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Crystal growers push nitride envelope

Michael Hatcher reports on a flurry of recent development activity in III-N materials that has seen numerous funding deals and the commercial shipment of AlN substrates.

There's never been any doubt that developers and manufacturers of nitride-based devices would benefit hugely from native nitride substrates on which to grow their epitaxial structures.

But, compared with silicon, GaAs and, to a lesser extent, InP, nitride substrates have proved far more troublesome. The main problem is the extremely high temperature and pressure required for molten crystal growth.


Thermal conductivity of typical substrate materials

Material	Thermal conductivity (W/m/K)
GaN	220
AlN	200
CVD diamond	1200
SiC	350-490
Silicon	149
Sapphire	40
InP	68
GaAs	46

Thermal conductivity

Recently, a few developments among a select band of crystal specialists suggest that makers of GaN, AlGaN and InGaN structures are increasingly set to follow in the footsteps of the more mature semiconductor materials through the use of native substrates and epiwafers.

One of these companies, Kyma Technologies, follows Cree and Nitronex as a spin-out of the influential Bob Davis research group at North Carolina State University. Unlike some, Kyma's aim is to develop a boule growth process similar to that which has proved successful for other semiconductor substrate materials. Although this is more technologically challenging than a faster growth method such as, say, hydride vapor-phase epitaxy, Kyma co-founder Drew Hanser maintains that in the longer term, the boule growth approach will prove essential.

Kyma has recently set up a number of development programs with the US Department of Defense. Two of these take place under the wing of the Missile Defense Agency, where the main aim is to develop larger substrates that will be essential for cost-effective manufacturing of relatively large transistors for RF applications, such as radar and X-band communications. Kyma has also signed two collaborative R&D agreements, this time with the US Navy and Air Force, under which it is supplying substrates for FET development and increasing its focus on material characterization.

Kyma indicated to *Compound Semiconductor* that its 2 inch GaN wafers would be shipping in substantial volumes within a year, with the first 3 inch material suitable for devices set to follow in mid to late 2007.

Encouragingly, a wide range of devices - including various transistors, Schottky diodes and optoelectronics - have already shown excellent performance on Kyma material, even from initial growth runs (e.g. a 600 V Schottky diode and 10 GHz FETs). "What we've seen with these early experimental devices is corroboration of the basic theoretical arguments in favor of a native substrate," said Kyma CEO Keith Evans.

As with any starting material, dislocation density is the critical attribute where device manufacturers want to see progress. Typically, Kyma's epiwafers feature etch-pit densities of around 10^6 cm^{-2}, although a 10-fold improvement on that has been seen in Kyma's best "hero" result. Further improvement will be necessary, however, with laser manufacturers specifying a defect density of 10^4 cm^{-2}. The way to improve quality is to make larger boules, and the nuances of this process are at the root of another development that Shuji Nakamura believes could revolutionize the whole field - non-polar GaN.

"Non-polar GaN material looks relatively enticing on paper," Evans said, explaining that the dislocation networks that develop in boule growth of c-plane GaN have geometrical aspects that may benefit non-polar substrates cut from those boules. Kyma has already produced some low-defect-density non-polar and semi-polar GaN. According to Hanser, semi-polar GaN could also ease some of the difficulties with epitaxial growth.

Like Kyma, LED and materials supplier The Fox Group is focused on developing a true boule growth process for AlN, a material that if anything is even more difficult to produce than GaN. But thanks to its proprietary crystal growth technology, based on a tantalum carbide crucible, The Fox Group is now shipping small quantities of epi-ready monocrystalline 15 mm diameter AlN substrates to a number of different device researchers, and is working on increasing wafer size to the 2 inch minimum requirement for future commercial use in devices with aluminum-rich active layers, such as ultraviolet LEDs and solar-blind detectors.

Barney O'Meara from the company, which grows AlN at its facility in Deer Park, NY, says that while dislocation density measurements are difficult to ascertain with any certainty, the quoted figure for its material is less than 10^7 cm^{-2}.

While the recurring theme in native wide-bandgap substrate materials is that of defect density reduction, innovation in non-native wafers continues apace. Californian start-up Group4 Labs is focused on improving the operation characteristics and reliability of GaN-based devices through the use of diamond substrates.

Because of the lattice mismatch between the two, the GaN layer is transferred - rather than deposited directly - onto diamond, but company founder Felix Ejeckam says that the defect density, quoted at around 10^9 cm^{-2}, is unaffected by this process.

Having announced its presence with a square, nitrogen-facing epiwafer, Group4 has swiftly followed up with gallium-facing material measuring a full two inches in diameter. "Never before have customers had access to a nitrogen-facing as well as a gallium-facing GaN epiwafer," claims Group4.

About the author

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