



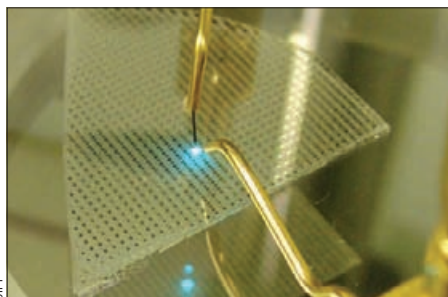
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TDI ups HVPE's versatility

Hydride vapor phase epitaxy is a promising deposition technology for manufacturing full-device structures. This high-growth-rate technique can produce high-quality epitaxial layers, including those with excellent p-type doping, at thicknesses that vary from a few nanometers to several millimeters, say **Alexander Syrkin**, **Larry Leung** and **Frazer Anderson** from Oxford Instruments.

HVPE is a well established, affordable and relatively simple technique for nitride growth. Early efforts have developed processes for GaN, AlN and AlGaIn growth, and more recently this has been extended to InN and InGaIn materials. Growth rates for HVPE deposition are typically several microns per minute. This fast rate, coupled with excellent material quality, makes HVPE a promising approach for lowering the manufacturing costs of nitride-based optoelectronic and electronics devices.

One of the strengths of HVPE stems from a process chemistry based on the reaction of group-III metals and hydride gases, such as ammonia (NH₃) and hydrogen chloride (HCl). Today the most obvious advantage of HVPE over the incumbent MOCVD



On-wafer testing of an InGaIn-based HVPE-grown blue-green emitting LED with a metallic probe.

technology is its ability to grow thick (15 μm–1 mm) GaN and AlN layers on foreign substrates, such as sapphire and SiC, which can form a high-quality platform for device growth. MOCVD can't produce

material that is this thick economically due to low growth rates, which are a consequence of the nature of the process and equipment-related issues (for example, cleaning deposits from the reactor).

HVPE also benefits from process gases that are readily available and relatively inexpensive, even for high-quality, reagent-grade sources. In comparison, MOCVD requires organo-metallic compounds, which add to its high running costs.

Not only are the gases for HVPE cheaper than those for MOCVD – they are also used more sparingly. Typical V-III ratios for MOCVD range from 10³ to 10⁴, which means that an enormous amount of NH₃ is needed for the epitaxial growth. In comparison, the V-III ratio for typical HVPE



Fig. 1. A cross-sectional TEM image of a 120 μm thick, crack-free layer of GaN on c-plane sapphire.

processes is significantly lower, possibly by several orders of magnitude, which reduces the costs of growth.

Most HVPE processes are conducted at atmospheric pressure in a hot-wall quartz chamber. Such a configuration does not require any vacuum pumping and simplifies routine reactor maintenance. Abatement of exhaust reactant gases, such as ammonia and hydrogen chloride, and gaseous by-products, such as hydrogen, can be dealt with by conventional scrubber systems.

HVPE does suffer from two significant weaknesses – parasitic deposition of group-III nitrides and the generation of ammonium chloride (NH_4Cl) particles. However, the former can be mitigated by *in situ* etching with gaseous HCl, while the generation of NH_4Cl can be handled with appropriate entrapment.

Multiwafer HVPE

At Oxford Instruments-TDI we have fabricated a multiwafer tool for the growth of high-quality nitrides by HVPE, which is capable of producing crack-free, thick films of GaN with high structural quality and low levels of background contamination (figure 1). Typically, net donor concentrations for undoped material are mid- 10^{15} cm^{-3} . Gaseous HCl produces a self-cleaning effect that removes oxygen and water from the chamber, and ultimately minimizes the background impurities in subsequent epitaxial layers.

Following years of development, we have recently demonstrated the ability of HVPE to controllably dope GaN with major n-type (silicon) and p-type (magnesium) impurities. This paves the way for the creation of whole-device structures.

