MANTECH sheds light on new applications

Compound Semiconductor Manufacturing Technology conference saw increased diversification and a new focus on photovoltaics in the light of inventory correction in established wireless markets, reports Mark Telford.

Falling just the week after the 21st IEEE conference on Indium Phosphide and Related Materials (IPRM 2009) in Newport Beach, CA, which drew just 110 delegates, attendance at this year's International Conference on Compound Semiconductor Manufacturing Technology (CS MANTECH 2009) in Tampa, FL (18–21 May) was also well down on last year (from 420 to 255 delegates) due to the ongoing impact of the credit crunch and ensuing economic downturn since last Autumn.

However, compared to IPRM, the MANTECH event is less dependent on delegates from Japan, where some firms imposed home quarantine on employees returning from the USA due to the H1N1 swine 'flu epidemic. Nevertheless, out of the 66 scheduled conference papers at MANTECH (including 25 non-US), several from Japan were either withdrawn or presented in their absence by international colleagues.

The exhibition likewise suffered several withdrawals (leaving about 50 exhibiting firms). These included China Crystal Technologies Co Ltd and the five AXT materials joint ventures in China, due to the quarantine regulations imposed by the Chinese government.

Nevertheless, despite there being just four delegates from the biggest RF component supplier, RF Micro Devices of Greensboro, NC (which has been cutting costs more severely than most during the downturn), there was still a healthy presence from less hard-hit rival GaAs RFIC makers Skyworks and TriQuint Semiconductor (from both its Oregon and Texas fabs).

Upheaval making industry leaner and broader

Conference chairman Scott Davis of Sumitomo Electric Industries opened the conference by describing how, in a turbulent year of economic change, compound semiconductor manufacturers have been having to adapt to unpredictable markets, inventory corrections, and tighter access to capital. Nevertheless, the industry is well positioned to weather the storm, he reckons. As a source of technological change, it enables more to be done with less, and will emerge from economic upheaval both leaner and broader, he believes.

Compared to previous MANTECH conferences, there were fewer reports of record-setting performances of transistors in R&D and more papers focusing on manufacturing and reliability issues. This is perhaps a healthy sign of the maturing of the industry and its focus on high-volume, cost-conscious mainstream applications. It was also perhaps an indication of concerns over the slowdown of established markets such as mobile wireless handsets as well as diversification through the potential application of technology to fast-developing markets such as LEDs and concentrator photovoltaic (CPV) solar cells.

Prospects for riding out the slump

In an invited presentation 'The Impact of the Financial Crisis on the Compound Semiconductor Industry' in the first plenary session, market analyst Earl J Lum of EJL Wireless Research LLC explained how, compared to the previous telecom downturn of 2001 (driven by the Asian financial crisis and the Internet bubble), the current financial crisis is neither regional nor sector-specific but global and wide ranging, with a greater impact on the banking sector and capital markets. With consumers choosing to upgrade their mobile handsets later than in prior years, 2009 will see the first annual decline in handset shipments. Lum pointed out that, whereas the compound semiconductor industry's growth has previously been fueled partly by extraordinarily forgiving capital markets, the difficulty in securing debt and equity financing in capital markets now will cascade into the compound semiconductor industry supply chain, placing companies low on cash reserves with marginal profitability (and debt payments due in the short to medium term) in a particularly precarious situation. The challenge is how to survive through the next 18–24 months of the downturn into 2011.

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However, Lum points out that, despite the credit situation being worse than in 2001, mobile operators now at least have cash reserves and are making money (and, unlike 3G, have no hefty license fees to pay for 4G, LTE and WiMAX). Also, compared to mobile phones being a luxury in 2001, they are now a necessity. Despite the downturn in shipments expected in 2009, the number of users is expected to grow from 1.2bn in 2008 to 5bn in 2012.

Nevertheless, the debt incurred in 2001–2003 is now due, so Lum anticipates further consolidation following Alcatel–Lucent and Nokia–Siemens in the last downturn (starting with Nortel Networks, currently in Chapter 11 bankruptcy). In particular, he expects that, after Ericsson, China's Huawei will become the second-biggest telecom infrastructure provider in 2009, closely followed by ZTE, such that domestic OEMs will take a 40–50% market share of contracts in China (fueled by ready funding from state-controlled banks). In total global handset shipments, he expects Motorola and SonyEricsson to be overtaken by Chinese firms breaking into the list of top 5 vendors (with Huawei and ZTE currently shipping 10m handsets per quarter, up from none in 2001).

Regarding GaAs component suppliers for wireless handsets, Lum points out that, since 2007, only Skyworks' stock price has remained relatively flat, compared to declines of 60% for TriQuint and about 85% for both Anadigics (after difficulties last year in expanding GaAs fab capacity) and RFMD (following concerns over its acquisitions and debt levels).

