GaAs industry back in equilibrium

The CS MANTECH 2007 conference in Austin, Texas evidenced much optimism about GaAs market growth (despite glitches with Motorola's handset business), as well as progress in GaN HEMT performance and reliability, reports Mark Telford.

Table 1. GaAs capacities.

Firm	Wafer size	Capacity
RFMD	6″	21%
Skyworks	4″	14%
TriQuint	6″	14%
Freescale	6″	7%
Anadigics	6″	6%
Other		38%

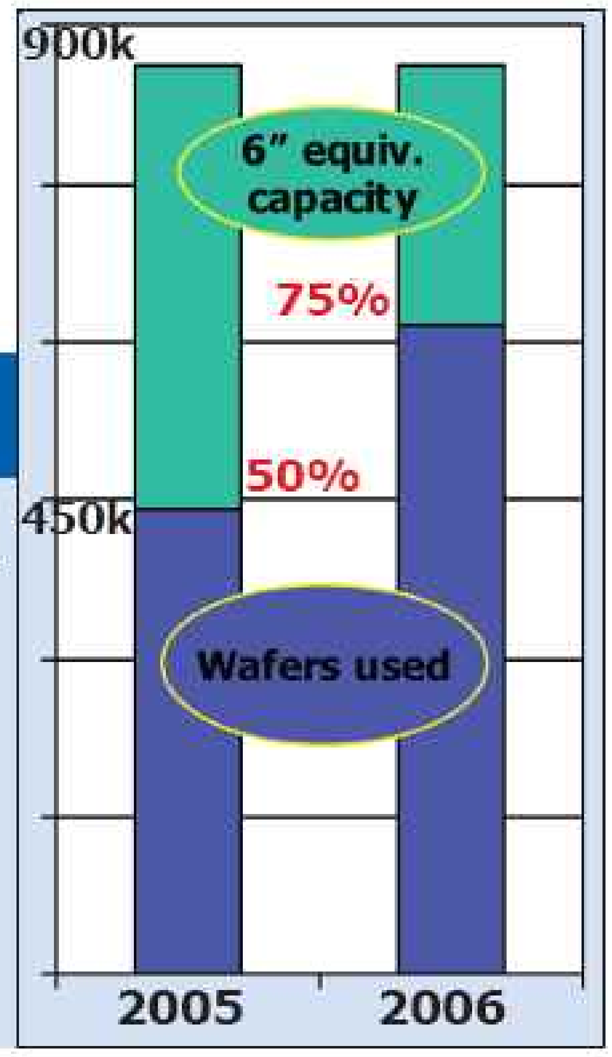


Figure 1. While GaAs manufacturing capacity stayed at 850,000 6″-equivalent wafers, 18% growth in the handset market and rising demand for GaAs ICs drove capacity utilization from 50% in 2005 to 75% in '06.

May's 22nd annual International Conference on Compound Semiconductor Manufacturing Technology (CS MANTECH 2007) in Austin, TX, USA drew a healthy attendance of 292 delegates (or about 400, including the exhibition), including strong representations from device makers TriQuint Semiconductor, Skyworks Solutions and Northrop Grumman.

Indeed, of the total of 73 papers, TriQuint's CEO Ralph Quinsey gave the opening invited talk, 'State of the Compound Semiconductor Industry: A Focus on Communications'.

GaAs sector reaches capacity equilibrium

After the pain of 2000–2005, when commoditization and over-capacity drained value and limited investment, 2006 was a transitional year, says Quinsey, as value moved back into the compound semiconductor sector: the first year in many when GaAs IC supply and

Mid-tier suppliers squeezed as GaAs industry bifurcates

About 50% of GaAs IC capacity is now controlled by the top three suppliers (RFMD, Skyworks and TriQuint, which are each executing strategies to add capacity to their supply chain), says TriQuint's Quinsey. Mid-tier suppliers control 30%, with the remaining 20% spread across a dozen or so companies that maintain small GaAs fabrication capability for strategic reasons.

The industry is bifurcating into top-tier suppliers, where participation in the largest market (personal voice and data) will continue to drive growth and technology investment, and small niche suppliers serving unique strategic needs (typically embedded into larger vertically integrated businesses as captive units).

Mid-tier players need to either grow or be consolidated — get bigger or get out.

