHP as they continue to innovate and execute on their mission."

The TurboDisc platform has been the foundation of Veeco's decades of expertise in compound semiconductor materials science. The proprietary technology is a key enabler

for demanding arsenide/phosphide (As/P) and gallium nitride (GaN) applications that are critical for next-generation communications infrastructure and highly efficient microelectronic devices. TurboDisc provides production ramping due to faster recipe capabilities up to 50% quicker than when using traditional batch tools.

In addition, the platform also includes Veeco's IsoFlange and SymmHeat technologies, which provide homogeneous laminar flow and uniform temperature profile across the entire wafer, delivering uniformity and repeatability.

www.veeco.com

www.ihp-microelectronics.com

Siltronic orders Aixtron MOCVD system to ramp GaN-on-Si epiwafer production

Fully automated AIX G5+ C system to be shipped in Q4/2020

To strengthen its position in the emerging gallium nitride on silicon (GaN-on-Si) market, silicon wafer manufacturer Siltronic AG of Munich, Germany has ordered an additional metal-organic chemical vapor deposition (MOCVD) system to be used for the production of 150mm and 200mm GaN-on-Si epiwafers for radio-frequency (RF) and power applications.

For shipment in fourth-quarter 2020 from deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany, the AIX G5+ C system is fully automated and equipped with in-situ cleaning and a cassette-to-cassette transfer module for high epitaxial stability and low defect ratios. The Planetary Reactor includes Aixtron's Auto-Feed Forward (AFF) individual on-wafer temperature control and has an 8x150mm and 5x200mm configuration.

RF, power devices and circuit are enabling high switching frequencies and efficient energy management with high power densities. These features are required for rapidly growing applications such as data centers, renewable energy and the next generation of wireless networks (5G), notes Aixtron. Alongside the smaller form factor, GaN-on-Si is a suitable candidate for rapid charging and car electrification.

"The GaN-on-Si market is an important future growth field. We have been very active early on within the GaN Power Program of imec, the research institute for nanoelectronics, to provide our customers with leading-edge performance," says Siltronic's CEO Dr Christoph von Plotho. "To position ourselves competitively in this market, we need a reactor which allows us to deliver our customers

with the best performance epiwafers while ramping up volume at lowest costs. We see the AIX G5+ C as the ideal solution in this regard both for GaN Power and RF devices to serve the growing applications and megatrends. The use of GaN-on-Si technology also makes a central contribution to improving the energy balance through decarbonization," he adds.

"GaN-on-Si technology has made impressive breakthroughs in the last years and devices are rapidly gaining acceptance into both consumer and industrial products for power and RF application," comments Aixtron's president Dr Felix Grawert. "The AIX G5+ C is a fully mature platform dedicated to these advanced applications," he adds.

www.siltronic.com

www.aixtron.com

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Aixtron's revenue rebounds by 37% in Q2

Orders up by 56% year-on-year, driven by demand for power electronics, optical datacoms and LEDs

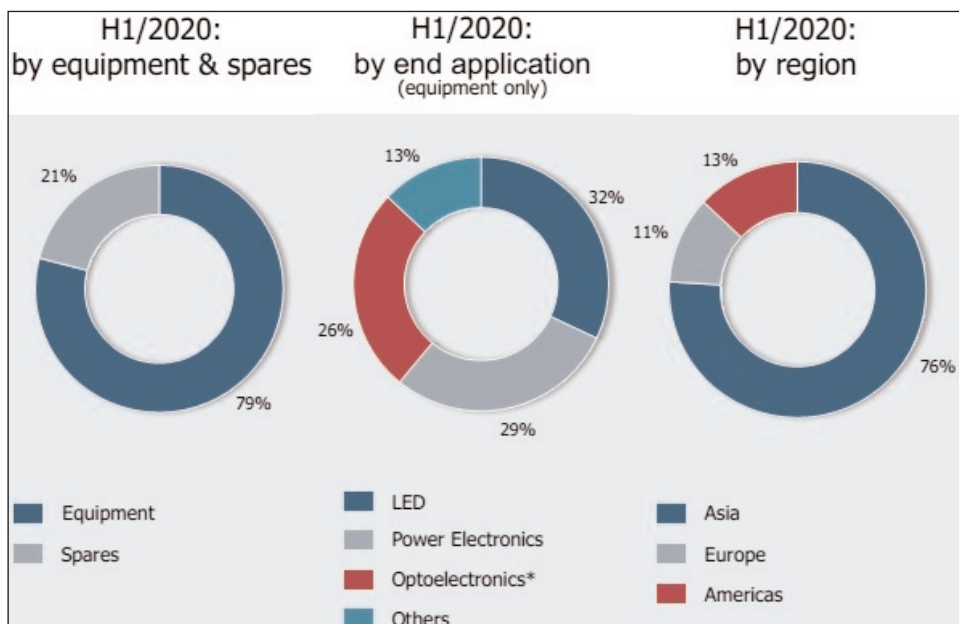
For first-half 2020 deposition equipment maker Aixtron SE of Herzogenrath, near Aachen, Germany has reported revenue (including spare parts and service) of €97m, down 27% on €132m a year ago as expected, remaining on track despite the COVID-19 pandemic as operations continued running without interruption due to early counter-measures and a stable supply chain. In fact, second-quarter 2020 revenue was €56m, down 11.5% on €63.3m a year ago but up 37% on €41m in Q1. The main drivers of demand are the growing markets for gallium nitride (GaN) and silicon carbide (SiC) power electronics, lasers for ultra-fast optical data transmission, and specialty LEDs for display and disinfection applications.

Equipment revenue in particular (excluding spare parts and service) has fallen by 28% from €106.5m (81% of total revenue) in first-half 2019 to €76.4m (79% of revenue) in first-half 2020. However, although still down on €50.3m (79% of revenue) in Q2/2019, quarterly revenue has rebounded by 56% from €29.9m (73% of revenue) in Q1/2020 to €46.5m (83% of revenue) in Q2.

On a regional basis, 76% of first-half 2020 revenue came from Asia, 13% from the Americas and 11% from Europe.

Despite regional coronavirus-related lockdowns (first in China and later in Europe and the USA) which led to the postponement of delivery and commissioning of a few systems at the request of customers, Aixtron has continued to show strong profitability and return on investment.

Gross margin fell only slightly from first-half 2019's 40% to 39% in first-half 2020, as the dip in Q1 to 36% (following delayed final acceptances of metal-organic chemical vapor deposition systems,



due mainly to pandemic-related travel restrictions) was compensated by a rebound to 41% in Q2/2020 (level with Q2/2019), aided an improved higher-margin product mix.

The significant increase in revenue and margins between April and June resulted in a significantly improved operating result (earnings before interest and taxes) from -€1.1m in Q1 to €3.3m in Q2. Overall, first-half 2020 EBIT of €2.2m (EBIT margin of 2% of revenue) compared with first-half 2019's €19.1m (margin of 14%).

R&D spending was €28.6m (30% of revenue) in first-half 2020, up 13% from first-half 2019's €25.3m (just 19% of revenue). R&D for leading-edge technologies is focused on the development and improvement programs for next-generation MOCVD systems — for all application markets — and the organic light-emitting diode (OLED) qualification project, where Aixtron has achieved some critical specifications and is working intensively on achieving further specs. In parallel, the firm is commencing discussions with the customer on the next steps in the joint OLED program.

As a result of the lower revenue

and margin in first-half 2020, net profit was just €2.5m, down from €15.8m in first-half 2019. However, the quarterly net result recovered from -€0.8m in Q1 to €3.3m in Q2/2020.

However, due to Aixtron's further build-up of inventories by €12.2m in first-half 2020 (from €79m to €85m during Q1 then €91.2m during Q2) in preparation for increasing shipments in second-half 2020, operating cash flow was -€7.9m in Q2 and hence -€3.2m in first-half 2020 (compared with +€1.8m in first-half 2019). Capital expenditure (CapEx) was €3.4m in Q2 and hence €5.2m in first-half 2020 (cut from €6.6m in first-half 2019). Free cash flow in first-half 2020 has therefore worsened from -€4.8m in first-half 2019 to -€8.4m in first-half 2020 (with -€11.3m in Q2 outweighing +€3m in Q1).

Cash and cash equivalents including short-term financial investments (bank deposits with a maturity of at least three months) hence fell during Q2, from €300.8m to €288.6m.

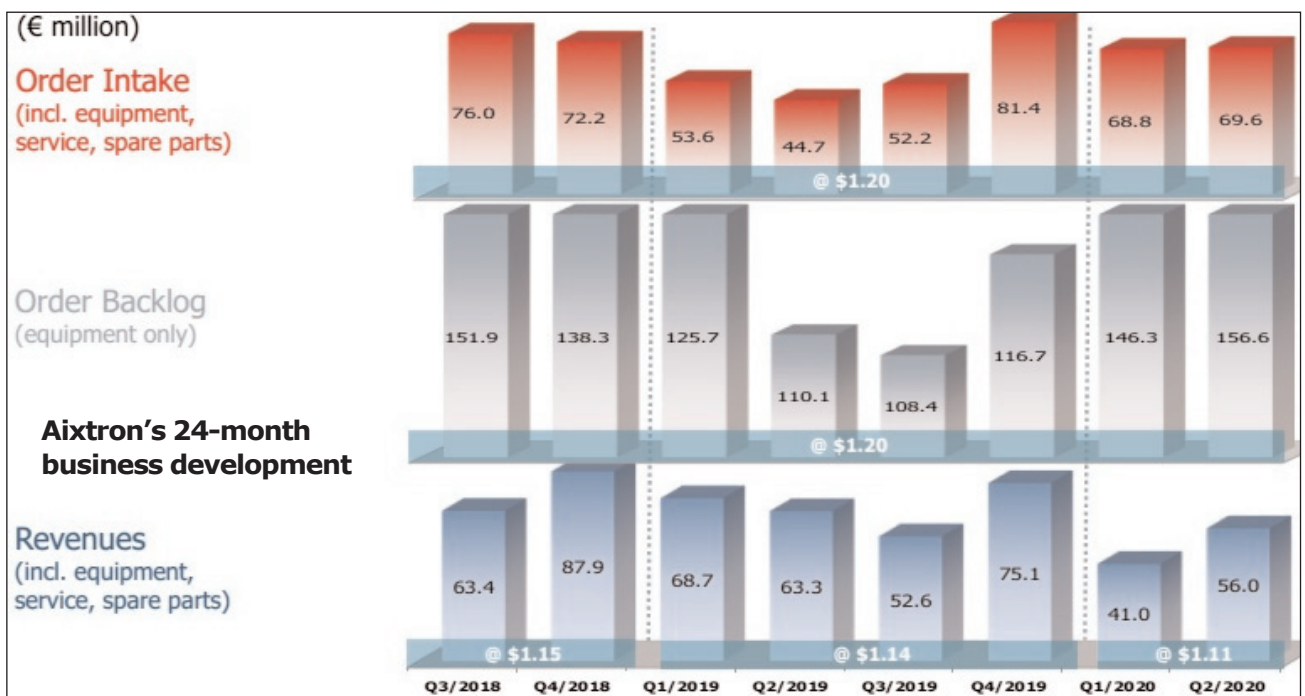
Total orders (including spares & services) have risen further, from €68.8m in Q1 to €69.6m in Q2/2020 (up 56% on €44.7m in Q2/2019), taking first-half orders to

€138.4m (up 41% on €98.3m a year ago) driven by continued strong demand from the power electronics, optical data communications and LED sectors.

Aixtron hence enters second-half 2020 with

strong order backlog (equipment only) of €156.6m, up 7% on €146.3m at the end of Q1/2020 and up 42% on €110.1m at the end of first-half 2019.

Based on (1) the solid order backlog, (2) the currently estimated low impact of the COVID-19 pandemic and (3) the budget exchange rate of \$1.20/€, Aixtron expects order intake for full-year 2020 to grow to €260–300m (up from €231.9m in 2019).



Based on equipment order backlog (convertible into 2020 revenue) of €130m at the end of first-half 2020, joined by €11–51m of expected order intake shippable in 2020 plus an estimated €22m of spares & services revenue, for full-year 2020 Aixtron still expects revenue of €260–300m, with gross margin of 40% and EBIT margin of 10–15%.

"In the second half of the year, our business should grow much more dynamically again," comments

president Dr Bernd Schulte. "We expect revenues to grow strongly in the third quarter and then again in the final quarter," he adds.

"The renewal of our product portfolio is making good progress," believes president Dr Felix Grawert. "With our new products we will be able to better support our customers in their growth in future markets such as 5G mobile network expansion and e-mobility".

www.aixtron.com

Azur orders system for entry into GaN-on-Si electronics epi market

Azur Space Solar Power GmbH of Heilbronn, Germany is using an Aixtron AIX G5+C MOCVD system for its expansion into the market for gallium nitride on silicon (GaN-on-Si) high-power electronics (HPE) and radio frequency (RF) epiwafers.

Azur, which develops and produces multi-junction solar cells for both space and terrestrial concentrated photovoltaic (CPV) applications, is a long-standing Aixtron customer and has been using the AIX 2800G4-TM and 2600G3 systems for its space solar application.

Featuring in-situ cleaning, a cassette-to-cassette wafer handler and Auto-Feed Forward (AFF) individual on-wafer temperature control, the now ordered fully

automated AIX G5+ C system guarantees what is claimed to be unmatched epitaxial stability and low defect ratios. Further, Aixtron's Planetary Reactor enables increases in productivity and performance via the highest throughput, lowest cost of ownership and highest yield performance, the firm adds.

The MOCVD platform can produce 150mm and 200mm epiwafers.

With the establishment of a second business line leveraging its III–V manufacturing expertise, Azur Space is positioning itself in the fast-growing market for GaN epiwafers for power electronics and RF applications. With the capacity to operate at higher frequency and in a smaller form factor, demand

for these epiwafers is driven mainly by the need for energy-efficient power systems, rapid charging solutions, renewable energies, server farms or the next generation of wireless networks (5G).

"Market entry will be a challenge. However, our more than 25 years of experience in III–V epitaxy technology with development and mass production is ideally complemented by Aixtron's system, so we have a very good starting position," reckons Azur's CEO Jürgen Heizmann. "Aixtron's state-of-the-art Planetary Reactor provides us with the excellent quality level of our epiwafers required to capture the future market for high-performance electronics."

www.azurspace.com

EVG completes construction of Cleanroom V building at corporate headquarters

Capabilities of NILPhotonics and Heterogeneous Integration Competence Centers strengthened

EV Group — a supplier of wafer bonding and lithography equipment for semiconductor, micro-electro-mechanical systems (MEMS) and nanotechnology applications — has completed construction of its new Cleanroom V building, which nearly doubles cleanroom capacity at its corporate headquarters in St Florian, Austria, and will be used for product and process development, equipment demonstrations, prototyping and pilot-line production services. The Cleanroom V building, which is part of a €30m investment announced last year, officially opens in August.

The new Cleanroom V building is directly connected to EVG's existing cleanroom and applications lab, and provides about 620m² of additional Class 10 cleanroom floor space. The new building also houses a modern training center with multiple dedicated areas for training customers and field service engineers on EVG equipment platforms. As part of the expansion investment, the existing cleanroom and applications lab facility have also been upgraded, including the creation of redundant systems to ensure the highest availability and new safety features.

Enhancing centers of technology excellence

The added capacity afforded by the new Cleanroom V building will strengthen the capabilities of EVG's NILPhotonics Competence Center and Heterogeneous Integration Competence Center, which provide process development services, and serve as open-access innovation incubators for customers and partners across the microelectronics supply chain. EVG says that, through these centers of technology excellence, it helps customers to accelerate technology development, minimize risk and develop



The new Cleanroom V facility nearly doubles cleanroom capacity at EVG's HQ.

differentiating technologies and products through the implementation of nanoimprint lithography and heterogeneous integration, respectively, while guaranteeing the highest IP protection standards that are required for working on pre-release products.

The new cleanroom is "arguably on par with some of the most technically advanced cleanrooms in Europe," says corporate technology development & IP director Markus Wimplinger. "This new facility will greatly enhance our ability to

The existing cleanroom and applications lab facility have also been upgraded, including the creation of redundant systems to ensure the highest availability and new safety features

co-develop future applications and technologies with our customers," he adds. "In particular, we see it benefiting our competence centers, which have seen particularly strong activity and demand. The unique services offered at our NILPhotonics and Heterogeneous Integration Competence Centers enable our customers and partners to shorten development cycles and create novel products in these critical application areas."

EVG reckons that, with its technology competence centers and strong customer partnerships, it is uniquely positioned to provide uninterrupted process development services and support for its customers. At the same time, its local installation and support teams as well as remote support capabilities enable continuous installation and service operations of EVG's equipment.

www.evgroup.com/products/process-services

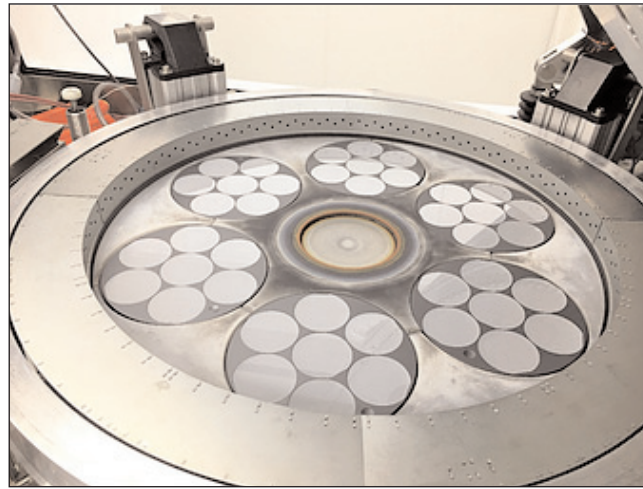
BluGlass commissions largest RPCVD system

Retrofitted AIX-2800G4 capable of 6x6"- or 42x2"-wafer deposition

BluGlass Ltd of Silverwater, Australia (which was spun off from the III-nitride department of Macquarie University in 2005) has commissioned the largest remote-plasma chemical vapour deposition (RPCVD) manufacturing platform to date. The BLG-500 commercial-scale RPCVD system has been retrofitted onto a modern-generation manufacturing platform, the AIX-2800G4 metal-organic chemical vapor deposition (MOCVD) system from Germany-based Aixtron SE. The commissioning forms a major part of BluGlass' commercial scaling activities.

BluGlass is commercializing RPCVD in the global laser diode, LED and micro-LED industries. The firm's patented hardware and processes offers semiconductor manufacturers unique performance advantages due to RPCVD's low temperature and hydrogen growth conditions.

Completed in collaboration with Aixtron, the new planetary deposition platform is capable of deposition on 6 x 6-inch wafers or 42 x 2-inch wafers. This is several times the capacity of the previous largest RPCVD system, the BLG-300,



capable of 1 x 6-inch or 19 x 2-inch wafer deposition. Now named the BLG-500, the new platform features dual axes of rotation to improve deposition uniformity of the thin-film properties across revolving and rotating wafers.

"The BLG-500 is the culmination of an enormous two-year design and build project to transform our unique R&D-scale technology to one with commercial manufacturing capability," says managing director Giles Bourne. "This step is critical to the future success of the company. The 500 is not an incremental next generation of our RPCVD platform, it is instead a radically re-engi-

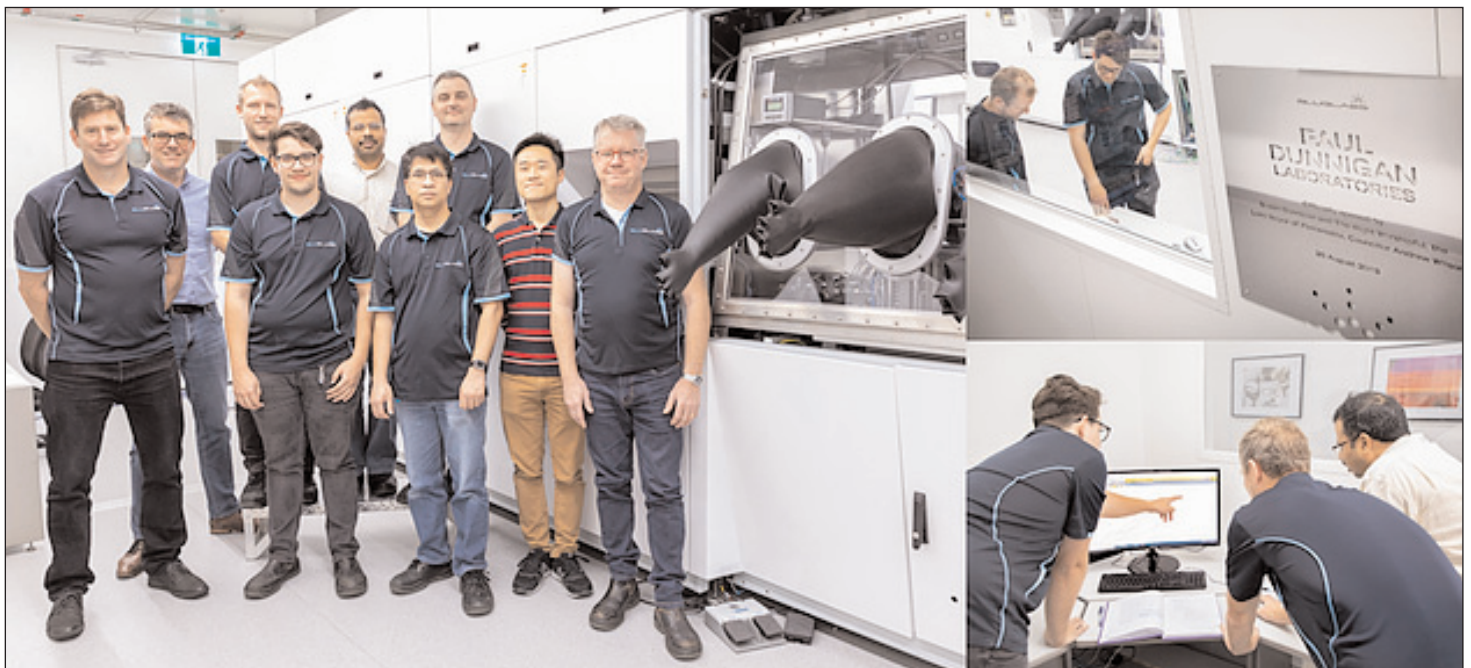
neered design to deliver ultra-precision uniformity and deposition quality at commercial scale".

The commissioning of the commercial-scale RPCVD system is a "significant technology demonstration milestone in the commercialization of the low-temperature growth platform," says the firm. The

BLG-500's large scale will significantly increase BluGlass' foundry customer output capacity at its Silverwater manufacturing facility. Performance testing and optimization on the new system continues before the BLG-500 can start to contribute to the product development roadmap for laser diodes and LEDs.

"I'd like to acknowledge the incredible work and dedication of the BluGlass team, specialist consultants and the collaborative support from Aixtron, all of whom have helped deliver this important milestone," concludes Bourne.

www.bluglass.com.au



MEI Wet Process Systems renamed RENA Technologies North America

RENA Technologies North America LLC (RENA NA) is the new name of the former MEI Wet Process Systems & Services LLC, the US-based wet-chemical specialist for semiconductor equipment headquartered in Albany, Oregon that was acquired in December 2019. RENA NA now becomes a member of Germany-based RENA Group.

The acquisition is part of RENA's strategy to further diversify its product and service portfolio as a global provider of wet-chemical equipment for surface processing. RENA NA's specialties include patented solutions for wet-processing applications, including metal lift-off, advanced wafer etching, wafer stripping and wafer cleaning solutions. Process control is provided through proprietary IDX Flexware process control software.

The firm reckons that, with RENA NA, it now has much better access to the US market for the whole product range. RENA can now offer machine and process solutions for



wet-chemical processing as MEI adds a complementary product portfolio, while both companies have regional strengths that together form a global player in the semiconductor market. RENA's main markets are Europe and Asia, while RENA NA is said to be an established market leader in the US semiconductor sector.

Synergistic sales, service and process technology teams have already joined forces to support the global customer base. Together, RENA now covers all wet-chemical process steps, from prime wafer processing to MEMS, silicon carbide (SiC) and semiconductor process-

ing including plating technology, batch immersion, batch spray, and single-wafer applications. RENA NA says that its new Inception single-wafer processing system shows the rapid progress in widening the firm's product platform.

"The long list of integration items are already complete just six months after closing," notes RENA's CEO Peter Schneidewind.

"The first phase of integration is now complete," says RENA NA's CEO Ed Jean. "Joining RENA takes us to the next level, where we can offer our customers an improved portfolio plus best-in-class, global support," he adds.

"Even under these challenging conditions, both RENA and RENA NA are on track to reach our order book plan for first half year, which shows the joint focus on customer needs," Schneidewind concludes.

www.rena.com

RENA launches Inception single-wafer processing system for wet clean, etch and strip

RENA Technologies has added to its portfolio of wet processing platforms by launching the Inception single-wafer platform, which enables the transition from R&D to pilot-line production and is capable of all semiconductor wet processes such as clean, etch, strip and dry.

The first Inception has already been shipped to a major compound semiconductor customer that will utilize its capabilities in an acid clean process.

"If all you have is a hammer, everything looks like a nail," says Ed Jean, CEO of RENA Technologies NA. "Batch immersion, batch spray and single-wafer tools all have their place in the wet process world. Most equipment suppliers however offer a one-size-fits-all

approach, trying to 'hammer' your application into the only platform they offer. With the addition of the Inception single-wafer tool to our product lineup, RENA provides the appropriate platform for any wet clean, etch or strip application," he adds.

"The Inception single-wafer platform provides our customers, who perform tests in beakers and pie plates, the consistency to develop a process of record and automate their process," says Heath Phillips, RENA Technologies NA Spray Product Manager.

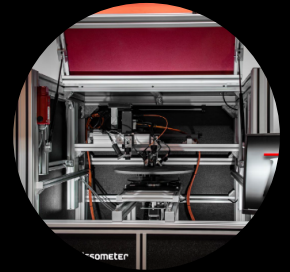
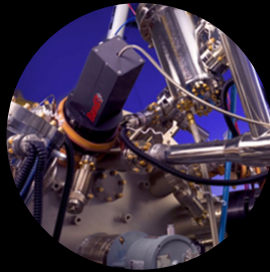
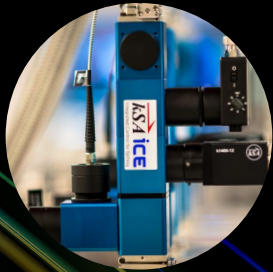
Features of the Inception single-wafer tool include:

- FEoL front-end-of-line (acid) and BEoL back-end-of-line (solvent) processing applications;

- automated wafer handling (manual load optional);
- wafers up to 200mm diameter and masks up to 7 x 7;
- dual moving spray arms with separate chem lines;
- stationary bottom spray nozzles for DI and N2;
- etch uniformity exceeds batch systems;
- standard dual-tank design providing multi-step processing (4-tank optional);
- single or dual load ports;
- low utilities consumption;
- small footprint – 36" width x 83" height x 76" length;
- highly flexible software enabling rapid process development.

www.rena.com/en/products/semiconductor

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AMEC launches Prismo HiT3 MOCVD system for DUV LED mass production

Prismo platform gains ultra-high-temperature AlN process capabilities

Shanghai-based Advanced Micro-Fabrication Equipment Inc China (AMEC) has debuted its Prismo HiT3 metal-organic chemical vapor deposition (MOCVD) system, which is engineered to mass produce deep-ultraviolet light-emitting diodes (DUV LEDs).

The system is the newest addition to AMEC's portfolio of Prismo MOCVD products, which are already in use for the production of blue LEDs. With a maximum reactor chamber temperature of 1400°C, the tool enables the growth of aluminium nitride (AlN) and high-aluminium component materials with what is claimed to be excellent process performance, superior wafer uniformity and low defectivity. Built for high throughput, the system can process up to 18 2-inch epitaxial wafers per run, with extendibility to 4-inch wafers.

Early customers include China-based Jason Semiconductor Co Ltd, a producer of DUV LEDs for home applications, medical instruments and products used for scientific research.

DUV light has been used for decades as a disinfectant for industrial and consumer applications. It works by disrupting the DNA of



bacteria and viruses, and killing their reproductive capabilities. The emergence of pathogens like SARS, MERS and COVID-19 has increased demand for DUV LED products with the wavelength power to destroy new micro-organisms. The existing state-of-the-art for this purpose is the DUV LED, with emission wavelengths of 260-280nm.

AMEC says that the Prismo HiT3 system's novel chamber design features a range of enabling technologies to grow AlN at extremely high process temperatures and delivers high yield. An automatic vacuum transfer system prevents particle generation and keeps defects low. The process is automated and offers what is claimed to be a longer mean time between maintenance (MTBM) than the closest competitive tool, further maxi-

mizing uptime and production capacity.

"Today, we're seeing the benefits of DUV LEDs in real time, with the technology now an important tool used to destroy harmful pathogens," notes Jason's chairman Jian Kang. "As the science of DUV LED technology continues to advance, we are proud to operate at the leading edge with products to disinfect public environments, as well as the home. AMEC's Prismo HiT3 system can meet the high-volume/low-cost-of-ownership manufacturing imperatives for DUV LEDs," he comments.

"The Prismo HiT3 system contains all the innovative features of our proven Prismo platform, now with new ultra-high-temperature process capabilities for AlN-based DUV LED applications," says executive VP & chief operating officer Dr Zhiyou Du. "Jason is an early user. The company is known for stretching the limits of LED technology and creating products that benefit human health," he adds. "We're glad that our equipment solutions are helping them meet their technology and cost goals for next-generation DUV LEDs."

www.amec-inc.com

Monocrystal ranked 'Outstanding' by Osram

New growth cycle fueled by mini-LEDs and micro-LEDs

Monocrystal Inc of Stavropol, Russia (which manufactures large-diameter sapphire substrates and ingots for LEDs) says that it was assigned the 'Outstanding' rank in a 2019 supplier evaluation conducted recently by LED manufacturer Osram Opto Semiconductors GmbH of Regensburg, Germany.

