Are silicon technologies poised to displace GaAs?

Asif Anwar of Strategy Analytics thinks not, and points out that GaAs technologies remain cost competitive in high-volume markets such as cellular handsets and are now also addressing the challenge of integration with new processes.

Low cost and higher levels of integration have allowed silicon technologies to displace gallium arsenide from prime markets in the past, displacing it completely from the digital IC market (remember Vitesse) as well as the cellular handset transceiver (as testified by TriQuint, M/A-COM, etc).

Current and future silicon technology capabilities, combined with cited advantages of a lower cost base and integration capabilities, are steadily improving to encompass millimeter-wave capabilities as well as aiming to displace the dominant position currently enjoyed by GaAs technologies in the cellular handset front-end. Given the historical precedent, are silicon technologies poised to displace GaAs?

Past trends and current status for GaAs

Lower costs and higher levels of integration achievable on silicon technologies have driven GaAs out of mainstream markets in the past. In the mid to late 90s, GaAs ICs for CDMA and TDMA handsets from companies such as M/A-COM, RF Micro Devices and TriQuint addressed the transmit/receive chain by integrating mixers, LNAs and gains blocks on chip. As the radio moved toward addressing multiple bands, GaAs processes were simply not able to match the complex integration offered by silicon processes. The superior integration capabilities of silicon completely displaced GaAs from the segment, effectively confining GaAs devices to the radio front-end, in which these devices are currently still the incumbent technology for both power amplifiers and switches.

Another example was the rapid decline of GaAs for use in digital ICs. In 2000, Vitesse was the largest GaAs device manufacturer in the world. When silicon CMOS performance caught up to GaAs while offering cheaper manufacturing costs and higher levels of integration, Vitesse's move to silicon CMOS effectively killed off the GaAs digital IC market. While it is reasonable to argue that this is an exceptional case (in which the market was effectively encompassed by one firm), this does not preclude similar trends being repeated in the current mainstream markets for GaAs.

Currently, GaAs industry revenues are dictated by wireless markets, with the total market for GaAs devices totalling $3.1bn in 2006, of which 84% was centred on MMIC devices. The cellular handset has been the main driver for GaAs MMICs, requiring greater numbers of heterojunction bipolar transistor (HBT) power amplifiers (PAs) and pseudomorphic high-electron mobility transistor (pHEMT) switches as the market moves towards multi-mode and multi-band architectures.

Infrastructure markets such as point-to-point radios and VSAT, where high frequency and high power are the desirable attributes, are also key markets for GaAs. Also, phased-array technology continues to drive demand for GaAs from the military sector, especially in the areas of radar and communications.

The challenge from silicon technologies

Integration has always been the unique selling point for silicon technologies and continues to be the primary argument used by companies looking to displace GaAs from the radio front-end of cellular handsets and other markets, including millimeter-wave applications such as automotive radar and point-to-point radio.