The 'stranded' mid-tier suppliers are feeling the pressure of either not reaching critical mass or not leveraging technology differentiation. "Mid-tier players need to either grow or be consolidated — get bigger or get out," remarks Quinsey. This may create an environment for foundry consolidation supporting a fabless business model. It is more likely, due to the success of standards bodies reducing the ASIC nature of RF products, that mid-tier suppliers will have to choose between consolidation or integration into a vertical business to survive.

The anticipated consolidation of the industry is quietly happening, with factory shutdowns, restructuring, or combinations since early 2003 among the following companies: Suntek, GEC Marconi, Vitesse, Philips, Celeritek, Sanders, Mitsubishi, Sumitomo, WJ Communications, Filtronics, GCTC, and WIN. "Healthy consolidation of the supply chain is continuing."

Also bifurcating is cost/value versus performance. By 2010, there will be two parallel technology roadmaps, predicts Quinsey:

- high-volume, low-cost multi-technology modules (incorporating an HBT PA and a pHEMT switch) for cellular 2G, 2.5G and 3G phones as well as WLAN;
- high-performance (high-frequency and high-power) components for WiMAX base-stations, VSAT, millimetre wave and military applications (including using GaN).

demand came back into balance (indeed, in mid-2006 the GaAs sector was briefly supply constrained, he adds).

Market research firm Strategy Analytics says that the GaAs market was about $3bn in 2006 — and is growing at a compound annual growth rate (CAGR) of 7% — with personal voice and data the highest-volume 'killer' application about 70% of the market. With 1bn units sold in 2006, cell phones remain the highest unit-volume consumer electronics device, representing an annual market of over 1bn units for components.

As cell phones have evolved down the learning curve for size, weight, cost and part count, the integration of more features, with increased performance, lower cost, and easier implementation has been the driving force for the semiconductor components, says Quinsey.

For power amplifiers (PAs) in the RF section, GaAs has proven to be the preferred technology for providing maximum battery life, starting with MESFET and migrating to HBT and pHEMT devices.

In particular, the continuing progress of GaAs down the cost learning curve has countered the threat to the GaAs market from the trade-off of performance for low cost using high-volume CMOS silicon-based technologies, with high-profile launches of CMOS PAs for the low-cost GSM/GPRS market not enjoying great success, says Quinsey. GaAs has confronted the silicon threat "at least for the foreseeable future", he reckons.

Also, although voice remains the killer application, the long-awaited commercialization of 3G, offering untethered broadband data access, should lead to the sale in 2007 of 150–170m multi-mode, multi-band handsets with more complex RF requirements. This solidifies the position of GaAs as a critical enabling RF technology, says Quinsey, since the more complex new-generation phones incorporating multi-mode (2.5G and 3G) and multi-band (800MHz to 2.6GHz) functionality multiply the usage of GaAs components per phone.

Average GaAs dollar content per phone is $0.35–0.80 for simple standalone PAs. This rises to $0.90–1.50 for modules (containing more RF front-end functionality), $1.50–2.50 for EDGE phones (with modules containing multiple RF front-ends), and $5.00–6.00 for 3G phones (incorporating EDGE and one or more WCDMA bands).