Monocrystal demonstrated a "high level of strategic cooperation, good quality of communication, service and support, outstanding quality and logistics performance, as well as

good technical know-how and willingness to follow Osram's requirements".

"Monocrystal dominates the 6-inch sapphire wafer market, with more than 50% market share," says the firm's CEO Oleg Kachalov. "Our wafers are essential for enabling applications with evolving technical requirements like mini- and micro-LED," he adds.

"The LED industry is about to enter a new growth cycle fueled by the mini-LED and micro-LED appli-

cations," notes Osram's Material Procurement senior director Stephan Maurer. "As competition increases, we will continue to develop new products exceeding the needs of our customers," he adds. "Aligning our supply chain to our R&D and cost-reduction programs will be crucial for our success. Monocrystal has been our integration partner for three years. Since then, we have had Monocrystal involved in several of our R&D [projects]."

www.monocrystal.com

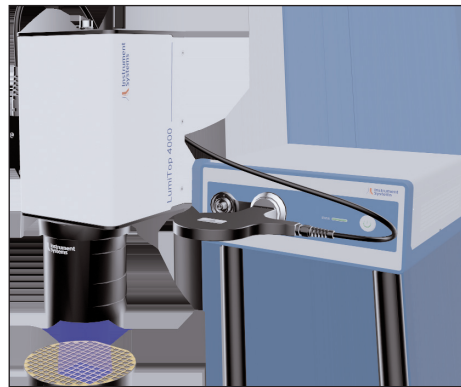
Instrument Systems offers comprehensive optical wafer testing for μ LEDs at single test station

Efficient, simultaneous testing of thousands of μ LEDs on wafer with a 2D camera system from LumiTop series

Instrument Systems GmbH of Munich, Germany is offering a unique camera-based measurement solution for μ LED wafer testing that generates two-dimensional, pixel-resolved optical analyses within given cycle times. The LumiTop 4000 has a resolution of 12MP and can detect the smallest of defects and inhomogeneities on the wafer. Due to a 100mm macro lens, the camera enables fast parallel inline analysis of all μ LEDs on a wafer at a single test station.

μ LEDs are renowned for being an exacting new display technology. They are smaller than 100 μ m and have exceptional optical properties that enable the manufacture of displays with a broad color gamut, high contrast and extremely high resolution. Particularly in mass production, they present new challenges for the optical quality tests required at every stage of production, i.e. including wafer level. This cannot be achieved with standard tests, i.e. sequential testing.

For efficient testing of thousands



of μ LEDs on a wafer, the test procedure must be parallelized. The manufacturer is thus required to simultaneously contact as many μ LEDs as possible. In addition, the optical inspection should be fast and accurate, and performed synchronous to the production flow. This functions only with a 2D measurement using specifically calibrated instruments to prevent measurement errors.

The innovative 2D camera systems of the LumiTop family from Instrument Systems offer a fast solution that has become established in production. The 2D cam-

era is combined with a high-end spectroradiometer that serves as a simultaneous reference measuring instrument for highly accurate readings. The LumiTop family includes a special version for test objects of all sizes. The new LumiTop 4000 with a 100mm lens is particularly well suited to μ LED wafer testing. With a field of view (FoV) of approximately 1.0cm by 1.4cm it can measure many thousands of μ LEDs in parallel with a minimum pixel size as low as 30 μ m. A hardware trigger synchronizes the camera with the given cycle time. The CMOS sensor offers a particularly broad dynamic range.

The accompanying comprehensive LumiSuite software enables wide-ranging analyses of the readings, including the preparation of a pixel intensity map or color map. Algorithms can search for and mark pixel defects according to selectable criteria. LumiTop systems are ideally suited for use in the laboratory and production line, says the firm.

www.instrumentsystems.com/sid2020

Nitride files amended complaint in US against Digi-Key UV LED products alleged to have infringed patent

Japan's Nitride Semiconductors Co Ltd (which was spun off from Tokushima University in 2000 and claims to have developed the first highly efficient ultraviolet light-emitting diode) says that it has filed an amended complaint against global electrical components distributor Digi-Key Corp in the US District Court for the District of Minnesota, alleging that UV LED products supplied by various LED companies — such as Lite-On Semiconductor, Luminus Devices, and Vishay Intertechnology — are infringing its UV LED patent.

Nitride first filed a patent infringe-

ment suit against Digi-Key in the US District Court for the District of Minnesota in September 2017.

With professor Shiro Sakai at Tokushima University, Nitride Semiconductors developed highly efficient UV-LEDs as early as 2000. It has continued to manufacture and sell UV-LEDs, and says that it has invested in R&D to develop and enhance its UV-LED technology.

To protect its UV LED patented technology, Nitride initiated its patent enforcement campaign starting in 2017. Subsequently, earlier this year a judgment was issued by the US District Court for

the Northern District of California against RayVio Corp for infringing Nitride's UV LED patent, as well as validating patent. The US Patent & Trademark Office has also confirmed the validity of the key claims of Nitride's patent in its final judgment on an Inter Parte Review case filed by RayVio.

Nitride says that, since it considers its intellectual property rights to be vitally important company assets, it will take any action necessary to enforce its patent against infringers in any country and uphold its patents and other intellectual property rights.

www.nitride.co.jp

ALLOS and KAUST co-developing high-efficiency nitride-based red LEDs on silicon

KAUST to grow red LED stack on ALLOS' GaN-on-Si-buffer layers

IP licensing & technology engineering firm ALLOS Semiconductors GmbH of Dresden, Germany is collaborating with professor Ohkawa and his team at Saudi Arabia's King Abdullah University of Science and Technology (KAUST) to realize high-efficiency nitride-based red LEDs on large-diameter silicon substrates.

The teams are addressing fundamental issues such as the large lattice mismatch and the quantum-confined Stark effect (QCSE), which are preventing the adoption of red nitride-based LEDs for practical industry usage. In particular, to reduce manufacturing complexity and cost for the emerging field of micro-LED displays there is strong demand to enable the growth of red LEDs on large-diameter wafers in addition to the established blue and green LEDs in the nitride system.

In this context, by using local strain compensation and a modified metal-organic chemical vapor deposition (MOCVD) reactor design, Ohkawa and team have developed an indium gallium nitride (InGaN)-based red LED stack with low forward voltage of less than 2.5V and high efficiency.

The team has already grown red LEDs on sapphire substrates and gallium oxide (Ga_2O_3) substrates

('633-nm InGaN-based red LEDs grown on thick GaN underlying layers with reducing in-plane residual stress', D Iida et al, Appl. Phys. Letters 116, 162101 (2020));

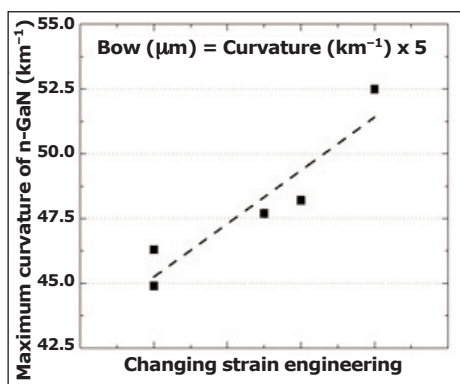


Figure 1: ALLOS' in-line process control enables $\pm 5\mu\text{m}$ bow range.

'Demonstration of low forward voltage InGaN-based red LEDs on $\beta\text{-Ga}_2\text{O}_3$ substrates', D Iida et al, Appl. Phys. Expr. 13, 031001 (2020)).

For potentially higher-performance red LEDs by using strain engineering at the wafer level — in particular for large-wafer diameters — the team is now extending its work to silicon substrates by collaborating with ALLOS. This also enables huge advantages for mass production due to the scalability up to 300mm diameter and thus processability in silicon process lines. For micro-LED displays — in particular monolithically integrated micro-displays for augmented reality (AR) application, for example — this is another important enabler, says ALLOS.

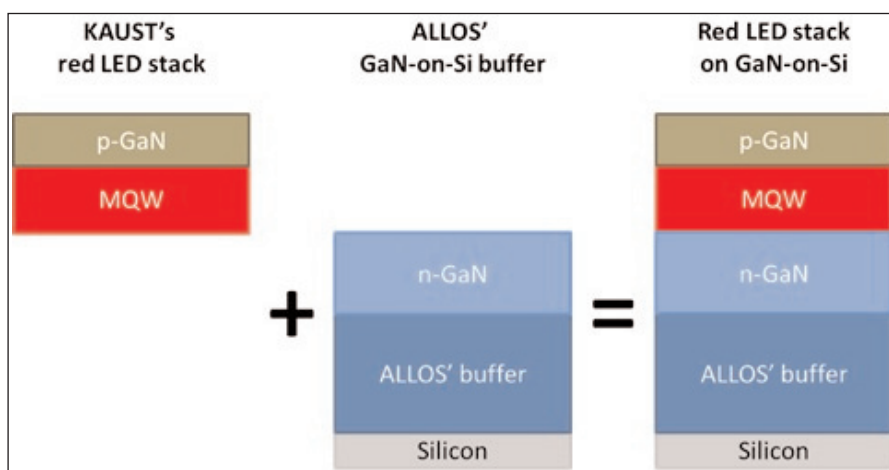


Figure 2: In the collaboration, ALLOS' established methods of integrating different LED stacks with its high crystal quality and strain-engineering buffer technolog.

The firm says that the unique high crystal quality of gallium nitride on silicon (GaN-on-Si) technology with a threading dislocation density (TDD) of $\sim 2 \times 10^8 \text{cm}^{-2}$ is the pre-condition to achieve at least the same performance red LED as on sapphire. Furthermore, ALLOS' precise strain-engineering - which enables excellent emission uniformity for blue and green LED as well as flat wafer bow for 200mm and 300mm diameters - is used to optimize the growth conditions for red LED.

Both teams combine their unique technologies to handle strain and optimize crystal growth conditions for GaN-on-Si and red LEDs. To this end, the KAUST team will grow its red LED stack on top of ALLOS' GaN-on-Si-buffer layers, which will be fine-tuned during the collaboration to optimize the performance of KAUST's red LED stack:

"From personal experience I am aware how challenging it is to realize high-efficiency red LED," says ALLOS' co-founder & chief technology officer Dr Atsushi Nishikawa. "From ALLOS' side we can provide our established blue and green high-quality GaN-on-Si micro-LED epiwafers of up to 300mm diameter. Furthermore, we see the opportunity that our unique strengths in strain engineering can contribute to improved red LED performance," he adds.

"Our team has developed a high-efficiency red LED stack and continues to push the boundaries in this very challenging field," says Ohkawa. "When talking to ALLOS, we of course were interested in the scalability up to 300mm — but the capability to control the strain engineering so precisely and in such a large process windows promises more progress for red LED performance."

www.allos-semiconductors.com
www.kaust.edu.sa

Compound Photonics unveils IntelliPix all-in-one micro-display technology platform

Micro-LED-focused, constant-current platform with MIPI interface enables pixel-to-pixel uniformity for real-time AR applications

Compound Photonics US Corporation (CP, also known as CP Display) of Vancouver, WA, USA, a provider of compact high-resolution microdisplay technologies for augmented reality (AR) and mixed reality (MR) applications, has unveiled its IntelliPix Microdisplay Technology Platform for micro-LEDs featuring multiple video pipeline and system integration innovations addressing power optimization, latency and bandwidth use (all key barriers to the true AR experience needed for widespread consumer adoption).

CP claims that it is now the only player in the market to introduce a micro-LED-focused, constant-current (iDrive) technology platform with a MIPI interface that enables pixel-to-pixel uniformity in the emerging sub-5 μ m-pixel micro-LED display space for AR/MR near-eye applications.

"At its core, CP departs from the traditional full-bandwidth, raster-based pipeline dating back to the birth of NTSC toward a data flow optimized for real-time AR applications," says co-CEO & chief technology officer Edmund Passon. Given that AR imagery, in general, does not fill the entire field of view, only transmitting active-pixel data results in the ability to drastically increase performance for those active pixels while reducing overall display sub-system power. "We have again revolutionized the drive architecture to manage images intelligently at the pixel level," he adds. "IntelliPix also integrates its real-time video pipeline and programmable drive scheme with adjustable constant-current iDrive or voltage-driven (vDrive) options into a single-chip solution. The overall technology advancement in IntelliPix enables up to 100x faster modulation while consuming 4x to 12x less system power across the

video pipeline versus CP's previous platforms while unlocking the real potential for micro-LED and future phase-based holographic systems."

Legacy video pipelines transport full frames/bandwidth to the display subsystem where every transition moves electrons, reducing battery life. OnDemand Pixels (the key component of IntelliPix) optimizes the drive of pixels based on both content and use environment. This proprietary feature provides significant power saving as the system modulates video parameters across the field of view, dependent on user activity. This active-pixel-based

approach also enables the bursts of increased performance by making more bandwidth and higher refresh rates available for demanding content regions. Additionally, when combined with eye tracking, OnDemand Pixels opens the door to foveated rendering with attendant benefits for optimized processing on the SoC/AP.

Single-chip design eliminates traditional distinctions between display pixel drive and display driver IC functions to reduce the overall physical volume and power consumption. Combined with CP's integration capabilities for mLED array bonding, device packaging & testing and optical engine designs, the IntelliPix platform opens up new possibilities for meeting or exceeding AR display size reduction demands

IntelliPix's 100x modulation speed increase takes full advantage of the faster response time of micro-LEDs, which can be applied to higher bit depth, refresh rates, or the ability to add multiple focal planes. For phase-based holographic systems, the 100x increase enables complex waveforms providing near-zero ripple. The platform also retains all key features of CP's current NOVA display drive architecture to achieve low latency and on-the-fly frame-by-frame control to avoid image lag.

The IntelliPix single-chip design eliminates traditional distinctions between display pixel drive (back-plane) and display driver IC (DDIC) functions to reduce the overall physical volume and power consumption. Combined with CP's integration capabilities for micro-LED array bonding, device packaging & testing and optical engine designs, the IntelliPix platform opens up new possibilities for meeting or exceeding AR display size reduction demands.

Available for demo in early 2021, the IntelliPix Microdisplay Technology Platform is customizable for resolutions up to 2048 x 2048 and beyond at pixel pitches from ~1.5 μ m and upwards. CP is presently engaged with micro-LED technology partners and eco-system providers for initial early integration.

During Display Week 2020 (3-4 August), CP's head of business & corporate development Mike Lee presented IntelliPix at the SID Business Conference and discussed with the display community about how the technology platform presents opportunities for the industry to accelerate mainstream AR adoption.

www.compoundphotonics.com
www.plesseysemiconductors.com/products/microleds

ROHM launches high-accuracy blue-green LEDs for Color Universal Design applications

Improving visibility for people with color vision deficiency

ROHM Semiconductor of Kyoto, Japan has launched the 1608-size SMLD12E2N1W and SMLD12E3N1W high-accuracy blue-green chip LEDs, which support the adoption of Color Universal Design (CUD) in a variety of applications such as fire alarm system indicator lights, industrial equipment warning lamps and public transportation information displays.

Over 200 million people with P-type and D-type color deficiencies around the world find it difficult to distinguish between red and green, possibly resulting in information being inaccurately conveyed — depending on the combination of colors used.

Furthermore, since color vision can vary from person to person, it is difficult to perceive how different people see certain colors, which can be very inconvenient and also problematic as other people may not notice this deficiency.

As a result, there is a growing need to implement Color Universal Design that takes into account the various types of color vision in order to deliver information accurately to as many people as possible.

While there are a variety of devices that transmit information using red and green colors, adopting blue-green and orange or yellow will make it easier for people with P-type or D-type color deficiency and difficulty to distinguish between red and green colors. As such, the color scheme is important for conveying information using LEDs.

ROHM has hence developed blue-green chip LEDs with special wavelengths, suitable for implementing Color Universal Design in a wide range of devices, utilizing a vertically integrated production system from the wafer fabrication stage.

The SMLD12E2N1W and SMLD12E3N1W are the first 1608-size LEDs to be certified by the Japanese non-profit Color Universal Design Organization

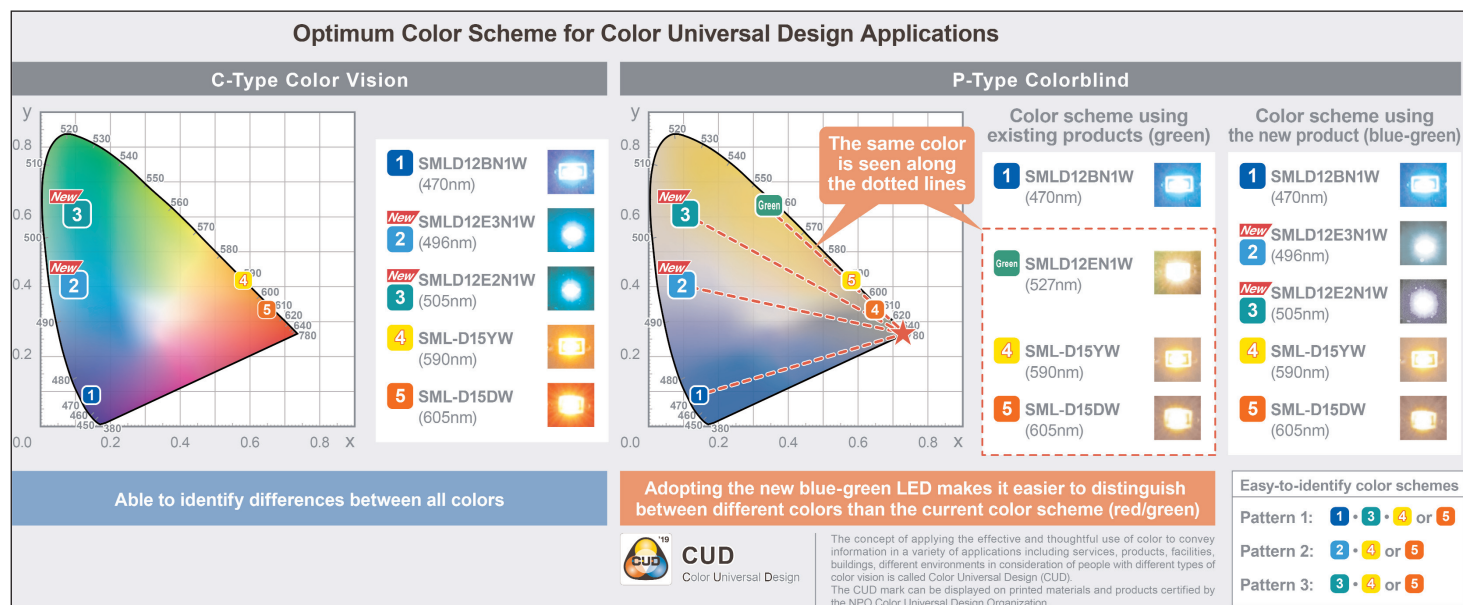
(CUDO). By acquiring CUD certification for the SMLD12E2N1W and SMLD12E3N1W blue-green LEDs, it is possible for people with various types of color vision and sensitivities to accurately identify color patterns that include the use of ROHM's blue LED (SMLD12BN1WT86, λ_D : 470nm) and warm color LEDs (SML-D15YW, λ_D : 590nm; SML-D15DW, λ_D : 605nm) — making them suitable for Color Universal Design applications.

In addition, adopting a new resin has allowed ROHM to significantly extend LED lifetime (by 20-fold) while reducing the degradation of light intensity compared with conventional epoxy resins and improving the mold strength (by 25-fold) compared with the silicone resins while providing superior reliability. The firm also offers AEC-Q102-qualified products that ensure worry-free use in automotive systems and industrial equipment demanding extreme reliability.

ROHM aims to continue to strengthen its lineup by developing high-reliability LEDs that deliver greater convenience and safety.

www.rohm.com

Adopting blue-green and orange or yellow will make it easier for people with P-type or D-type color deficiency and difficulty to distinguish between red and green colors



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Giving our customers the lead through mass production of high performance TCOs, metals and DBRs with the best cost of ownership is our daily business. However, leveraging our know how to help customers develop new more demanding processes or ramp up production of next generation Optoelectronic devices like Micro LED or OLED on CMOS is where we add value too, and in this edition of LAYERS you can also read about solutions we can offer for exactly that.

Stefan Seifried, Head of BU Optoelectronics

Lumileds' new LUXEON HL2X boosts field-usable lumens More usable light targets streetlights and outdoor area fixtures

LED manufacturer Lumileds LLC of San Jose, CA, USA has launched the LUXEON HL2X LED, suitable for roadway lighting and sports lighting fixtures, in an industry-standard package.

"With 318+ lumens at 700mA and 85°C, LUXEON HL2X delivers more 'field-usable lumens,'" says senior product marketing manager Alvin Yeoh. "Lumileds attention to beam angle, field angle, color over angle and optical efficiency gives engineers more lumens to work with and better quality of light than has

been previously possible. The result is an outdoor fixture with leading optical properties and exceptional efficiency," he claims.

The LUXEON HL2X enables customers to meet the requirements of DLC Premium V5.1, enabling fixture manufacturers to access the best utility rebates while reducing energy consumption, says Lumileds. The low thermal resistivity substrate (<2.6°C/W) shrinks the size of heatsinks and simplifies the thermal design of fixtures. Superior color over angle (<40 pts)

ensures high uniformity in the application.

The LUXEON HL2X is available in a standard 3.5mm x 3.5mm (3535) 3-stripe footprint, which is optically compatible with the LUXEON TX LED, enabling a low-touch upgrade.

The LUXEON HL2X is immediately available across a wide range of color temperatures of 2700-6500K and 70CRI (color rendering index); 80CRI and 90CRI options for indoor applications will be introduced in the coming months.

www.lumileds.com/luxeonhl2x

Lumileds enhances LUXEON 2835 Color Line performance

Lumileds LLC of San Jose, CA, USA has introduced a boost in luminous flux to its LUXEON 2835 Color Line LEDs.

Featuring 11 colors and three white correlated color temperatures (CCTs), the LUXEON 2835 Color Line now delivers a 25% brighter red-orange and 6% brighter red, which are especially key to the performance of emergency vehicle lights and color-tunable lamps. "Emergency vehicle lamps typically combine red-orange, blue, PC amber and white," notes product marketing manager LP Liew. "The dramatic

increase in flux of red-orange will boost the performance of these designs," he adds. "Additionally, lamp and fixture designers now have even higher-performing and cost-effective options."

Like the high-power LUXEON C, CZ and Z Color lines, the LUXEON 2835 colors range from far red to royal blue and includes PC lime, mint and amber colors to achieve what is claimed to be the greatest number of color points in LED lighting. Flux of the red-orange LUXEON 2835 LED is 25lm when driven at a current of 120mA and reaches 38lm at 200mA (claimed

to be the highest in the industry). Color mixing in lamps, emergency vehicle and architectural fixtures benefits from the widest color selection.

Lumileds says that its Color LED portfolio has flawless color mixing due to the equal focal length on every LED, which eases integration with secondary optics. To further speed the design and manufacturing of new lamps, the LUXEON 2835 Color Line features identical polarity on every color, simplifying PCB design.

www.lumileds.com/products/color-leds/luxeon-2835-color-line

Lumileds unveils complete LUXEON 3030 HE LED range

Lumileds LLC of San Jose, CA, USA has unveiled its complete line of LUXEON 3030 HE LEDs, targeted at a wide variety of fixture applications including architectural, office, high-impact retail, and indoor area illumination.

"The LUXEON 3030 HE is built to achieve outstanding efficiency and productivity, superior quality of light with 2 and 3 SDCM options, while simplifying design and production of new fixtures," says Mei Yi, product marketing manager of Mid Power Products at Lumileds. "The LUXEON 3030 HE LEDs were



engineered for exacting control of forward voltage within 0.1V and enable easy driver design and uniform power output."

The new LUXEON 3030 HE portfolio builds on the LUXEON 3030 HE

Plus introduced in September 2019. The expanded line now includes LEDs with a minimum color rendering index (CRI) of 80 and 90 across a color temperature range of 2700-6500K. Luminous efficacy is 195lm/W at 4000K and 80CRI or 151lm/W at 2700K and 90CRI, when driven at 65mA.

The 3.0mm x 3.0mm surface-mount package facilitates rapid design-in for spotlights, panel lights, troffers and linear luminaires.

www.lumileds.com/products/mid-power-leds/luxeon-3030-he

Lumileds boosts LUXEON 5050 LED's flux and efficacy Increasing demands of streetlights and high-bay fixtures addressed

With streetlights and high-bay fixtures requiring high flux and efficacy to meet the ever increasing demands for system efficiency and energy cost reduction for these applications, Lumileds of San Jose, CA, USA says that its LUXEON 5050 LEDs has been upgraded in both flux and efficacy. Typical performance is now 675lm with 172lm/W in full bin shipments and higher performance is available.

"LUXEON 5050 LEDs are already installed in millions of fixtures

worldwide, and this performance enhancement extends the energy efficiency and long-life benefits that cities and business require," says product marketing manager Mei Yi. "Our manufacturing capabilities allow us to offer even higher typical performance — 684 lumens with our two lowest Vf bins — for customers that require extraordinary light output."

With color stability and consistency also being critical factors in most outdoor and sports arena

types of applications, LUXEON 5050 LEDs are hot-color tested to ensure the LEDs fall within the specified color bins at typical application conditions of 85°C. LUXEON 5050 with the round light-emitting surface (LES) is offered in color temperatures of 2200–6500K at 70, 80 and 90 color rendering index (CRI), and with 6V or 24V options. It is a suitable drop-in replacement for emitters with industry-standard 5.0mm x 5.0mm footprint.

www.lumileds.com/products/

BluGlass wins AMGC grant to develop large-scale plasma deposition source

Collaborations with AKELA Laser and Objective 3D to complete project

BluGlass Ltd of Silverwater, Australia (which was spun off from the III-nitride department of Macquarie University in 2005) has been awarded a AUS\$250,000 matched-funding innovation grant by the Advanced Manufacturing Growth Centre (AMGC) to manufacture more efficient plasma deposition sources for the firm's 300 series remote plasma chemical vapor deposition (RPCVD) manufacturing platforms.

The project aims to design and produce a high-density, large-scale plasma source to produce ultra-precision uniformity for the deposition of high-value semiconductor devices such as laser diodes and next-generation LEDs. The unique distributed plasma source design aims to provide a scalable, uniform platform suitable for the retrofit of even the largest industrial systems, accommodating multiple wafers up to 8" diameter. The grant project will specifically focus on a new plasma source for the BLG-300 system to upgrade its capability for uniform deposition on a single 12" wafer or multiple 4" wafers. The 4" wafer size will be key for the firm's laser diode product roadmap.



"BluGlass is a great example of an Australian manufacturer embracing the competitive advantages borne from a commitment to deep research and development," comments AMGC's managing director Dr Jens Goennemann. "Its technology promises laser diodes that are higher performing and more efficient. It's a game-changing development that delivers better-value products to the market."

BluGlass is collaborating with several industry partners and organizations including AKELA Laser on laser diode device packaging & testing and Objective 3D on

metal 3D design, testing and rapid prototyping of critical plasma source components for the successful delivery of the project.

The project "aims to give RPCVD a number of new competitive edges for commercialization," says

BluGlass' chief technology officer Dr Ian Mann. "The new design will also support scalability on virtually any MOCVD platform in the industry and be capable of hybrid (both MOCVD and RPCVD growth) in a single deposition chamber, enabling for the first time the advantages of each growth technique in a single platform".

The project is expected to improve advanced manufacturing capabilities in Australia and help to facilitate the revenue growth of BluGlass' direct-to-market laser diode business.

www.bluglass.com.au

ams' VCSELS used in Ibeo's solid-state LiDAR for Great Wall Motor

Level-3 automated driving on production vehicles targeted from 2022

The vertical-cavity surface-emitting laser (VCSEL) technology of high-performance sensor designer and manufacturer ams AG of Premstaetten, Austria is a core component of the newly developed ibeoNEXT solid-state light detection & ranging (LiDAR) sensor system of Ibeo Automotive Systems GmbH of Hamburg, Germany, which is to be used in Level-3 automated driving on production vehicles at Great Wall Motor Company starting in 2022.

LiDAR systems emit laser pulses and then evaluate the light reflected from various objects. From the time-of-flight (the time it takes for the reflected laser pulse to reach the sensor again), software calculates the distance to the surrounding objects. Modern LiDAR systems can process many laser pulses in parallel. The result is a 3D model of the environment that recognizes crash barriers and road markings as well as cars, cyclists and pedestrians, their position and movement. In combination with a long range and high

spatial resolution, this accuracy is a key advantage of LiDAR technology. Unlike other LiDARs, the solid-state solution means no moving beam-steering mechanism, such as mechanical or micro-electro-mechanical system (MEMS) mirrors, bringing significant benefits in terms of reliability and complexity.

Leveraging 20 years of automotive experience — including ISO 26262 — and a footprint in 3D consumer electronics, ams' VCSEL array has what is claimed to be best-in-industry power density, conversion efficiency and pitch. The firm says that its R&D provides enhancements around integrated functional-safety standard and eye-safety features, leading to a highly robust technology. The specially designed VCSEL manufacturing technology allows for great flexibility in layout design regarding the number of pixels, their size and pitch, and specific addressability patterns. ams also says that it has the required capabilities to co-develop emitter, current driver

and optics. The firm's high-power VCSELS can differentiate in scan and flash applications as they are less sensitive to individual emitter failures, are more stable in temperature ranges, and are easy to integrate.

Through coupling Ibeo's expertise in both software and technology, the flagship ibeoNEXT solid-state LiDAR sensor is claimed to offer best-in-class large detection range, high resolution and large vertical angle. The sensor will be used in Great Wall vehicles to enable a highway pilot to drive semi-autonomously at Level 3, as a milestone towards fully automated driving.

ams and Ibeo commenced joint LiDAR development in 2018 with the aim of providing solid-state LiDAR to the automotive market first for advanced driver assistance systems (ADAS) and moving toward autonomous driving adoption.

www.ams.com/lidar

www.ibeo-as.com

Ushio mass producing new single-mode 670nm red lasers Extra 10°C operating margin suits use without active cooling

Ushio Inc of Tokyo, Japan has begun mass production of the HL67191MG and HL67192MG 670nm-wavelength red laser diodes (LDs). Providing optical output power of 15mW (continuous-wave operation) and 30mW (pulsed operation), the single-mode lasers deliver high-temperature performance (up to 70°C) within Ushio standard MG (TO-56) compact 5.6mm-diameter can package. Both lasers achieve a low operating current of 30mA at 25°C (15mW in CW operation) and feature built-in monitoring photodiodes.

