Gallium oxide: The race to power the next-generation grid and EV infrastructure

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In an exclusive OAG Q&A interview, Professor Singisetti from the Department of Electrical Engineering at the University at Buffalo discusses the commercialisation path for Gallium Oxide in high-power electronics

The exponential growth of Artificial Intelligence (AI) requires massive computing power, leading to a concurrent spike in energy consumption from Hyperscale data centres. This demand makes the adoption of high-efficiency, Ultra-Wide Bandgap (UWBG) semiconductors crucial for power grid stability and performance.

Q: Given the explosive growth of AI data centres and their substantial energy demands, how critical is the window of opportunity for ultra- wide bandgap semiconductors like Gallium Oxide to gain traction in power grid integration?

A: That's actually an excellent question; the window of opportunity is very much present and is happening now. Major tech companies are making heavy investments to build these data centres, which have substantial, long-term power requirements. While Gallium Oxide is not yet commercially available, the demand for efficient power infrastructure will only grow as AI adoption increases. If the Gallium Oxide community can aggressively demonstrate a cost-performance advantage over existing technologies, it can gain significant traction within the realistic timeline of this expanding infrastructure.

Q: What is the timeline you project for Gallium Oxide high-voltage switches to move from advanced prototypes to commercial deployment in grid-level power applications?

A: Projecting a timeline is difficult, as many factors outside of technical performance come into play. However, we can look at the successful commercialisation of Gallium Nitride and Silicon Carbide as a precedent.

A best-case scenario is that within a five-year timeframe, commercial companies (including several startups globally) will have high-voltage Gallium Oxide transistors available on the market for purchase. Once commercially accessible, power circuit designers can acquire and test them at high current and voltage, accelerating the evaluation process.

For actual grid-level deployment, the timeline is longer. Grid installations operate on time scales of 20 to 30 years and require extremely stringent reliability criteria. Full evaluation and widespread adoption may take an additional 5 to 10 years after commercial market availability. This is a common timescale in the high-power semiconductor world.

EV and Transportation

The electric vehicle (EV) market is a key application area, where the performance benefits of UWBG materials directly translate into longer driving range and faster charging.

Q: How does the projected performance of a Gallium Oxide- based inverter or on-board charger for an electric vehicle compare against current state-of-the-art Silicon Carbide solutions in terms of efficiency, size, and weight?

A: On a fundamental level, based on the known semiconductor properties, Gallium Oxide should offer an advantage in terms of efficiency, size, and weight, particularly in high-power components like the main inverter (operating at 600V, 1200V, and higher). However, for EV applications, the most significant factor for market adoption will be cost- performance: can Gallium Oxide deliver higher efficiency and be manufactured at a lower cost than the current state-of- the-art Silicon Carbide solutions?

Q: For heavy-duty electric vehicles (vans, buses) and other high-power applications, where voltages are higher than standard passenger EVs, what unique advantages does Gallium Oxide offer?

A: This is where Gallium Oxide offers a substantial advantage, similar to its potential in grid applications. A single Gallium Oxide transistor can easily operate at 5 kilovolts or more.

In contrast, power electronics engineers currently achieve high voltages by stacking multiple lower-voltage switches (e.g., MOSFETs) in series. While effective, this series connection requires complex control circuitry to track, match, and ensure reliability across every individual unit, which adds significant system cost and complexity.

Gallium Oxide’s high-voltage capability enables the use of fewer switches, eliminating the need for extensive series connections and simplifying the required control circuitry, thus reducing overall system cost.

Q: The material’s low thermal conductivity is a known challenge. How does your research address this for vehicle applications, which often have tight thermal budgets and packaging constraints, compared to the advanced cooling available in grid applications?

A: Low thermal conductivity is indeed a key challenge, but it is important to look at the system-level solution. My group works with collaborators on co-designing solutions to address both electrical and thermal aspects simultaneously.

The critical insight for the EV domain is that electric vehicles already have a highly sophisticated thermal management system dedicated to the battery pack, which has very stringent thermal and safety requirements (to prevent thermal runaway).

The key is to leverage this existing thermal infrastructure. By designing the Gallium Oxide power electronics to utilise the already-present battery cooling system, we avoid adding a separate, costly, and complex thermal management system specifically for the power switches.

The availability of existing thermal infrastructure in both EV and some grid applications is a factor that can ultimately contribute to a cost advantage.

Manufacturing and Commercialisation

The long-term viability of any new semiconductor material hinges on its manufacturability and cost advantage at scale.

Q: The availability of low-cost, melt-grown substrates is a major value proposition for Gallium Oxide. How significant is this cost advantage when considering the total manufacturing cost of a final power module, including epitaxy, fabrication, and packaging?

A: The cost advantage of the substrate is highly significant. Historically, even after decades of scale-up, the substrate cost in Silicon Carbide remains a major component of the final device price, sometimes accounting for 30% to 50% of the total cost.

The key benefit of Gallium Oxide is that its crystals can be grown using melt- growth methods, which are similar to those used to mass-produce low-cost Silicon wafers. This contrasts sharply with the expensive, cost-heavy processes required for Silicon Carbide.

If the epitaxy, fabrication, and packaging costs are kept consistent with other UWBG materials, the lower cost of the melt-grown Gallium Oxide substrate itself could provide a significant overall cost advantage for the final power module.

Q: What is the most crucial milestone you believe the research community needs to achieve in the next two to three years to secure large-scale commercial investment?

A: The most crucial milestone is the circuit-level demonstration of reliable, high-power performance. It cannot be just a lab-scale device demonstration; it must be shown at the circuit level that Gallium Oxide:

1. Exceeds the performance of incumbent technologies.
2. Manages the thermal aspects effectively within the system.
3. Shows reliability under repeated stress (e.g., thousands or hundreds of thousands of switching cycles) without performance degradation.

At the device level, this translates to demonstrating consistent operation at 1 to 10 Amperes of current and 5 to 10 kilovolts of blocking voltage. Achieving this combination of high current and high voltage capability, and demonstrating its reliability in a power circuit, will be the signal that secures large-scale investment from both venture capital and established power electronics companies.

Conclusion

While Gallium Oxide shows immense promise as the next-generation UWBG semiconductor, it is not yet fully commercialised. The research community must continue to focus on addressing the full-stack of challenges – from the growth of the substrates and the epitaxy, to device design and circuit-level innovations – to mature the technology and fully leverage its potential

for high-power, high-efficiency applications across the AI grid and e-mobility sectors. Additionally, niche applications such as harsh environment power electronics (high temperature, nuclear plants, hypersonic vehicles, outer space) may provide lower barriers to enter for gallium oxide power devices. Moreover, the power electronics market is large with diverse requirements that it can accommodate existing silicon, silicon carbide, gallium nitride and emerging gallium oxide technologies with their respective strengths and advantages.
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