Silicon carbide epitaxy for growing market

A move to 6-inch substrates and emerging markets is driving expansion for SiC. Mike Cooke reports.

Silicon carbide (SiC) is a semiconductor that is very hard to create and work. Despite this, market analyst firm Yole Developpement believes that SiC devices will net a billion dollars in revenue within a decade.

The interest in SiC as a device medium comes from its wide bandgap, which generally means that the material should be able to withstand larger electric fields and hence potential differences before breakdown. High breakdown voltages are of interest in electric power generation, distribution and heavy-duty application.

Another potential benefit of the wideband gap is higher-temperature operation that could allow reduced cooling requirements for SiC-based power systems. Also, the chemical inertness of SiC that makes it so difficult to work means that, once fabricated, SiC devices can operate in harsh environments.

Research has been carried out over many years with military, state, and industrial funding sources. A wide range of device types have been suggested for the range of applications in which SiC may find profitable application: Schottky diodes, metal oxide semiconductor field-effect transistors (MOSFETs), junction field-effect transistors (JFETs), bipolar junction transistors (BJTs), thyristors, gate-turn-off devices (GTOs) and insulated-gate bipolar transistors (IGBTs). These are generally produced from wafers with SiC epitaxial layers grown on SiC or silicon substrates.

In the past year, renewed interest in SiC device technology has been indicated with a number of orders for the tools needed to produce SiC epiwafers. Here, we look at some of the developments and the companies behind them.

Toolshop

Aixtron is the company that is most often mentioned for SiC chemical vapor deposition (CVD) epitaxy tools. The firm's latest AIX G5 WW Planetary Reactor is designed to reach the extreme temperatures needed for SiC growth on substrates up to 150mm. The G5 can handle 6x150mm wafers per run (or 10x100mm). The company sees opportunities in supporting producers of power rectifiers and switches for power conversion and distribution applications.

Figure 1. An Aixtron AIX G5 Planetary Reactor.

The Aixtron G5 is based on its fifth-generation system that is also used for GaN epitaxy. Both materials need higher-temperature processes than arsenic- or phosphorus-based compound semiconductors — the range for GaN tools is given as 1200–1300ºC, as opposed to 1500–1700ºC for SiC. These figures compare with the cooler 850ºC needed for As/P-based materials.

Veeco, the main competitor with Aixtron in the metal-organic CVD market, does not appear to offer SiC epitaxy products. Other firms do market more general CVD tools for this challenging application, but one must distinguish between SiC epitaxy and coating. (SiC CVD coating is used as a material able to withstand high temperature and chemically reactive environments, for example, in semiconductor processing chambers.)

In Italy, the company LPE produces the ACiS range of SiC epitaxial reactors based on hot-wall CVD. The firm quotes power consumption figures of the induction heating system for both 1550ºC (20kW) and 2000ºC (36kW), giving an indication of the temperature range of the tools. The smaller M8 machine is capable of handling batch loads of 6x2-inch, 3x3-inch or 1x4-inch substrates. The larger M10 can handle batches of 9x2-inch, 5x3-inch or 3x4-inch.

LPE reported in July 2012 that it had installed a 6-inch (150mm) SiC epitaxy tool at E.T.C. (Epitaxial Technology Center) in Catania, Italy. The tool is being used in the context of the ENIAC-LASTPOWER Project of the

European Union. LASTPOWER began in April 2010 and is due to complete this October. The budget was €16.3m.

ETC has two further LPE SiC epitaxial reactors (ACiS M8 and ACiS M10) for R&D and volume production. ETC also has SiC-on-silicon capability up to 200mm diameter.

In Japan, Tokyo Electron Limited (TEL) has the Probus CVD system for SiC epitaxy on substrates up to 6-inch diameter. The system can be configured with two process chambers. An auto-loader can also be added. Infineon bought a TEL tool in early 2012 for mass production of advanced SiC power devices.

Epitaxy and substrate producer

In any discussion of SiC epitaxy one must look at Cree in the USA. The company produces SiC substrates, SiC/SiC epitaxial wafers, SiC/III-nitride epitaxial wafers, along with LED and power and RF electronics devices.

The firm's most recent announcements in SiC epitaxy have concerned low-basal plane defect density 100mm epiwafers and the development of larger 6-inch (150mm) diameter products.