Ushio says that, despite maintaining high quality, the new red laser

diodes offer a number of improvements over some existing models. In keeping with Ushio's habit of providing customization options, engineers gain more freedom to fit the lasers into their preferred electrical circuit structure, with the added possibility of featuring an extra pin-out for the new models.

Ushio's previous 670nm laser diodes (HL6714G; HL6748MG; HL6756MG) are able to withstand ambient temperatures of up to 60°C. Now, with the release of the two new models, an additional 10°C margin brings a new level of durability to Ushio's laser line-up. Not only does this allow the lasers

to remain fully operational in hotter environments, but they remain unaffected in situations that would previously contribute to the premature failure of the lasers. This feature increases their suitability to be implemented into devices that do not feature an active cooling element.

These qualities combine to result in a pair of high-reliability, cost-efficient emitters that are suitable for applications include barcode reading, measurement and sensing (specifically battery-powered sensing and precise measurement equipment), says the firm.

www.ushio.eu

Osram adds its first intelligent 3D sensing emitter module, using VCSEL for time-of-flight applications

Germany's Osram says that its first intelligent emitter module for 3D sensing allows smartphones to take high-quality images and videos with a staggered depth of field. In portrait shots, the person's face remains in focus, while the background becomes blurred. Besides optimizing image content, the module can also be used for 3D object recognition or augmented reality (AR) apps.

Smartphones, tablets and other mobile devices have more functionalities than ever, so required components need to fit into ever smaller spaces. A central task for manufacturers has been to find the right emitters, photodiodes and vertical-cavity surface-emitting laser (VCSEL) driver chips (ICs), then calibrate and install them in the end device. With the VCSEL-based module Bidos PLPVDC 940_P_L01 for time-of-flight (ToF) applications, Osram says that it has now reduced the need for manufacturers to perform many of these tasks.

The module features a black package, a 3W infrared VCSEL with a wavelength of 940nm, a



Osram's Bidos PLPVDC 940_P_L01 emitter module for 3D sensing.

matching optical system, an integrated intelligent microcontroller for driving the VCSEL, and a photodiode. Together, the individual components have a footprint of 3.6mm x 5.46mm.

Osram says that the efficiency of its own VCSEL technology ensures low power consumption, facilitating not only energy management but also integration of the component into the end device. The high optical power enables the acquisition of depth information by ToF technology at a distance of up to 7m. In addition to optimizing image content, users can also use the

depth information for other functions in the smartphone, including 3D object recognition and augmented reality applications like games and interior design.

"As smartphone technology continues to become more sophisticated, we're always looking for ways to make it easier for manufacturers to adopt these innovations without having to sacrifice space," says Eric Kuerzel, senior global product marketing manager at Osram Opto Semiconductors GmbH of Regensburg, Germany. "With the Bidos PLPVDC 940_P_L01, smartphone manufacturers can provide their customers with more advanced photography features now, and also open up endless opportunities for 3D-based applications in the future."

Also, for eye safety, special safety mechanisms have been integrated into the module. If the photodiode registers a change in the incidence of light — for example, if the optics are damaged after a fall — the current supply to the VCSEL is interrupted.

www.osram-os.com

CST Global employee wins IET Postgraduate prize

Adam McKenzie, a University of Glasgow PhD research student employed by III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Glasgow, Scotland, UK, has won an IET Postgraduate prize for his photonic-crystal surface-emitting lasers (PCSELS) project.

Critical to the development of quantum dot (QD) lasers, PCSELS achieve vertical, narrow-linewidth, single-mode emission, they can be tuned, and they are stable at room temperature. This has singled them out as the laser of choice for multi-gigabit transmission applications, such as in data centers, without the need for cooling.

McKenzie's project was supervised by professor Richard Hogg of the University of Glasgow, in collaboration with Dr Kouichi Akahane of the National Institute of Information and Communications Technology (NIICT) in Tokyo, Japan. The PCSELS were produced on Glasgow's MOCVD reactor, housed and managed at CST Global for such industry-based PhD research projects.

"PCSELS rely on the formation of nanometer-scale air voids within the device during the epitaxial regrowth process. The size and shape of these voids is used to tune the device characteristics, so our focus was on how they form at an atomic level," says McKenzie. "This is Dr Akahane's

area of expertise, which we drew on in this collaboration. It has helped CST successfully develop tunable PCSELS and also strengthened the company's in-house epitaxial regrowth capabilities still further," he adds.

"Adam also received an award from the Henry Royce Institute last year in support of a material characterization atom probe tomography project; this time a collaboration with Oxford University," notes CST's chief technology officer Andrew McKee. "Adam holds an Industrial Fellowship from the 'Royal Commission for the Exhibition of 1851', which contributes to his university fees and expenses."

www.CSTGlobal.uk

FBH delivers laser diode benches for MERLIN climate satellite

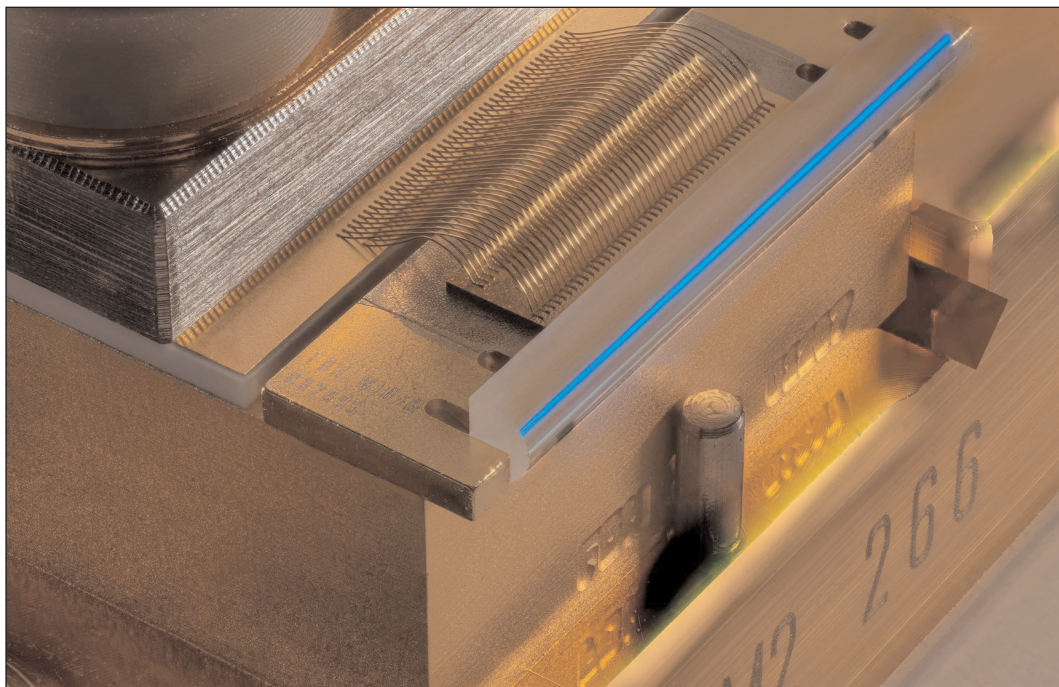
LiDAR to measure methane in atmosphere

The Franco-German satellite MERLIN is due to be launched into space in 2025 to measure the methane concentration in the Earth's atmosphere. Important components of the light detection & ranging (LiDAR) measurement system come from the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenz-technik (FBH) of Berlin, Germany, which has now delivered the required laser diode benches to the project partner.

The MERLIN mission aims to better understand the effect of the greenhouse gas methane on global warming. A radar-like laser system on the satellite measures natural and anthropogenic methane

emissions: The Integrated Path Differential Absorption (IPDA) LiDAR sends laser light to the Earth's surface and analyses the backscattered signal.

FBH has therefore developed and manufactured reliable laser diode benches (LDBs) for the MERLIN climate satellite. Six of these space-qualified LDBs have now been integrated into three pump modules from the Fraunhofer Institute for Laser Technology (ILT) of Aachen, Germany and delivered to the project partner ready for use. The modules generate the necessary pump energy for the oscillator of a Nd:YAG solid-state laser and are integrated into the LiDAR system by ILT. The solid-state laser, in turn, serves as the light source for a tunable optical parametric oscillator (OPO) that generates double pulses with different wavelengths in the infrared range around $1.6\mu\text{m}$. One of these pulses is strongly absorbed by methane, the other is not. This way, the methane content can be determined from the ratio of intensities of the backscattered light.



Laser diode bench made by FBH, before mounting into the pump module.

Robust, space-qualified diode laser technology

The centerpieces of the pump modules are the laser diode benches supplied by FBH. Each LDB generates a pump power of over 60W in double pulses with a repetition rate of 20Hz and $150\mu\text{s}$ pulse width. Laser diode mini-bars are an essential component of the LDB and ensure efficient light generation. Due to the fast-axis collimation lenses integrated in the LDB, the laser beam can be coupled into an optical fiber with a minimum of loss. Two of these LDBs are integrated into each module and provide a joint pump power of 120W.

The diode laser, fast-axis collimation and LDB technology was first comprehensively tested at FBH and confirmed as being suitable for space applications. Subsequently, the laser diode benches were qualified by the European Space Research and Technology Center (ESTEC) in The Netherlands. The extensive life-cycle tests performed by ESTEC showed that the power degrades only minimally even after

a long operating time of more than 4 billion pulses. The scientific team is therefore confident that the MERLIN measuring system will function failure-free even under space conditions.

Delivery of LDBs for the MERLIN mission has been made possible by the many years of comprehensive expertise accumulated at FBH in the development of space-qualified diode lasers. FBH technology will thus contribute to the detailed investigation of important and up to now little-known sources of global warming on the climate satellite – a milestone in European climate research, it is reckoned.

As part of the MERLIN satellite project, a collaboration between DLR RfM and CNES, the Fraunhofer ILT is developing the beam source (the laser optical assembly) of the laser transmitter under contract to Airbus DS GmbH. The work is being carried out on behalf of the Federal Ministry of Economics and Energy BMWi under grant number 50EP1601.

www.ilt.fraunhofer.de

www.fbh-berlin.de

German government-funded EKOLAS project yields high-efficiency, high-performance laser bars

Osram presents powerful infrared laser bars for metal processing

Although the number of infrared light-based applications has increased rapidly in recent years, early manufacturers developed infrared lasers long before infrared light-emitting diodes (LEDs) and vertical-cavity surface-emitting lasers (VCSELs) were used more recently as light sources for facial recognition in smartphones.

In particular, Osram Opto Semiconductors GmbH of Regensburg, Germany has been working for many years on high-power lasers for special applications such as metal processing using welding robots in the automotive industry. Osram, along with its partners, is now presenting results of laser bar performance and efficiency from the latest EKOLAS (Effiziente Konverterlaser) project funded by the German Federal Ministry of Education and Research (BMBF).

In recent years, laser technology has increasingly become an indispensable component of various industries — from medical technology to car manufacturing. The research alliance EffiLAS ('Effiziente Hochleistungs-Laserstrahlquellen', or 'Efficient high-performance laser beam sources') is focused on securing and further expanding

Germany's technological and economic position in photonics. In regard to the laser light sources, the aim is to further optimize various parameters like performance and energy efficiency.

Together with project partners Laserline, Heraeus, Fraunhofer ILT, fiberware and Welser Profile, Osram Opto has worked on various assignments in the EffiLAS joint project EKOLAS. The main aim was to develop highly efficient infrared laser bars with outstanding output powers and to demonstrate them in industrial materials processing. About 10 years ago, the best laser bars achieved a power of 200W with an efficiency of about 63%. Five years later, an output of 250W at an efficiency of no less than 60% was expected to be the limit of what could be achieved with the existing technologies. Conversion efficiency and cooling limited the output power of lasers at that time. The EKOLAS project, which was completed in February, led to an infrared laser bar with a maximum output of 400W in continuous-wave operation. With an output of 300W, the bar sets a new standard with an efficiency of about 70% at wavelengths of 1000nm and 1020nm.

The project partners were able to draw on experience gained in other ventures under the EffiLAS umbrella organization including an understanding of materials science and simulation in the field of epitaxy, as well as fundamental expertise in chip and facet technologies.

"We are very excited to achieve, and in some cases even exceed, all of our targets in this project," says Sebastian Hein, EKOLAS project manager at Osram Opto. "The key to success was the development of innovative software tools for simulating the electro-optical properties of the lasers, which take into account the thermal distribution, temperature-dependent material properties and mode-dependent wave propagation in the resonator. These tools considerably accelerated and simplified the necessary test runs, making a fundamental contribution to the results of the project."

The newly gained knowledge from the simulation of certain processes can now be transferred to other product groups and wavelengths in the range 800–1060nm.

[www.effilas.de
/de/verbuende/ekolas.html](http://www.effilas.de/de/verbuende/ekolas.html)

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CompoundTek & STAr collaborating on high-volume silicon photonics wafer test

Foundry and test firm to develop standards and solutions

Singapore-based silicon photonic (SiPh) foundry services provider CompoundTek Pte Ltd and reliability test system and probe-card supplier STAr Technologies Inc of Hsinchu, Taiwan have formed a strategic collaboration to develop standards and solutions for cost-effective high-volume SiPh wafer test.

Addressing the growing need for consistency and reliability across all applications of SiPh technology, the SiPh Wafer Test aims to spearhead the development of more standard processes and facilitate wider industry adoption and innovations from design through to test and inspection.

Currently, the integration of optical components on a chip creates a host of new challenges in wafer-level probing of SiPh devices, as large volumes of device performance data are required to carry a design from concept to qualification and subsequently into production.

"To accelerate the market for wider adoption of wafer-level silicon photonics test, cost and efficiencies must be improved," says CompoundTek's CEO Raj Kumar. "To do so, we believe it is necessary to take a holistic approach by establishing partnerships that leverage expertise within the test technology value chain and that of the fabrication process," he adds. "It is this synergy of measurement instrumentation, positioning and commercialization technologies that will further standardize the way testing is done, the way the

chip is laid out for ease of tests, that both CompoundTek and STAr effectively bring to the marketplace."

Currently, SiPh testing is fragmented, with no recognized standards. Most companies have a homegrown SiPh bench solution, which is good for small-scale engineering characterization during the design verification phase but inefficient for the high-throughput and low-cost test required for testing during the mass-production phase. There is no independent SiPh wafer test service provider with a cost-efficient solution to address this market gap. Availing these capabilities helps the industry to drive down associated product costs from prototyping to mass manufacturing, and accelerate their time to market.

"When you think of working in a lab on an initial prototype, and spending a few hours to set up and align a single device for measurements, it seems feasible," says Dr Jeffrey Lam, STAr's general manager & VP of engineering. "It is not the case, however, in high-volume SiPh manufacturing, where time- and effort-intensive methods are not practical and time-to-market is a critical factor. This has inhibited the rapid adoption of SiPh, a challenge we aim to effectively address with methods and strategies that have a unique relative emphasis on accuracy, throughput and test flexibility through our combined SiPh Wafer Test approach."

The technology shift in the form of SiPh demonstrates the potential for measurable gains in speed, power efficiency and density. The first wave of the SiPh revolution is poised to roll over to data-centers around the world with optical interconnects that break the barriers set by copper wire, the firms say.

Shipments of SiPh transceivers for data-centers reached almost 3.5 million units in 2019, generating revenue of about US\$364m from the development of transceivers for telecom/datacom applications, reckons Yole Développement in its report 'Silicon Photonics Market and Technology 2020'. Led by demand from global network traffic such as applications in cloud, video streaming and Internet of Things (IoT), the SiPh transceiver market is expected to reach US\$3.6bn in 2025, with 24 million units shipped.

In parallel, the development of SiPh transceivers has resulted in increased demand of cost-effective wafer test solutions, enabling the industry to improve their quality-control coverage at wafer-level, potentially driving down product costs due to failures after packaging.

Since its formation in 2017, CompoundTek has accrued 20 commercial customers and over 20 research institutes and universities in applications such as telecoms, automotive radar, datacoms, bio-sensing, artificial intelligence, quantum computing and smart sensors.

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CompoundTek adds 106Gbps PAM4 MZI silicon modulator to enhanced PDK

Singapore-based silicon photonic (SiPh) foundry services provider CompoundTek has added a high-speed 106Gbps PAM4 Mach-Zehnder interferometer (MZI) silicon modulator to its intellectual property (IP) process design kit (PDK).

Offering capabilities in 400G/600G/800G applications for an industry where more than two iterations to meet specifications are a norm, the new modulator enables high levels of productivity, says CompoundTek. Further minimizing manufacturing risk with fewer re-spins, customers can expect improved yield results in a better return on investment and accelerated time-to-market, the firm adds.

"This innovation is in line with CompoundTek's services expansion goals, ensuring we bring to customers solutions that save both time and significant investment dollars while meeting performance metrics throughout their prototype-to-market journey," says chief operating officer K.S. Ang. "With this transceiver-focused IP design, customers looking to strengthen their 400G-800G capabilities and reduce the number of iterations can be assured that critical pain points are addressed."

Design flows continue to mature to meet the cost and scalability demands of manufacturing necessary for broad commercial markets. Today, silicon photonic integrated circuits are more widespread, par-

ticularly in applications related to datacom, radio frequency (RF) and sensing, says CompoundTek. In 2019, shipments of silicon photonic transceivers for data-centers reached almost 3.5 million units, with revenue of about US\$364m attributed largely to the development of silicon photonics transceivers for telecom/datacom applications (according to Yole Développement's report 'Silicon Photonics Market and Technology 2020').

The modulator is a critical integral component in transceiver design, and availability of the 106Gbps PAM4 MZI Si modulator will accelerate the development of customers' next-generation silicon photonic products, specifically in the transceiver market, CompoundTek reckons.

The performance specification for the 106Gbps PAM4 MZI Si modulator has been verified both in simulation and fabricated on-chip through CompoundTek's proprietary process flow, with measurements undertaken by a third-party independent company. Showing test results that are claimed to be above the typical industry standard, the 2.5mm-length modulator's typical reach is 3dB OE bandwidth of 40GHz @ 4V, 3.25dB loss, 4dB extinction ratio (ER) with modulator efficiency of 17V.mm. Recognizing its potential, a leading commercial customer has recently

licensed this special IP block, leveraging CompoundTek's post-fab copper (Cu) pillars/bump integration with suspended edge coupler, and silicon deep trench for electronic circuits integration.

Since its launch in 2017, CompoundTek has been involved with more than 20 global commercial customers and over 20 research institutes and universities in various applications such as telecoms, automotive LIDAR sensor, datacoms, bio-sensing, artificial intelligence, quantum computing and smart sensors. It aims to tap into rapidly growing markets, led by the demand from global network traffic such as applications in cloud, video streaming, and Internet of Things (IoT), with a focus in the SiPh transceiver market, which is expected to be worth US\$3.6bn in 2025 (with 24 million units shipped). The firm reckons that its solutions portfolio and foundry capabilities are well positioned to leverage increased demand for data-center storage and bandwidth as the industry transitions from the current 100G data rate to next-generation 400G or higher in the next five years.

CompoundTek is scheduled to showcase its solutions at the 22nd China International Optoelectronic Exposition (CIOE 2020) at the Shenzhen World Exhibition & Convention Centre (9-11 September).

<https://compoundtek.com>

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Open Eye Consortium 53Gbps-per-lane multi-mode SR4 and single-mode LR PAM-4 specs available to public for data-center and wireless fronthaul applications

MSA consortium gains three new contributing members

The Open Eye Consortium multi-source agreement (Open Eye MSA) has announced two new specifications targeted for 53Gbps-per-lane applications: SR4 for 100m reach over a multi-mode fiber and LR for 10km reach over a single-mode fiber, complementing the existing 200Gbps FR4 spec. The single-mode LR spec is to be finalized and available at the 22nd China International Optoelectronic Exposition (CIOE 2020) in Shenzhen, China (9-11 September).

The MSA defines the requirements for analog PAM-4 (4-level pulse amplitude modulation) solutions for 50G SFP, 100G DSFP, 100G SFP-DD, 200G QSFP, 400G QSFP-DD and OSFP modules.

Due to the growing demand for data, wireless, enterprise and data-center network managers are continually looking for ways to drive lower power, smaller size and lower costs. The Open Eye MSA's new specifications will provide customers with an alternative to higher-power and higher-cost digital signal processing (DSP)-based solutions. These specs are suitable for 53Gbps SFP28 long-reach (LR) and 200Gbps QSFP short-reach (SR) optical module designs for next-generation 5G wireless, enterprise and data-center networking applications.

The Open Eye MSA aims to accelerate the adoption of PAM-4 optical interconnects scaling to 50Gbps, 100Gbps, 200Gbps and 400Gbps by expanding on existing standards to enable optical module implementations using less complex, lower-cost, lower-power and optimized analog clock & data recovery (CDR)-based architectures in addition to existing DSP architectures.

For interested parties to learn more about the Open Eye's MSA mission and latest technical information, a whitepaper is available to view and download from the Open Eye Consortium's website.

In addition, the Open Eye MSA is hosting two webinars (available to the general public) aimed at introducing network planners and optical module developers to the new technology:

1: (26 August) 'Reduce Cost, Power and Latency with Open Eye MSA based Optical Connectivity' - targeted for data-center, enterprise and telecom network architects. Presenters overview the benefits of the Open Eye MSA approach enabling low-cost, low-power and low-latency optical modules for 200Gbps and 400Gbps connectivity deployments.

2: (2 September) 'Reducing the Cost of 200Gbps and 400Gbps Optics using Open Eye MSA compli-

ant Chipset Solutions' - targeted for manufacturers of optical modules. The Open Eye MSA approach is a natural evolution relative to today's high-volume optical nodes, enabling users to scale to next-generation Baud rates. Presenters overview chip-set and test solutions for implementation of modules based on Open Eye MSA specifications.

The Open Eye MSA also says that its membership has grown to 37 with the addition of Credo Semiconductor, Fuji Xerox and Lumentum.

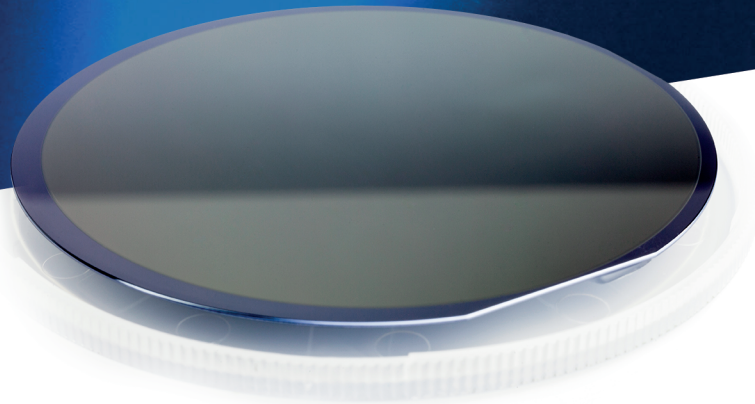
Promoters include: Applied Optoelectronics Inc, Cambridge Industries Group (CIG), Juniper Networks, Luxshare-ICT, MACOM Technology Solutions Inc, Molex, and Semtech Corp.

Contributors include: Accelink, Anritsu, Broadex Technologies, Cloud Light Technology, ColorChip, Credo Semiconductor, Fujitsu Optical Components, Fuji Xerox, HG Genuine, HiLight Semiconductor, InnoLight, Inopticals, Keysight Technologies, Lumentum, Marvell, Maxim Integrated, MultiLane, O-Net, Optomind, Renesas, SAMTEC, Sicoya, Source Photonics, Sumitomo Electric, TE Connectivity, Tektronix, TRUMPF and two more members.

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AOI's revenue rebounds by 61% in Q2 post-COVID

Growth driven by data-center customer diversification and 5G deployments in China

For second-quarter 2020, Applied Optoelectronics Inc (AOI) of Sugar Land, TX, USA — a designer and manufacturer of optical components, modules and equipment for fiber access networks in the Internet data-center, cable TV broadband, fiber-to-the-home (FTTH) and telecom markets — has reported revenue of \$65.2m, up 50% on \$43.4m a year ago and 61% on \$40.5m last quarter.

"We had disruptions in operations in our China factory during Q1," notes chief financial officer & chief strategy officer Dr Stefan Murry. "However, due to the hard work and dedication of our employees and supply chain partners, we are back to normal operations and have increased capacity in both our wafer fab in Sugar Land as well as our factories in China and Taiwan compared to our capacity pre-COVID."

Revenue was well above the \$55–60m guidance, driven by strong demand from new data-center customers, increased customer diversification, and record revenue in the telecom segment led by increased deployments of 5G mobile technology in China.

Cable television (CATV) product revenue was \$6.1m (9% of total revenue), down 38% on \$9.8m a year ago but up 45% on \$4.2m last quarter, as the firm resumed manufacturing at a normal capacity, driven by increased 5G activity and increased order flow in North America for CATV upgrades.

Telecom product revenue was a record \$6.2m (10% of total revenue), up 141% on \$2.6m last quarter and up 279% on \$1.6m a year ago, as it outpaced CATV business.

Data-center revenue was the highest in two years at \$52.5m (81% of total revenue), up 58% on \$33.3m last quarter and 65% on \$31.8m a year ago. Of this, 33%

came from 40G transceiver products and 64% from 100G products (up 350%, the second consecutive quarter of year-on-year growth in 100G transceivers). "We continued to see increased data-center demand during Q2 from a diverse set of customers," notes Murry.

"We are encouraged by the increased contributions from our newer customers, which has led to a meaningful improvement in customer and end-market diversification," says founder, president & CEO Dr Thompson Lin.

The top 10 customers comprised 86.9% of revenue (down from 90.9% a year ago). Three were 10%-or-greater customers (all in the data-center segment) contributing 35% and 15% and 12% of total revenue, respectively. One of these was a new 10% customer (a US-based hyperscale cloud operator, mainly purchasing 100G transceivers), where AOI has been gaining share. AOI has also seen increasing revenue from a large US-based switch router vendor that approached the 10% revenue level. Rounding out the top five was a data-center customer in China. There were three other customers that each contributed 5–10% of total revenue. Overall, this compares with only two 10%-or-greater customers and one at 5–10% a year ago, versus six customers each over 5% now.

"Our efforts in diversifying our customer base continue to show tangi-

ble results, and many of these new customers are contributing meaningfully to our results," notes Murry.

"In addition to the market diversity, our top 10 customers are also geographically diverse. Out of our 5%-or-greater customers in Q2, all but one were US-based multinationals, and the remaining one was a China-based switch router vendor primarily serving the data-center market," he adds. "Looking at our top 10 customers in Q2, seven were US-based multinational corporations, two were based in China and one in Europe."

On a non-GAAP basis, gross margin was 23.1%, up from 19.5% last quarter but down from 27.2% a year ago, and at the low end of the 23–25% guidance range due to an unfavorable product mix (mostly in the data-center segment) as well as some continued COVID-19-related expenses (including manufacturing and shipping costs).

Operating expenses were \$20.6m (31.6% of revenue), up from \$19.5m (44.9% of revenue) a year ago, due mainly to increased shipping costs, sales commissions and insurance costs.

Net loss was \$5m (\$0.24 per share), cut from \$5.2m (\$0.26 per share) a year ago and \$8.8m (\$0.44 per share) last quarter.

Cash used in operations was \$15.5m. Capital expenditure (CapEx) was \$5.8m, including \$5m in production equipment and machinery plus an immaterial amount on construction and building improvements. This is lower than expected, due primarily to a COVID-related pause in construction on the firm's new China factory.

Regarding the after-market offering announced in February, AOI has so far raised gross proceeds of \$22m (including \$7.7m in July, after the end of Q2/2020). The firm intends to use the proceeds for continued investment, including

We expect gross margins to recover to pre-COVID levels as we implement cost reductions that were delayed by the pandemic. More favorable product mix will lead to improving gross margin over the next several quarters

new equipment and machinery for production and R&D.

Overall during the quarter, cash, cash equivalents, short-term investments and restricted cash fell from \$62.5m to \$58.9m.

Inventory rose from \$87.1m to \$97.3m, driven by additional raw materials purchased for production orders on hand and forecasted orders.

"During the quarter, we have had design wins, including four with telecom customers which are related to 5G network deployments, mainly in China. The other four design wins were with existing customers in our data-center segment," says Lin. "Looking ahead, we expect this momentum to continue into the third quarter, driven by similar trends in increased

demand from both our data-center and telecom end-markets," he adds.

"We continue to see high demand from our data-center customers, who remain focused on improving network performance in light of the increased traffic related to the shift toward working from home," says Murry. "We also received our first orders from CATV customers that we believe are related to network upgrades by MSOs also responding to stresses on their networks," he adds. "For the remainder of the year, we expect to ramp up production to meet order demand."

For third-quarter 2020, AOI expects revenue to grow 20% sequentially to \$76–83m. Gross margin should rise to 25–26.5%. Net loss is expected to be cut to

\$4.6–0.6m (\$0.20–0.03 per share).

"We expect gross margins to recover to pre-COVID levels as we implement cost reductions that were delayed by the pandemic," says Murry. "More favorable product mix will lead to improving gross margin over the next several quarters," adds Lin.

"We expect to resume spending on our new facility in China in Q3, and we anticipate this to be reflected in increased spending on construction and building improvements," says Murry. "Including this resumption in building expenditures and other equipment necessary to increase our production capacity, we expect total 2020 CapEx to be about \$42m."

www.ao-inc.com

AOI's laser production hits record 1.1 million in July Production nearly 65% higher than pre-COVID levels

AOI says that its production of laser diodes in July reached a record of over 1.1 million units, nearly 65% higher than pre-COVID levels.