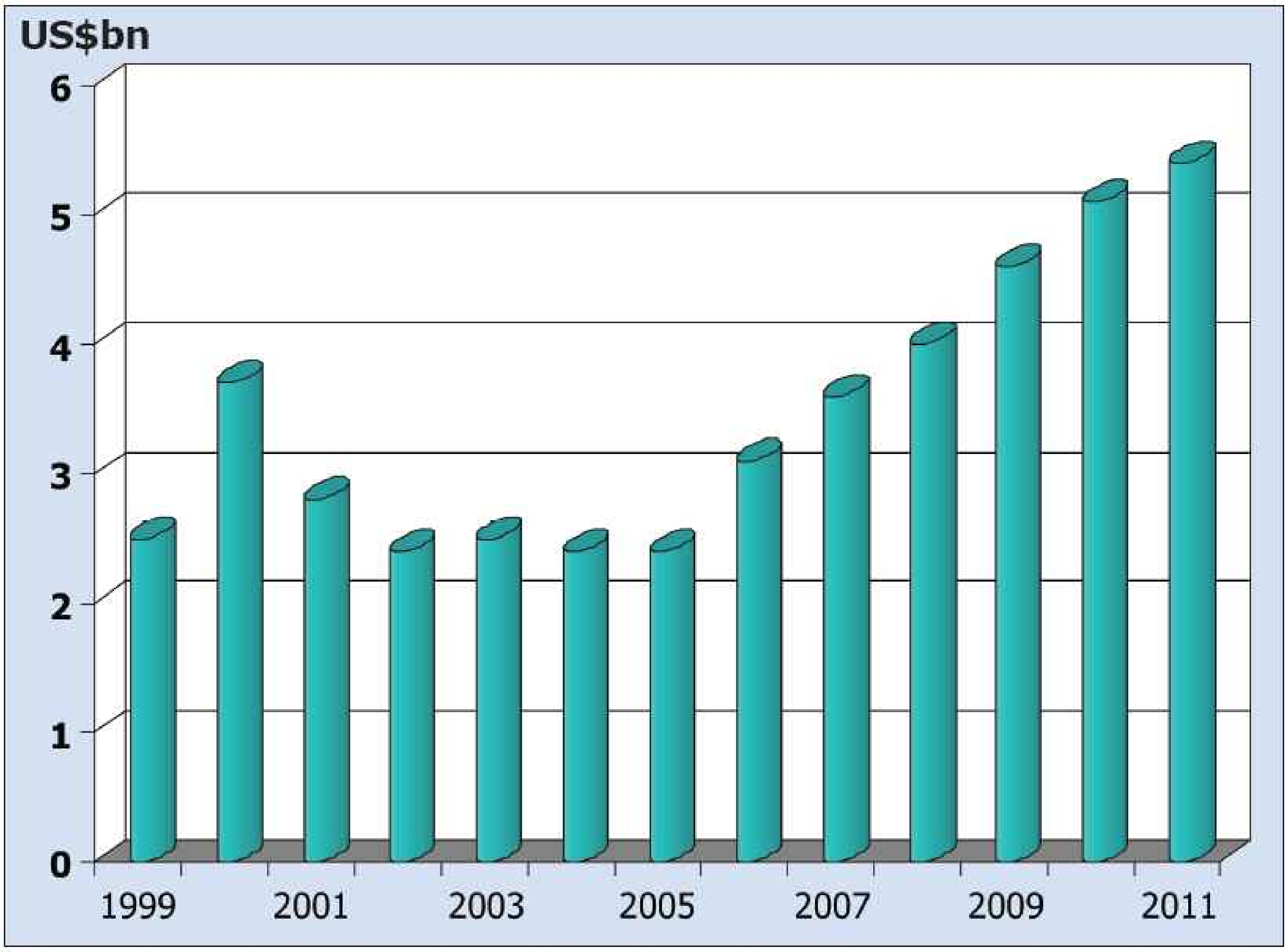
Companies such as Axiom Microdevices and Jazz Semiconductor are targeting the cellular handset front-end, with the aim of taking market share from GaAs-based multi-chip module solutions.

Axiom Microdevices claims to be on track to ship 10 million units of its 0.13μm Si CMOS AX502 quad-band GPRS PA in 2007. The AX502 is approved on a number of major semiconductor platforms and is selling to handset manufacturers such as ZTE for low-cost handset solutions. The company is also looking at developing solutions for EDGE and WCMDA platforms and cites the future potential for one-chip solutions (with the PA integrated with the transceiver and the base-band).

Jazz recently announced its 'Silicon Radio' platform, which is again aiming for a single-chip solution in the future that will encompass the transceiver, PA, antenna switch and power controller. In the shorter term, the company is introducing a solution that integrates the

PA, power controller and antenna switch on a single die, effectively looking to replace GaAs-based discrete technology (GaAs HBT PAs and pHEMT switches) solutions from the radio front-end of cellular handsets. The initial solution targets extended GSM (EGSM), but the firm also has EDGE and WCDMA solutions on its product development roadmap.

Both of these companies have targeted the cellular front-end largely on the basis of integration, but cost is also an integral part of the argument. Axiom cites a typical cost of $1000 for an 8-inch 0.13μm CMOS foundry wafer, compared to a GaAs 6-inch foundry wafer that could be as costly as $2500. Jazz also cites a similar sliding scale for silicon wafers from about $1000 for CMOS, rising to $2500 depending upon the layers of metallization and additional processes added to the original CMOS.



GaAs device market, 1999–2011 (in $bn). Source: Strategy Analytics.

Peregrine Semiconductor has targeted the handset switch market with its UltraCMOS silicon-on-sapphire process, based on integration and performance and not necessarily cost. The key to the firm's success was the initial superior performance of its parts in meeting and exceeding the 3GPP IM3 specifications for WCDMA/GSM operation. Coupled with the advantages of integration, Peregrine's switches are rapidly displacing silicon-based p-i-n diodes in antenna-switch modules and have also been used in PA-switch modules, displacing the pHEMT switches normally used in these products.