Basal-plane defects (BPDs) can cause forward voltage drifting that adversely affects the long-term reliability of SiC components. Cree's new wafers have reduced BPD density to less than $1/cm^2$. In addition, the particular type of BPD that causes voltage drift has been reduced to less than $0.1/cm^2$.

John Palmour, chief technology officer of Cree's Power & RF division reports: "This low-BPD material enables very high-voltage bipolar devices such as IGBTs (insulated-gate bipolar transistors) and GTOs (gate turn-off thyristors) to have improved stability over time. This recent development helps remove roadblocks to commercialization of these extremely high-power devices."

The increased-diameter products are expected to lead to significant product cost reductions and increased throughput.

Cree offers SiC and III-nitride epitaxy on n-, p-type and high-purity semi-insulating (HPSI) substrates. The firm sees applications for SiC/SiC epiwafers as being optoelectronics, power factor correction (PFC), solar inverters, and industrial motor drives. III-nitride epitaxy on SiC is seen as being more suited to high-power RF, graphene, and terahertz development.

Other companies have announced 150mm epiwafers in the last year.

Dow Corning, which is also US-based, has a range of SiC wafer products. In the middle of last year, the company expanded production by ordering two extra Aixtron AIX 2800G4 WW Planetary Reactors. The platforms installed at Dow Corning are able to handle 10x100mm or 6x150mm SiC substrates. Dow Corning also offers 4H n+ conductive SiC wafers in test grades for research, in commercial grade for high-volume production, or 'prime' for top-end wafer specifications. The firm also supplies epiwafers with n^+ and n^- conductivity with layer thicknesses up to 20µm.

Figure 2. Tokyo Electron's Probus CVD system.

Showa Denko produces SiC epitaxial wafers at its Chichibu facility in Japan. Last year, the company prepared an expansion of its product line to 150mm-diameter wafers with the purchase of a SiC Warm-Wall Planetary Reactor system from Aixtron. The new system is capable of handling ten 100mm or six 150mm wafers. The firm already offers 4-inch (100mm) SiC epitaxy products for power device application.

Complete portfolio

Sweden's Norstel has more than 15 years experience in SiC epitaxy and crystal growth using its patented High Temperature Chemical Vapor Deposition (HTCVD) technique. The company claims to be the only SiC supplier besides Cree with a complete product portfolio of conductive substrates, semi-insulating substrates and SiC epi capability.

Nortsel's epitaxial capability has been at 100mm diameter for almost two years. The firm operates two Aixtron machines for industrial (Aixtron/Epigress VP-2400HW) and R&D (Aixtron/Epigress VP-508) epitaxy. Both these machines use 'hot-wall' techniques pioneered at Linköping University and further refined by Norstel. The firm developed out of a collaboration on SiC epitaxy between Swiss power company ABB and Linköping in 1993.

Norstel will soon be releasing 100mm conductive substrates for sale after extensive pre-release customer testing. The 100mm substrates were developed using low-stress crystal growth techniques with defect-free

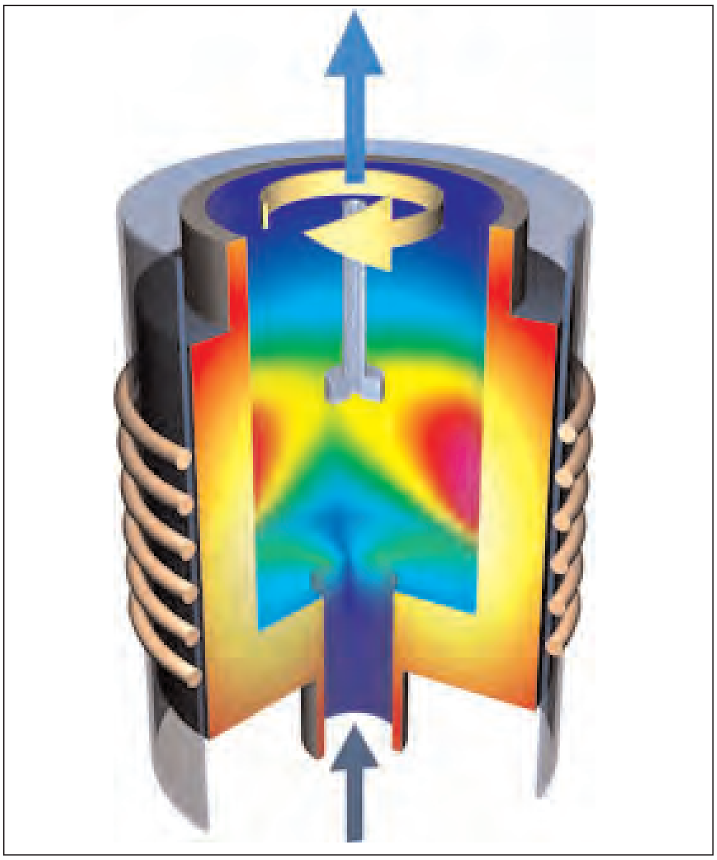

Figure 3. Norstel's HTCVD furnace.