Lum says that RFMD's late 2007 acquisition of Sirenza Microdevices of Broomfield, CO was completed at an extremely high valuation, draining its cash reserves (to $257m at the end of 2008) and sharply increasing long-term debt due in 2010–2014 (to $582m) just as the financial crisis was beginning. The firm's reduced market capitalization (barely more than its cash reserves) makes it difficult to refinance this debt, but also diminishes the firm's appeal as a takeover target, says Lum. However, he points out that, after its rapid cost-cutting efforts of Q4/2008, in Q1/2009 RFMD generated $50m in free cash flow, allowing it to repurchase $22m of debt and add $28m to cash reserves. RFMD reckons on generating $80–120m in free cash flow per quarter during Q2–Q4/2009. At the current profitability level, RFMD should be able to make its debt payments, says Lum.

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In contrast, at the end of 2008, Skyworks' total debt of $238m was outweighed by its cash reserves of $391m (which also grew in Q1/2009). TriQuint has just $43m in cash reserves, but this also rose in Q1/2009, and the firm has no long-term debt.

CS MANTECH awards

For last year's CS MANTECH 2008, the Best Paper Award was presented to Dorothy June, M. Hamada and William J. Roesch for 'Reliability and MMIC Technology Development and Production'.

The Best Student Paper was co-awarded to: the University of Illinois' William Snodgrass and Milton Feng for 'Nano-scale Type-II InP/GaAsSb DHBTs to reach THz Cutoff Frequencies' and Pennsylvania State University's David J. Meyer, Joseph R. Flemish and Joan M. Redwing for 'Pre-passivation Plasma Surface Treatment Effects on Critical Device Electrical Parameters of AlGaN/GaN HEMTs'.

Anadigics had $136.8m in cash reserves at the end of 2008, but made a net loss of $22m in Q1/2009 and is expected to have cash burn of $5–7m per quarter during Q2–Q4/2009. Lum therefore reckons that Anadigics will need to raise funds by 2012.

Regarding epiwafer suppliers, Kopin of Taunton, MA has more than $100m in cash reserves, no long-term debt, and a long-term supply relationship with the best-performing GaAs IC maker, Skyworks. In contrast, IQE has 'significant' debt obligations and little cash.

Regarding bulk GaAs substrate suppliers, AXT Inc of Fremont, CA has no significant debt plus cash reserves of $31.3m, but needs to balance its revenues ($7.7m, down 51% on the prior quarter) with its cost structure (making a loss of $5.5m in Q1/2009). At an expected cash burn rate of $2–3m per quarter during Q2–Q4/09, if its financial picture does not improve then it could run out of cash in 24 months, says Lum. With a market capitalization below $30m, AXT has been mentioned by securities analysts as a possible acquisition target.

If Anadigics and AXT can stabilize their cash burn by 2010, then they should be able to raise cash from the capital markets, ensuring survival

In contrast, rival GaAs substrate makers Sumitomo Electric and Hitachi Cable of Japan have ample cash reserves, while Germany-based Freiberger Compound Materials can draw on the reserves of main shareholder Federman Enterprises Ltd.

Despite the concerns, Lum concludes that, if Anadigics and AXT can stabilize their cash burn by 2010, then they should be able to raise cash from the capital markets, ensuring survival.

Overall, Lum thinks that the economic slump will bottom by the end of 2009/early 2010. In 2010, although the infrastructure market will continue to be weak (except in China and India), the handset market should be stable (with shipments of 1bn, ±10%), boosted by a high mix of smart-phones. ►

New focus on photovoltaics

This year's MANTECH conference was also distinguished by the increased focus on photovoltaic technology with, for the first time, a whole session on solar cells (chaired by Noren Pan of III-V based PV cell maker MicroLink Devices in Niles, Chicago, IL).

Walter Wohlmuth, manager of the transparent conducting oxide (TCO) R&D group at First Solar Inc in Perrysburg, OH (and formerly of RFMD and TriQuint), gave an overview of the firm's manufacturing of cadmium telluride (CdTe) thin-film photovoltaic modules (using simple deposition technology on glass or metal substrates), which are in direct competition with silicon-based solar cells for flat panel applications. Wohlmuth reported that, after lowering the cost per module below $1/Watt in Q4/2008, it has now reached $0.93/W. Also, although the cell efficiency is currently just 11%, First Solar has a roadmap to improve this, including gains through improving the current collector (1%), conversion and transport (0.35%), and light collection (2.1%). Also, it does not yet use anti-reflection coatings.

In a contributed paper, Ruediger Schreiner, director sales project management of MOCVD equipment maker Aixtron, described the improvement of deposition quality and the reduction in cost of growing epilayer structures for triple-junction photovoltaic cells (by boosting the efficiency of source material usage as well as increasing the deposition speed). This is done by using a more flexible three-fold gas inlet head (already production proven for nitride-based LEDs, and now released as a standard feature for Aixtron's AIX2800G4 reactor).

