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A Star is Born: Gallium nitride and the coming age of compound semiconductors

By: Wei Zhao, Onto Innovation

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Not so long ago, Blu-ray was hailed as a technological advancement in the world of digital video. But in the streaming era, Blu-ray's luster has faded. However, the technology responsible for the blue laser diode that gave the Blu-ray player its name – gallium nitride (GaN) – is emerging as one of a number of exciting new developments in the semiconductor industry.

Today, GaN is used by the military for radar systems, consumer and automotive electronics as a super-fast power charger and the telecommunications industry in base stations and data servers. GaN offers several advantages over silicon. For starters, GaN offers a significant increase in electron mobility over silicon – 1,000 times more electron mobility, according to various articles – a benefit that leads to other advantages. In addition, GaN is resistant to heat, consumes less energy than other semiconductors, operates at a lower voltage, enables increased miniaturization, offers wider bandwidth and allows for increased electron mobility.

Aside from these significant selling points, one factor may take precedence over all others in the wider adoption of this compound semiconductor: cost. Fortunately, GaN is quickly becoming a competitive choice, with market trends indicating that it will soon match MOSFETS in both cost and market value.

Areas of Growth

In January 2022, 5G reached a significant milestone: for the first time 5G handset sales achieved greater penetration than 4G handsets, capturing 51% of the global market, according to Counterpoint Technology Market Research. GaN's application in the 5G space as a substrate for 5G base stations is very much now due to the compound semiconductor's efficiency, reduced power needs, heat resistance and wider bandwidth. In addition, GaN is growing increasingly popular as a power charger for mobile devices. Because electrons move faster through GaN, such chargers can power up a smart phone or laptop in half the time as Si devices, and these GaN chargers can do so while being physically smaller and lighter than chargers using Si power devices.

Speaking of mobile devices, microLEDS are another area where GaN devices have the potential to disrupt the market.

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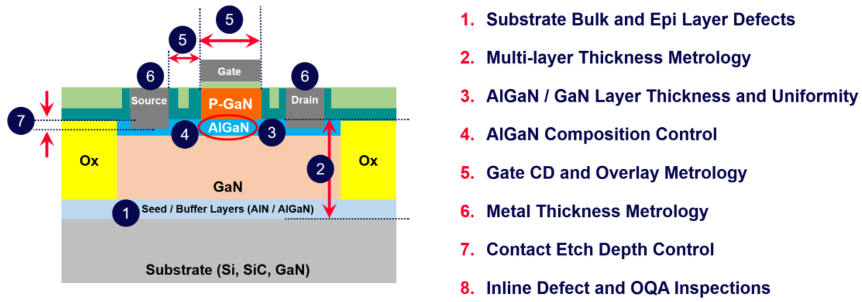

Figure 1: GaN HEMT Manufacturing Challenges

However, with those disruptions and growth opportunities comes a series of challenges manufacturers need to face, including:

Substrate Bulk and Epi Layer Defects: Wafer bowing stress caused by mismatched thermal expansion coefficients between GaN and the substrate may result in cracked surfaces or introduce defects.

Multi-layer Thickness Metrology: Consistent buffer and channel layer thickness minimize the variations of deep trap concentration, gate leakage current and breakdown characteristics. Epi thickness control is one of the most important parameters to deliver consistent device performance and yield.

AlGaN/GaN Layer Thickness and Uniformity: Consistent buffer and channel layer thickness will minimize the variations of deep trap concentration, gate leakage current and breakdown characteristics. Multi-epi thickness control is often viewed as one of the most important parameters for high-electron mobility transistor (HEMT).

AlGaN Composition Control: The electron density of HEMT GaN devices in two-dimensional electron gas (2DEG) saturation states varies with changes in aluminum concentration. During HEMT device fabrication, the aluminum composition percentage measure for AlGaN 2DEG is critical in controlling device electrical properties.

Gate CD and Overlay Metrology and Control: Proper gate length design and control is crucial for HEMT GaN devices to achieve optimization of carrier intensity of 2DEG within the GaN channel and to allow the gate to reasonably control the channel. The output current and transconductance of GaN-based HEMTs is highly dependent on gate/channel length and source/gate overlay.

Metal Thickness Metrology: The saturation drain current is dependent on contact pad metal thickness, thus effectively monitoring metal thickness is increasing critical for current stability while device requirements are evolving. The ability to simultaneously and non-

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destructively monitor multi-layer metal thickness at a range tens of nanometers to tens of microns directly on devices inline is increasingly needed for state-of-art device fabrication.

Contact Etch Depth Control: Precision control of source and drain contacts, recess etch depth and critical dimension is crucial to achieving the optimized carrier current during the device operation.

Inline Defect Inspection/Final Outgoing Quality Assurance (OQA): Following deposition and etching, defect inspection is required to monitor process cleanness and healthiness. OQA inspection is often required following front-end of the line (FEOL) processing, in addition to during and following the packaging of GaN devices. These devices are often packed with silicon devices, which also require additional defect inspection and monitoring before and/or after assembly.

Inspection Needed For: Particles and etch/pattern fidelity defects, epi-layer dislocation post-FEOL processing and OQA. GaN packaging inspection is critical for:

- Identifying underdeveloped vias, which cause poor bonding of solder or poor electrical connection.
- Identifying missing/damaged bumps or shorts.
- Maintaining bump critical dimension, height and coplanarity control.

Time to Shine

Fortunately, there are a number of available tools that can meet the manufacturing challenges posed by GaN. Given this, and GaN's many strong pluses, it's no wonder this compound semiconductor is emerging as an industry powerhouse, one that plays an increasing important role in enabling green technologies, including consumer chargers, photovoltaics chargers, on-board chargers for electric vehicles and many other devices which demand high switching frequency and efficiency. For those operating in this space, this is clearly an exciting time.

The future of the compound semiconductor responsible for the blue laser has moved onto its second act. And while GaN won't be taking home a golden statue on Oscar night, there's no doubt a new star is on the horizon.

About the author

Wei Zhao is strategic marketing director of specialty markets for Onto Innovation.