expansion, giving wafers with a micropipe density less than $1/cm^2$ and a basal plane dislocation density of less than $5000/cm^2$. The research team at Norstel now has its sights set on even lower defect densities and 150mm diameters.

To meet expected demand for its new products, Norstel is installing new manufacturing capacity to ramp up production during second-half 2013.

A further development is 100mm semi-insulating substrates, as preferred for RF devices. The first batch is due to ship soon for testing and device manufacturing as part of the European Defense Agency sponsored program 'MANGA — Manufacturable GaN'. Norstel has been involved in MANGA since 2010.

"We expect to start selling these 100mm semi-insulating wafers during the second quarter, and we will then have a full 100mm diameter product portfolio," comments Norstel's director of sales & marketing Niklas Henelius.

Emerging market

In China, companies have announced competing claims to be first in the SiC epitaxy arena.

Dongguan Tianyu Semicoductor Technology Co Ltd, claimed to be the first manufacturer of silicon carbide (SiC) epitaxial wafers in China, has been expanding its capacity. The expansion will include an increase in the maximum substrate diameter to 6 inches.

The company produces n-type epitaxial 4H SiC with silicon face on wafers up to 4 inches (100mm) diameter. On the largest wafers the non-uniformity of carrier concentration ($5x10^{15}$–$2x10^{18}/cm^3$) is less than 20% and typically is about 15%. Better uniformity is achieved over smaller areas. The thickness range is 5–15μm with non-uniformity less than 10% and typically 5% on 4-inch substrate.

The present equipment base (according to the firm's website) consists of an Aixtron 2800G4 WW production system (10x4-inch substrate per run) and two R&D tools (6x2-inch and 7x3-inch). Power+Energy Inc of the USA reported last year that it was to supply a second hydrogen purifier system. Such purifiers are designed for use with Aixtron MOCVD systems, suggesting that Tianyu may already have a second such system, presumably 6-inch capable, on order or even installed.

Tianyu was founded at the beginning of 2009 and is based at Songshan Lake National High-tech Industrial Development Zone of Dongguan City, Guangdong province. The technical team includes six Chinese Academy of Sciences researchers. The engineering staff consists of 30 SiC growth technologists. The $20,000m^2$ plant area and $10,000m^2$ workshop has the claimed capacity to ship 10,000 wafers per month.

EpiWorld International in Xiamen, China also claimed the first commercial availability of and orders in China for 3-inch and 4-inch 4H-SiC epitaxial wafers in March 2012. The company is a joint venture with investors from the USA, Japan and China. The equipment base is described as "multiple most advanced epitaxial systems for 3", 4", and 6" SiC epitaxy, auto defect identification and mapping system in a class-100 cleanroom". A photo on the firm's website shows an Aixtron Planetary Reactor.

Silicon carbide on silicon

Although most development of SiC epitaxy uses SiC substrates, some researchers have sought to create SiC epitaxial layers on silicon. In July 2012, Griffith University's Queensland Micro- and Nanotechnology Centre in Brisbane, Australia, was awarded AUS$1m in research funding by the Queensland Government for such work, with the aim of production processes for LED, micro-electro-mechanical systems (MEMS) and power electronics. The center has enlisted the help of UK company SPTS for plasma etch, deposition and thermal processing expertise.

SiC epitaxy on silicon generally creates 3C polytype crystals, as opposed to the 4H (or more rarely 6H) polytype generally offered on SiC substrate. Griffith has used silicon substrate epitaxy to create SiC-based memory with charge retention times at 85ºC in excess of 10 years. The group's further achievements include low-temperature epitaxy of 3C SiC on Si, and MOS purity oxides to enable quality MOS devices in SiC. ■

Author: Mike Cooke