"AOI has been investing in capacity by adding additional production equipment, improving our manufacturing processes to increase yield and enhance quality, and adding staff," says founder & CEO Dr Thompson Lin. "The result of this hard work and investment is

that we've reached a significant milestone in terms of laser production capacity. The vast majority of our current laser production is 25G lasers, which are in high demand now in our data-center and telecom segments, including 5G wireless. This additional capacity will help us meet this increased demand," he adds.

"Having produced over 1.1 million tested and qualified lasers in the month of July is a significant

step to achieve our near-term goal of producing 1.5 million lasers per month, which we expect to reach in Q4 of this year," says Dr Fred Chang, senior VP & North America general manager. "Even more importantly, the significant improvements we've made in our manufacturing process have increased our manufacturing yield, which in many cases have also resulted in improved reliability that is critical for our customers."

II–VI Inc wins Strategic Supplier Award from Xinghan High-power laser diodes used in fiber-coupled pump laser modules

Engineered materials and optoelectronic component maker II–VI Inc of Saxonburg, PA, USA, which makes high-power semiconductor lasers, has won the Strategic Supplier Award from Shenzhen Xinghan Laser Technology Co Ltd in recognition of its "outstanding performance" as a supplier of high-power laser diode chips for Xinghan's fiber-coupled pump laser modules. The presentation was at LASER World of Photonics China 2020 in Shanghai (3–5 July).

"II–VI continues to be a strategic supplier of high-power laser diode chips with a strong record of technical innovation, quality and delivery performance," comments Xinghan's CEO & president Shaofeng Zhou.

"We look forward to growing our relationship with II–VI by leveraging its portfolio of high-power laser components, one of the most complete in the industry," he adds.

"Xinghan's award is an honor and a strong recognition of II–VI's ability

to deliver high-power semiconductor laser chips with high quality and at scale," says Dr Karlheinz Gulden, senior VP, Laser Devices and Systems business unit. "II–VI's laser diodes' output power is market-leading and enables industrial laser designs with fewer pump modules, which lowers the cost of cutting, welding, brazing and laser additive manufacturing," he claims.

www.ii-vi.com

NeoPhotonics' Q2 revenue rises a more-than-expected 26% year-on-year

400G-and-above products driving growth and customer diversification

For second-quarter 2020, NeoPhotonics Corp of San Jose, CA, USA — a vertically integrated designer and manufacturer of silicon photonics and hybrid photonic integrated circuit (PIC)-based lasers, modules and subsystems for high-speed communications — has reported revenue of \$103.2m, up 6% on \$97.4m last quarter and up 26% on \$81.7m a year ago, and exceeding the \$94–102m guidance.

Sequential growth was driven by cloud and data-center demand as 64-gigabaud and other products for 400G-and-above applications accelerate. High-speed products (for 100G-and-above data rates) now consistently comprise over 90% of revenue.

Based on a review of products that NeoPhotonics ships, revenue was not materially impacted by the addition in late May of China's FiberHome Technologies Group to the US Department of Commerce's Bureau of Industry and Security (BIS) Export Administration Regulations (EAR) Entity List (joining Huawei Technologies, added in May 2019).

Similarly, revenue was not materially impacted by the BIS' latest ban (announced this May) on the use of US software and technology worldwide to design and manufacture chips supplied to Huawei, since NeoPhotonics designs all of its own products.

"We were expecting about \$10m of supply-chain headwinds," says senior VP & chief financial officer Beth Eby. "We were able to mitigate almost all of those, which is how we got the revenue over our guidance range."

Largest customer Huawei again contributed 52% of total revenue, with the next four customers contributing 30% (down from 33% last quarter). "Our 400G-and-above solutions are also increasing our customer revenue diversification,"

says president, CEO & chairman Tim Jenks. "Almost all of the world's leading network equipment customers leverage NeoPhotonics' products for their 400G-and-faster systems. Moreover, these customers are now ramping their deployments," he adds. Excluding NeoPhotonics's top two customers, the other eight in the top 10 grew revenue collectively by 35% in Q2 over Q1/2020, and this trend is expected to continue.

On a non-GAAP basis, gross margin has risen further, from 25.6% a year ago and 31.2% last quarter to 33.2% (toward the high end of the 30–34% guidance range). Within this, product margins were 36.3%, up from 32% a year ago and 35.8% last quarter due to increased volume. Other cost-of-sales charges had an impact of 3.1 percentage points (an improvement from 4.5 points last quarter), consisting of about 1 point of warranty charges, 1 point of residual tariff adjustments, and 0.5 point of under-utilization and other minor charges.

Operating expense is up from \$20.3m (20.9% of revenue) last quarter to \$23.6m (22.9% of revenue), but this is lower than the expected \$24–25m due to continued pushouts related to the impact of the COVID-19 pandemic.

Net income was \$8.7m (\$0.16 per diluted share), down from \$9.1m (\$0.17 per diluted share) last quarter but a big improvement on a net loss of \$1.2m (\$0.03 per diluted share) a year ago, and exceeding the \$0.05–0.15 guidance range as a result of "outstanding execution" in a challenging quarter.

Cash generated from operations was \$9.6m, down from \$24.9m last quarter but up from just \$0.7m a year ago. "We have now had eight quarters of delivering year-over-year revenue growth, expanding gross margin and positive free cash flow," notes Eby. "We have also

delivered four quarters in a row of profitability."

During the quarter, the firm paid down \$4m of debt. Cash and cash equivalents, short-term investments and restricted cash rose by about \$4m from \$109.5m to \$113.3m.

Inventory has been increased from \$46.1m to \$50.4m. "Increasing our inventory is planned to buffer continued supply-chain volatility," notes Eby.

"Over the last year, we have reported that our largest customer, Huawei [and their affiliate HiSilicon], has had a plan to build strategic inventory due to trade tensions," says Jenks. "This action is now complete and future orders will better reflect end-customer demand," believes Eby. "Given the strength and demand of our highest-speed products, we expect that our other customers will continue to ramp, largely offsetting the Huawei decrease. The net result is a Q3 revenue outlook which is nominally in line with Q2," she adds. "We are still seeing supply-chain impacts [of COVID-19] in Q3 but, based on our experience in Q1 and in Q2, we believe that we will be able to mitigate those through the quarter. The spending delays are not impacting our project timing."

For third-quarter 2020, NeoPhotonics expects revenue of \$97–105m. Gross margin should be 30–34%, reflecting some increase in under-utilization charges as a result of slower-than-planned deployment by a couple of customers (due to COVID-19) of silicon photonics-based transceivers that use NeoPhotonics' fixed-wavelength lasers. Operating expenses will rise to \$25–26m. "We expect to make up the first-half underspend in the back half of the year to ensure continued success of our 64-gigabaud and 400ZR programs [NeoPhotonics' 400ZR and 400ZR+ pluggable coherent modules for cloud and

Ethernet applications were launched in fourth-quarter 2019, moved from initial sampling in Q1/2020, and are in customer qualifications now].... Investment will continue to drive revenue growth and customer diversification in 2021 and beyond," says Eby. Earnings per share are hence expected to fall to \$0.03–0.13.

"With increasing momentum in 400G-and-above product design wins across almost all of the major network equipment manufacturers globally, and with increasing momentum in 400ZR opportunities, we remain optimistic about the growth prospects for NeoPhotonics,"

says Jenks. "Our products for 400G-and-above applications will approach 20% of our total revenue this year," he adds.

"We will have additional industry leaders become 10% customers during second-half 2020, based on our existing customer orders and delivery commitments for 400G-and-above products," believes Jenks.

"Trade tensions are causing market share shifts between our customers due to the breadth of our design wins and customer base. NeoPhotonics is likely to be a beneficiary of these shifts. For example, a market share shift of one 400G-and-above port, away from our largest customer

and to another industry leader, would likely be favorable to NeoPhotonics in revenue terms. Similarly, a market share shift of one 100G port away from our largest customer and to another leader would likely be roughly equivalent to NeoPhotonics in revenue terms," he adds.

"As our next group of customers ramp their respective systems for 400G-and-above applications, we believe the strength of deployments from these customers will offset potential revenue impact from Huawei's inventory adjustments," Jenks concludes.

www.neophotonics.com

NeoPhotonics & Inphi complete first interoperability demonstration of 400ZR over 120km

NeoPhotonics and Inphi Corp of Santa Clara, CA, USA (a provider of high-speed mixed-signal ICs for communications, computing and data-center markets) have completed what they say is the industry's first interoperability demonstration of OIF 400ZR Implementation Agreement (IA)-compliant coherent transceivers, operating across the C-band over 120km of optical fiber.

Transceiver pairs consisting of Inphi's COLORZ II QSFP-DD with its Canopus 7nm Coherent DSP and NeoPhotonics 400ZR ClearLight OSFP were successfully linked. Both 400ZR coherent optics transceivers carried error-free traffic over a typical data-center interconnect (DCI) link configuration (amplified over 120km of fiber) at several wavelengths across the C-band using Arista 7060 data-center switches.

Interoperation of NeoPhotonics and Inphi 400ZR transceivers demonstrates the availability of interoperable coherent transceivers for the 400ZR ecosystem, a key step in enabling the next generation of DCI links, the firms say. 400ZR pluggable transceiver modules significantly reduce the cost and power consumption of

DCIs by eliminating the transport network equipment layer.

"This demonstration proves the readiness to deliver the flexibility of high-bandwidth DWDM connectivity between data centers with the ability to rapidly scale capacity and meet our customers' demands for standards-based pluggable coherent solutions," says Josef Berger, AVP of marketing, Optical Interconnect at Inphi.

"NeoPhotonics has worked closely with Inphi to combine their Canopus DSP with our high-performance laser and coherent optics into a standards-based ClearLight OSFP and QSFP-DD transceiver modules that can meet the needs of our hyper-scale customers," says Marc Stiller, VP of Coherent Modules at NeoPhotonics. "Supporting the interoperable CFEC standard, as defined by OIF, has been a critical part of our design effort, and we're very pleased to announce this milestone as we continue to work with customers to implement this game-changing technology."

Inphi's COLORZ II is said to be the industry's first 400ZR QSFP-DD pluggable coherent transceiver that enables large cloud operators to connect metro data centers at a

fraction of the cost of traditional coherent transport systems as well as enable switch and router companies to offer the same density for both coherent DWDM and client optics in the same chassis. For end users looking for performance beyond 400ZR, Inphi's Canopus 7nm coherent DSP is claimed to be an industry first, offering a multitude of reach and data-rate options for metro and long-haul performance.

NeoPhotonics' ClearLight 400ZR transceiver family, including QSFP-DD and OSFP for Cloud and Ethernet applications and the CFP2 form factor for telecom networks, offers what is claimed to be industry-leading coherent optical transmission performance in low-power, pluggable form factors compatible with switch and router platforms. These modules utilize NeoPhotonics' coherent optical components including its silicon photonics coherent optical subassembly (COSA) and low-power-consumption, ultra-narrow linewidth Nano-ITLA (integrated tunable laser assembly). These components further enable operation over the full 6THz Super-C band transmission window.

www.inphi.com

Lumentum's revenue falls a less-than-expected 9% in June quarter

InP chip fab capacity to be doubled over next 18 months, and GaAs device capacity to be expanded

For full-year fiscal 2020 (ended 27 June), Lumentum Holdings Inc of San Jose, CA, USA (which designs and makes photonics products for optical networks and lasers for industrial and consumer markets) has reported record revenue of \$1678.6m, up 7.2% on fiscal 2019's \$1565.3m (including revenue from the acquisition of San Jose-based optical communications component and module maker Oclaro Inc from 10 December 2018). The growth is despite the impact of product-line exits and divestitures and, more recently, COVID-19 and geopolitical headwinds, namely:

- China's Huawei falling from \$238m (15.2% of revenue) to \$221m (13.2% of revenue) after the US Department of Commerce's Bureau of Industry and Security (BIS) on 16 May added Huawei to its 'Entity List', requiring a license for products covered by the Export Administration Regulations (EAR);
- a \$100m impact in second-half fiscal 2020 from the COVID-19 pandemic;
- a drop of \$90m (to \$62m) in revenue from discontinuing low-margin product lines, including:
 - in April 2019 divesting the datacom transceiver module business (manufactured by subsidiary Oclaro Japan Inc) to Shanghai-based Cambridge Industries Group (CIG) in exchange for a long-term strategic supply agreement for Lumentum's photonic chips;
 - in December 2019 divesting the lithium niobate (LiNbO₃)-based optical component wafer fab in San Donato, Italy to China-based passive optical component provider Advanced Fiber Resources (Zhuhai) Ltd (AFR).

"Fiscal 2020 was a record year for revenue, margins and earnings... driven by a product mix rich in differentiated high-margin products

and the attainment of significant acquisition synergies," says president & CEO Alan Lowe.

Optical Communications segment revenue grew by 10.6% from \$1370m to \$1515m, driven by growth in vertical-cavity surface-emitting lasers (VCSELs) for 3D sensing, plus Datacom chips and Telecom transmission, and the contribution of the Oclaro acquisition.

Commercial Laser segment revenue fell by 16.2% from \$195.1m to \$163.5m, with the impact of COVID-19 strongly exacerbating an already slow lasers market.

Fiscal fourth-quarter 2020 revenue was \$368.1m, down 8.6% on \$402.8m last quarter and 9% on \$404.6m a year ago (with sales to China's Huawei declining further, by 6% sequentially to about \$45m, following a 20% decline to \$48m in fiscal Q3 from fiscal Q2's \$60m, having been \$80m a year ago). However, Lumentum's fiscal Q4 revenue was above the \$325–365m guidance after the impact of COVID-19 was less than the \$90m expected due to strengthening in 3D sensing and lasers.

Commercial Lasers segment revenue was \$37.8m (10.3% of total revenue), down 13.1% on \$43.5m last quarter and 20.9% on \$47.8m a year ago, due to lower fiber-laser sales (driven by the macro-economic slowdown). However, this was a smaller decline than expected due to strong sales of solid-state lasers into the semiconductor processing end-market.

Optical Communications segment revenue was \$330.3m (89.7% of total revenue), down 8.1% on \$359.3m last quarter (due primarily to 3D sensing seasonality) and down 7.4% on \$356.8m a year ago (due to lower Telecom & Datacom revenue through exiting the Datacom module business). Of this:

- **Telecom & Datacom** revenue was \$256.4m, down 4.8% on \$269.2m a year ago after being impacted by COVID-19. However, this was a 2% rebound from \$251m last quarter, as production exited fiscal Q4 above pre-pandemic levels. Demand was very strong especially in datacom chips, coherent components and modules, and high-end reconfigurable optical add/drop multiplexer (ROADMs), but supply constraints for these products limited revenue. Specifically:
 - *Telecom transmission* was the most impacted by COVID-19 supply challenges and, as a result, declined a few million dollars sequentially, however new high-baud-rate components and DCO (digital coherent optics) modules are ramping up;

- *Telecom transport* grew sequentially due to strong pump-laser sales and increased sales of wavelength-management and ROADM products, with next-generation contentionless MxN and high-port-count ROADMs ramping up;
- *Datacom* revenue growth continued, driven by strong sales of chips (\$50m, surpassing 95% of Datacom revenue) although growth is still limited by wafer fab capacity (with Datacom chip backlog rising to nearly \$150m).

- **Industrial & Consumer** revenue was \$73.9m, down 31.8% on \$108.3m last quarter and 15.6% on \$87.6m a year ago due to normal seasonality plus the timing of new customer programs. However, this exceeded the guidance (of a sequential decline of more than 40%) due to stronger-than-expected demand. The firm is also ramping shipments of next-generation chips for contactless biometric authentication, computation photography, and light detection & ranging (LiDAR).

“Through the quarter, we saw some of the supply limitations free up... Our contract manufacturer in Malaysia is now back to full speed,” says Lowe. “We’ve added capacity. They’ve added people. So we’re running at full speed there,” he adds.

“Strong market demand and solid execution drove better-than-projected results across all financial metrics in our fourth quarter, especially gross margin and EPS,” notes Lowe.

Despite COVID-19 impacting revenue, quarterly gross margin has risen further, from 38.9% a year ago and 45.5% last quarter to 47.2% (only just below the record 47.4% of fiscal Q2/2020). By segment, Commercial Lasers margin rose from 43.5% a year ago and 49.7% last quarter to 52.9% due to product mix and lower manufacturing costs. Optical Communications margin was 46.6%, up from 45% last quarter and 38.3% a year ago (due to acquisition synergies and a better product mix within Telecom & Datacom sectors). Specifically, data-center chip product mix is improving through higher speeds, PAM4 (4-level pulse amplitude modulation) and 5G designs.

Full-year fiscal 2020 gross margin hence rose from 2019’s 39.5% to 2020’s 46.5% (with each quarter above 45%).

Full-year operating expenses increased from \$297.9m (19% of revenue) in fiscal 2019 to \$333.4m (20% of revenue) in fiscal 2020, reflecting the full year of incremental acquisition expenses and an increase in R&D investments in new technology and customer programs. Quarterly operating expenses were \$82.5m (22.4% of revenue) in fiscal Q4, roughly level with \$82.7m (20.5% of revenue) in fiscal Q3, a little lower than normal run rates due to COVID-19 reducing travel to trade shows etc. Specifically, selling, general & administrative (SG&A) expense was \$36.6m (down from \$38.4m last quarter). In contrast, R&D expense was \$45.9m (up from \$44.3m last quarter).

“We have been simultaneously attaining R&D-related acquisition synergies and cutting investments

in under-performing product lines, while ramping investments in areas with stronger outlooks and returns,” notes chief financial officer Wajid Ali.

Quarterly operating income was \$91.4m (operating margin of 24.8% of revenue), down from \$100.7m (25% margin) last quarter but up from \$76.7m (19% margin) a year ago (and above the expected 18–21%), driven by gross margin improvement. Full-year operating income rose from \$320.6m (20.5% margin) in fiscal 2019 to \$446.8m (26.6% margin) in fiscal 2020.

Likewise, net income for fiscal Q4/2020 was \$91.7m (\$1.18 per diluted share), down from \$98m (\$1.26 per diluted share) in fiscal Q3 but up on \$70.4m (\$0.91 per diluted share) a year ago (and much better than the projected \$0.70–0.90 per diluted share). Full-year net income rose from fiscal 2019’s \$305.4m (\$4.25 per diluted share) to \$420.5m (\$5.42 per diluted share) for fiscal 2020.

During fiscal Q4, total cash, cash equivalents and short-term investments rose by \$102.4m, from \$1451.4m to \$1553.8m. The firm has \$1.5bn in aggregate principal convertible notes and no term debt. Of these convertible notes, \$450m is due in 2024 and \$1.05bn is due in 2026. The associated total cash interest expense is about \$6m per year. “We are well-positioned financially with a strong margin model, high levels of cash with low interest expense, and long maturity financing,” reckons Ali.

“We head into fiscal 2021 with demand increasingly driven by new products and technologies, strengthened market positions, and an improving financial model with accruing

benefits from acquisition synergies,” says Lowe.

For fiscal first-quarter 2021 (to end-September), Lumentum expects revenue to rise to \$430–455m, despite sales to Huawei declining further. “For products that they can get from other non-US suppliers, I think they have generally moved away from us. What remains in our revenue are products where we are the only guy or the other supplier is another US-based supplier,” says senior VP, strategy & corporate development Chris Coldren. “While most of the products we supply are indispensable to Huawei and we don’t have visibility to any sharp demand reduction, given the current geopolitical uncertainty, we are taking a cautious approach to Huawei in our outlook,” says Lowe. “We have lots of other customers for those products and we’re capacity constrained on most of them,” continues Coldren. “Therefore, even if we were to see a limitation coming from Huawei from a demand standpoint, we should be able to redirect that to other customers.”

Commercial Lasers segment revenue is expected to fall by 25% due to end-market demand being impacted by the global slowdown in industrial production). Lasers revenue is expected to decline further over the next two quarters, since the second half of the calendar year is seasonally softer for the firm’s solid-state lasers.

In the Optical Communications segment, Telecom & Datacom sales should be the highest in more than a year due to strong demand and recovery from COVID-19 supply constraints (despite revenue from a discontinued product line falling by \$4–5m from fiscal Q4/2020’s \$7m). “We are increasing production capacity in our fabs and our backend assembly & test facilities,” says Lowe. “As additional capacity and new production staff have been coming online, we have been increasing our wafer starts to satisfy our very strong company backlog.”

Lumentum’s fiscal Q4 revenue was above the \$325–365m guidance after the impact of COVID-19 was less than the \$90m expected due to strengthening in 3D sensing and lasers

► Industrial & Consumer sales should be up strongly due to the seasonal consumer electronics product cycle, and because Lumentum is already shipping high volumes of new products for future customer product launches. The new product shipments include Lumentum's latest chips for user-facing and world-facing 3D sensing applications. This seasonal ramp started only late last year, so fiscal Q2 shipments should be higher than fiscal Q1's shipments (unlike last year). "While we continue to make very good progress on new Android opportunities, we are taking a conservative approach to Android revenue in our first-quarter projections due to COVID-19 and geopolitical factors," notes Lowe.

Fiscal Q1/2021 operating margin is expected to rise to 28–30%. Diluted earnings per share should increase to \$1.40–1.55.

"Based on our view of the long-term opportunities ahead of us, we are strongly investing in R&D to further accelerate our leadership positions and enter new markets that benefit from our capabilities," says Lowe.

"Additionally, notable manufacturing capacity increases include the following major three investments: (1) doubling of our indium phosphide wafer fab capacity over the next 18 months, as we believe the performance and capabilities provided by our InP laser chips and photonic integrated circuits (PICs) will be central to every telecom and datacom communication network, and, perhaps over time, increasingly in 3D sensing and LiDAR applications; (2) expanding gallium arsenide device production capacity for our 3D sensing, automotive, industrial laser and telecom & datacom products as applications for these products are expanding rapidly; and (3) expanding capacity for next-generation, high-port-count and MxN ROADMs as customers globally are designing their new networks based on these technologies," adds Lowe.

"We'd like to keep CapEx at a rate that hovers around depreciation [which was \$113.3m in fiscal 2021]," says Ali. "In fiscal 2020 [for which depreciation was \$102.9m], we were a little bit lower than that." For full-year fiscal 2021, Lumentum

is therefore aiming for CapEx to rise by 20–25% year-on-year to \$100–110m. "We're putting that CapEx investment around products that have higher gross margins, and where we see a lot of backlog and a lot of customer demand [i.e. Datacom chips and telecom transmission]," says Ali. "We are either the major supplier or the number one and only supplier for those products."

At Lumentum's existing production capacity run rate of \$50m per quarter for Datacom chips, the firm's \$150m order backlog equates to three quarters. But the plans to double InP production capacity over the next 18 months mean that, six quarters from now, it could be shipping \$100m of Datacom chips per quarter. "We're working to try to overcome and increase yields, increase productivity and get more out of the assets we have, while at the same time increasing our capabilities in our fab," says Lowe.

"Our balance sheet is healthy with ample cash to fund further organic and inorganic growth," he concludes.

www.lumentum.com

Infinera's chief operating officer to succeed CEO

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical network systems incorporating its indium phosphide (InP)-based photonic integrated circuits (PICs), has announced a succession plan to transition its leadership in the coming months.

Tom Fallon will be stepping down as CEO, to be succeeded by chief operating officer David Heard, by the end of 2020 (on a date to be determined). Fallon, in his 17th year with Infinera and 11th as CEO, will remain on the board of directors.

"When David joined Infinera three years ago, our objective was to bring onboard a chief operating officer who would be positioned to take over as CEO at the right time," notes Fallon. "David's contributions since joining the company have been substantial, making us more

scalable as he led us through a major acquisition, driving synergies through operational improvements, aligning our product and service portfolio and focusing our investments on the highest-value areas for our customers and shareholders."

Having served as COO since October 2018 and led a publicly traded company as CEO in the past, Heard has over 25 years of industry experience in executive leadership roles that span a breadth of technology companies, including JDS Uniphase, BigBand Networks (now part of CommScope), Somera (now part of Jabil), Tekelec (now part of Oracle), and Lucent Technologies (now part of Nokia). He holds an M.B.A. from the University of Dayton, an M.S. in management from the Stanford Graduate School of Business, where he was a Sloan

Fellow, and a B.A. in production and operations management from Ohio State University.

In conjunction with this transition, Kambiz Hooshmand will be stepping down as chairman of the board on the same date as the CEO transition, while remaining on the board. Hooshmand has served as chairman since October 2010. He will be succeeded by existing board member George Riedel.

"We are very fortunate to have someone of George's industry experience, knowledge and strategic leadership abilities step into the chairman role and partner with David as he assumes the CEO mantle later this year," comments Fallon. "These succession changes have been thoughtfully planned and we anticipate a smooth transition."

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Emcore grows revenue 14% in June quarter, despite COVID-19-related constraints

Work-from-home trend boosting CATV demand

For fiscal third-quarter 2020 (to end-June), Emcore Corp of Alhambra, CA, USA — which provides mixed-signal products for the aerospace & defense and broadband communications markets — has reported revenue of \$27.3m, up 14% on \$23.8m last quarter and up 59% on \$17.2m a year ago, as revenue increased for both business segments.

Aerospace & Defense (A&D) revenue was \$14m, up 8% on \$13m last quarter, driven predominantly by sales of Quartz MEMS (micro-electro-mechanical system) navigation products — acquired in buying Systron Donner Inertial (SDI) of Concord, CA, in June 2019 — rebounding strongly from its seasonally soft March quarter, plus Defense Optoelectronics revenue roughly level with its high-growth fiscal Q2 (maintaining high double-digit growth year-on-year). This was partially offset by fiber-optic gyroscopes (FOG) revenue falling due to COVID-related constraints on access to testing facilities for new products and the ability to collaborate with customers to complete the necessary qualification work.

Broadband revenue was \$13.3m, up 22% on \$10.8m last quarter, driven largely by increased sales of cable TV (CATV) transmitters and components, as well as chips and sensing products.

“Our four manufacturing operations improved their productivity thanks to the diligent efforts of our supply chain, manufacturing partners and, more importantly, because of the commitment of the team at Emcore,” says president & CEO Jeff Rittichier. “Although we settled into a rhythm to deal with most of the COVID-19 outbreak, new challenges constantly emerge that have to be dealt with. In Q3, we saw surprise push-outs and cancellations of key component deliveries, which required signifi-

cant creativity to resolve,” he adds. “In addition to the risks from identifiable areas such as labor, material supplies and logistics services, the pandemic continued to increase the general level of friction in ongoing business activities. Tasks take longer than they should; customer development schedules continue to be pushed to the right, and we’ve had to adjust our plans accordingly.”

“Despite facing a full quarter’s impact from the COVID pandemic, top-line growth and ongoing operational improvements resulted in a seven-point improvement in gross margin, led by our QMEMS team,” says Rittichier.

On a non-GAAP basis, gross margin has risen further, from 22.3% a year ago and 28% last quarter to 34%. This was due largely to Aerospace & Defense segment gross margin rising from 23% last quarter to 36%, driven by improvements for Defense Optoelectronics and by raising QMEMS margins to be in line with the corporate average (mainly through better production yields and a more favorable product mix). Broadband segment gross margin fell slightly from 34% last quarter to 33%, as the higher volume was offset by a less favorable product mix. Following two back-to-back fiscal years of gross margin at 23%, fiscal 2020 year-to-date gross margin has climbed to over 30%, as consolidated and both segment gross margins were all at 31% through the first three quarters of the year.

Operating expenses were cut from \$10.4m last quarter to \$10.1m, due mainly to headcount-related reductions (including lower travel expenses) as well as a non-recurring expense recorded last quarter. This was partly offset by higher insurance expense and Broadband R&D expenses rising from \$0.49m to \$0.81m (whereas Aerospace &

Defense R&D expenses remained about \$3.85m). Expense reduction actions over the past three quarters have lowered quarterly OpEx by \$2.3m (18%). For example, restructuring actions and enterprise resource planning (ERP) implementation in Concord (completed in the March and June quarters) resulted in a net decrease in headcount. “We’ve also begun to realize the synergies projected as part of the SDI acquisition by applying Six Sigma discipline to the QMEMS manufacturing process,” says Rittichier.

Net loss has been cut further, from \$5m (\$0.18 per share) a year ago and \$3.8m (\$0.13 per share) last quarter to \$0.74m (\$0.03 per share).

Operating cash flow was \$0.7m. In addition, \$1.4m was received in connection with a prior-quarter shipment of CATV manufacturing equipment as part of a production asset sale agreement with Hytera. This was offset by capital expenditure (CapEx) of \$1m. Free cash flow was hence \$1.1m.

During the quarter, cash and cash equivalents rose from \$22.1m to \$29.7m (or \$23.2m, net of a \$6.5m loan payable).

“The transition of our cable TV manufacturing operations at Hytera’s Bangkok facility continues to face a fluid schedule,” notes Rittichier. “On the positive side, cable TV’s demand is very strong, which requires that we minimize the downtime of a major line move from Beijing to Bangkok to meet critical customer demand. On the negative side, our manufacturing engineers still can’t travel to Thailand to complete the transfer of target yields. Therefore, the best strategy for mitigating the risk and maximizing the revenue is to delay the final transmitter-line move to the end of the September quarter and the remaining operations to the end of December,” he adds. “We’ve also taken additional steps

to build out a stronger Thai manufacturing engineering team to support the schedule, should travel continue to be restricted. This move to variable-cost manufacturing is a critically important strategic initiative. As more operations move from Beijing to Thailand, we will see upward pressure on the gross margins from cable television."

"MSOs continued to invest in their networks to break the bottlenecks created by bandwidth demand from both work-from-home initiatives and stay-at-home entertainment.

This has resulted in a full order book for Emcore's cable TV products through the December quarter," says Rittichier. "Beyond this point, we remain cautious of the ultimate duration of the upgrade cycle, and are working to complete our move to variable-cost manufacturing while orders are strong," he adds.

"Looking ahead into our September quarter, the demand picture from our CATV and Aerospace & Defense customers remains strong, which should allow us to stay on the path of improved operational results

despite the global impact of the pandemic," says Rittichier.