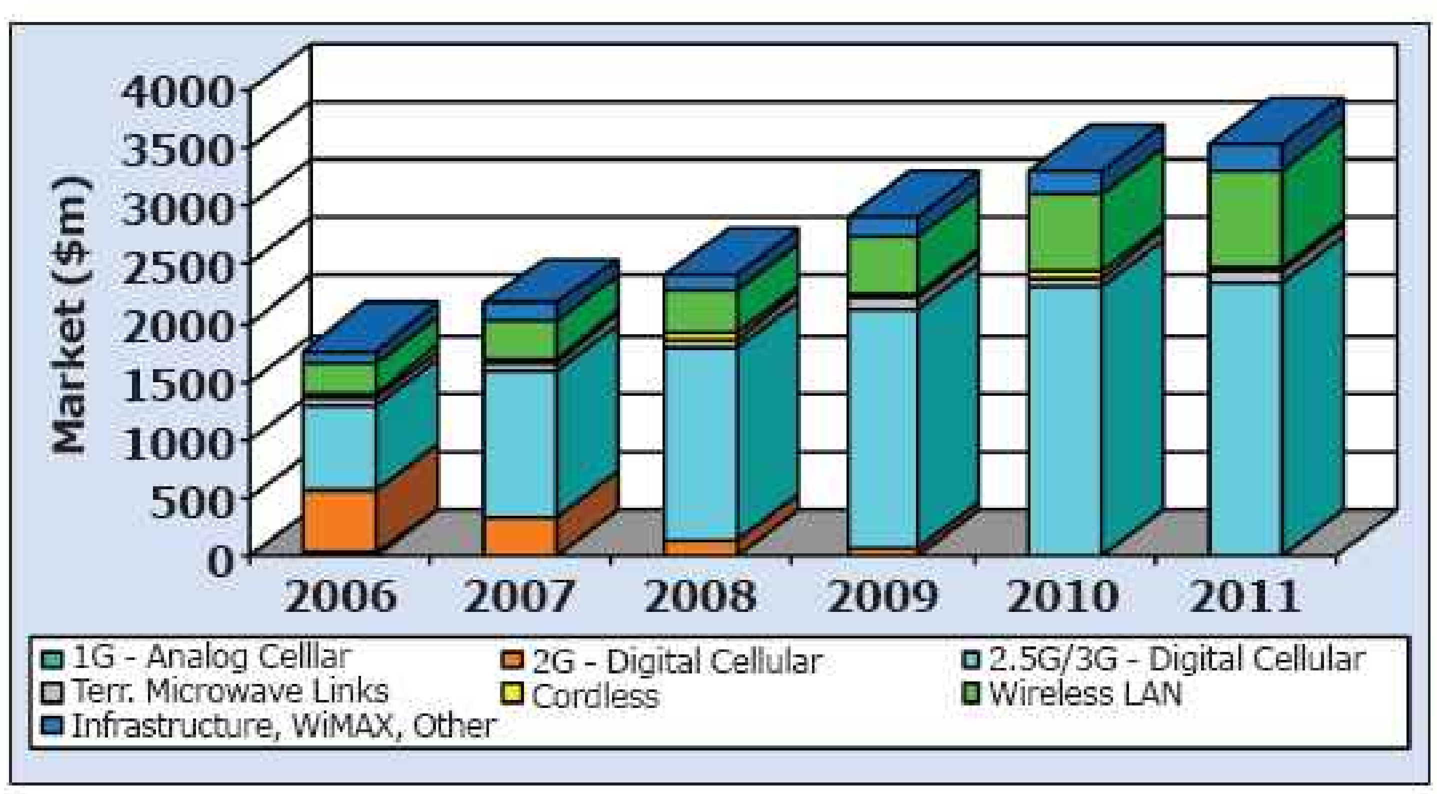


Figure 2. Wireless communications market sectors.

Likewise, for wireless LAN, a similar trend is occurring (albeit behind handsets), especially as silicon or SiGe PAs for single-band 2.4GHz WLAN have been displaced by GaAs for dual-band 2.4/5GHz WLAN: average GaAs dollar content is $0.39 for the 802.11b specification, $0.46 for 802.11b/g, $0.90 for 802.11b/g/n, $1.56 for 802.11a/b/g, and $3.12 for 802.11a/b/g/n, with 802.11n (or MIMO, multiple-input-multiple-output, which is currently moving from development into production) containing up to three RF sections.

Meanwhile, for the more commercial wide-area broadband networks, WiMAX promises further opportunities for GaAs and, possibly, GaN technology. (Compound annual growth rates are 15% for wireless, 27% for 3G, 28% for WLAN, and 54% for WiMAX.)

Developments in GaN HEMT technology

In the session on 'Devices & Models', Ming-Yih Kao et al from TriQuint reported what it claims is the first demonstration of GaN HEMTs with state-of-the-art noise and power performance simultaneously (potentially simplifying GaN foundry process offerings).