The GaAs response

As new cellular standards come to the fore, handset makers look for a proven technology that can meet their requirements across the spectrum of leading-edge to ultra-low-cost platforms. In this context, it is clear that GaAs HBT PA and pHEMT switch technologies currently meet handset OEM requirements for performance, time to market, packaging and even cost (though some myths abound in this last area, which are addressed below).

GaAs also remains the key technology for infrastructure markets requiring high frequency and/or high power performance, where the technology has a strong heritage derived from a military background.

While GaAs technology performance and multi-mode and multi-band architectures have served to increase the overall GaAs content being used over the years, GaAs device makers have also continued to improve the integration capabilities of GaAs technology, increasing the value-add to their customers.

Anadigics' BiFET process combines HBT and FET structures on one substrate and forms the basis for the firm's cellular handset PA modules, which are designed to lower/minimize current consumption while maximizing power added efficiencies, especially in the 16dBm regime where handsets are typically operating for the majority of the time. Using its BiFET technology, Anadigics has also showcased a fully integrated 802.11 a/b/g WLAN front-end IC that integrates the high- and low-band PAs and low-noise amplfiers (LNAs), the RF switches, filters and all other associated circuitry on a single die, with the final product measuring 4.0mm x 4.0mm.

Skyworks' BiFET process also combines a FET on a HBT substrate to offer biasing and power output on a single chip for both cellular handset and Wi-Fi front-ends. The power output stage of its BiFET process outperforms conventional GaAs HBT PAs, while the addition of the FET on the same chip eliminates the need for separate silicon ICs used for biasing control and offers the handset maker a smaller-footprint solution.

Other companies are following suit with their own variations of the BiFET processes. The early implementation by Anadigics and Skyworks has focused on using an HBT wafer with the FET grown on top or alongside using etch stops to separate the different devices. ➤

Other firms such as WIN Semiconductor are starting with a HEMT wafer with an HBT and E/D-mode pHEMT device optimized separately on the same wafer, again using etch stops. Adding a more complex E/D-mode pHEMT device gives the potential to offer both switch and power amplification on the same die, plus associated logic control, which would enable another function typically performed by a separate Si CMOS-based die. Other companies are following suit with their own variations of the BiFET processes. TriQuint's TQBiHEMT process combines TriQuint's high volume InGaP HBT process, TQHBT3 with it's InGaAs E/D pHEMT process, TQPED, to enable the creation of single chip products, incorporating the best possible PA, switch and LNA components. RFMD is also working on the development of BiFET processes.

Finally, enhancement mode pHEMT technology has also been demonstrated as a viable tool for achieving greater levels of integration on GaAs. Avago Technologies has demonstrated a fully integrated front-end IC for 802.11 a/b/g that integrates high- and low-band PAs and LNAs, the RF switches, filters and all other associated circuitry on a single die, with the final solution occupying a footprint of just 1.5mm x 2.6mm.

Exposing the true cost of GaAs

One of the key arguments from the silicon camp is that GaAs is an expensive, exotic technology that is tolerated by end-users as it currently offers the best performance.

Si or SiGe-based PA foundry wafers cost between $1000 for a Si CMOS process and around $2500 for a SiGe-based product. Furthermore, production is on an 8-inch substrate platform, so the die cost is significantly cheaper, with the potential to yield almost double the product from one wafer. If we compare commercial wafer foundry costs, then clearly GaAs is at a disadvantage, with commercial foundry wafers potentially costing up to $2500 for an HBT cellular handset PA wafer.

However, it must be remembered that more than 95% of GaAs HBT PA and pHEMT switch manufacturing for cellular handsets is performed by integrated device manufacturers (IDMs) such as RFMD, Skyworks, TriQuint and Anadigics, who have their own manufacturing facilities. We estimate that the cost of an internally manufactured HBT PA wafer is closer to $800, which significantly reduces the silicon cost advantage, especially compared to a SiGe foundry wafer. Another way to consider this argument is that GaAs technology is successfully competing against silicon CMOS-based solutions for ultra-low-cost handsets (for example, TriQuint recently announced the start of volume production shipments to China's ZTE for Vodafone's ultra-low-cost handsets) as well as being the technology of choice in emerging areas.

Considering infrastructure markets, while we argue that there is still a potential performance gap in most markets (with the exception of automotive radar), a review of technical papers confirms that silicon technologies are capable of millimeter-wave performance, which suggests that silicon technologies should be able to displace GaAs on the basis of cost from low-volume markets such as wireless infrastructure, cellular backhaul (point-to-point radio), satcoms, military and automotive radar.