For fiscal fourth-quarter 2020 (to end-September), Emcore expects revenue to grow to \$29-31m, and would have been higher without COVID-19-related order push-outs (related to the commercial aviation side of the QMEMS business).

"We're expecting to see a strong performance from cable television, QMEMS and our Defense Optoelectronic product lines while we work through the challenges caused by the pandemic," concludes Rittichier.

www.emcore.com

Acacia samples 100G QSFP-DD coherent pluggable module Fixed-wavelength hot-pluggable module designed for unamplified point-to-point edge and access links up to 120km

Acacia Communications Inc of Maynard, MA, USA (which develops and manufactures high-speed coherent optical interconnect products) is sampling new 100G coherent pluggable solutions specifically designed for optimization in edge and access applications with unamplified links up to 120km.

Offered in a QSFP-DD form factor widely used for client-optics, the new 100G coherent point-to-point (P2P) edge and access solutions were designed to provide network operators the ability to scale to higher data rates to meet growing bandwidth demands over the most challenging optical links, while also providing operational simplicity that may lead to overall network savings.

"Acacia has a long-standing track record of driving coherent into new market applications by delivering the technology, scalability, feature set and innovation that service providers need to maintain and grow their networks over time," says Acacia's director of product management Anuj Malik. "Leveraging our 10 years of high-performance coherent transmission expertise, we specifically designed our new 100G coherent P2P solutions to meet the needs of edge and access applications in terms of form factor,

power consumption and cost, building on our technology leadership in silicon photonics and low-power digital signal processors (DSPs)."

Compared with alternative direct-detect solutions, coherent P2P solutions are extremely tolerant to fiber types, chromatic dispersion, polarization-mode dispersion (PMD) and back reflections, which simplifies operational deployment. Edge and access networks, particularly those offering 5G wireless and enterprise services, can benefit from coherent technology because it has ample optical margins that can easily handle the condition and reaches of the access fiber plant, resulting in shorter provisioning times. Coherent P2P solutions are user friendly in deployment and provisioning due to low laser emission, wide tolerance range and rich monitoring and diagnostic features, says Acacia. Pluggable coherent solutions in QSFP-DD were designed to enable network scalability to ensure that data rates can scale up by leveraging the QSFP-DD slots with 200G and 400G versions in the future.

"Technology advancements have reached a point where coherent pluggables match the QSFP-DD form factor of grey optics, enabling a change in the way our customers

build networks," says Keven Wollenweber, VP product management for Cisco's Routing Portfolio. "100G edge and access optimized coherent pluggables will not only provide operational simplicity but also scalability, making access networks more future proof," he adds.

"Over the past decade, coherent technology has moved beyond its long-haul origins and is now firmly entrenched in the metro," comments Sterling Perrin, senior principal analyst at Heavy Reading. "With the coming of 5G and edge computing, the time is right for coherent optics to take the next step and migrate to edge and access networks. Operators looking for scale and operational simplicity will find QSFP-DD coherent pluggables a compelling option compared to direct detect alternatives."

Acacia's 100G QSFP-DD P2P fixed-wavelength hot-pluggable module is designed to operate over various types of unamplified single-mode edge and access fiber links up to 120km. The solution leverages Acacia's 3D Siliconization approach, which uses high-volume manufacturing processes and benefits from the maturity of Acacia's silicon photonics technology.

www.acacia-inc.com

Fraunhofer ISE raises efficiency record for III–V/silicon tandem cell grown directly on silicon from 24.3% to 25.9%

Inexpensive grinding and etching used on silicon substrate rather than CMP

In photovoltaics, intensive research is being carried out to continually improve solar cell efficiency.

Increasingly, the focus is on tandem photovoltaics, in which high-performance solar cell materials are brought together in various combinations in order to use the solar spectrum even more efficiently when converting light into electrical energy. Fraunhofer Institute for Solar Energy Systems ISE of Freiburg, Germany has now reported a record efficiency of 25.9% for a III–V/silicon tandem solar cell grown directly on silicon. This cell was produced on a low-cost silicon substrate for the first time — marking an important milestone on the way to economical solutions for tandem photovoltaics.

Fraunhofer ISE has been working for many years on multi-junction solar cells, in which two or three sub-cells stacked on top of another absorb different portions of the solar spectrum and convert it into electricity. Silicon is a suitable absorber for the infrared part of the spectrum. Several micron-thin layers of III–V compound semiconductors are deposited on top of the

silicon. These sub-cells efficiently convert light from the ultraviolet, visible and near-infrared parts of the spectrum into electricity.

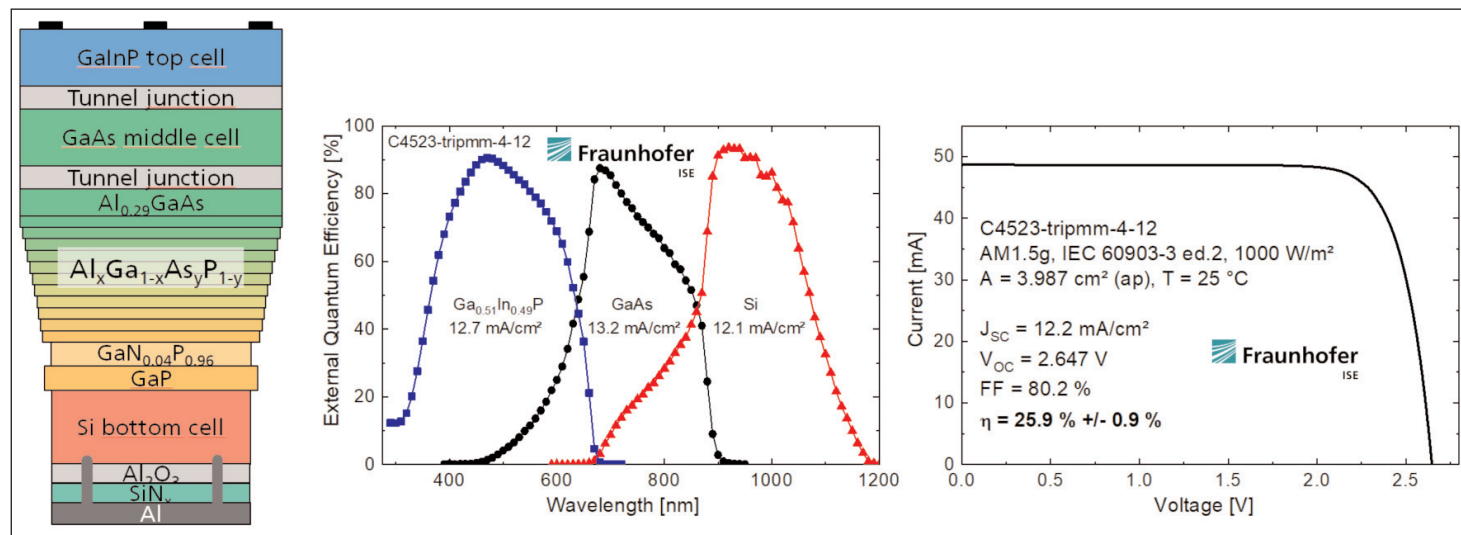
III–V solar cells on germanium substrates are often used in space as well as in concentrator photovoltaics (CPV). Through the development of better and more cost-effective processes in combination with the use of silicon as the bottom sub-cell, tandem technology can become accessible for wide-range use in almost all photovoltaic applications in the future, says Fraunhofer ISE. However, there is still much work to be done before this objective can be achieved.

25.9% for III–V/Si tandem solar cells grown directly on silicon

Several different approaches for producing combinations of III–V and silicon solar cells exist. For example, Fraunhofer ISE held the record efficiency of 34.1% (now 34.5%) for a tandem solar cell in which the III–V layers are transferred from a gallium arsenide to a silicon substrate and connected by wafer bonding. This technology is very efficient but expensive.

For this reason, Fraunhofer ISE has been working for many years on more direct manufacturing processes in which the III–V layers are grown directly onto a silicon solar cell. In this process it is crucial that all layers maintain high crystal quality, and this presents a major challenge. Now a new efficiency record of 25.9% has been achieved for a III–V/Si tandem solar cell grown directly on silicon.

Fraunhofer ISE's Markus Feifel recently presented his results at the (online) 47th IEEE Photovoltaic Specialists Conference, where his work was distinguished with the Student Award in the Category of Hybrid Tandem Solar Cells. "The complex inner structure of the cell is not visible from the outside, since all of the separate absorbers are internally interconnected by additional crystal layers and electrically series connected," says Feifel, who was able to improve his results from 24.3% to 25.9% in less than a year. "This was achieved by replacing a single thin layer within the multi-junction cell," he adds. "A careful analysis of our cells showed that this layer created a



III–V/silicon multi-junction solar cell layer structure, quantum efficiency and IV characteristics under AM1.5g spectral conditions.

potential barrier for electrons moving through the crystal structure.”

Since 2007 the Fraunhofer researchers have been developing this technology in small steps together with the Ilmenau University of Technology, the Philipps University of Marburg and deposition system manufacturer Aixtron, for example setting up special epitaxial equipment and examining every single layer of the structure. These developments were funded by the German Federal Ministry of Education and Research (BMBF) as part of the III-V-Si project and the MehrSi project.

A particular highlight of the new tandem solar cell is that the III-V layers were not grown on a chemomechanically polished substrate, as in previous cases, but directly on a silicon wafer which, after sawing, was treated in a simple process using only inexpensive grinding and etching processes. The Danish

company Topil developed this silicon wafer in the European SiTaSol project, realizing an important step towards the economical production of the new multi-junction solar cells.

In the future, the focus will be to increase the efficiency even further as well as to realize faster layer deposition, with higher throughput, and thus improve the cost-effectiveness of production. The ultimate objective is that tandem photovoltaics will be able to make an important contribution to the expansion of photovoltaics.

Key technology for energy transition

In many parts of the world, electricity from solar cells is the cheapest form of energy generation. “In Europe the photovoltaic research community is working on numerous concepts to further improve the efficiency of this key technology, which plays a central role in the

energy transition,” says professor Stefan Glunz, Division Director of the Photovoltaics Research at Fraunhofer ISE. “Not only are we working to make silicon solar cell production more sustainable and cost effective but we are also breaking new ground,” he adds. “We are aiming to reach even higher efficiencies using the tried and tested silicon in combination with other semiconductor materials, and have achieved this in the field of tandem photovoltaics.”

This technology not only opens the door to the future of power generation but is also suited to electrolysis (i.e. using electricity to split water into hydrogen and oxygen). Thus, tandem photovoltaics can be used to produce hydrogen, an energy storage medium and important building block for the energy transition.

www.ise.fraunhofer.de/en/research-projects/mehrsi.html

Emerging photovoltaics market to grow to \$38bn in 2040 CIGS sales exceed \$2bn in just ten years

The market for emerging photovoltaics will grow to \$38bn in 2040 without colliding with the silicon-in-glass ‘power station’ business, according to forecasts in IDTechEx’s report ‘Materials Opportunities in Emerging Photovoltaics 2020-2040’.

There will be many opportunities for premium pricing of new specialist materials, the report notes. For example, over \$10,000/W is currently paid for a record 30%-efficient III-V compound semiconductor (PV) in a designer watch, as an array on a satellite, or on the surface of a high-altitude drone.

Another emerging PV technology, copper indium gallium di-selenide (CIGS), has recently shot to over \$2bn sales in only ten years.

Most of the emerging PV technology is thin film, flexible and some will be stretchable, making possible many new markets, such as tightly rollable PVs in your mobile phone,

regular aircraft skin, billions of Internet of Things nodes etc.

Hundreds of millions more building facades need such lightweight PVs, says IDTechEx chairman Dr Peter Harrop. Also, triple-efficiency indoor III-V PV is newly on sale, to be followed by underwater applications. Researchers are even targeting three types of technology for PV paint. Vehicle retrofit from boats to buses... this list goes on and on, adds Harrop. (Those interested in radically new formats for electronics and electrics in general can refer to IDTechEx’s report ‘Electronics Reshaped 2020-2040’).

The PV research pipeline guarantees robust further improvements to the already dramatic leap in lifetime, efficiency, cost etc in recent years, says Harrop. CIGS will join organic photovoltaics (OPV) in being totally free of the heavy metals that could be emitted during

either misuse or wrongful disposal of the materials. Also, rare materials subject to price hikes are being bypassed. Transparency, biodegradability, availability of wide-area film, layering different technologies on top of each other - all these factors open up more sales.

But with silicon near its theoretical limits and taking up massive areas of real estate - often prime agricultural land and lakes - that multi-junction, compound semiconductor PV being developed by Toyota for mounting on a car may even compete with ‘power station’ silicon one day by affordably providing the same power in half the area, and therefore being much more widely deployable and acceptable, concludes IDTechEx.

www.idtechex.com/en/research-report/materials-opportunities-in-emerging-photovoltaics-2020-2040/758

First Solar joins RE100 and pledges to power 100% of global operations renewably by 2028

All US operations to go renewable by 2026

First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services — has committed to powering 100% of its global photovoltaic (PV) solar manufacturing operations with renewable energy by 2028. As part of an interim goal, the firm has pledged to transition its facilities in the USA to carbon-free electricity by 2026.

The commitments (which cover both 'Scope 1' direct emissions from First Solar-owned or -controlled sources and 'Scope 2' indirect emissions from the generation of electricity purchased from third-party sources) were announced as First Solar joined RE100, a global, collaborative initiative bringing together influential businesses committed to 100% renewable power. RE100 is led by international non-profit the Climate Group in partnership with CDP.

"With this pledge, we will further lower our embodied carbon footprint, already the lowest in the industry, and move towards realizing the full promise of cleaner

solar," says CEO Mark Widmar. "The solar manufacturing industry has a collective responsibility to set challenging decarbonization goals for itself, and we hope that our decision encourages other PV manufacturers to make their own commitments."

The only US company among the world's largest solar manufacturers, First Solar celebrated two decades since its founding in 1999 and has shipped over 25GWDC of PV modules to over 45 countries around the world. With facilities in the USA, Malaysia and Vietnam, First Solar exited 2019 with a total global annualized manufacturing capacity of 5.5GWDC. It is also the Western Hemisphere's largest solar manufacturer, with a 1.9GWDC manufacturing footprint in Ohio.

"By relying on long-term, fixed-price renewable energy, we're not only investing in reducing our exposure to energy price volatility, but we're also investing in a sustainable energy future," says chief manufacturing operations officer Mike Koralewski. "As part of our strategy, we will strive to support the delivery of additional renewable

energy capacity, especially in emerging corporate renewables markets in Malaysia and Vietnam."

Designed and developed at the its R&D centers in California and Ohio, First Solar's thin-film PV module technology has a carbon footprint that is said to be up to six times lower than crystalline silicon PV panels manufactured using conventional, energy-intensive production methods. Its modules already deliver the lowest carbon solar electricity available, it is claimed, and the firm expects the carbon footprint of its modules to fall by an additional 40% by 2028.

"We're glad to see First Solar leverage its extensive experience in enabling corporate renewables to decarbonize its own operations," comments Sam Kimmins, head of RE100, the Climate Group. "Today's RE100 pledge is the natural evolution of its commitment to sustainability and carbon-efficient manufacturing. We urge others in the solar manufacturing industry to follow suit and commit to 100% renewable electricity."

www.firstsolar.com
www.there100.org

First Solar selling North American O&M business to NovaSource

220 O&M staff to be transferred with business

Cadmium telluride (CdTe) thin-film photovoltaic module maker First Solar Inc of Tempe, AZ, USA has entered into a membership interest purchase agreement for NovaSource Power Services, a portfolio company of Toronto-based private equity firm Clairvest Group Inc, to acquire its North American operations and maintenance (O&M) business.

Upon closing of the transaction, about 220 First Solar O&M associ-

ates are expected to be transferred with the acquired business.

In May, Clairvest supported a management buy-out of SunPower Corp's O&M business, which was subsequently renamed NovaSource. NovaSource oversees solar projects in the USA and currently operates in nine countries.

Completion of the transaction is subject to closing conditions including the receipt of third-party consents, the expiration of the

waiting period under the Hart-Scott-Rodino (HSR) Antitrust Improvements Act of 1976, and review by the Committee on Foreign Investment in the United States (CFIUS).

Additionally, the transaction is subject to certain other customary closing conditions. Assuming satisfaction of these, the transaction is expected to close in fourth-quarter 2020.

www.firstsolar.com

First Solar chief operating officer Tymen deJong to retire

Transition to lead to senior leadership changes

First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services — says that chief operating officer (COO) Philip Tymen deJong has decided to retire from the company, effective April 2021. In addition, First Solar has announced a series of senior leadership changes.

deJong's career spans over four decades, with ten years of service to First Solar, five of which includes his tenure as COO. He played a fundamental role in establishing the firm's international Series 6 module manufacturing footprint, with five announced factories currently in production, and a sixth on track to begin production during first-quarter 2021.

deJong will continue to serve as COO for an eight-month transition period, during which he will oversee certain priority projects, while transitioning most of his responsibilities to chief manufacturing operations officer Michael Koralewski, chief manufacturing engineering officer Kuntal Kumar Verma, and chief quality & reliability officer Patrick Buehler, each of whom will join First Solar's executive leadership team.

"After a decade of stewardship of our manufacturing, supply chain and enterprise-wide operations, Tymen's retirement is well earned," comments CEO Mark Widmar. "He will continue to serve the company on several key initiatives until his retirement."

Koralewski provides nearly 15 years of global operational experience to the executive leadership team. As chief manufacturing operations officer, he is responsible for First Solar's site operations and supply chain management. He joined First Solar in 2006 and has held progressively more senior roles in operations and quality management with global responsibility, including VP –

global quality, VP – site operations (global) and plant manager, and senior VP – global manufacturing.

Since joining First Solar more than 15 years ago, Verma has been instrumental in scaling up First Solar's manufacturing capabilities, including the first- and second-generation CdTe manufacturing lines. As chief manufacturing engineering officer, he is responsible for global manufacturing replication and performance. Previously, Verma held a variety of engineering roles, including as VP – global manufacturing engineering, director – manufacturing engineering, and engineering manager – deposition.

Buehler brings over a decade of experience in quality and reliability to the executive leadership team. As chief quality & reliability officer, he is responsible for global manufacturing quality, product reliability, performance and prediction analytics, customer service, sustainability, and environmental, health & safety. He joined First Solar in 2006 and has held progressively more senior technical and operations roles in quality & reliability, including serving as VP – quality & reliability since March 2019.

"With Series 6 deployed, and a strong team in place to carry it forward, I am confident that the timing is right for me to retire with the business in good hands," says deJong. "I am working closely with Mike, Kuntal and Pat to effect a seamless transition."

First Solar also says that Markus Gloeckler has been appointed co-

chief technology officer alongside Raffi Garabedian, First Solar's chief technology officer since 2012, as part of First Solar's new co-CTO structure. Gloeckler will join First Solar's executive leadership team.

"Moving to a co-CTO structure will enhance our platform for growth and aligns with our vision to excel in technology," says Widmar. "As co-CTOs, Markus will continue to drive our Series 6 platform, enabling Raffi to focus on advanced R&D and further pursue the capabilities of our industry-leading cadmium telluride thin-film module technology."

Gloeckler has extensive experience guiding strategic R&D activities. Prior to being named co-chief technology officer, he served as VP – chief scientist, before being promoted to senior VP – module R&D. He was instrumental in enabling First Solar's achievement of a record conversion efficiency for a CdTe solar cell.

In addition, First Solar says that Jason Dymbort will join its executive leadership team as general counsel & secretary after serving in this capacity on an interim basis since March. During his time at First Solar, which began in 2008, he has held numerous legal roles, helping to grow the firm's internal legal capabilities in support of a broad range of subject matter areas. Between 2015 and 2018, Dymbort served as general counsel & secretary for the general partner of 8point3 Energy Partners (then a publicly traded yieldco and affiliate of First Solar). Before joining First Solar, he was a corporate attorney at Cravath, Swaine & Moore LLP.

The additions to the executive leadership team will "better align our manufacturing, technical, and commercial capabilities, and set the company up for continued growth," believes chief people & communications officer Caroline Stockdale.

www.firstsolar.com

Markus Gloeckler has been appointed co-CTO alongside Raffi Garabedian. Markus will continue to drive our Series 6 platform, enabling Raffi to focus on advanced R&D

Carrier-localization engineering for DUV LEDs

Researchers use self-assembled sidewall quantum well structures to boost light output power and quantum efficiency of III-nitride material on sapphire.

China's Peking University has used deep-ultraviolet (DUV, <300nm wavelength) light-emitting 'self-assembled sidewall quantum well (SQW)' structures to improve light output power performance of diodes based on aluminium gallium nitride (AlGaIn) compound semiconductor alloys [Y. H. Sun et al, Appl. Phys. Lett., vol116, p212102, 2020].

The sidewall structures arose from bunching effects during multiple quantum well (MQW) material growth processing on (0001) c-plane sapphire substrates with different miscut angles. [One should stress here that the SQW abbreviation for 'sidewall quantum well' is non-standard; more normally, SQW is used for 'single quantum well'.]

Potential applications for DUV light-emitting diodes (LEDs) include water/air purification, non-line-of-sight communication, biological/chemical analysis, ultraviolet curing, environmental sensing, and plant growth lighting. Present DUV LEDs, however, suffer from poor efficiency and low light output power performance.

These problems are related to defects in the materials used in such devices.

One approach to improved performance would be to increase material quality by using AlN substrates to enable closer lattice matching with AlGaIn heterostructures, compared with sapphire. However, AlN substrates of appropriate quality, size and cost have yet to be developed.

The Beijing researchers see their SQW approach as being a potential "subversive framework" that involves "an active region structure with low sensitivity to the density of defects to reduce the tough requirements on the quality of AlN and AlGaIn". An additional factor is that the SQW structures create carrier localization effects that can improve recombination into photons, and avoid carriers being trapped by dislocations and then transitioning to the ground state with no light emitted.

The material was grown on miscut (0001) c-plane sapphire using metal-organic chemical vapor deposition

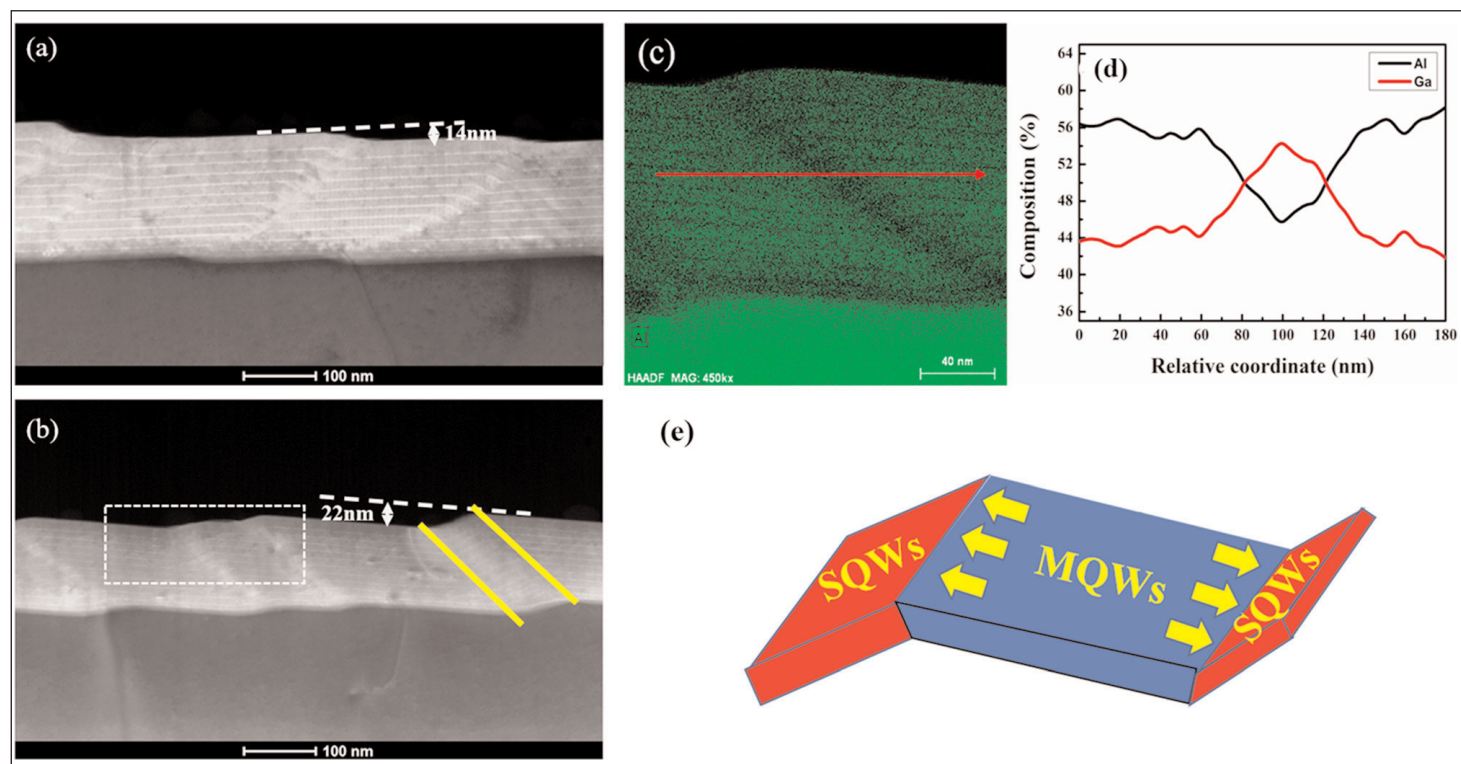


Figure 1. Cross-sectional HAADF-STEM images of sample B (a) and sample C (b), and EDS mapping of selected area in sample C (c), (Al composition shown by green intensity); (d) relative Al and Ga compositions along horizontal red arrow in (c); (e) schematic images of exciton movement in MQW and SQW regions.

(MOCVD). The precursors were trimethylgallium/aluminium and ammonia (NH_3). The miscut angles, relative to the m-plane, were 0.2° (sample A), 2° (B), and 4° (C).

The nucleation layer was 20nm 930°C AlN. The main $1\mu\text{m}$ AlN template layer was grown at 1250°C . Further 1250°C growth consisted of a $0.5\mu\text{m}$ AlN/ $\text{Al}_{0.55}\text{Ga}_{0.45}\text{N}$ superlattice, and $1.5\mu\text{m}$ silicon-doped n- $\text{Al}_{0.55}\text{Ga}_{0.45}\text{N}$ as the electron source/n-contact.

The temperature was then reduced to 1070°C for the final 10-period MQW structure of $2.3\text{nm}/10\text{nm}$ $\text{Al}_{0.37}\text{Ga}_{0.63}\text{N}/\text{Al}_{0.5}\text{Ga}_{0.5}\text{N}$ pairs.

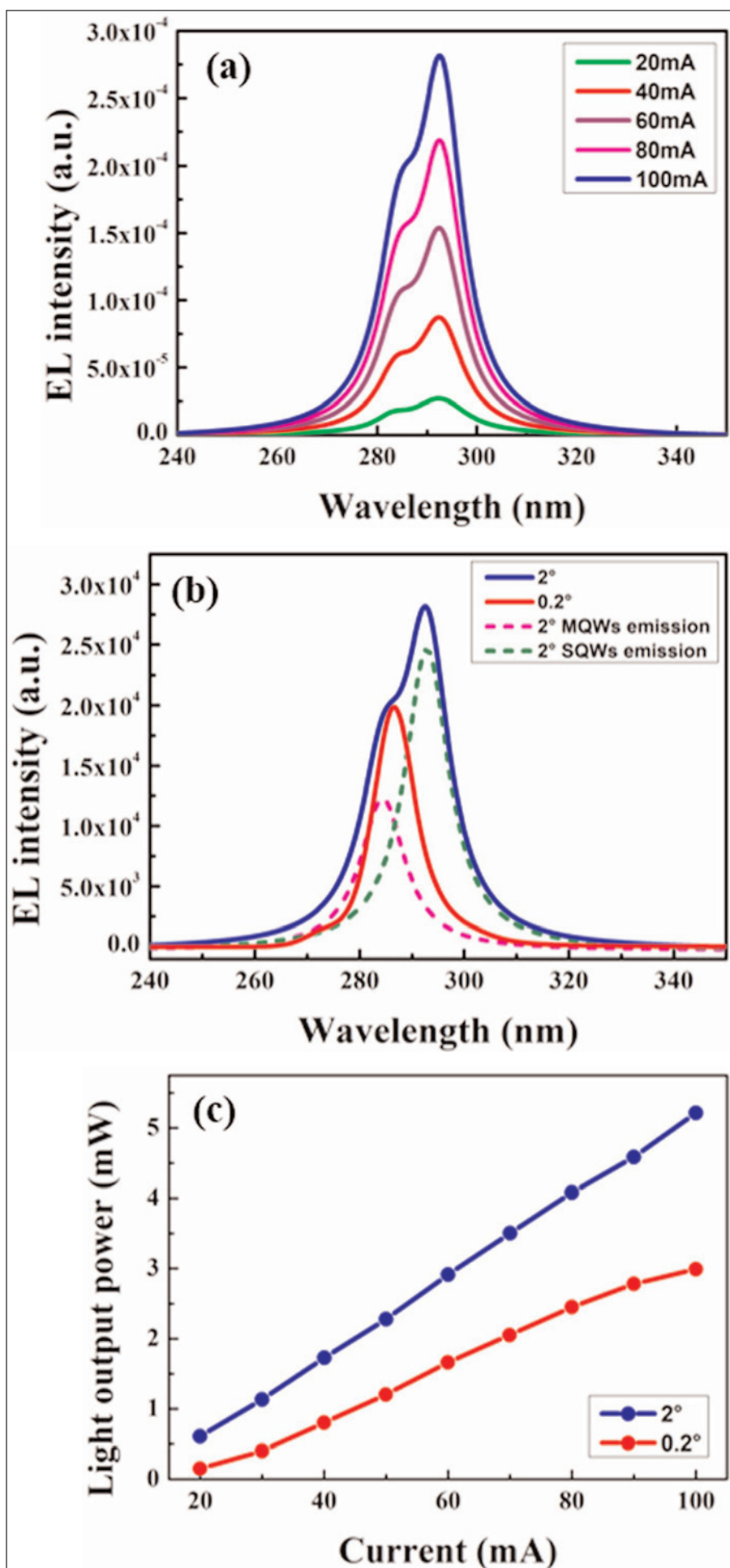
Atomic force microscopy (AFM) showed an increased surface roughness as the miscut angle increased: 0.71nm root mean square (RMS) for sample A, and 3.85nm and 6.3nm for samples B and C, respectively. The increased angle also increased the density of macrostep bunches.