LED manufacture by MOCVD involves a post-growth thermal activation step to activate the magnesium dopants. HVPE growth, on the other hand, produces incredibly low levels of background hydrogen

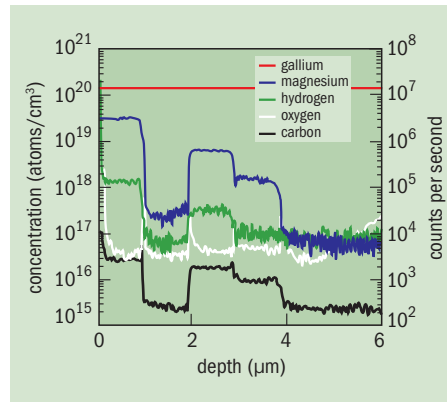


Fig. 2. A secondary ion mass spectrometry profile of a HVPE GaN layer doped with different levels of magnesium reveals low background impurity levels and abrupt control over magnesium concentration.

impurities, so there is no need for a magnesium acceptor activation anneal. This thermal activation step limits the p-type GaN region thickness in MOCVD-grown structures to fractions of a micron, because thermal activation only occurs in the thin surface area. In contrast, HVPE-grown magnesium-doped GaN has p-type conductivity throughout the whole layer thickness, even without thermal activation.

The low level of residual hydrogen in HVPE-grown GaN doped with magnesium is confirmed by secondary ion mass spectrometry (figure 2). Such high-quality material could open the door to new LED designs with a p-side down configuration.

We have also devoted significant effort to developing nanometer-scale thickness control for GaN, AlN and AlGaIn material growth. This will allow the production of multi-quantum-well structures, which form the active region in efficient, high-brightness LEDs.

Cross-sectional transmission electron microscopy (TEM) images of one of our HVPE-grown nitride heterostructures, which has a 2 μm thick GaN base layer and five pairs of GaN/Al_{0.28}Ga_{0.72}N, reveal that the thickness of GaN in the active region varies from 2 to 16 nm (figure 3). The AlGaIn layer thickness is kept between 22 and 24 nm. These results show that there is a new way to control defects and stresses in HVPE-grown materials. In addition, they demonstrate that in a single HVPE process it is possible to controllably deposit nitride layers with thicknesses from 1 nm to hundreds of microns.

The ability to grow nanometer-scale structures is a significant step towards HVPE manufacture of LEDs and laser diodes.

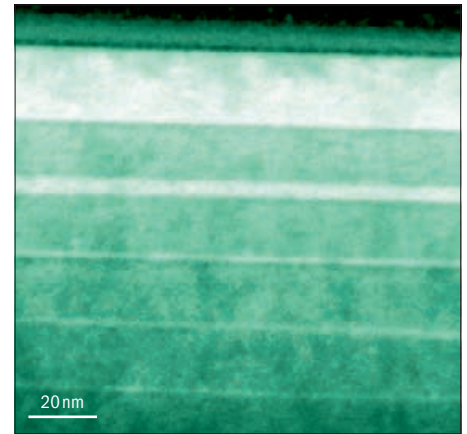


Fig. 3. A cross-sectional TEM image shows the high quality of a multi-quantum-well GaN/AlGaIn epitaxial structure grown on c-plane sapphire by HVPE.

Recent development of HVPE growth of indium-containing nitrides further extends this opportunity for a whole-HVPE device-oriented concept. This approach also draws on the recently developed thin layers and doping capabilities, as well as the commonly recognized advantages of HVPE in the growth of template substrate materials.

The most appealing feature of this approach is the incorporation of all of these capabilities in one tool that ideally produces the whole device structure in a single run. To illustrate the concept, we have grown a set of n-InGaIn layers and InGaIn/InGaIn-based multilayer structures with different InN contents on p-type GaN/sapphire template substrates. On-wafer probe electroluminescence measurements show that these LEDs cover the blue-green spectral region (450–510 nm).

Our efforts are not solely focused on light-emitting materials. We can also demonstrate substantial developments in the field of base materials for high-power, high-frequency transistors and amplifiers, including 100 mm diameter AlN-based semi-insulating substrates. These consist of 10–20 μm of single crystal AlN film deposited on an electrically conductive 100 mm SiC substrate.

The introduction of multiwafer, high-throughput HVPE production tools that are founded on the years of process and technology developments at TDI has allowed us to attract the interest of major nitride material and device manufacturers. Our HVPE technology and process solutions offer a promising alternative to MOCVD for mass production of materials and device structures for solid-state lighting and power-management electronics.