However, closer analysis reveals that silicon technologies can actually be significantly more expensive than GaAs when considered for these low-volume markets when the cost of mask-sets is taken into account. We estimate that GaAs mask-set costs typically range from $25,000 to $50,000 per mask-set compared to $50,000 to $300,000 (and, in extreme cases, more than $1m) for silicon processes.

Tie this in with longer design cycle times (which can exceed 8 weeks) and silicon solutions become a much more costly option for a fabless design house targeting these aforementioned low-volume markets, as it will take significantly longer to amortize costs. We believe that silicon solutions can only be cost effective for low-volume markets such as millimeter-wave radios or automotive radar with silicon IDMs at the helm, e.g. Infineon, NXP Semiconductor, Freescale, M/A-COM etc, which can run specialized processes on conventional high-volume manufacturing lines (thus offsetting the higher cost associated with supplying low-volume markets). The automotive radar market is one example where this model is being applied by M/A-COM and Infineon and is an area where SiGe-based solutions will potentially displace GaAs in both long- and short-range platforms.

Ultimately, however, GaAs technologies remain the most cost-effective solution for high-power, high-frequency applications.

GaAs market forecast through 2011

Demand from cellular handsets will continue to be the primary growth engine for the GaAs industry. We estimate that 3G platforms accounted for 13% of the global market in 2006, and this will rise to 61% of global market shipments by 2011. WCDMA/EDGE-based handsets will account for 42%, while EDGE/GPRS will still account for over 37% in 2011. Simply put, the bulk of unit growth will be in the high-end of the market, where complex multi-mode, multi-band front-ends will be required.

While there will be a mix of approaches used in the cellular handset front-end, we forecast that GaAs will dominate this function and will be used in a variety of modules, including PA modules, PA-filter modules and PA-switch modules.

GaAs technologies will also dominate the millimeter-wave markets, including military applications, satellite communications (space and ground) as well as cellular backhaul. Not only does GaAs technology offer the best performance for these applications, but we maintain that GaAs technologies are also the most cost-effective solutions for these markets.

Coupled with demand from other markets such as cable TV (CATV), direct broadcast satellite (DBS), telecoms and datacoms, the overall market for GaAs devices will exceed $5bn in 2011.

Implications

- For high-volume markets such as cellular handsets, GaAs currently offers the best performance and fastest time to market, which is essential as new standards come to the fore and handset makers look for a proven technology that can meet their requirements. This strength is recognized by handset OEMs such as Nokia who, while continuing to actively assess alternative technologies including SiGe, see GaAs as the mainstream technology for the future.
- Silicon technologies are steadily improving to encompass millimeter-wave capabilities as well as aiming to displace GaAs technologies from the dominant position in the mainstream radio front-end of the cellular handset. Integration capabilities and cost remain the primary arguments for adoption of silicon technologies.
- The integration capabilities of GaAs technology are improving, with single-die front-end modules demonstrated for Wi-Fi applications and BiFET technologies also being used to displace silicon-based biasing circuitry in cellular handset PAs.
- Silicon is cheaper than GaAs in high volume. However, GaAs offers the most cost-effective solution at millimeter-wave frequencies, where unit shipments are measured in tens of thousands rather than tens of millions. Mask-set costs for silicon processes can be more than 10x those for GaAs.
- Even though Si CMOS PAs are winning design slots in low-cost GPRS/GSM markets, this is not necessarily at the expense of GaAs PAs. Conversely, Si technologies are still working to catch up to GaAs for EDGE and WCDMA capabilities and are typically two generations behind GaAs, especially when considering raw performance.
- If it can be done in silicon, then it WILL be done in silicon, but radio performance requirements from the cellular handset market are still a moving target. The market continues to demand greater linearity, higher frequencies and multi-mode, multi-band capabilities, which are not necessarily going to be achievable in a single-chip solution in the short-term.
- Longer term, the laws of physics dictate that silicon technologies will have to give way to alternative technologies as the limits of electron mobility (among other factors) are reached. One way around these limits in the future may be to integrate compound semiconductors into silicon circuit designs, in order to provide the performance enhancements of compound semiconductors and the manufacturing scale and cost advantages of silicon. ■

This article stems from a presentation given by Strategy Analytics at European Microwave Week 2007. For accompanying presentation slides, see:
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