Based on cross-sectional high-angle annular dark-field scanning transmission electron microscopy (HAADF-STEM) and energy dispersive spectroscopy (EDS) analysis, the researchers give an average terrace widths for samples B and C of 320nm and 200nm , respectively (Figure 1). The narrower terraces of sample C reflect the higher density of macrostep bunches. The step heights were 14nm for sample B and 22nm for C.

The EDS mapping showed $\sim 10\%$ reduced Al content in the regions of the steps. The researchers explain this as being due to the higher surface mobility of Ga relative to Al in the growth process. The reduced Al means that the effective bandgap will be reduced in the step area, attracting free carriers and creating localization. Such effects can lead to increased recombination into photons, relative to non-radiative dissipation of the input power.

Cathodoluminescence (CL) on a sample with 0.5° miscut substrate suggested that the bandgap in the step region was such

Figure 2. (a) EL spectra of DUV-LED on 2° -miscut sapphire at different currents; (b) EL spectra from DUV-LEDs with miscut angles of 0.2° and 2° at 100mA injection; (c) LOP at different injection currents.



as to produce a spectral peak around 293nm wavelength, compared with 280nm from the smooth terraces. The longer wavelength at the step suggest a narrower bandgap. The relatively small miscut angle of 0.5° was used due to experimental limitations of the CL technique.

Temperature-dependent photoluminescence (TDPL) also showed two spectral peaks with the shorter wavelength associated to the smooth MQW terraces and the longer wavelength to the SQW step regions, in accordance with the CL study.

The internal quantum efficiency (IQE) was assessed by comparing the room-temperature and 10K PL intensities. The intensity at 10K was assumed to result from 100% IQE. For samples A-C, the room-temperature IQE was determined at 46%, 54% and 59%, respectively. By separating the behaviors of the SQW and MQW emissions using Lorentz curve fits, the IQE of the SQW region of sample B was estimated to be 56%, while the MQWs only managed 45.6%.

X-ray analysis of MQWs grown directly on the AlN template layer suggested threading dislocation densities (TDD) of $1.56 \times 10^{10}/\text{cm}^2$, $1.17 \times 10^{10}/\text{cm}^2$ and $6.4 \times 10^9/\text{cm}^2$ for substrate miscut angles of 0.2°, 2° and 4°, respectively. While the density was much reduced for the 4° sample, these are all relatively high values. The researchers see the lower TDD value for the 4° MQW structure as "a main factor contributing to the increase in IQE".

The team adds: "Another factor accounting for the increased IQE is the effect of the additional one-dimensional carrier confinement, resulting in much stronger localization of carriers to avoid interactions with TDs."

Time-resolved PL was used to determine fluorescence

lifetimes: 126ps for sample A and 508ps for C. Sample B was studied more closely, separating the MQW and SQW parts: 155.9ps and 208.9ps, respectively. "These results show that the fluorescence lifetime of the SQWs is significantly prolonged than that of MQWs, indicating that the non-radiative recombination in SQWs is more effectively suppressed compared to the case of MQWs," the team explains.

DUV LEDs were produced on 0.2° and 2° miscut substrate materials. The 4° miscut material was found to have problems with electrical leakage effects arising from the large surface fluctuations.

The 2° 'SQW sample' was found to have a double, overlapping peak spectrum (Figure 2). The light output power (LOP) was 5.1mW with 100mA injection, compared with 2.99mW for the 'MQW sample' with 0.2° miscut substrate.

Again separating the 'SQW sample' into SQW and MQW components, the researchers found the intensity of the SQW emission to be greater than from the MQW emission from the 0.2° 'MQW sample', while the MQW component was less intense. The researchers point out that the effective emission area of the MQW component was restricted by the presence of SQW structures. The wavelengths of both peaks in the SQW sample were shorter than 300nm, putting them in the 'DUV' range.

The researchers comment: "These results further verify that the proposed active region involving SQWs has much greater potential in device performance than that with only MQWs, especially when the material quality of AlN and AlGaIn remains at a poor or medium level." ■

<https://doi.org/10.1063/5.0008339>

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Effectively releasing tensile stress in AlN thick film for low-defect-density AlN/sapphire template

A medium-temperature AlN interlayer has been used to reduce curvature and cracking in deep-ultraviolet LED growth.

Researchers in China have demonstrated how to effectively release tensile stress in aluminium nitride (AlN) thick film by using high-temperature (HT) metal-organic chemical vapor deposition (MOCVD), permitting the growth of low-defect-density AlN/sapphire template [Chenguang He et al, 'Fast growth of crack-free thick AlN film on sputtered AlN/sapphire by introducing high-density nano-voids', *J. Phys. D: Appl. Phys.* 53 (2020) 405303]. The team hopes that this technique can enable improved performance for deep-ultraviolet light-emitting diodes (DUV LEDs).

DUV LEDs have wide application potential in water/air/surface sterilization, non-line-of-sight communication, photoionization and gas/DNA sensing. Due to the lack of large-scale and low-cost native AlN substrate, existing DUV LEDs are mainly fabricated on AlN/sapphire templates. However, the large thermal mismatch and lattice mismatch between AlN epilayers and

Figure 1. Curvature transients of (a) the AlN thick film without MT interlayer and (b) the AlN thick film with MT interlayer during growth and cool-down processes.

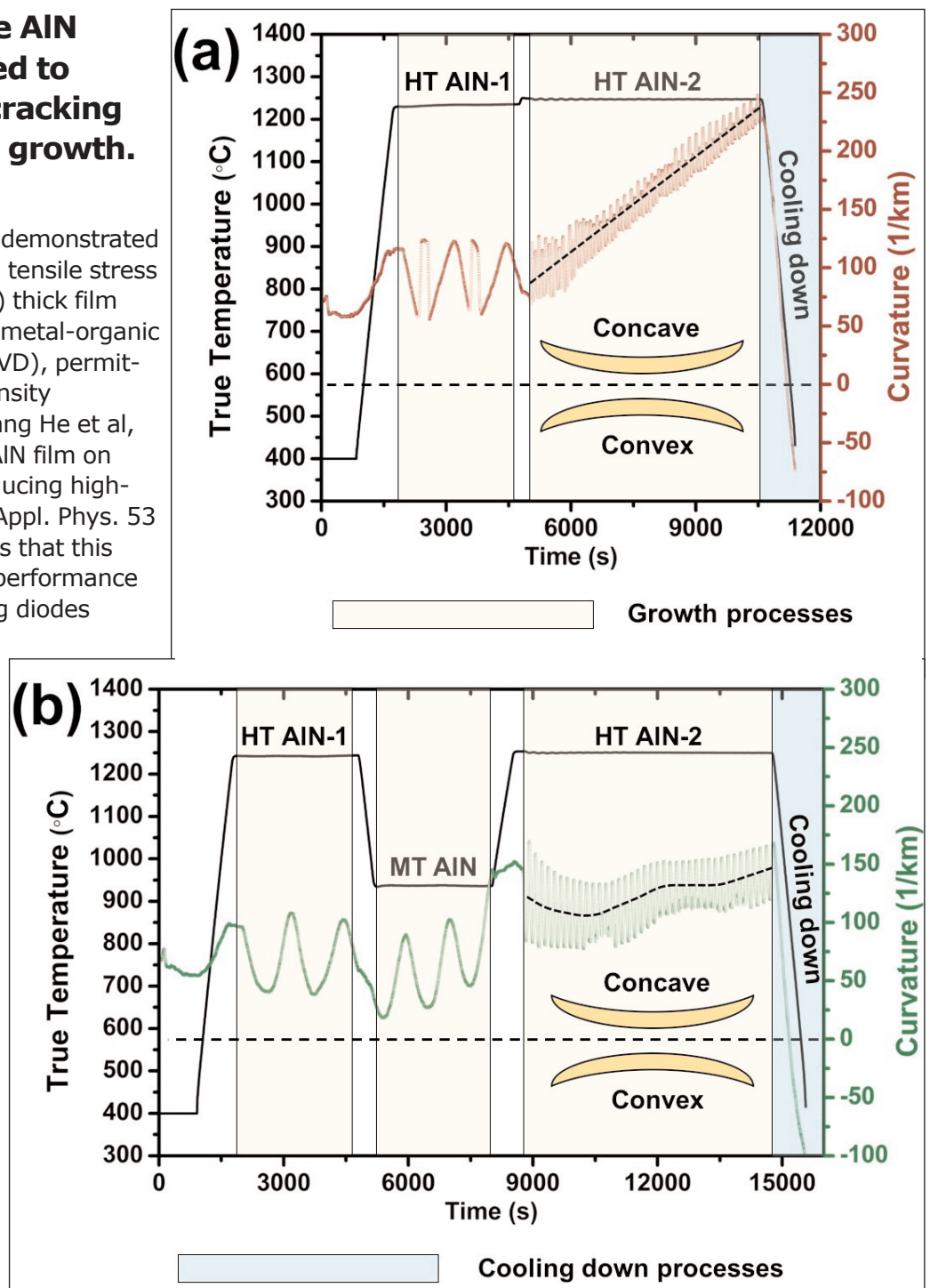


Figure 2. Photographs of (a) the AlN thick film without MT interlayer and (c) the AlN thick film with MT interlayer. Optical images of (b) the AlN thick film without MT interlayer and (d) the AlN thick film with MT interlayer.

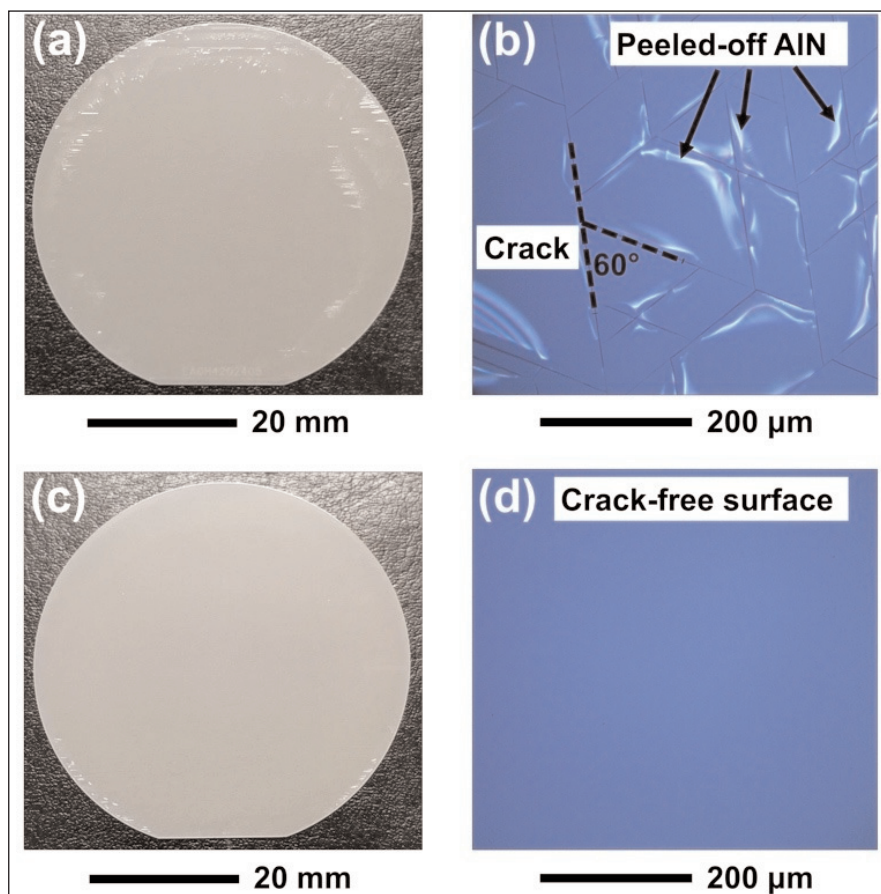
sapphire substrates result in a high threading dislocation density (TDD). As a result, the indium-free DUV LEDs, which are extremely sensitive to TDD, have suffered from low light output power.

The researchers at China's Guangdong Institute of Semiconductor Industrial Technology (GISIT), Guangzhou University, Peking University etc proposed to reduce TDD in an AlN/sapphire template by growing AlN thick film, which allows dislocations to climb long distances for mutual annihilation. The key to this technique is effectively releasing tensile stress in AlN thick film by introducing high-density nano-voids.

The growth of AlN film was initiated from a 20nm-thick AlN buffer sputtered on a 2-inch (0001) sapphire substrate within a NAURA iTops A230 AlN sputter system.

Subsequently, the thick AlN film was fabricated on the sputtered AlN/sapphire by employing an Aixtron close-coupled showerhead (CCS) high-temperature (HT) metal-organic chemical vapor deposition (MOCVD) system. The subsequent structure consists of a 300nm-thick HT AlN-1 layer (1230°C), a 350nm-thick medium-temperature (MT) AlN interlayer (930°C) and a 4950nm-thick HT AlN-2 layer (1235°C). The total thickness of AlN film is about 5.6 μ m. In addition, a 5.6 μ m-thick AlN film without MT interlayer was also grown for comparison.

The in-situ curvature transients show that, during the growth of HT AlN-2, the rate of curvature increase of the AlN thick film with MT interlayer (Figure 1(b)) was much smaller than that of the AlN thick film without



MT interlayer (Figure 1(a)), indicating much weaker tensile stress. The ultimate tensile stress intensities in the AlN thick film with MT interlayer was calculated to be 0.18GPa, demonstrating a 64% reduction compared with its counterpart without MT interlayer.

The photograph of the AlN thick film without MT interlayer (Figure 2) demonstrates that the crack-free region only accounts for 44% of the total wafer area. Cracking and peeling off took place with very high probability. In sharp contrast, the AlN thick film with MT interlayer demonstrates a mirror-like surface without any cracks except the 2mm margin. Generally, such a thick and crack-free AlN can only be obtained using the epitaxial lateral overgrowth (ELOG) technique. It further certifies that introducing an MT AlN

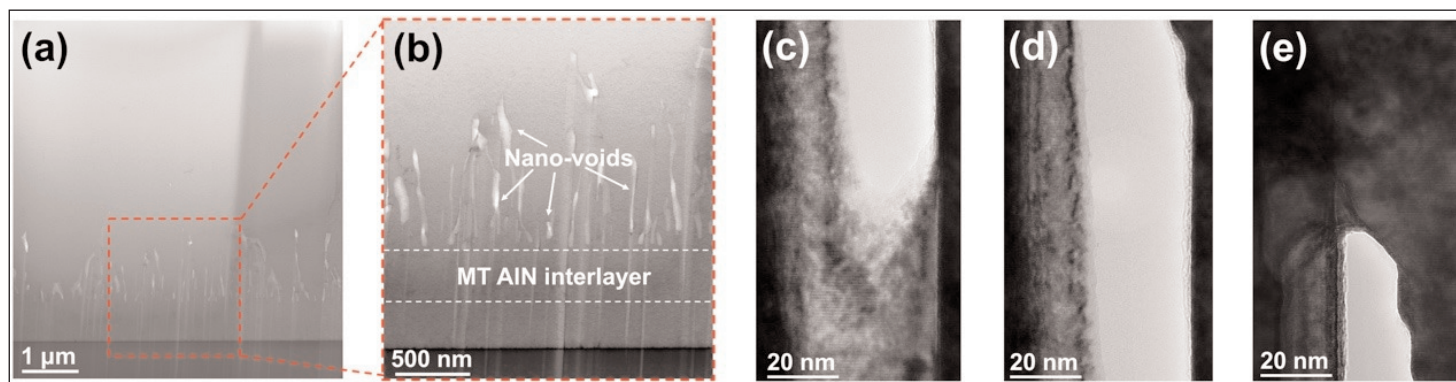


Figure 3. (a) Cross-sectional STEM morphology image of the AlN thick film with MT interlayer. (b) The enlarged cross-sectional morphology image of the red dashed area. Morphology images of a typical nano-void in the (c) bottom, (d) middle, and (e) top areas.

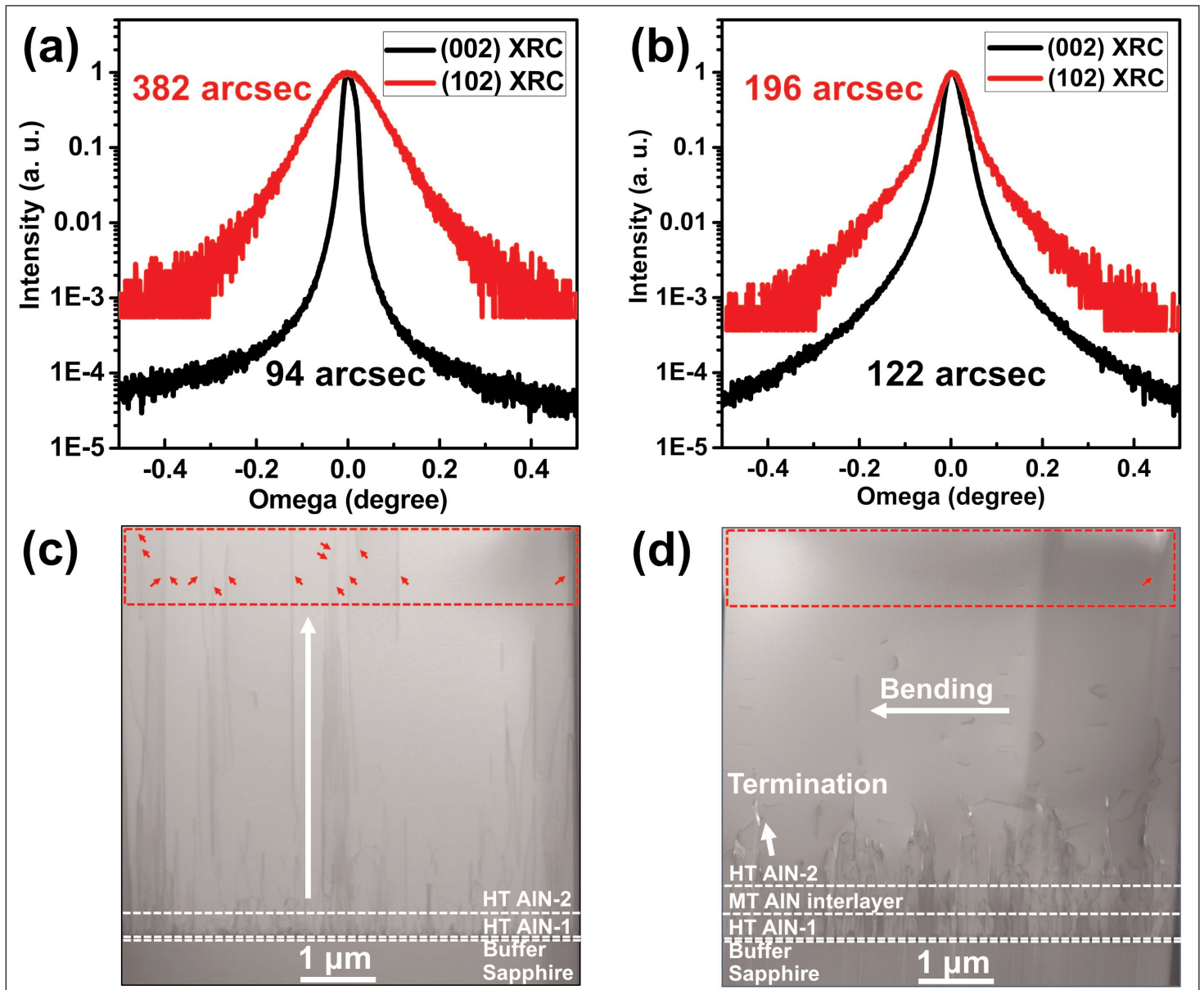


Figure 4. X-ray rocking curve scans of (002) and (102) reflections for (a) the AIN thick film without MT interlayer and (b) the AIN thick film with MT interlayer. Cross-sectional STEM images of (c) the AIN thick film without MT interlayer and (d) the AIN thick film with MT interlayer.

interlayer can effectively alleviate tensile stress.

The cross-sectional scanning transmission electron microscope (STEM) morphology images in Figure 3 show that the introduction of the MT interlayer induced the generation of high-density ($1.7 \times 10^{10} \text{cm}^{-2}$) nano-voids, which are 40–700 nm long and 10–90 nm wide. These nano-voids are believed to effectively destroy the coherence between the MT interlayer and the subsequent epilayer by reducing contact area, contributing to the significantly reduced tensile stress.

High-resolution x-ray diffraction (HR-XRD) measurement shows that the crystalline quality of AIN film with MT interlayer is also significantly improved. The FWHMs of (002) and (102) reflections for the AIN thick film without MT interlayer are 94 arcsec and 382 arcsec, respectively. Although the FWHM of the (002) reflection for the AIN thick film with MT interlayer

slightly increases to 122 arcsec, the FWHM of the (102) reflection decreases dramatically to 196 arcsec. Cross-sectional STEM reveals that nano-voids in the AIN thick film with MT interlayer can induce dislocation termination, and nearly no new dislocations are generated at the coalescence boundaries owing to the large length-width ratios of the voids. Furthermore, during the subsequent growth process, a large proportion of the residual dislocations in sample B experience a 90° bending. Finally, the TDD of the AIN thick film with MT interlayer is reduced to an extremely low value of $4.7 \times 10^7 \text{cm}^{-2}$.

The researchers reckon that this technique paves the way for achieving high-performance deep-ultraviolet LEDs and other AIN-based optoelectronic/electronic devices. ■

<https://iopscience.iop.org/article/10.1088/>

Phosphor-free white LEDs for efficient displays and communications

Semi-polar bulk gallium nitride substrate enables partially polarized radiation and higher modulation bandwidth.

University of California Santa Barbara (UCSB) in the USA has developed phosphor-free 'white' light emitting diodes (LEDs) using semi-polar yellow and blue indium gallium nitride (InGaN) quantum wells (QWs) [Hongjian Li et al, *Optics Express*, vol.28, p13569, 2020]. Low-cost 'white' LEDs generally consist of blue InGaN devices with a phosphor layer that converts some of the generated light into a yellow component.

In addition, the devices demonstrated a natural polarization direction, which could enable more efficient use of back-lights in liquid-crystal displays (LCDs). Further, having the blue and yellow light electrically generated in the UCSB phosphor-free devices improved the modulation bandwidth, giving potential for higher-speed visual light communications (VLC). Phosphor-based light suffers from delays between absorption and emission of light, along with energy losses.

The researchers used semi-polar (20 $\bar{2}$ 1) bulk GaN substrates from Japan's Mitsubishi Chemical Corp. Atmospheric-pressure metal-organic chemical vapor deposition (AP-MOCVD) was used to create an epitaxial

heterostructure: 2 μ m n-GaN, 30-period 2nm/2nm In_{0.06}Ga_{0.94}N/GaN superlattice, 3nm In_{0.28}Ga_{0.72}N yellow QW, 30nm GaN barrier, 3nm In_{0.13}Ga_{0.87}N blue QW, 30nm GaN spacer, 15nm AlGaIn electron-blocking layer, 120nm p-GaN, and 20nm p⁺-GaIn contact. The indium content of the yellow and blue QWs was derived from atom probe tomography (APT).

The use of semi-polar material reduces efficiency-sapping quantum-confined Stark effects (QCSE), where electric fields from the different charge polarizations of the chemical bonds in the heterostructure pulls apart electrons and holes, inhibiting their recombination into photons. The effect has a larger and larger impact as the emission wavelength gets longer.

A range of sub-millimeter and μ LEDs were fabricated with 110nm indium tin oxide (ITO) transparent conductor on the p-GaN, and aluminium/nickel/gold metal n- and p-contacts. The LED structures were formed with silicon tetrachloride reactive-ion etch. Silicon dioxide/tantalum pentoxide dielectric omni-directional reflectors were applied by ion-beam deposition, along with an aluminium oxide cap. Atomic layer deposition (ALD) silicon dioxide was used as a 50nm passivation layer

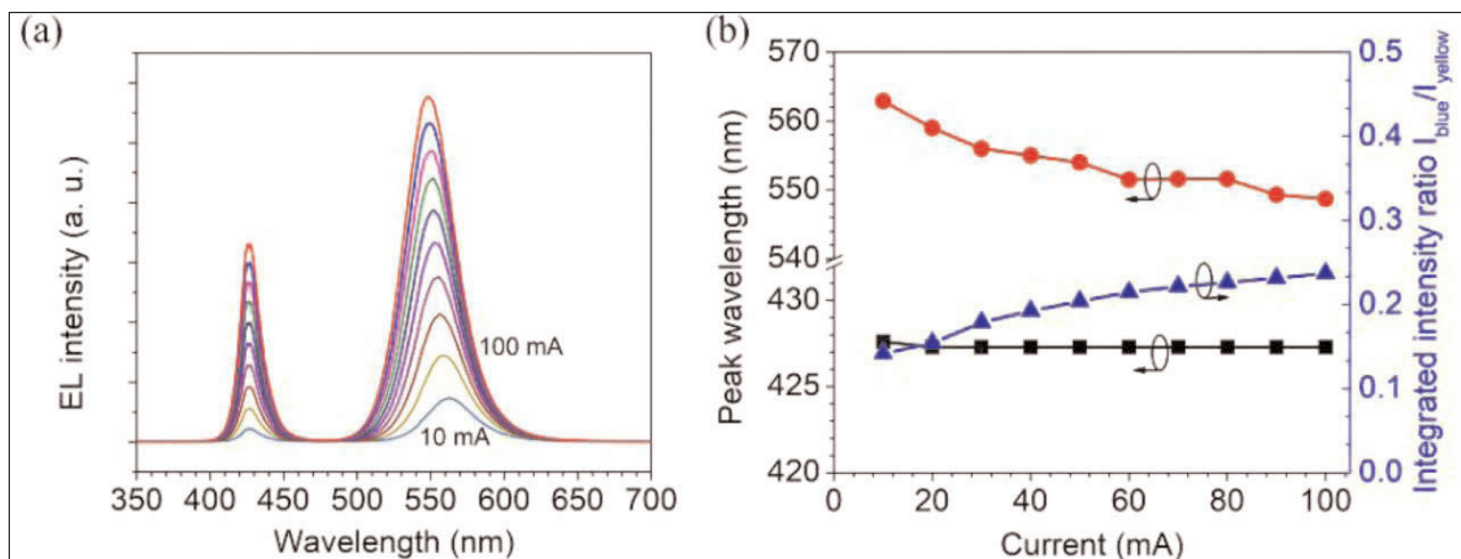


Figure 1. (a) Electroluminescence spectra versus current from 10 to 100mA; (b) peak wavelength of blue and yellow QWs and blue/yellow intensity ratio over the injection current range.

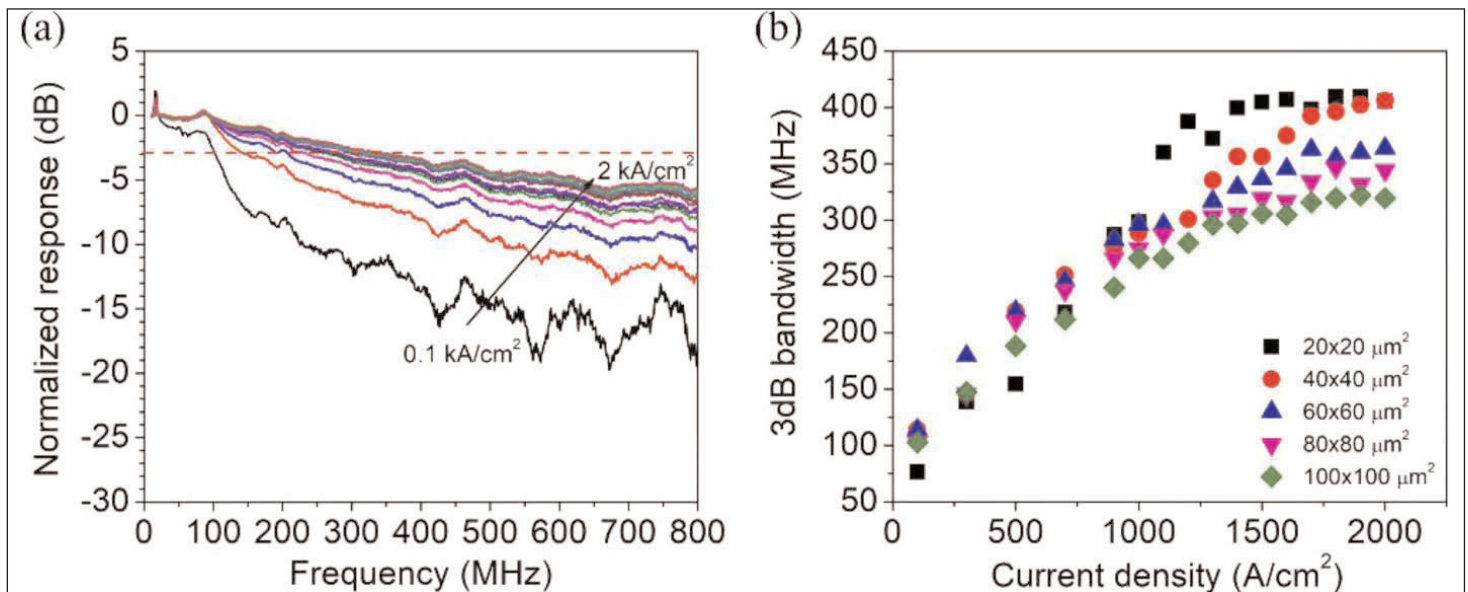


Figure 2. (a) Frequency response of square μ LED with $60\mu\text{m}$ sides, and (b) 3dB modulation bandwidth versus current density for different size square μ LEDs.

for the sidewalls of the devices.

