Towards low-cost high power density devices

Gallium nitride power electronics are now ready to address a $3.5bn market, reckons Philippe Roussel of market research firm Yole Développement.

Gallium nitride is already widely used for blue/white LED manufacturing — consuming an equivalent of more than 5 million 2″ wafers this year — and the related GaN industry is now maturing. In addition, since GaN's wide energy bandgap allows a high breakdown voltage, the material is suited to use in power electronics applications.

Silicon-based power electronics is forecasted to represent a $13.5bn market for discrete devices in 2007. We estimate that GaN technology can address least $3.5bn of this. The main applications that are feasible include power factor corrector (PFC) circuits, hybrid automotive, uninterruptible power supplies (UPS), and solar-panel and industrial motor control. To achieve this, nitride devices have to compete not only with silicon on cost but also with SiC on performance. This very challenging position is driving much activity in the nitride community to develop new GaN power devices.

GaN can cut device price by 30% versus SiC

Since 2001, possible GaN market segments have been partly covered by SiC technologies. SiC Schottky diodes are in full production at Cree and Infineon and the first commercial offerings in transistors are available from firms like SemiSouth, TranSiC and SiCed.

However, SiC devices remain very expensive compared to silicon, essentially due to the SiC single-crystal substrate price, which is generally more than 50% of the overall device cost. This can be dramatically improved in the GaN world, where substrate technology can benefit from long-term experience with LEDs and can lead to improved material at an affordable price (see Table).

The first initiative in GaN power devices came when Velox Semiconductor, a spin off from Emcore, unveiled 600V GaN Schottky diodes with zero recovery time for power supply applications. The firm claims to have achieved performances comparable to SiC diodes (see Figure 1) but at a fraction of their cost (30% less than the SiC-based Schottky selling price). GaN Schottky diodes are grown on 4″ sapphire substrates. GaN dislocation density (which has plagued blue lasers) remains in the $10^8 cm^{-2}$ range but seems to have a relatively low impact on the device performance. Velox has developed GaN diodes operating at 600V and currents of 2, 4, 6 and 8 Amperes and has teamed with STMicroelectronics for devices production and distribution.

Strengths	Weaknesses
• Breakdown voltage close to SiC's • Electron mobility twice SiC's • 4″ epiwafers already available (Nitronex, Picogiga, IMEC, Azzurro): scalable technology • Micropipe-free material. • Only one polytype	• Thermal conductivity ¼ of SiC's • No bulk GaN substrate available at reasonable price • GaN epi substrates (sapphire, Si+AlN buffer) are insulators: no vertical device easily feasible • Lateral devices limited in breakdown voltage & current density for given device footprint
Opportunities	**Threats**
• Many possible suppliers: no monopoly situation • GaN industry is mature, thanks to opto markets • GaN HEMT can be transferred from RF to power applications • GaN Schottky diodes already proven and adopted (Velox, ST) • 30% device price reduction expected compared to SiC	• No GaN switch on market yet • GaN power device development started 10 years after SiC

GaN power electronics to boost epi market

The SiC-based power electronics industry has emerged due to the availability of bulk single-crystal SiC, enabling the growth of SiC epilayers in a homo-epitaxial process. This approach allows perfect lattice matching between the active layer and the substrate.

For GaN, the situation is more complicated: bulk GaN substrates remain very expensive ($3–7000) and are only available at 2″ diameter (although recent announcements from Hitachi Cable makes 3″ GaN close to commercialization). Optoelectronics applications like blue laser diodes are helping to cut pricing by increasing demand for bulk crystal, but even the most optimistic roadmap shows bulk GaN remaining uncompetitive in price compared to SiC for quite a long time.

The first solution came from sapphire, which up to now has been the cheapest substrate available for growing GaN. This also means that GaN growth is based on a hetero-epitaxial process. However, sapphire

