Meeting manufacturing challenges for GaN-on-Si power IC devices

Veeco's chief technology officer and its senior director, MOCVD Technology discuss how systems with single-wafer chambers can address the transition of gallium nitride on silicon power devices from R&D to volume production.

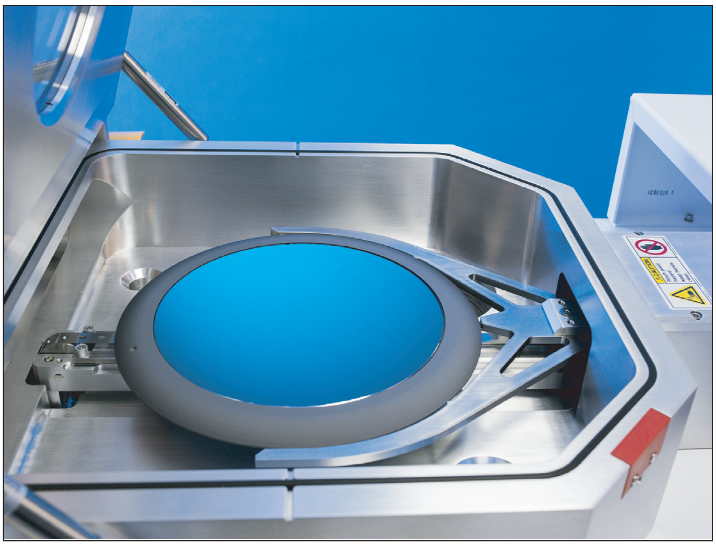
The research and development efforts put into growing gallium nitride (GaN) layers on silicon wafer substrates (GaN-on-Si) over the past five years are beginning to pay off with the introduction of some exciting new products. While much of the discussion has centered on the introduction of LED chips grown on silicon wafers to help reduce the cost of solid-state lighting, breakthroughs are also occurring in power IC markets thanks to the technology's potential to deliver more cost-effective and energy-efficient devices. This is especially true for the power-switching device market. If current product development efforts stay on track, we should see increasing device shipments in 2016, targeting higher-end, less price-sensitive applications.

As production ramps and costs fall, GaN-on-Si device power ICs are being targeted for a broad range of applications such as consumer electronics, solar and wind power, power supplies and automotive applications. Various industry analyst firms, such as IHS Research, are predicting a compound annual growth rate (CAGR) of 90% between 2015 and 2020.

The power-switching market today is largely served by silicon IC devices. The promise of devices fabricated on GaN layers is a smaller form factor with better thermal properties and greater efficiency — ideal for applications such as IT servers, where heat generation is a growing problem as server banks become larger and where heat management and energy efficiency are increasingly important factors.

Market still in initial stages of product development

While GaN-on-Si power devices are showing great promise, they are currently still in development. A few 200V GaN-on-Si devices are starting to appear. One or two OEMs have introduced long-anticipated 600V GaN high-electron-mobility transistors (HEMTs) to the market, but these products are still considered to be in their infancy. Current data indicates that products such as servers and white-box goods using these GaN power ICs have yet to ship. OEMs are currently perfecting device architectures and developing manufacturing processes.



Wafer in Veeco's Propel PowerGaN MOCVD system.

To help speed the development of GaN-on-Si power devices, Veeco has developed the Propel PowerGaN single-wafer manufacturing system, based on the core metal-organic chemical vapor deposition (MOCVD) technologies used in its multi-wafer TurboDisc EPIK700 and MaxBright batch systems. A 200mm-wafer-capable system, Propel allows power-device OEMs to leverage Veeco's years of MOCVD technical experience and market expertise. Significant orders are anticipated in 2015 as OEMs rush to finish GaN IC development, which should allow adoption of these devices in 2016 – for IT servers initially, with white-box applications shipping in 2017.

The Propel system is designed to assist users in solving product development issues for GaN-on-Si devices. The three key challenges are to deliver a device that has:
1. low ON-state resistance (enabling the device to produce less heat and be more energy efficient);
2. low current leakage; and
3. high breakdown voltage.

"The GaN material system offers great potential for the future of power electronics," says Karl Knieriem, senior epitaxial engineer with Toshiba America Electronic Components. "The capability to grow GaN material on silicon grants access to existing power electronic silicon fabs—allowing for easy adoption," he adds. "The Veeco Propel system provides capabilities for GaN-on-Si growth that go beyond what can be achieved using other systems in existence today."

Because the Propel system is a single-wafer tool, it can deliver very high film uniformity across the wafer and can demonstrate wafer-to-wafer repeatability. Uniformity is key to the device's ultimate performance and reliability. For instance, a film thickness variance of just ±1nm can result in threshold voltage variance of ±0.5V across the wafer, which will significantly impact device performance. Also, since Propel is a single-chamber system (rather than a batch MOCVD tool), it can offer very tight chamber temperature control utilizing Veeco's proprietary SymmHeat technology. This precise thermal control provides excellent thickness and compositional uniformity. The single-chamber architecture also permits faster heat-up and cool-down times. For product development, this translates to short cycle times and a broad process window, giving OEMs greater flexibility to help speed architectural design, testing and recipe development.

Also important to device development is flexibility in the IC stack design and doping process of specific layers. Here, again, uniformity is a critical aspect — both for the aluminum (Al) containing layers, which contribute to threshold voltages, and for the doping layers, which are critical to device performance. When the Al and doped layers are uniform, device performance is uniform.

Transition from R&D to volume production

Market analyst firm Yole Développement predicts that, as the manufacturing costs for GaN power devices come down, market demand will rise rapidly. If 600V devices are as successful as anticipated, this will open a broad range of applications that will culminate in a market size of $600m by 2020 (see 'GaN: Primed for Power', Compound Semiconductor, Issue VI 2014).

As device OEMs transition from R&D to volume production, throughput will become a critical issue for reducing costs. Single-wafer tools can create a severe fab bottleneck. To address this problem, Veeco designed the Propel system so that multiple single-wafer chambers can be attached to a single backbone, creating a cluster tool capable of achieving much faster throughput while maintaining the same uniformity and reliability performance. While traditional batch MOCVD tools such as Veeco's K465i and MaxBright have been used for R&D, customer feedback has consistently stressed the need for single-wafer-like performance to meet device performance and production yield targets.

Veeco anticipates that Propel will enable its customers to enter volume production and meet the burgeoning market demand.

Of further benefit to device OEMs, Veeco's MOCVD system architecture provides inherent system-level advantages over systems that typically use a close-coupled showerhead (CCS) or vertical reactor design. First, Veeco's technology provides OEMs greater flexibility. The unique reactor design gives manufacturers easy scalability of flow, pressure and disc rotation speed, and enhanced thermal control within the reactor chamber. Second, the approach is far cleaner. Cleaner operation permits greater system up-times, since the frequency of maintenance cycles is reduced, thereby improving overall system throughput.

Conclusion

During any new technology adoption process, there are many challenges to be overcome and, often, surprising lessons to be learned as the technology moves from the laboratory to the fab floor. This will be no less true for the transition of GaN-on-Si technology into volume production. The industry is currently at this stage in adopting GaN-on-Si for power-switching devices. The greater the flexibility of the manufacturing systems that device OEMs have to work with, the shorter the time to market.

Veeco is working with customers to utilize proven technologies integrated with a flexible platform — a platform optimized for development but also adaptable to volume production while seamlessly transitioning the recipe and manufacturing processes. With this approach, we hope to both speed product development and assist with the cost-reduction challenges of volume production.

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