A regular LED with 0.1mm^2 effective area achieved a light output power of 0.9mW at 20mA current injection and 3.1V forward voltage. The measurement was made on-wafer and the devices did not have any backside roughening to enhance light extraction. The researchers say that their experience leads them to believe that backside roughening, along with resin encapsulation and mounting in a silver header, should increase the light output approximately three-fold.

The team also claims that the higher light output and lower forward voltage represent “a significant improvement of performance” over previously reported phosphor-free white semi-polar LEDs.

The wavelength spectrum of the devices at 20mA (Figure 1) consisted of two peaks at 427nm (blue) and 560nm (yellow). The full-widths at half maximum (FWHMs) were 18nm and 38nm , respectively. The blue peak showed less than 1nm variation in the $10\text{--}100\text{mA}$ range of current injection. By contrast, the yellow peak experienced a blue-shift of 13nm over the same range. Even so, the yellow shift was small compared to that of devices grown in the conventional polar c -direction.

The relative blue content increased as the current increased with the blue/yellow intensity ratio going from 0.14 to 0.24 . The researchers suggest that the yellow emission is a combination of electroluminescence from current injection and optical pumping from the blue photons being converted to yellow through photoluminescence.

In terms of Commission Internationale de l’Eclairage (CIE) (x, y) chromaticity, the device emitted light with $(0.32, 0.50)$ co-ordinates at 20mA . The researchers comment: “It is noted that the emission spectrum, CIE and color rendering index (CRI) can be precisely tailored by manipulating the QWs numbers and/or the

indium composition in our design.”

The emitted light was also found to be partially polarized, attributed to a strain-related separation of the valence bands in the InGaN layers. In c -plane devices, emitted light is unpolarized. The yellow light was found to be more polarized at 0.41 ratio, compared with 0.34 for the blue radiation. The overall ratio for the monolithic white LED was 0.40 . In an LCD, the polarization could be used to reduce losses from the need to input polarized light. With c -plane devices more than half the radiation power is lost in going through a polarizer sheet.

To assess the switching capability of the LEDs for VLC applications, micro-devices were used to enable high current densities. The 3dB modulation bandwidth was found to increase with current density (Figure 2). The researchers attribute the improvement to “screening of built-in electric field and the reduced carrier lifetime by a higher injected carrier density”.

Also, smaller devices had slightly higher bandwidth. Square devices with sides of $20\mu\text{m}$ and $40\mu\text{m}$ demonstrated bandwidths of up to 410MHz . Better performance has been achieved with the non-polar m -plane blue LEDs, but the team expects “optimizing the barriers/wells thickness and the number of blue/yellow QWs” to improve the bandwidth of the yellow/blue LEDs. The researchers point out that there is generally a trade-off between efficiency and modulation bandwidth.

The team comments: “it is promising to achieve a high luminous efficiency in monolithic white LEDs by integrating blue and yellow QWs directly grown on semi-polar $(20\bar{2}1)$ GaN substrate in one growth.” ■

www.osapublishing.org/oe/abstract.cfm?uri=oe-28-9-13569

Author: Mike Cooke

Baking and plasma-enhanced low-temperature GaN atomic layer deposition

Sapphire substrate pretreatment enables single-crystal nucleation at 350°C with reduced impact of thermal expansion mismatch.

Researchers based in China and the USA have improved the crystal quality of gallium nitride (GaN) thin films on sapphire from a 350°C low-temperature plasma-enhanced atomic layer deposition process (PE-ALD) using an in-situ bake and plasma substrate pretreatment [Sanjie Liu et al, Appl. Phys. Lett., vol116, p211601, 2020].

The team – from University of Science and Technology Beijing, Hunan Normal University, Beijing National Laboratory for Condensed Matter Physics, China, and University of California Riverside, USA – hope that the process could enable improved nucleation for GaN-on-sapphire growth.

Low-temperature growth is attractive since substrates such as sapphire, or silicon, have a large thermal expansion mismatch with GaN. Standard high-temperature growth processes, typically 800–1100°C, are limited by the risk of large biaxial stress and even cracking developing in the thin-film material, degrading device efficiency and crushing production yields.

The researchers comment: “Since ALD depends dramatically on the surface reactions, the initial nucleation step influences the crystalline quality of deposited GaN.” GaN ALD on sapphire tends to result in polycrystalline films.

High-quality wide-bandgap (3.4eV) GaN semiconductor material has a wide range of present and potential future applications for short-wavelength visible and near-UV light emission, high-frequency/high-power-density electronics, and so on. High-frequency power amplification of 5G wireless

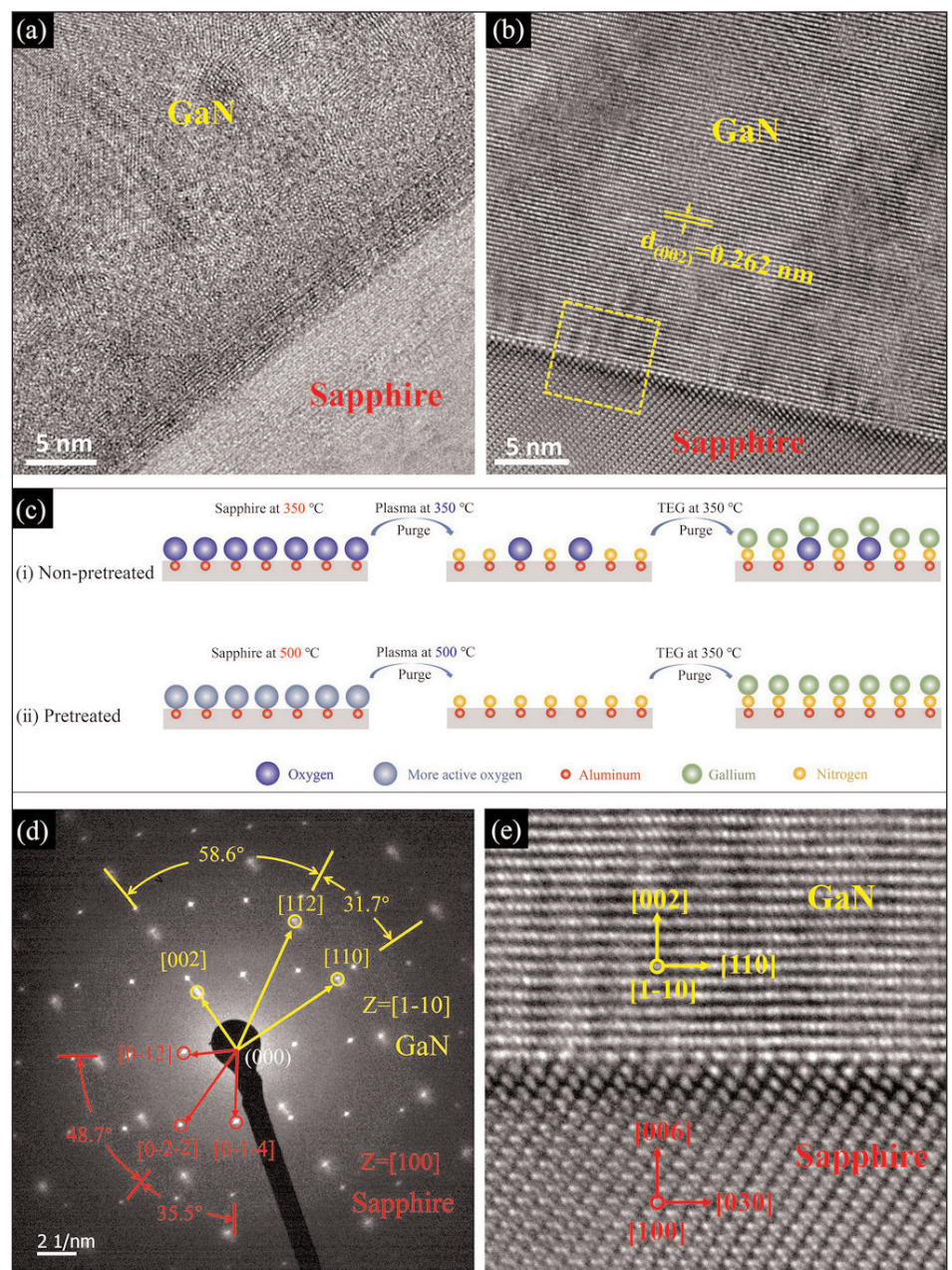


Figure 1. (a) and (b) HRTEM images of non-pretreated and pretreated GaN/sapphire interfaces, respectively. (c) Schematic of initial pretreated and non-pretreated GaN growth. (d) Selected-area electron diffraction (SAED) of pretreated GaN thin film. (e) GaN/sapphire interface magnification of yellow rectangle in (b).

Figure 2. (a) XPS depth profile and (b) AFM image of pretreated GaN thin film.

communication and radar signals are a particularly hoped-for coming attraction.

The PE-ALD process used triethylgallium (TEG) and an argon/nitrogen/hydrogen gas mix in the Ga and N deposition steps. The sapphire substrates were ultrasonically cleaned with a sequence of solvents: acetone, methanol, and de-ionized water.

The next preparation step was a 4-hour bake at 500°C in argon at 0.4Torr pressure in the ALD reaction chamber. Just before the PE-ALD there was a 30-second plasma treatment with argon/nitrogen/hydrogen.

The PE-ALD process temperature was at a cooler 350°C. A reference sample was also produced using substrates without the 500°C bake and plasma treatments.

X-ray diffraction analysis showed a series of peaks that could be associated with reflections from various planes of the expected GaN crystal structure. The researchers conclude: "Accordingly, we can infer that the pretreated GaN thin film is single crystalline with a hexagonal structure."

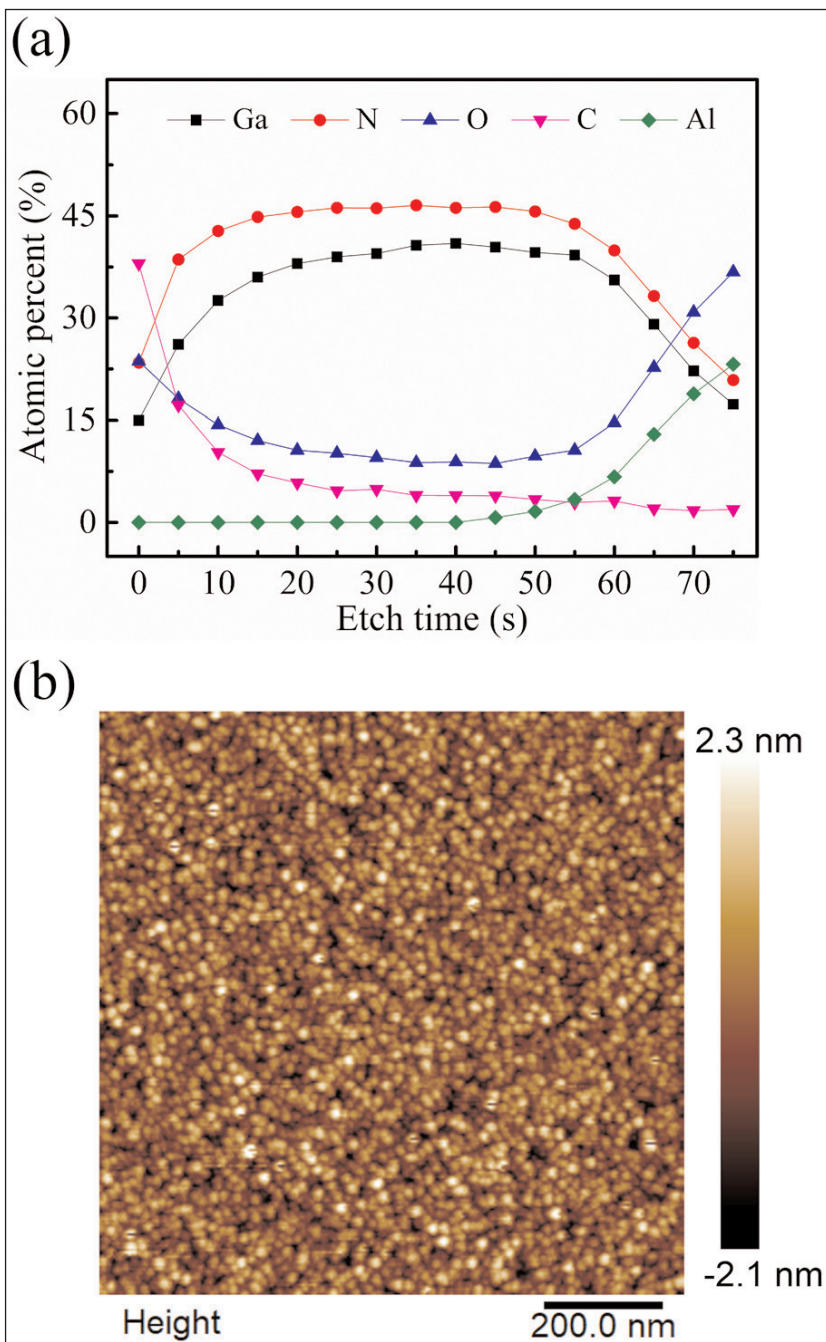
The full-width at half maximum (FWHM) for the (002) plane reflection rocking-curve was 666arcsec, comparable to the values obtained for higher-temperature pulsed layer deposition. The non-pretreated samples gave much broader peaks, indicating the polycrystalline nature of the resulting GaN film in that case.

The calculated c-axis lattice constant of 5.200Å was close to the 5.185Å value for unstrained GaN. The c-axis strain was therefore estimated at 0.0029. The longer c-axis constant suggests that the GaN layers were under compression.

High-resolution transmission electron microscopic (HRTEM) analysis backed up the conclusions from x-ray diffraction (Figure 1). The GaN was found to be epitaxial with a $[1\bar{1}0]_{\text{GaN}}//[100]_{\text{sapphire}}$ plane alignment. The GaN/sapphire interface was sharp.

The researchers believe that the baking treatment activates the sapphire surface by providing energy for adatoms from the plasma treatment to diffuse rapidly over the surface to activate surface reaction sites. The plasma treatment replaces the oxygen termination of the sapphire, aluminium oxide (Al_2O_3), with nitrogen, enhancing subsequent GaN growth.

The team suggests the higher 500°C temperature enables such replacement to be more widespread, "perhaps even total", across the surface, compared with a plasma pretreatment at the main process temperature of 350°C.



X-ray photoelectron spectral (XPS) depth profiling revealed carbon contamination in the range 3–7% and oxygen of 9–12% (Figure 2).

The high level of oxygen was blamed on the use of a quartz (SiO_2) tube plasma source in the ALD reaction chamber. The replacement of quartz with a stainless-steel hollow cathode for the plasma generation has been found to reduce such contamination.

The carbon came from the metal-organic TEG component. XPS also showed the GaN layer to be nitrogen-rich.

Surface roughness was assessed using atomic force microscopy (AFM), giving a root-mean square value of 0.64nm for the pretreated GaN layer. Surface roughness of GaN layers produced using MOCVD (metal-organic chemical vapor deposition) on sapphire is $\sim 2\text{nm}$. ■

<https://doi.org/10.1063/5.0003021>

Author: Mike Cooke

Boosting mobility in InAlGaN-barrier heterostructure

Researchers have claimed the first high-electron-mobility transistor performance using a gallium nitride interlayer to improve material quality.

Taiwan's National Chiao Tung University has used a gallium nitride interlayer (IL) to improve the performance of indium aluminium gallium nitride (InAlGaN)-barrier high-electron-mobility transistors (HEMTs) on low-cost silicon [Min-Lu Kao et al, Appl. Phys. Express, vol13, p065501, 2020]. The team claims that their work demonstrates the first high-electron-mobility performance in InAlGaN-barrier HEMT structures.

III-nitride devices are being developed for high-frequency and high-power electronics serving the millimeter-wave part of the electromagnetic spectrum (30–300GHz, or 'extremely high frequency'/EHF). Such radio signals are proposed for 5G wireless telecommunications and various flavors of radar.

Up to now, InAlGaN-barrier HEMTs have suffered from low mobility, compared with AlGaN- and InAlN-based devices. InAlGaN-barrier structures could result in higher polarization charge density, with potential benefits for high-power/high-frequency operation. The higher

polarization level results in high sheet carrier density in the two-dimensional electron gas (2DEG) channel. Unfortunately, carrier scattering from rough interfaces between layers severely impacts mobility, increasing sheet

resistance.

Experience with AlN and InAlN barrier layers suggests that a GaN IL could improve mobility in InAlGaN structures. The use of silicon should reduce material costs and enable economies of scale based on the larger substrates that are commercially available.

The researchers used 6-inch (111) silicon substrates to grow the various heterostructures (Figure 1) by metal-organic chemical vapor deposition (MOCVD). The buffer between the silicon substrate and device layers consisted of 250nm AlN nucleation and 600nm AlGaN transition layers. The InAlGaN quaternary barrier was grown at 875°C temperature and 100Torr pressure. The GaN IL was grown at 1080°C at the same pressure. The thickness was varied by changing the growth time over the range 0–12s, resulting in five samples labeled A–E.

Atomic force microscopy of the samples showed reduced occurrence of spiral hillocks on the surface with the 2s GaN IL (sample B), compared with 0s (sample A, no GaN IL), or with 12s growth (sample E).

In _{0.11} Al _{0.71} Ga _{0.18} N barrier layer 10 nm	Sample	Growth time of GaN interlayer (s)
GaN interlayer (0~12s)		
AlN spacer layer 1 nm	A	0
GaN channel layer 500 nm	B	2
Al _{0.02} Ga _{0.98} N back-barrier layer 1.1 μm	C	4
Buffer layer	D	8
Silicon	E	12

Figure 1. Schematics of InAlGaN/GaN HEMT material for samples A–E.

The reduced hillock formation in sample B suggests that 'step-flow' growth is enabled, resulting in a smoother surface and reduced interface roughness deeper in the sample. The hope would be that smoother interface roughness would decrease carrier scattering, improving mobility.

The GaN has a higher vapor pressure relative to the subsequent InAlGaN barrier. The high vapor pressure is associated with decomposition of the GaN IL. It is suggested that too long growth of the IL results in a degraded surface for the InAlGaN barrier to grow on.

Of course, the main interest is whether the improved surface quality results in improved electrical performance. In Hall measurements, sample B showed the lowest sheet resistance, along with the highest mobility and carrier concentration. Sample B achieved $228.2\Omega/\text{square}$ sheet resistance, and $1540\text{cm}^2/\text{V}\cdot\text{s}$ electron mobility.

HEMT fabrication used chlorine plasma etch for mesa isolation, electron-beam evaporation and annealing of titanium/aluminium/nickel/gold ohmic source-drain electrodes, nickel/gold for the gate electrode, and 100nm plasma-enhanced chemical vapor deposition (PECVD) silicon nitride passivation. The gate length was 170nm, while the source-drain spacing was $2\mu\text{m}$. The gate was placed in the middle of the source-drain gap.

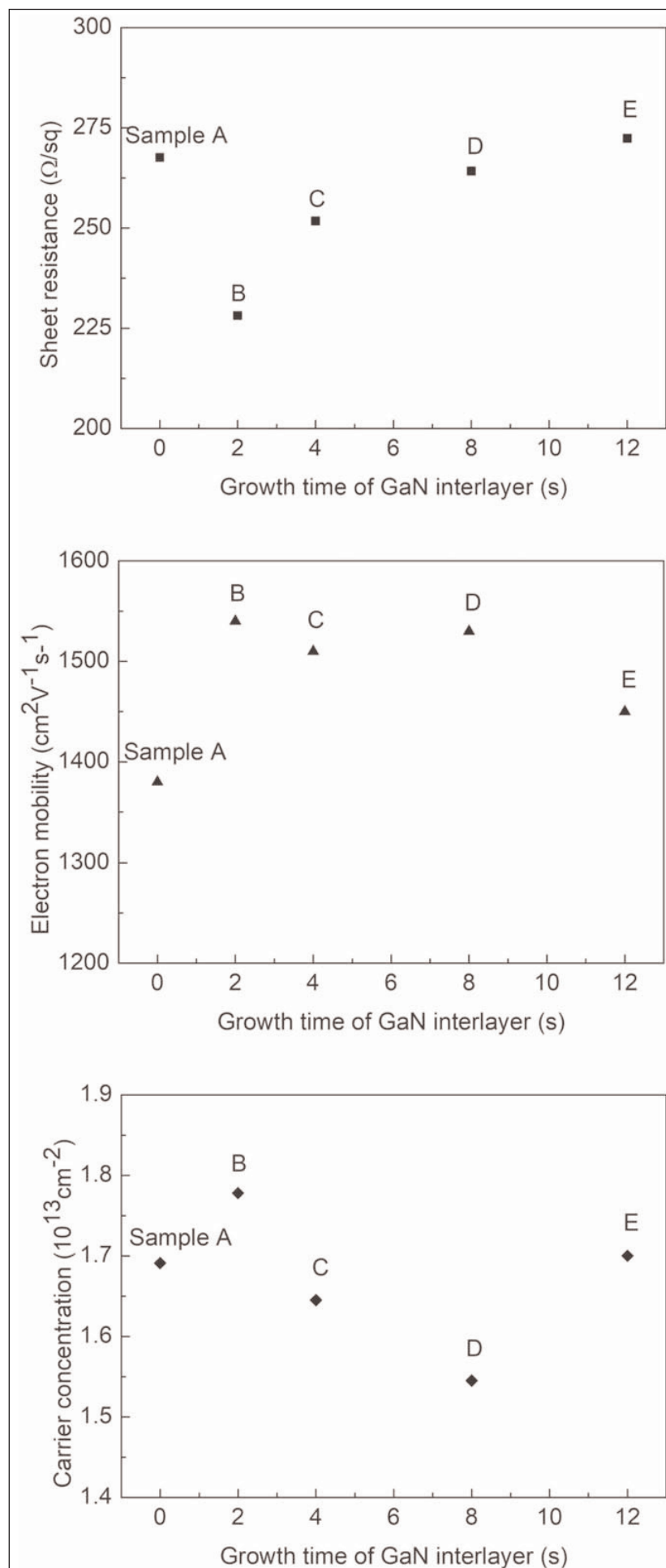
A HEMT based on sample A achieved a maximum drain current density of $943\text{mA}/\text{mm}$, compared with sample B's $1490\text{mA}/\text{mm}$, at a 2V gate-source potential difference and 10V drain bias. The higher electron mobility of sample B also results in a higher peak extrinsic transconductance of $401\text{mS}/\text{mm}$ at 2V gate, compared with $204\text{mS}/\text{mm}$ for sample A.

The researchers offer two possible explanations for sample B's better HEMT performance: "(1) alloy and interface roughness scattering are effectively suppressed due to the improvement of the interface roughness, thus enhancing the electron mobility for sample with GaN IL; (2) compared to the sample with InAlGaN directly grown on AlN, the crystal quality of InAlGaN barrier layer may be improved by GaN IL due to less lattice mismatch between InAlGaN and GaN." ■

<https://doi.org/10.35848/1882-0786/ab8b51>

Author: Mike Cooke

Figure 2. Sheet resistance, electron mobility and carrier concentration as function of sample growth time.



GaN complementary logic on silicon using normally-off transistors

Researchers have used regrowth-free fabrication for the first demonstration of logic inverter operation at 300°C, along with record gain measurement at room temperature.

Researchers in the USA and China have integrated gallium nitride (GaN) n- and p-channel field-effect transistors (FETs) in complementary inverter circuits on silicon substrates [Nadim Chowdhury et al, IEEE Electron Device Letters, volume 41 (2020), issue 6 (June), p820]. The fabrication avoided complicated regrowth steps that could add to production costs. The circuit used enhancement-mode (normally-off) devices, reducing power consumption.

The team at Massachusetts Institute of Technology in the USA, Enkris Semiconductor Inc in China and Intel Corp in the USA see monolithic integration as a key way to increase switching speeds in power devices through reducing the parasitic inductance between driver circuitry and gate electrodes.

The team also claims “the first demonstration of operation at 300°C of any complementary logic technology, which confirm the potential of GaN for low-power digital applications under harsh-environment operation.” In addition, this could bring important applications for integrated CMOS driver circuits, CMOS logic, logic and signal conditioning under challenging conditions.

Enkris produced the epitaxial material on 6-inch-diameter (111) silicon substrate through metal-organic chemical vapor deposition (MOCVD) — see Figure 1. The p-GaN layers were activated with an in-situ 750°C anneal in the reaction chamber. The threading dislocation

density was in the range 10^9 – $10^{10}/\text{cm}^2$, as determined by x-ray diffraction analysis.

The epitaxial structure with aluminium gallium nitride (AlGaN) sandwiched between GaN layers was expected to result in two-dimensional electron (2DEG) and two-dimensional hole (2DHG) gases near the respective interfaces, due to charge polarization contrasts between the chemical bonds in the layers.

The n-FET region of the inverter was fabricated first with dry etch selectively removing the p-type layers, and forming annealed titanium/aluminium/nickel/gold (Ti/Al/Ni/Au) ohmic source/drain contacts with the 2DEG.

Dry mesa etching was then performed for electrical isolation of both the n- and p-FETs. Another dry etch created the gate recess for the p-FET. The sample was then dipped into heated tetramethylammonium hydroxide (TMAH) solution to remove the photoresist and smooth the surfaces resulting from the various dry etching steps.

Next, Ni/Au was applied to give the ohmic source/drain contacts of the p-FET and the gate electrode of the n-FET. The sample was then annealed in oxygen to oxidize the nickel to improve ohmic contact with the underlying p^{++} -GaN layer.

The final steps formed the gate electrode of the p-FET and provided the interconnections for the inverter circuit: 20nm aluminium oxide atomic layer deposition (ALD)

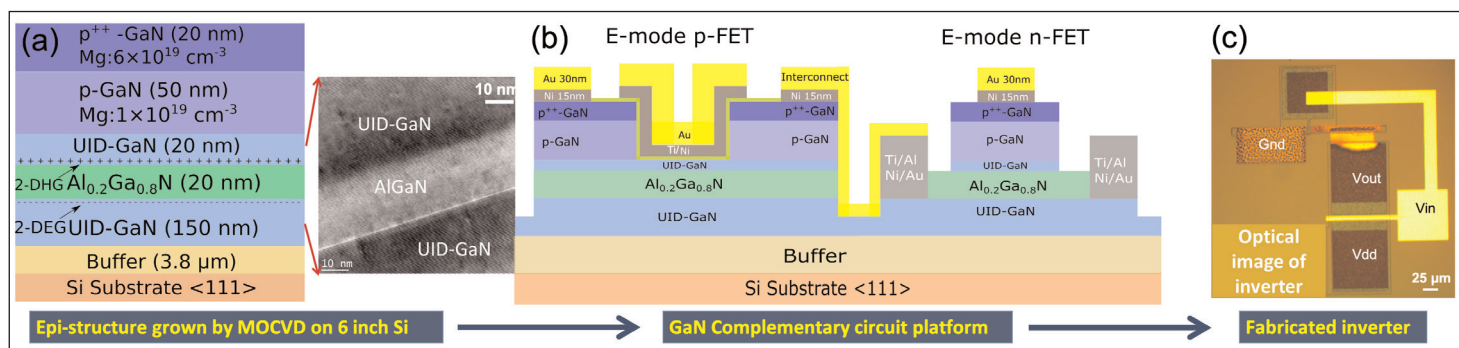


Figure 1. (a) Cross-sectional schematic of epitaxial structure and transmission electron micrograph image of channel regions; (b) Schematic of complementary circuit platform; (c) Optical image of fabricated logic inverter.

for the gate dielectric, and Ti/Au lift-off for the gate electrode and inverter interconnection. The widths of the n- and p-FETs were 12 μ m and 110 μ m, respectively.

As would be expected, the p-FET performed worse than the n-FET: the normalized on-resistances were 23k Ω -mm and 6 Ω -mm, respectively, while the on/off current ratios were $\sim 10^4$ and $\sim 10^7$, in the same order. The threshold of the n-FET was +0.2V, and the p-FET -1V. Both devices are described as having "good pinch-off behavior".

The researchers comment: "The poor performance of p-FET in terms of ON-resistance can mainly be attributed to the higher ohmic contact resistances".

With a 5V supply voltage (V_{DD}), the inverter circuit is reported to have a "very good switching transition from high to low voltage with a swing voltage V_{swing} of 4.91V" (Figure 2). An input voltage 0.59V yielded a maximum voltage gain of $\sim 27V/V$. The 27V/V figure is claimed to be a record by the researchers.

The high-low transition occurs around 0.2V due to the low threshold of the n-FET — an ideal transition would occur around 2.5V, half the value of V_{DD} . The researchers suggest that the n-FET threshold could be increased with a fin-FET trigate structure.