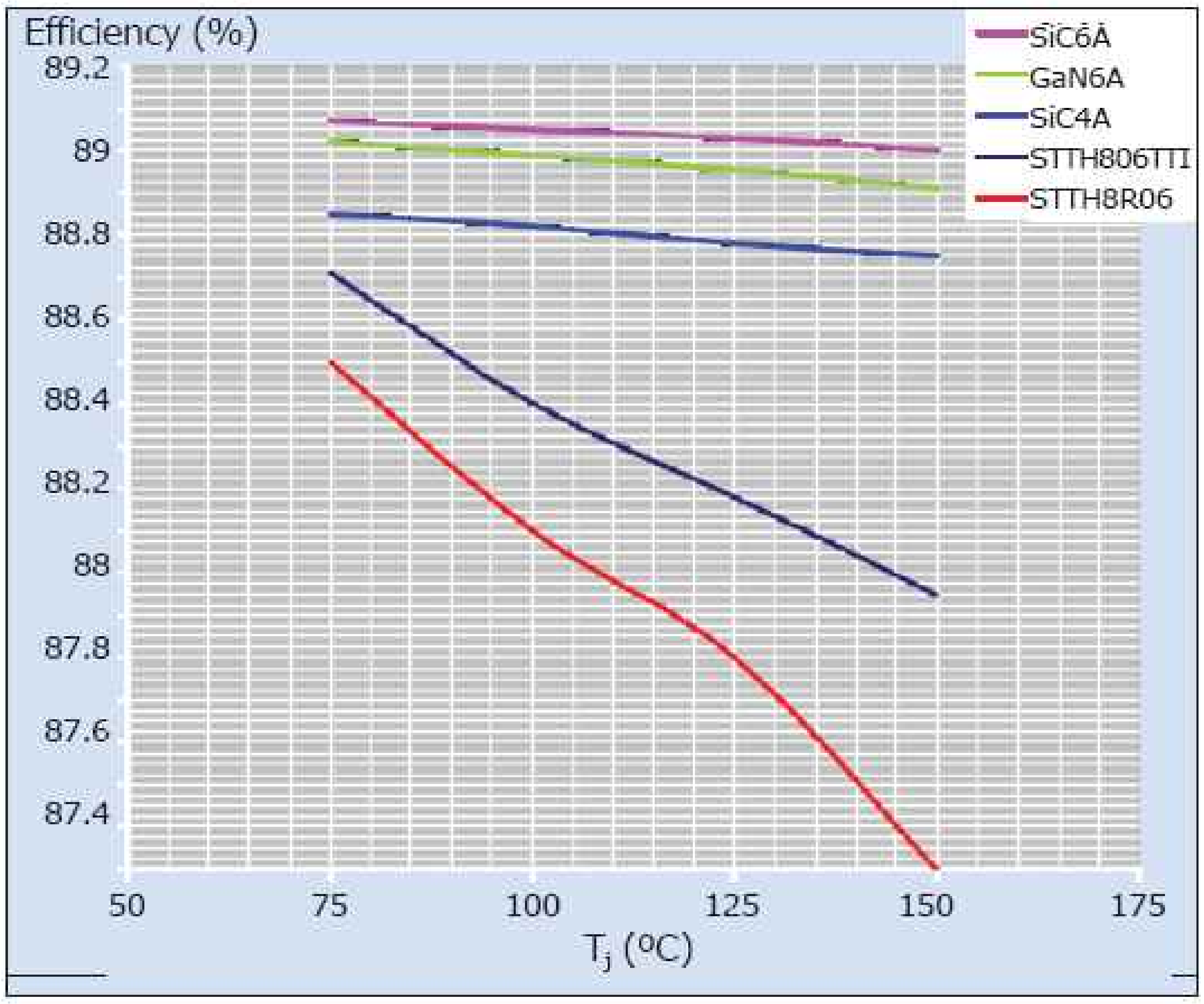

Figure 1. PFC efficiency comparison as a function of junction temperature and Schottky diode type (Si, SiC and GaN). Courtesy of STMicroelectronics.

is an insulator (thermally and electrically) so devices need lateral designs. Lateral devices are limited in term of breakdown voltage compared to vertical devices and rapidly become bulky for high power densities.

New developments are now focusing on decreasing the epiwafer cost by using silicon as a substrate for GaN growth. GaN/silicon substrates for power electronics has been proposed by companies like Picogiga, IMEC, Nitronex, IQE, Azzurro, NTT and Covalent Materials, and is commercially available in 4″ and even 6″ diameters.

Another promising material for GaN growth comes from Soitec subsidiary Picogiga, which proposes its SopSiC substrates, made of a thin silicon layer bonded onto a poly-silicon carbide wafer. This approach offers a thermally enhanced substrate compared to GaN/silicon and can be used as a template to grow GaN the same way as on bulk silicon. The product is now commercially available at a diameter of 4″ (with 6″ expected soon).

However, even grown on a Si substrate, GaN epiwafers won't allow vertical design, because of the AlN insulating buffer layer generally used to match Si and GaN crystals.

In summary, the challenge facing GaN power electronics is a subtle balance between substrate diameter, power density, chip size and device cost. In other terms, GaN power devices on sapphire or silicon can compete with SiC from a cost point of view by using larger 4″ and 6″ substrates to compensate for the bigger chip size at a given power density. We forecast a strong market ramp-up by 2010 and expect demand of more than 150,000 x 4″ GaN epiwafers in 2012 (Figure 2).