The three-fold gas inlet head comprises a group-III metalorganic inlet for tri-methyl alkyls (e.g. TMGa, TMIn, TMAl) sandwiched between upper and lower group-V hydride inlets for phosphine (PH_3) or arsine (AsH_3). With the aid of computational fluid dynamics (CFD) simulation of flow field velocity patterns, the ratio of flows on the upper and lower group-V inlets was adjusted in order to tune the steering of the source reactants towards the growth surface as well as to improve the uniformity of the growth rate on the rotated wafer satellite (settling on a 30:70 split between upper:lower flow rates).

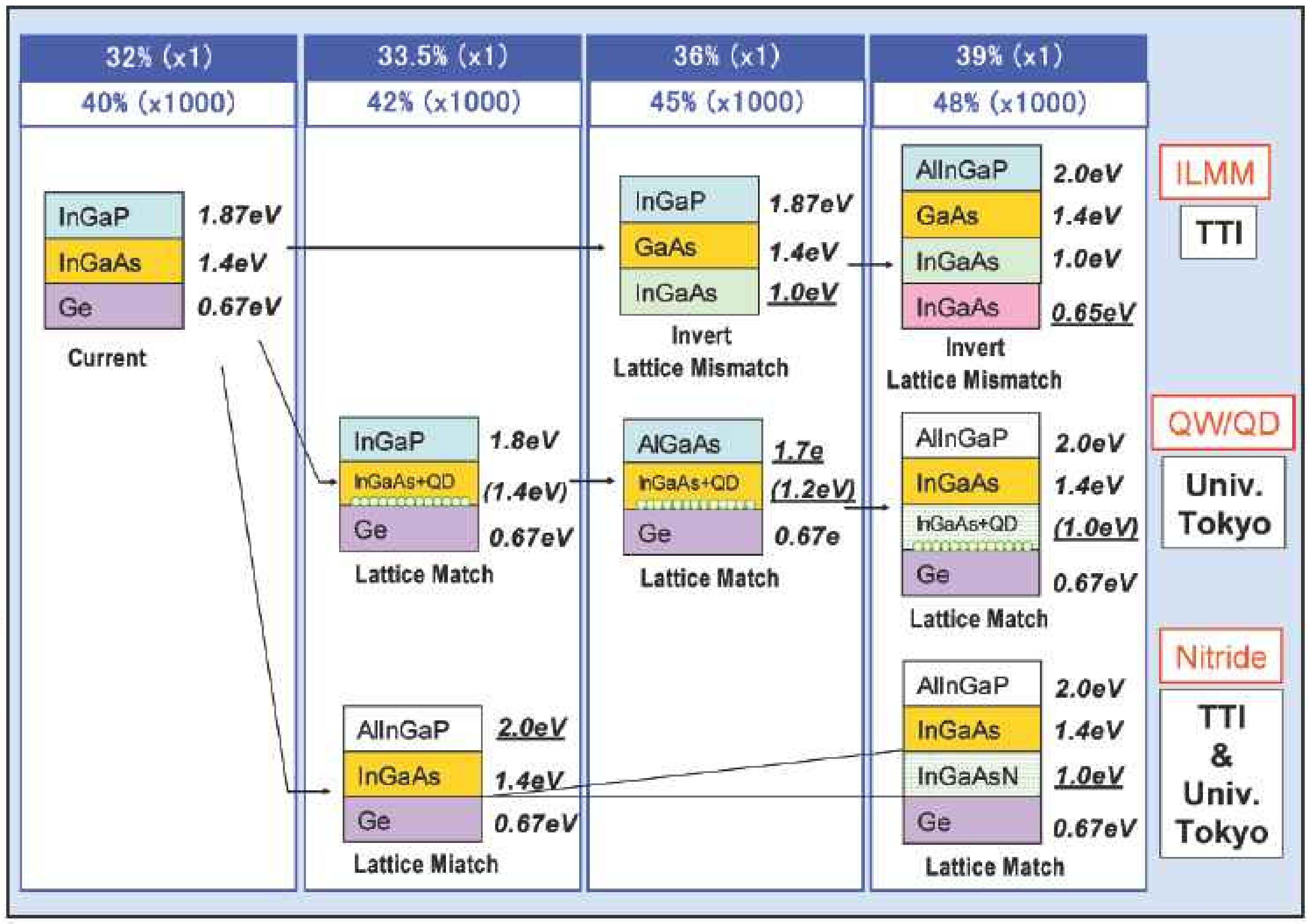
Experiments were performed using four 2" wafers across the 8" satellite of an Aixtron AIX2800G4 reactor, allowing an estimate of the transferability of results to 8" wafers (for which uniformity is key for managing strain in the growing epilayers and hence wafer bow, especially for GaAs-based devices on Ge substrates).

The experiments achieved Group-III precursor efficiencies of 42.7% (AlAs/GaAs) and 39.9% (GaInP) for TMGa, and 37.8% and 34.2% for TMAl and TMIn, respectively (showing an increase of about 1.3% on average for all precursors). In addition, growth rates as high as 15.2μm per hour were achieved for InGaAs (at a reactor total pressure of 50mbar) without any roll-off from the linear dependence on the group-III molar flow. Combined, these two factors can cut the cost of ownership for mass production of terrestrial triple-junction photovoltaic cells, Aixtron reckons.