At 5V V_{DD} , there is a rise in response at higher voltages above 3.6V, due to "gate leakage from the p-GaN gated n-FET", according to the team. Restricting the V_{DD} to 3V eliminated the gate leakage problem. Under these conditions the swing was 2.91V and the

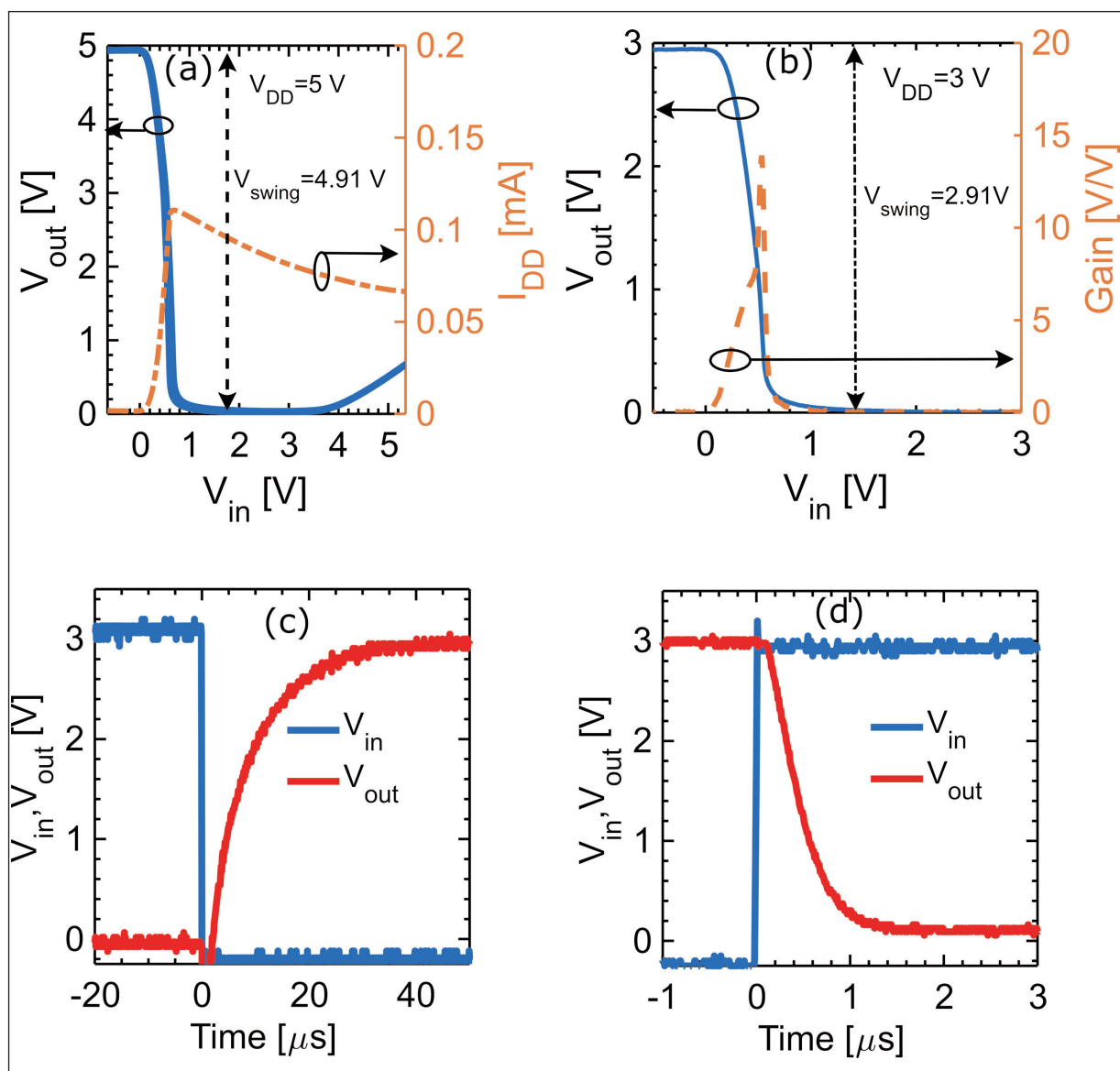


Figure 2. Direct current transfer curve of fabricated inverter with (a) 5V and (b) 3V supply. Transient response showing (c) rise and (d) fall times.

maximum gain was $\sim 15V/V$.

Keeping the V_{DD} at 3V, the researchers subjected the circuit to pulsed signals between -0.2V and 3V with a 100ns ramp. The fall time at the output was 1 μ s, while the rise time was 20 μ s. The researchers suggest that these values represent upper limits since the oscilloscope used had a relatively high input capacitance of 350pF.

Increasing the operating temperature of the device up to 300 $^{\circ}$ C was found to reduce the gain, along with the maximum available voltage swing. The reduced swing is attributed to a lowering of the on/off current ratio of the p-FET at high temperature. The higher temperature also had adverse impacts on high- and low-level noise margins: 2.24V/0.12V and 1.75V/0.04V at room temperature and 300 $^{\circ}$ C, respectively. ■

<https://doi.org/10.1109/LED.2020.2987003>

Author: Mike Cooke

ALLOS transferring RF & power electronics patents & know-how to new GaN-on-Si entrant Azur

ALLOS is focusing on developing GaN-on-Si technology for micro-LEDs, notes Knowmade.

On 8 July, IP licensing & technology engineering firm ALLOS Semiconductors GmbH of Dresden, Germany disclosed a deal to sell its gallium nitride (GaN) RF and power electronics business to Azur Space Solar Power GmbH of Heilbronn, Germany, which develops and produces multi-junction solar cells, with a view to focusing on its GaN-on-silicon micro-LED epiwafer technology for up to 300mm.

Patent analysis and technology intelligence firm Knowmade notes that Azur Space is a new entrant in the power electronics business, with no pre-existing intellectual property assets related to GaN-on-Si epitaxy and power GaN device technology, but it does have the ability to leverage its manufacturing expertise and facilities for high-volume production with a relatively limited initial investment (€10m).

Since its foundation in 2014, ALLOS has made its epiwafer technology – inherited from Azzurro Semiconductors – available through licensing and technology transfer to “high-power electronics companies that would like to enter the GaN-on-Si sector and avoid the cost, risk and uncertainty of starting their own epi development from scratch”. In other words, ALLOS would enable new players to safely enter the GaN-on-Si business, relying on its patented and proprietary growth techniques and epi-structures.

In 2017, the licensing & technology engineering firm further strengthened its value proposition by disclosing a carbon-doping-free GaN-on-Si technology, offering good dynamic resistance, good crystal quality and extremely low leakage current all at once, enabling customers to overcome the usual trade-off between these parameters when using carbon doping in epi-

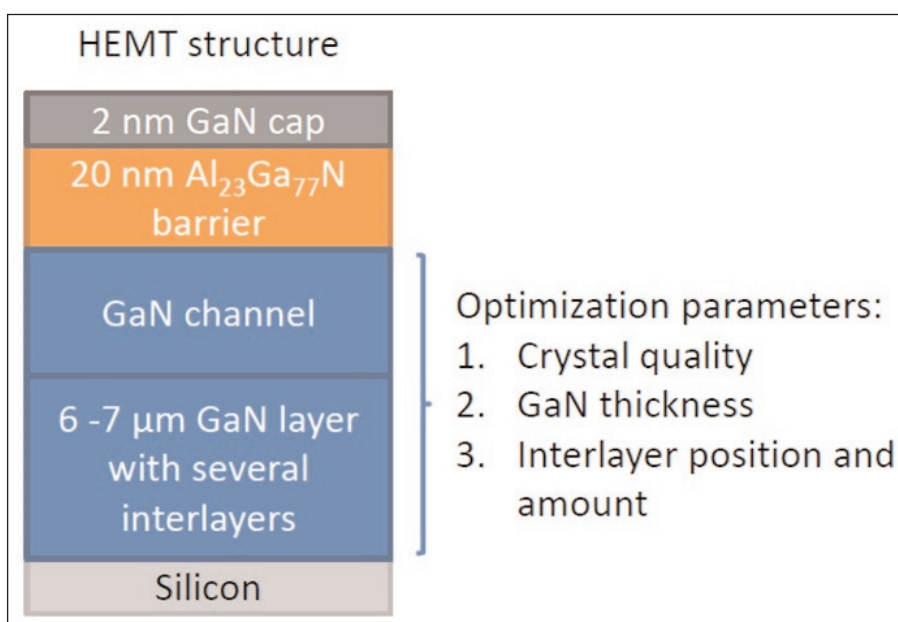


Figure 1: Typical GaN-HEMT epi-structures grown by MOCVD without intentional carbon doping or other doping. Electrical performance is optimized by position and number of interlayers. Source: ‘Low vertical leakage current of 0.07μm/mm² at 600V without intentional doping for 7μm-thick GaN-on-Si’ presented at ICNS-12 in Strasbourg, France (July 2017).

structures. Moreover, it would provide an effective way for customers to avoid conflicts with well-established IP competitors relying on carbon doping to achieve the power electronics industry’s requirements. As of 2017, ALLOS’ approach was based on the insertion of multiple interlayers in an unintentionally doped thick GaN buffer layer (Figure 1). Knowmade says that, to its knowledge, neither ALLOS nor Azzurro has filed patents describing such a structure, or how to design and grow the interlayers in order to effectively reduce the leakage current in high-voltage applications.

At the time of Azzurro’s bankruptcy, the GaN-on-Si epi-foundry had filed 29 patent families (i.e. single inventions patented in multiple countries). Most of

them were reviewed by Knowmade in the 'GaN-on-Silicon Patent Landscape 2020'. However, since ALLOS was created in 2014 and acquired Azzurro's technology, know-how and patents, the engineering and consulting company has not relied on patents to protect new inventions. As a result, ALLOS' IP portfolio has shrunk to eight alive patent families (21 of Azzurro's inventions were abandoned and no patent application has been filed by ALLOS), grouping less than 50 patents and patent applications filed in the main area of interest for Azzurro's business: Europe (12), USA (9), China (8), Korea (5), Japan (2) and Taiwan (2). Furthermore, as of 2020, all of ALLOS' live patent families have already been the subject of a transfer of rights to Azur Space.

Indeed, the first patent transfers between the two companies occurred in 2015 and concerned the most relevant inventions for power applications, filed by Azzurro in 2013:

- 'P-doping of group-III-nitride buffer layer structure on a hetero-substrate', to provide good stress management and the high resistivity required for RF & power applications (Figure 2, US Patent 9,496,349);
- 'Layer structure for a group-III nitride normally-off transistor', with a recess-free design (Figure 3, US Patent 9,773,896).

Both patent families were granted thereafter with protection in main market areas such as Europe, USA, China and Korea, with the notable exception of Japan. Moreover, four domestic granted patents (filed only in

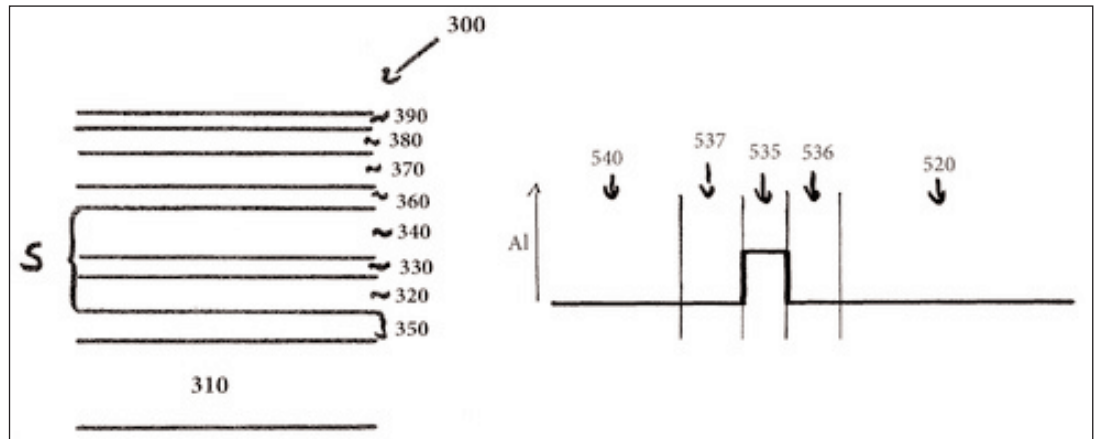
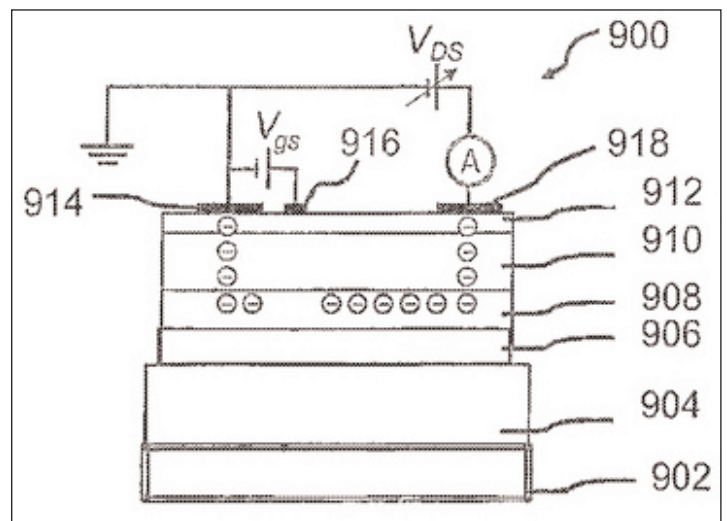


Figure 2: (US Patent 9,496,349) The buffer-layer structure comprises at least one stress-management layer sequence S including an interlayer structure arranged between and adjacent to a first and second III-N layer, wherein the interlayer structure comprises a III-N interlayer material with a larger bandgap than the materials of the first and second III-N layers, and wherein a p-type dopant concentration profile drops.

Germany), dealing with electronics as well as optoelectronics, were transferred to Azur Space in 2016:

- 'III-nitride p-channel transistor structures to produce logic components comprises growing an aluminum indium nitride barrier layer on a group-III nitride buffer layer' (patent DE10200403434);
- 'Field-effect transistors, comprises an aluminum-gallium-indium-nitrogen layer, aluminum-gallium-nitrogen intermediate layer, and another aluminum-gallium-indium-nitrogen layer' (patent DE102006030305);
- 'Group-III nitride transistor component on a Si substrate for high temperature and microwaves, with a buffer layer formed by gas phase epitaxy', iron-doping of GaN-based buffer layers (patent DE10256911);
- 'Production of a planar tear-free light emitter structure comprises applying an aluminum-containing group III-V seed layer, aluminum-containing group III-V intermediate layers, and silicon nitride intermediate layers on a Si substrate' (patent DE10151092).

Figure 3: (US Patent 9,773,896) An III-N electron-supply layer (910), a III-N back-barrier layer (906), a III-N channel layer (908) between the electron-supply layer (910) and the back-barrier layer (906) with bandgap energy lower than the bandgap energies of the other layers. The back-barrier layer (906) is of p-type conductivity, while the electron-supply layer (910) and channel layer (908) materials are not of p-type conductivity, the bandgap energy of the electron-supply layer (910) is smaller than that of the back-barrier layer (906); in the absence of an external voltage a lower conduction-band-edge of the third III-N material in the channel layer (908) is higher in energy than the Fermi level of the material in the channel layer (908).



Eventually, ALLOS completed the IP transfer in second-quarter 2020 with two additional patent families related to improvements in terms of stress management when using a masking layer (e.g. SiN) for the growth of high-quality GaN epilayers on silicon substrates, especially for LED applications (EP patent 2,112,699 and US patent 9,406,505).

Interestingly, in 2019 Azur Space also acquired IP rights on two patent families filed by the Ulm University spin-off MicroGaN related to a diode circuit combining a GaN high-electron-mobility transistor (HEMT) and a GaN Schottky barrier diode (EP patent 2,633,555) including a GaN-on-Si embodiment, and a method of contacting a number of GaN devices together in a more compact way (US patent 8,748,944).

In conclusion, the present deal provides Azur Space with very relevant patents to develop GaN-on-Si technology and stand out from competitors, assesses Knowmade. Besides patents, it can rely on ALLOS' expertise in the field, although not all aspects of ALLOS' technology are visible in patents. Indeed, the company seems to have put the emphasis on know-how and technology transfer rather than IP licensing in the development of its business. In fact, ALLOS is actively

developing its GaN-on-Si technology for micro-LEDs and, according to the latest announcement, will focus its activities on micro-LEDs in the coming years. However, this has not yet translated into patenting activity, so it is likely to follow the same strategy as for power & RF electronics, focusing on trade secrets and technology transfer.

The power GaN patent landscape and GaN-on-Si patent landscape have been evolving rapidly in recent years, notes Knowmade, with numerous innovative startups and major power electronics' players aiming to strengthen their position, to prepare for the promising power GaN markets. For any of them, GaN-on-Si is crucial and has fostered multiple acquisitions and partnerships with well-established players in the field. In this very dynamic environment, Knowmade has set up a GaN Power & RF Patent Monitor service to track and analyze, month by month, the latest patenting activity of IP competitors engaged in the development of these technologies. ■

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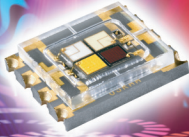


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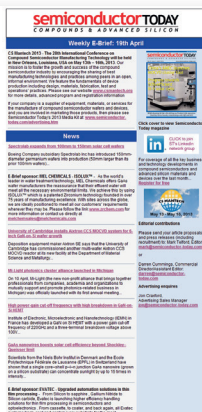


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Smartphone shipments fall 15.7% year-on-year to 279.7 million in Q2

COVID-19 is impacting the market, but Huawei has overtaken Samsung, according to [Infirma](#).

Even as some countries and regions have begun to loosen restrictions, other countries are still dealing with the initial wave of the ongoing global COVID-19 pandemic. For smartphone OEMs, this means that second-quarter 2020 was another quarter with extraordinary circumstances and quickly changing realities on the ground. The result is a 15.7% decline year-on-year in unit shipments from 331.8 million in Q2/2019 to 279.7 million in Q2/2020, according to a report by Omdia.

For most OEMs, Q2 was another quarter of negative growth. However, of the major OEMs, Apple was most successful in navigating the marketplace, expanding shipments by 13.1% on the back of its iPhone 11 and iPhone SE products.

Huawei beats Samsung to top spot for first time

Shipping 55.8 million units in Q2/2020, Huawei surpassed Samsung, which shipped 54.3 million units, for the first time. Because of the recovery in China, Huawei's shipments are down only 4.9% on the 58.7 million units it shipped in Q2/2019. Despite facing sanctions from the US government that are now entering their second year, Huawei has been able to mitigate impacts on its international business enough to compete with Samsung and finally claim the global top spot.

Samsung, on the other hand, saw unit shipments fall by 27.7% year-on-year, from 75 million in Q2/2019 to 54.3 million units in Q2/2020. Many of its most important markets were significantly impacted by COVID-19, especially emerging markets, which accounted for more than 70% of Samsung's overall shipment in 2019. China is not a large-scale market for Samsung, so the firm cannot benefit from the recovery there. In Western Europe, reopening and loosening of restrictions started near the end of the quarter, meaning that much of the first and second quarters were impacted for many of Samsung's key markets.

Apple's product mix helps in Q2

Only Apple, iTel, Tecno and Infinix had unit shipments up year-on-year in Q2. Apple shipped 39.9 million units, up 13.1% from 35.3 million units. The iPhone SE, a model with mid-range pricing, and the iPhone 11 helped Apple to expand its unit shipments.

"With the launch of the iPhone SE in April, Apple has released a long-desired product, with an attractive price," says Jusy Hong, director of smartphone research at Omdia. "The launch added a new iPhone model into Apple's product mix just as lockdown restrictions had reached important markets, such as the USA. A \$399 starting price point makes the iPhone SE an attractive new device, especially in the face of continued economic uncertainty in many markets. For existing iPhone users who needed to upgrade their smartphones in the second quarter, the new SE represented an affordable option that does not require a large down-payment or high monthly repayment rates."

Regional focus aids Transsion Holdings

The other brands with year-on-year growth in shipments (iTel at 35.3%, Tecno at 36.9% and Infinix at 17.3%) are all part of Transsion Holdings, which collectively shipped 12 million units in Q2/2020, up from 9.1 million units in Q2/2019.

All three brands focus on the Middle East and Africa as their main target markets. Because of Huawei's weakening presence in the market, and the return of production in China at the end of the first quarter of 2020, these three brands were less affected by the pandemic than other brands.

Market environment challenging for most OEMs

In first-quarter 2020, Realme was one of the few OEMs whose growth was spurred by resilience in the Indian market. Now, however, Realme has joined all other OEMs in facing declining shipments in Q2. Realme's shipments fell 7.3% year-on-year, from 4.5 million units to 4.2 million units.

Rank	OEM	Q2'20		Q1'20		Q2'19		QoQ	YoY
		Shipment	M/S	Shipment	M/S	Shipment	M/S		
1	Huawei	55.8	20%	49.0	18%	58.7	18%	14%	-4.9%
2	Samsung	54.3	19%	58.9	21%	75.0	23%	-8%	-27.7%
3	Apple	39.9	14%	38.5	14%	35.3	11%	4%	13.1%
4	Xiaomi	28.9	10%	27.8	10%	32.4	10%	4%	-10.7%
5	Oppo	22.5	8%	20.4	7%	30.8	9%	10%	-26.9%
6	vivo	23.7	8%	19.5	7%	28.4	9%	22%	-16.7%
7	Motorola	7.4	3%	5.5	2%	8.3	3%	34%	-10.8%
8	LG	6.7	2%	5.4	2%	8.9	3%	25%	-24.4%
9	Tecno	5.3	2%	3.5	1%	3.9	1%	50%	36.9%
10	Realme	4.2	1%	6.1	2%	4.5	1%	-32%	-7.3%
	Others	31.1	11%	41.1	15%	45.7	14%	-24%	-31.9%
	Total	279.7	100%	275.7	100%	331.8	100%	1%	-15.7%

Global smartphone market share in Q2/2020.

Tensions between the Indian and Chinese governments have impacted the smartphone market in India, even though many Chinese OEMs have invested significantly over the last 18 months to increase their production and customer service operations in the country. For OEMs like Realme, vivo and Xiaomi, which focus on this market, the pandemic and governmental issues contributed to a difficult Q2/2020.

Vivo saw shipments decline 16.7%, from 28.4 million units in Q2/2019 to 23.7 million units in Q2/2020. OPPO saw an even larger decline, of 26.9%, from 30.8 million to 22.5 million units. Xiaomi's shipments, on the other hand, declined 10.7% from 32.4 million to 28.9 million units.

The rest of the top 10 global OEMs all saw shipments decline. LG's shipments fell by 24.4%, from 8.9 million to 6.7 million units, as the firm continues to struggle against mid-range competition from Chinese OEMs in many markets.

Motorola had another quarter of 10.8% year-on-year shipment decline, from 8.3 million units in Q2/2019 to 7.4 million units in Q2/2020. The pandemic has impacted the launch of the new RAZR, the firm's first foldable device, and is making it difficult for Motorola

to break through a difficult market with its latest devices. The COVID-19 crisis is occurring just as the company was set to return to unit and market share expansion.

Ongoing challenges

Although many countries have lifted some restrictions on movement and business activities, and others are working towards a return to normal, other countries still continue to be in the midst of the initial outbreak. There are also signs of potential new outbreaks in countries where the virus has been brought under control. In this continued environment of uncertainty, the smartphone market will continue to be impacted in the third and fourth quarters of 2020, reckons Omdia. While smartphone OEMs have found their footing in terms of releasing new devices and continuing on the path of their product roadmaps, user purchasing behavior will continue to depend on the strides made in fighting the outbreak and containment of the subsequent threat of new outbreaks, the firm concludes.

<https://technology.informa.com/625568/covid-19-continues-to-negatively-impact-the-global-smartphone-market-in-q2but-huawei-takes-the-lead>

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Index

- | | |
|---|--|
| 1 Bulk crystal source materials p94 | 13 Characterization equipment p97 |
| 2 Bulk crystal growth equipment p94 | 14 Chip test equipment p97 |
| 3 Substrates p94 | 15 Assembly/packaging materials p97 |
| 4 Epiwafer foundry p95 | 16 Assembly/packaging equipment p98 |
| 5 Deposition materials p95 | 17 Assembly/packaging foundry p98 |
| 6 Deposition equipment p95 | 18 Chip foundry p98 |
| 7 Wafer processing materials p96 | 19 Facility equipment p98 |
| 8 Wafer processing equipment p96 | 20 Facility consumables p98 |
| 9 Materials and metals p96 | 21 Computer hardware & software p98 |
| 10 Gas & liquid handling equipment p97 | 22 Used equipment p98 |
| 11 Process monitoring and control p97 | 23 Services p99 |
| 12 Inspection equipment p97 | 24 Resources p99 |

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(see section 3 for full contact details)

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 Fax: +1 716 833 2926
www.williams-adv.com

16 Assembly/packaging equipment

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 Tel: +44 (0) 1698 722072
www.cstglobal.uk

Kulicke & Soffa Industries

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 Fax: +1 215 784 6001
www.kns.com

Palomar Technologies Inc

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 Fax: +1 760 931 5191
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PI (Physik Instrumente) L.P.

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 USA
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 Fax: +1 508-832-0506
www.pi.ws
www.pi-usa.us

TECDIA Inc

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 Tel: +1 408 748 0100
 Fax: +1 408 748 0111
www.tecdia.com

17 Assembly/packaging foundry

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 Fax: +1 8586 74 4681
www.quikicpak.com

18 Chip foundry

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 Tel: +44 (0) 1698 722072
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United Monolithic Semiconductors

Route departementale 128,
 BP46, Orsay, 91401,
 France
 Tel: +33 1 69 33 04 72
 Fax: +33 169 33 02 92
www.ums-gaas.com

19 Facility equipment

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3838 Western Way NE,
 Albany, OR 97321,
 USA
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www.rena-na.com

20 Facility consumables

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 info@plansee.com
www.plansee.com

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MD 21921-4236,
 USA
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 Fax: +1 410 506 8749
www.gore.com

21 Computer hardware & software

Crosslight Software Inc

121-3989 Henning Dr.,
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 Canada
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 Fax: +1 604 320 1734
www.crosslight.com

Semiconductor Technology Research Inc

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www.semitech.us

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23 Services

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www.tecdia.com

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Hofburg Palace, Vienna, Austria

E-mail: ispsd2020@guarant.cz

www.ispsd2020.com

7–11 September 2020

22nd European Conference on Power Electronics and Applications (EPE 2020 ECCE Europe)

Lyon, France

E-mail: info@epe2020.com

www.epe2020.com

9–11 September 2020

22nd China International Optoelectronic Exposition (CIOE 2020)

Shenzhen World Exhibition & Convention Center, China

E-mail: cioe@cioe.cn

www.cioe.cn/en

13–17 September 2020

(postponed to 24–28 October 2021)

13th European Conference on Silicon Carbide and Related Materials (ECSCRM 2020-2021)

Vinci International Convention Centre, Tours, France

E-mail: ecscrm-2020@univ-tours.fr

www.ecscrm-2020.com

13–18 September 2020

(postponed to 10–15 January 2021)

23rd European Microwave Week (EuMW 2020)

Utrecht, The Netherlands

E-mail: eumwreg@itnint.com

www.eumweek.com

23–25 September 2020

SEMICON Taiwan 2020

Taipei Nangang Exhibition Center, Hall 1 (TaiNEX 1),

Taiwan

E-mail: semicontaiwan@semi.org

www.semicontaiwan.org/en

10–13 November 2020

SEMICON Europa 2020

Munich, Germany

E-mail: SEMICONEuropa@semi.org

www.semiconeuropa.org

16–18 November 2020

PCIM (Power Conversion, Intelligent Motion) Asia 2020

Shanghai World Expo Exhibition and Convention Center, Shanghai, China

E-mail: pcimasia@china.messefrankfurt.com

www.pcimasia-expo.com

6–8 December 2020

2020 IEEE 51st Semiconductor Interface Specialists Conference (SISC)

San Diego, CA, USA

E-mail: msslack@ieeesisc.org

www.ieeesisc.org

6–10 December 2020

(postponed from 20–24 September)

46th European Conference on Optical Communication (ECOC 2020)

Brussels Expo, Brussels, Belgium

E-mail: info@ecoc2020.org

www.ecoco2020.org

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Applied Energy Systems	37	Fuji Electric	23
CS Clean Solutions	25	IQE	5
Evatec	49	k-Space	43
EV Group	0, 2	VIGO Systems	59

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Radisson Blu Hotel Lietuva,

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E-mail: neringa.norbutaite@epic-assoc.comwww.epic-assoc.com/epic-annual-general-meeting-2020**20–22 April 2021****Components for Military & Space Electronics Conference & Exhibition (CMSE 2021)**

Four Points by Sheraton (LAX) Los Angeles,

CA, USA

E-mail: info@tjgreenllc.comwww.tjgreenllc.com/cmse**9–14 May 2021****2021 Conference on Lasers & Electro-Optics (CLEO)**

San Jose Convention Center, San Jose, CA, USA

E-mail: CLEO@compusystems.comwww.cleoconference.org**11–14 May 2021****10th World Congress of Nano S&T 2021**

Venetian Macao Resort Hotel, Macao, China

E-mail: esther@bitcongress.comwww.bitcongress.com/nano2021-macao**22–24 June 2021 (postponed from 9–11 Feb 2021)****Strategies in Light 2021**

Santa Clara Convention Center, Santa Clara, CA, USA

E-mail: registration@endeavorb2b.comwww.strategiesinlight.com**4–9 July 2021 (postponed from 14–19 June 2020)****20th International Conference on Metal Organic Vapor Phase Epitaxy (ICMOVPE XX)**

Stuttgart, Germany

E-mail: info@icmovpexx.euwww.icmovpexx.eu**12–17 September 2021 (postponed to 2022)****19th International Conference on Silicon Carbide and Related Materials (ICSCRM 2021-2022)**

Davos, Switzerland

E-mail: info@icscrm2021.orgwww.icscrm2021.org**20–22 September 2021****47th European Conference on Optical Communication (ECOC 2021)**

Bordeaux, France

E-mail: info@ecoc2020.orgwww.ecoco2020.org**24–28 October 2021****(postponed from 13–17 September 2020)****13th European Conference on Silicon Carbide and Related Materials (ECSCRM 2020-2021)**

Vinci International Convention Centre, Tours, France

E-mail: ecscrm-2020@univ-tours.frwww.ecscrm-2020.com**13–15 December 2021****67th IEEE International Electron Devices Meeting (IEDM 2021)**

San Francisco, CA USA

E-mail: info@ieee-iedm.orgwww.ieee-iedm.org**15–20 May 2022****2022 Conference on Lasers & Electro-Optics (CLEO)**

San Jose Convention Center, San Jose, CA, USA

E-mail: CLEO@compusystems.comwww.cleoconference.org



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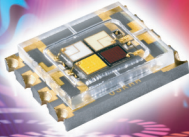


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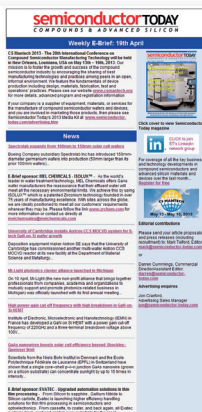


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