So, with the introduction of affordable large-diameter epiwafers (4″ or more), GaN power electronics is perfectly matched to target the 0–600V market in the short term, aided by the development of dedicated device technology. GaN power transistors can benefit

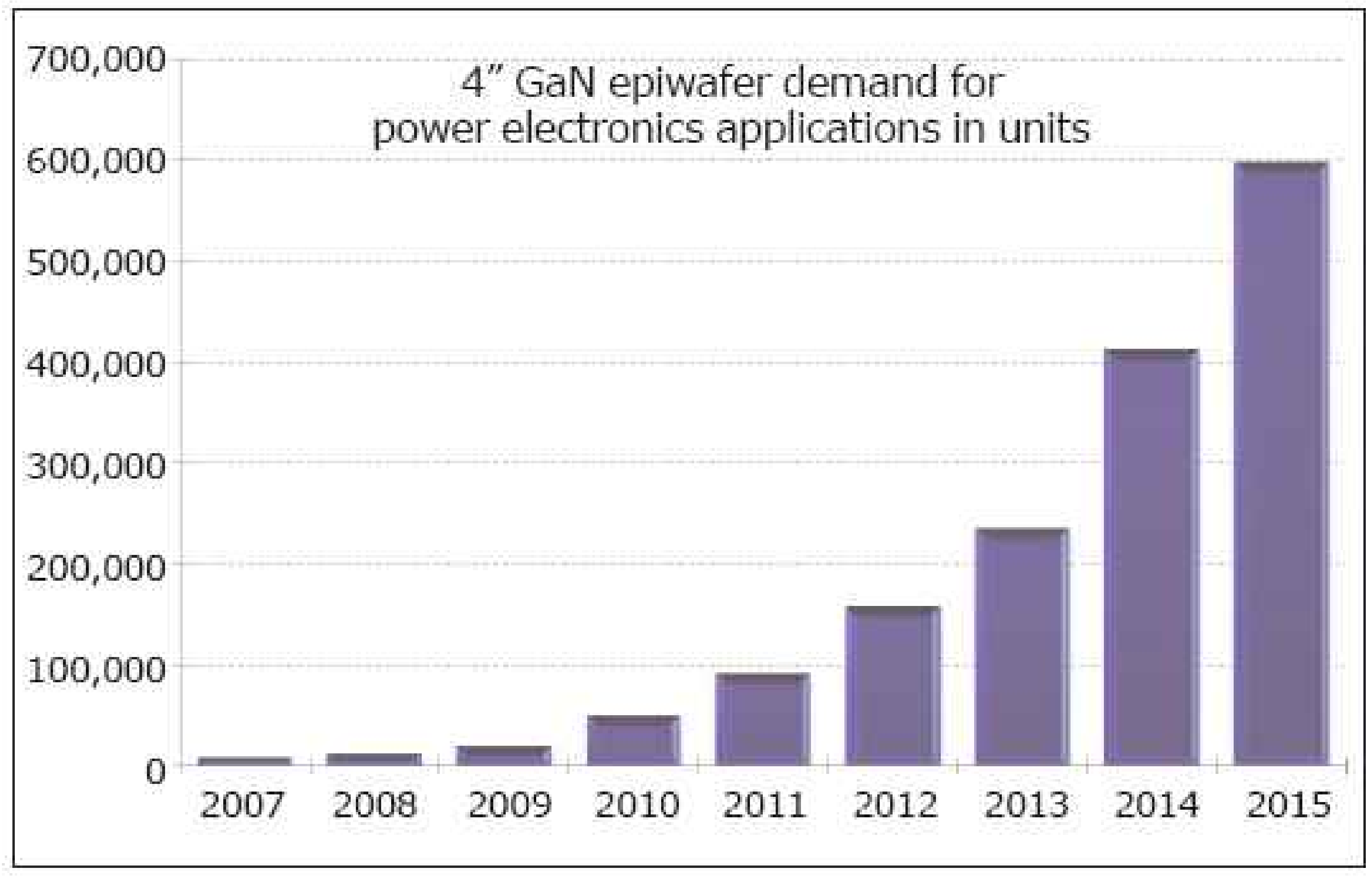

Figure 2: Unit forecasts for 4″ GaN epiwafers.

from the long experience of developing GaN RF HEMTs. This can speed the emergence of a GaN low-frequency transistor, to be coupled with existing Schottky diodes.

GaN has now entered the power electronics battlefield. The first challenge is facing SiC technology but, with price reduction, silicon will become the main target.

*Dr Philippe Roussel of Yole Développement of Lyon, France (**www.yole.fr**) is now editing the latest market report 'GaN'07' dealing with new GaN developments and markets from a material and device points of view.*