N.B. Comparative studies using an Aixtron AIX2800G4 HT reactor for GaN growth showed that increasing the reactor total pressure leads to roll-off in linearity with increasing TMGa flow at lower growth rates (due to the onset of gas-phase pre-reactions before the leading edge of the wafer). So, the growth rate cannot be increased infinitely by increasing the flow rate.

Dr Tatsuya Takamoto of Sharp provided an overview of the current status of various solar cell technologies. Solar cells based on Ge substrates are used for most high-efficiency solar panels for satellite applications. Research on high-efficiency PVs was covered, including inverted metamorphic, quantum dots, and wide-bandgap cells based on nitride materials, referring to work with University of Tokyo and Toyota Technological Institute on a program sponsored by Japan's New Energy and Industrial Technology Development Organization (NEDO).

Sharp reported preliminary results for inverted metamorphic triple-junction photovoltaic cells, achieving an efficiency of 30.4% without concentration. The firm has previously achieved an efficiency of 24.8% for thin-film InGaP/GaAs dual-junction cells, on thin, flexible 'solar sheets' (without a substrate) for space applications.



Roadmap for NEDO photovoltaic development program.

Also, the opening plenary session included an invited presentation from Sarah Kurtz of the US National Renewable Energy Laboratory (NREL) giving an overview of the competitive position of the emerging concentrating photovoltaics sector (with respect to other solar technologies that currently dominate the market) as well as future prospects. This drew much interest from microelectronics-focused delegates from companies interested in diversifying into such a promising growth sector (as exemplified by the recent announcement of RFMD's collaboration with NREL on developing PV processes and high-volume manufacturing).

Kurtz summarized how annual photovoltaic production capacity has grown from 371MW in 2001, through 2006 (when the weight of silicon used for solar cells exceeded that used for microelectronics) to 7GW in 2008 (leading to a shortage of silicon).

Although there will not be much growth this year (partly due to the strong Spanish government incentive program expiring), if the solar industry returns to doubling in capacity every year, then it should grow from comprising just 0.1% of electricity generation now to 5% in 2020, generating 100GW per year without any need for storage (or 4TW/yr with storage), she reckons.

For CPVs in particular, 2008 was the first year that multiple companies surpassed 1MW of installations, Kurtz says, concurring with a figure in PHOTON International of 14MW in total (including 6.5MW of high-concentration, multi-junction CPV systems). Kurtz counts more than 30 firms that are developing CPV systems. Although many are just getting started, many have already deployed 1–100kW in the field and are ramping up production, and several claim to have annual manufacturing capacity of more than 10MW (which she deems to be the threshold for low-cost manufacturing). For 2009, 50MW of high- and low-concentration CPV systems are expected to be installed, which could be a "turning point", says Kurtz (providing that the macroeconomic environment does not limit firms' ability to negotiate contracts). Citing other PV technologies requiring years of development before large-scale success (e.g. First Solar's current rapid expansion), she says that the multi-junction CPV industry is currently in the process of emerging from the development phase.

Firms with cell assembly capabilities may be targeted for acquisition as the industry moves toward vertical integration

Just as some silicon PV companies are moving toward vertical integration, many CPV firms are considering vertical integration with cell companies to ensure adequate cell supply. In contrast, cell companies want to retain their ability to supply many CPV firms. However, this is easing as the established concentrator cell suppliers Spectrolab and Emcore in the USA and Azur Space in Germany (which is now the primary supplier to some CPV systems makers) have been joined by several new entrants demonstrating epitaxial (single-crystal) growth of multi-junction concentrator cells. These include Spire (Bandwidth), Cyrium and Microlink Devices in the USA, CESI, Energies Nouvelles et Environnement (ENE), IQE and QuantaSol in Europe, and Japan's Sharp and Taiwan's Arima, Epistar and VPEC in Asia (making more than a dozen firms developing multi-junction concentrator cell manufacturing).

However, Kurtz cites the example of system integrators benefiting the LED industry, saying that the same is needed in the CPV industry. Given the small number of firms supplying multi-junction CPV cell assemblies, in the long term firms with cell assembly capabilities may be targeted for acquisition as the industry moves toward vertical integration, believes Kurtz.

News from Exhibitor's Forum

In the 'CVD/Deposition' session of MANTECH's Exhibitor's Forum, Jean-Luc Ledys, CEO of SOITEC subsidiary Picogiga International of Courtaboeuf, France, outlined the firm's R&D roadmap and product strategy.