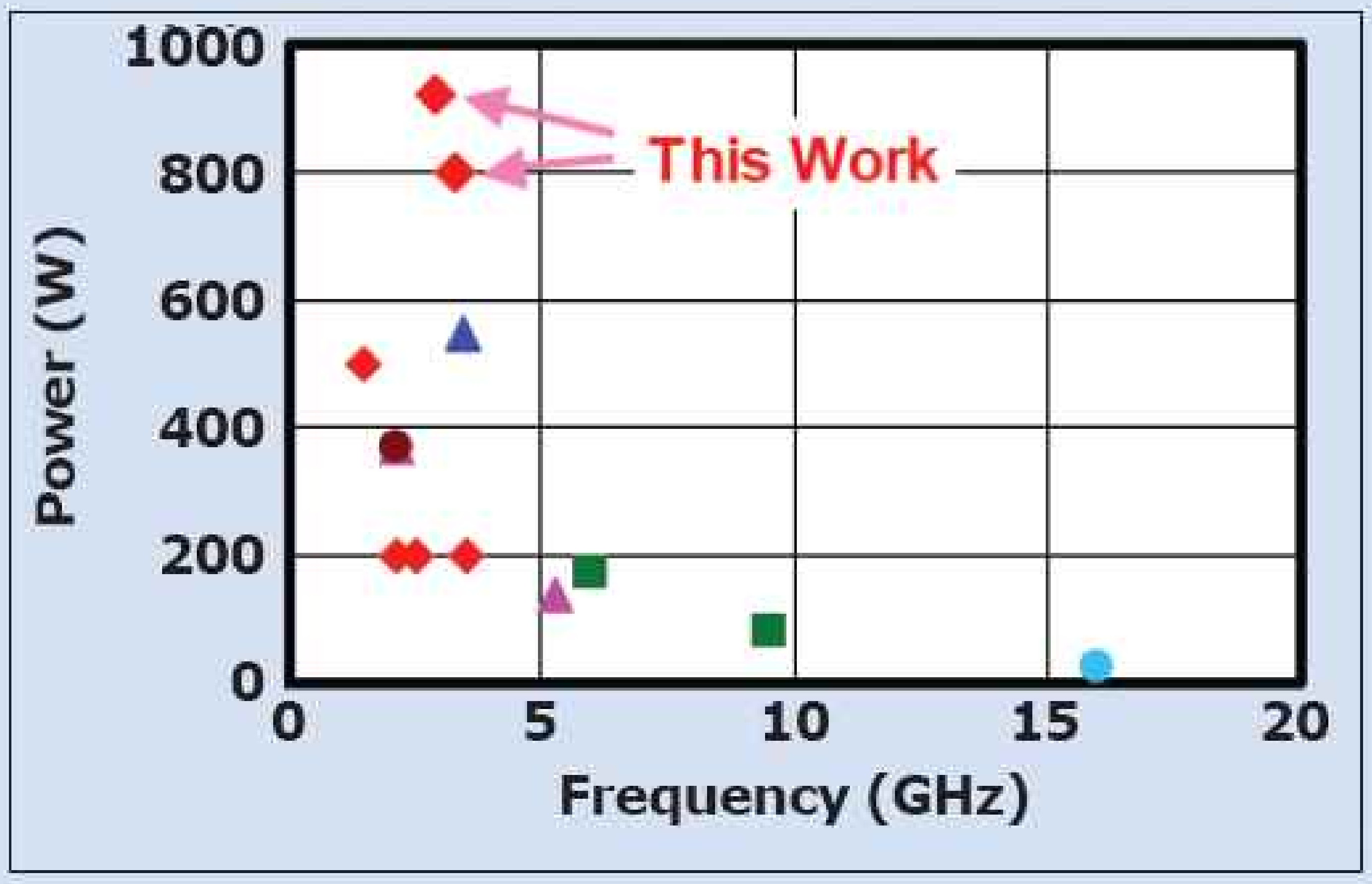
The recessed 200μm-wide, 0.25μm-gate-length AlGaN/GaN HEMTs, grown by MOCVD on 3" SiC wafers, has high power-added efficiency (PAE) of 62%, 57% and 41% at 10, 20 and 35GHz, respectively, and low minimum noise figures of 1.0dB and 1.4dB at 18 and 26GHz,

Eudyna reports record 800W S-band transistor

In the session 'GaN & SiC Power Devices', Eizo Mitani of Japan's Eudyna Devices Inc reported a AlGaN/GaN HEMT (grown on SiC) with what is claimed to be a record power output for an S-band transistor: peak power of 912W, together with 56.4% drain efficiency at 2.9GHz, operating at a drain bias voltage of 70V.