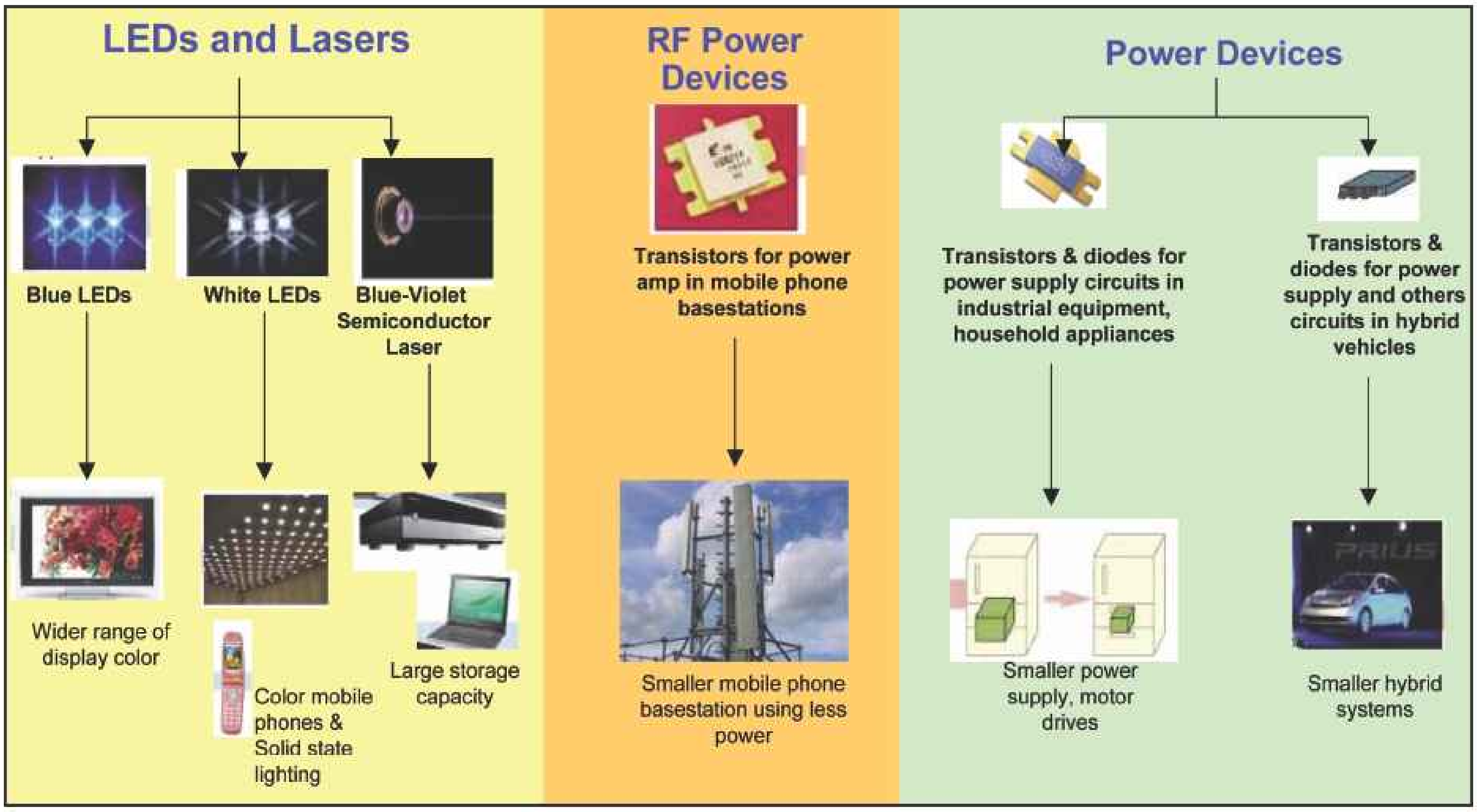
Since 2006, the firm has been providing GaN epitaxy grown by molecular beam epitaxy (MBE) on multiple 3/4-inch or single 6-inch substrates of either sapphire, silicon or silicon carbide (SiC) for low-volume applications (e.g. mobile phone base-stations). Compared to MOCVD, MBE yields no reaction by-products and hence fewer impurities/traps, leading to a reduced kink effect in HEMT devices as well as better reliability. The firm offers 1.8–3μm thick epilayers for RF/low-voltage (<400V) power HEMT devices.

Also, from this year, for higher-volume power device applications (e.g. power supplies, motor drives, hybrid systems for vehicles) Picogiga is offering MBE-grown 3–4μm GaN epi on silicon for normally-on HEMT power transistors operating at 600V and 10A.

However, in the last few months Picogiga has acquired a 6-inch MOCVD reactor. MOCVD growth is faster and allows the firm to grow thicker epilayers for such high-voltage devices. From 2010, it aims to start supplying 4–6μm thick GaN epi on silicon for normally-on HEMT power transistors operating at 600V and 10A.

Meanwhile, beginning this year, the firm also aims to start offering MOCVD-grown horizontal Schottky barrier diodes using 3–4μm GaN epi on silicon, followed next year by Schottky barrier diodes using both 3–4μm GaN epi on silicon and GaNopSiC (GaN on polycrystalline silicon carbide).

In addition, Picogiga has designed its own hydride vapor phase epitaxy (HVPE) reactor. Compared to MOCVD, HVPE allows faster growth rates as well as lower threading dislocation densities (TDD). It therefore enables re-growth of thicker epilayers on free-



Device applications targeted by Picogiga with its gallium nitride epitaxy technology.

standing GaN donor substrates with TDD reduced from about 10^8/cm^2 to 10^4–10^6/cm^2, i.e. GaNoX (GaN on either sapphire or pSiC). Starting in 2011, it aims to use this to offer normally-off vertical FET power transistors using 6–8μm thick GaNoX for operation at 600–1000V and more than 20A, followed in 2012 by 10μm thick GaNoX for operation at more than 1000V and more than 50A.

Apart from RF and power devices, Picogiga also has plans to offer GaN epi for LED and laser devices.

In another presentation on GaN epi, Ivan Eliashevich of IQE RF in Somerset, NJ, USA said that epiwafer foundry IQE is currently transitioning from 3-inch to 4-inch (100mm) substrates for its GaN HEMT epiwafer production. Eliashevich explained how IQE has achieved the same uniformity on 100mm as on 3-inch wafers (±1% for thickness), as well as wafer warp of less than 20μm and wafer bow of less than 10μm. In addition, 100mm substrate prices are equal to or less than those for 3-inch substrates on a dollar per area basis, he added.

Greg Mills of Cree Inc of Durham, NC, which makes not only LED chips, lamps and lighting fixtures as well as GaN- and SiC-based RF/power transistors but also SiC substrates, reported how the firm just in the month prior to MANTECH had implemented as standard its 'CMP4' chemical-mechanical polishing process for all its high-purity semi-insulating silicon carbide (SiC) substrate products. Mills detailed how the new process had improved the quality of the wafer surface regarding scratches and defects. He added that the CMP4 process will also be implemented on all Cree's other SiC products (i.e. semiconducting SiC wafers) by the end of this year.

Also present at CS MANTECH was local firm Plasma-Therm LLC of St Petersburg, FL, USA, which was highlighting its re-emergence as an independent company following late January's management buy-out, after being owned since 2000 by Oerlikon (Unaxis).

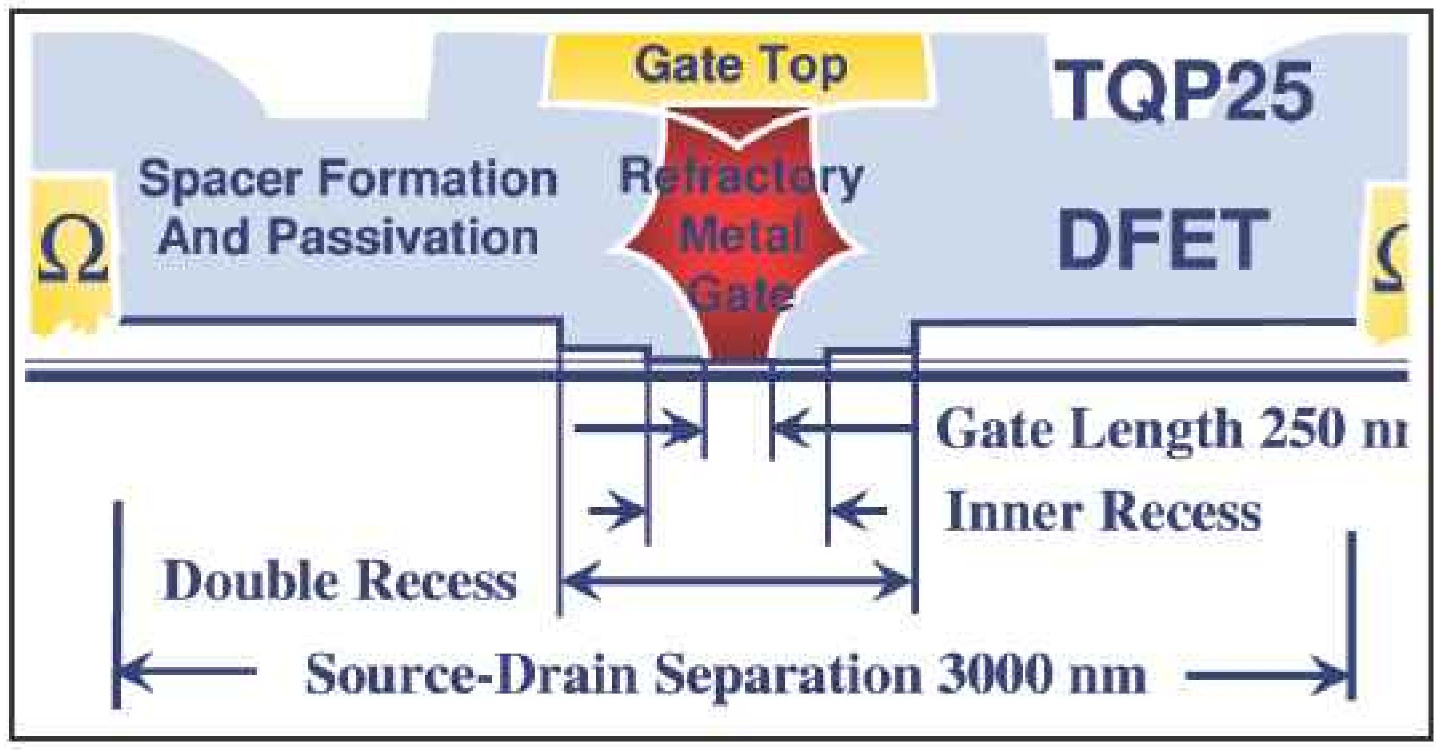
As well as continuing to offer photomask etch systems (including launching its latest Gen V product for the technology node at 32nm and below), Plasma-Therm also offers a range of plasma-enhanced chemical vapor deposition (PECVD) toolsets targeting markets from R&D and batch production (with the 790 series) to fully automated cassette-to-cassette Versaline systems. The firm has also secured the rights to market and support the Nextral range of equipment.