Operating at 65V under pulsed conditions (a duty of 10% and pulse width of 200μs), the device has a power output of over 800W, a high linear gain of 14dB and a high efficiency of 50% over the wide frequency range of 2.9–3.3GHz. The chip structure is the same as that used in Eudyna's standard GaN HEMT products. The results were also reported at June's IEEE MTT-S event.

The researchers had previously reported (at the June 2006 IEEE MTT-S International Microwave Symposium) a 500W AlGaN/GaN HEMT power amplifier at 1.5GHz and demonstrated high power L-band performance. At S-band frequencies, an internally matched 550W peak-power GaN HEMT at 3.45GHz with a very short pulse of 2μs at a duty of 2% was reported by Cree at December's IEEE International Electron Devices Meeting.



Output powers of reported GaN HEMT devices.

For Eudyna's 800W AlGaN/GaN HEMT, power droop and phase droop at an output power of 59.0dBm are 0.31dB and 3.9°, respectively, suiting S-band high-power applications like radar. Also, peak channel temperature is about 10°C for a pulse width of 500μs with 10% duty, and 110°C for a pulse width of 200μs with 20% duty, showing that it has sufficient thermal handling ability.

respectively, for 100, 200 and 300μm gate widths.

Hence, PAE, gain and noise performance are similar to those of the best reported GaAs-based pHEMT devices (the dominant technology for X- to Q-band power MMICs over the last decade), but output power densities are 4–5 times higher (potentially replacing GaAs pHEMTs or HBTs in high-power amplifiers, transmit/receive and multi-function MMICs for S- to Q-band applications).

Previously, in 2004 minimum noise figures of 0.98dB at 18GHz for 0.25μm GaN HEMTs were reported by University of Illinois at Urbana-Champaign's J. Lee et al (Microwave and Wireless Components Letters, Vol. 14, No. 6, p259), and in 2005 Ka-band power performance for GaN-based devices and MMICs with maximum PAEs of 50% and 45% at 10 and 30GHz, respectively, were reported by J. Moon et al of HRL Labs LLC (IEEE Electron Device Letters, Vol. 26, No. 6, p348).

AlGaN/GaN HEMTs have achieved high voltages and current densities to obtain the required charge for power electronics, but only by relying on both piezoelectric and spontaneous polarization as well as strain (via barrier thicknesses exceeding 160Å). This leads to short-channel effects (limiting the frequency response) for gate lengths as large as 250nm. For the higher device operating frequencies required, gate lengths of 100nm or less are desired. Gate recesses can be used to mitigate short-channel effects, but they typically rely on a timed etch and can introduce unintended effects at the interface. Another solution is to grow the barrier layer very thin.

Table 2. pHEMT vs AlGaN/GaN HEMT comparison.

Device	NF_{min} 26GHz (dB)	PAE 35GHz (%)	Gain (dB)	Power density (W/mm)
pHEMT	1.1–1.5	38–44	5.5–6	0.7–0.9[a]
GaN HEMT	1.3–1.5	37–41	5.0–6	3.0–6.1[b]
Comparison	Similar	Similar	Similar	4–6x

[a]at 6V; [b]at 15–28V

In 2001, J Kuzmik showed that InAlN/GaN interfaces can produce a large spontaneous polarization charge due to the large conduction band offset. Lattice-matched materials such as InAlN/GaN reduce the strain and the piezoelectric contribution to the charge in the channel, reducing sensitivity to processing and growth changes, and allowing thinner barrier layers while maintaining high sheet charge densities. Last year Higashiwaki et al demonstrated 6nm InAlN layer MISHEMTs with impressive small-signal performance using a 3nm SiN layer. But even with the gate 9nm from the channel, short-channel effects are still observed.

Now, at CS MANTECH 2007, J. K. Gillespie et al of the Air Force Research Laboratory, using MOCVD material grown by Northrop Grumman Electronic Systems, have reported the first unstrained InAlN/GaN HEMT on SiC with an InAlN barrier thickness of 75Å. With a gate length of 250nm, the device demonstrated an open channel current of I_{max} = 861mA/mm and a frequency response of f_T = 43GHz. Power density was 2.0W/mm, and peak PAE was 29.3% at X-band frequencies. AFRL aims to optimize the growth and device design to achieve I_{max} > 2A/mm and f_T >120GHz. ■