With a history stretching back to 1974, the firm's Ed Ostan says that Plasma-Therm has more than 1300 installed systems. The company has also re-initiated its network of sales representatives worldwide, enabling a renewed focus on the specialty semiconductor markets.

Optical lithography of 0.25-0.15μm pHEMTs

The 'Process/Etch' session (chaired by Michelle Bourke of Surface Technology Systems and Scott Sheppard of Cree) was affected by the non-appearance of Fujitsu Laboratories Ltd's Naoya Okamoto from Japan, who had been due to discuss the optimization of a 3-inch SiC backside via-hole process for GaN HEMT MMIC devices that uses ICP etching to etch a via at 2μm/min (claimed to be higher than any previously reported rate).

Corey Nevers of TriQuint Semiconductor in Hillsboro, OR introduced the new TQP25 high-volume 0.25μm AlGaAs/InGaAs enhancement/depletion (E/D)-mode pHEMT process on 150mm GaAs. This combines the firm's double-recessed 0.25μm depletion-mode FET (DFET) with a 0.35μm enhancement-mode FET (EFET) using standard i-line optical stepper technology (avoiding the higher cost and lower throughput of electron-beam or deep UV stepper gate formation used for many sub-0.5μm processes).



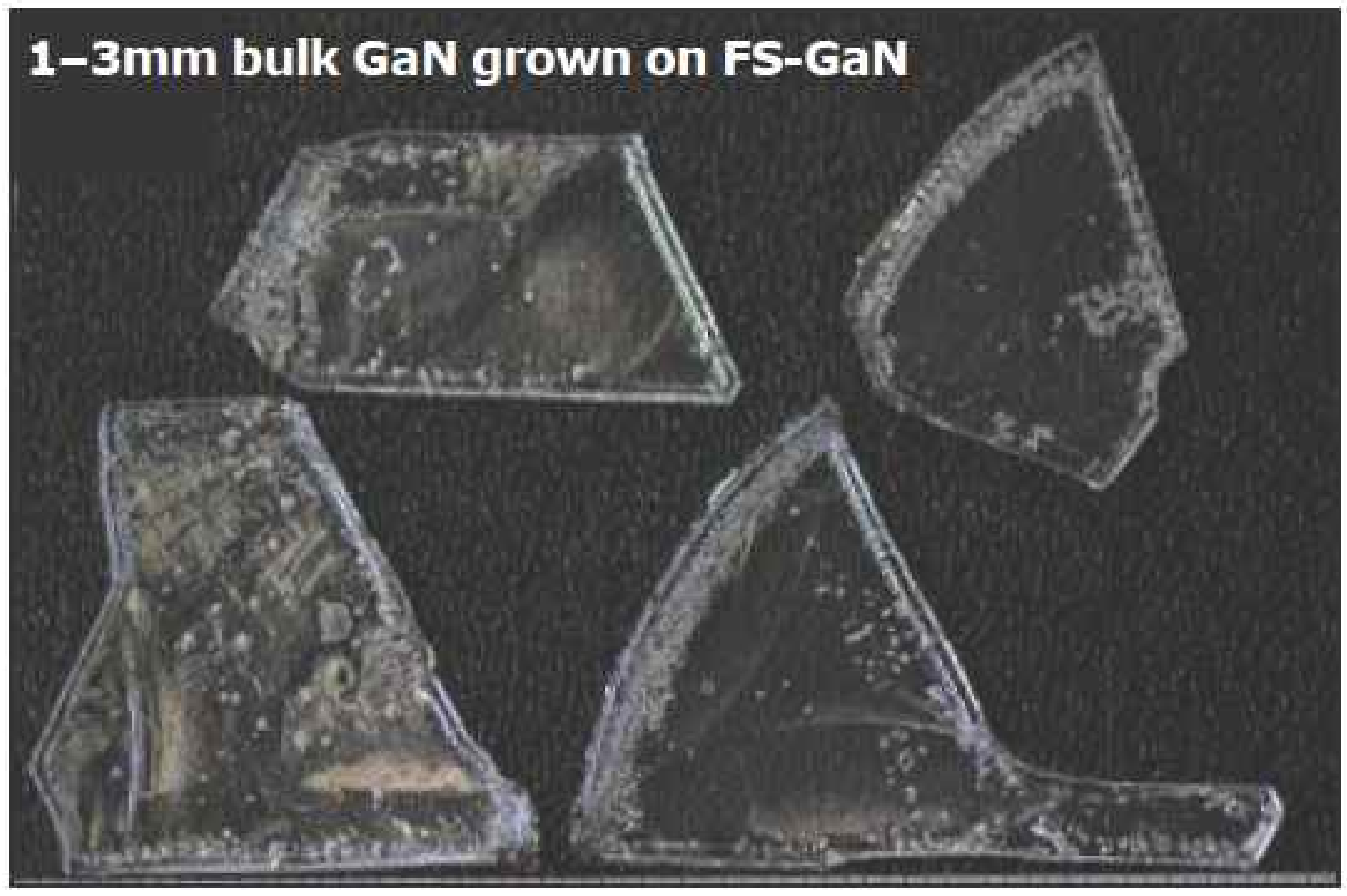
Schematic cross section of a TQP25 DFET.

The 0.25μm gate length is enabled by using a side-wall spacer process and is a hybrid of TriQuint's 0.5μm TQPED E/D process (reported at the 2004 MANTECH conference) and its 0.13μm TQP13 pHEMT process (reported at the 2005 MANTECH conference), allowing functionality typically seen at the 0.5μm node. However, the reduced gate length allows higher-frequency DFET and EFET designs and E/D logic blocks to be realized. Typical parameters include a unity current gain cut-off frequency (f_T) of 50GHz for the DFET and 45GHz for the EFET. Additionally, the aggressive TQP25 layout design rules, the low off-capacitance (0.25pF/mm) and on-resistance of 1.0Ω-mm allow very high-performance switches, low-noise amplifiers, and power amplifiers to be designed, allowing unique flexibility spanning the range between cellular handset bands through X-band to the Ku-band frequencies.

Furthermore, TriQuint has also developed the technology into the D-mode-only TQP15 0.15μm power process (again, using i-line optical lithography on 150mm GaAs wafers) in order to address the low-cost power amplifier markets for 30–60GHz Ka- and Ku-band applications. The typical f_T is 85GHz. Nevers told Semiconductor Today that there has already been 'heavy customer interest' in the TQP15 process, which is due to be released for production on the existing 150mm production line in Hillsboro in second-half 2010.

GaN growth and characterization

In the session 'GaN Growth and Characterization' (chaired by John Blevins of the US Air Force Research Laboratory's Materials and Manufacturing Directorate and Ruediger Schreiner of Aixtron) a multi-disciplinary group from the Radboud University Nijmegen, The Netherlands and the Wroclaw University of Technology described their use of hydride vapor phase epitaxy (HVPE) to grow bulk-like GaN about 3mm thick on free-standing (FS) GaN substrates. Conventionally, FS-GaN is grown by HVPE and then the substrate is removed by using either the void-assisted method, laser lift-off or facet-controlled epitaxial overgrowth. However, obtaining crack-free, large-size FS-GaN by laser lift-off is difficult due to fracturing during laser



1–3mm bulk GaN grown on FS-GaN

irradiation, while all techniques require complicated and time-consuming substrate processing prior to growth.

In contrast, the researchers used an optimized process to initially grow crack-free 200–350μm thick layers of GaN directly on the sapphire substrate. These layers were then used for overgrowth. However, high thermal stress built up between the GaN layer and the sapphire substrate causes spontaneous lift-off of a FS-GaN layer 400–650μm thick and up to 2-inches wide. The FS-GaN layer was then used for HVPE growth of bulk-like GaN that is 1–3mm thick. Defect densities are just $10^6/cm^2$ on average (and in some cases $10^5/cm^2$). However, as was also reported in other work at the International workshop on Nitride Semiconductors (IWN 2008) in Montreux, Switzerland, the polygonal-shaped pits (of varying size and depth) in the bulk-like GaN recurred in successive overgrowth processes even if polished out of the surface first.

Ed Preble, chief operating officer of Kyma Technologies, reported the development of a hydride vapor phase epitaxy (HVPE) process for the growth of 2-inch diameter bulk GaN on sapphire (with an Al interfacial seed layer deposited by physical vapor deposition) that overcomes the difficulties associated with orientation control due to the lattice-mismatch-induced stress in the GaN leading to bowing of the underlying sapphire substrate and tilt of the crystal as it grows.

The method uses x-ray diffraction (XRD) to identify the material orientation followed by a lapping procedure for correction. This leads to control of the substrate orientation to within ±0.25° of the desired cut. A chemical-mechanical polishing (CMP) process then produced epi-ready surfaces with roughness values of less than 1nm.

N.B. Further coverage of CS MANTECH 2009 will be continued in the next issue of Semiconductor Today. ■

● Next year's International Conference on Compound Semiconductor Manufacturing Technology (CS MANTECH 2010) will take place at the Portland Marriott Downtown Waterfront hotel (17–20 May).
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