The RF and microwave industry is on the cusp of a major technology transition that will impact our industry and others in profound ways for decades. The benefits of Gallium Nitride (GaN) as a wideband gap semiconductor in RF and microwave applications are becoming widely understood, and mainstream commercial applications are becoming increasingly clear.

Today, GaN is poised to make the transition from an esoteric, government-funded technology to a high-volume commercial mainstay. Two things are needed to facilitate such a transition. First, the technical merits of GaN technology must be fully realized and clearly demonstrated on silicon substrates. Second, a scalable, stable supply chain must be established, tapping into large commercial markets that can drive economies of scale.

It is important to understand that there are two “flavors” of GaN technology - Gallium Nitride on Silicon Carbide (GaN on SiC) and Gallium Nitride on Silicon (GaN on Si). Both hold a place in today’s RF and microwave applications. As we saw with GaAs and its life cycle, we expect to see a bifurcation in the GaN supply chain. Cost-sensitive applications will go the path of 8-inch GaN on Si. At the same time, capital-lite fabs will service diverse, low-volume applications with specialty GaN processes. It’s fair to expect a plethora of technology variants for niche applications based on GaN on SiC.

**GaN Technology and the Physics**

GaN on SiC will remain the purview of low-volume, niche applications due to the inherent cost structure of substrate material. Fundamentally, at a physics level, SiC boules grow 200X to 300X slower than silicon [1]. The cost of producing substrates - notably capital depreciation and energy consumption during material growth - scales proportionally to production time. Thus, GaN on SiC will remain perpetually higher cost and therefore prohibitive for mainstream commercial use. Therefore, GaN on SiC production for the highest power density and defense applications will play to the strength of capital-lite fabs that aren’t exposed to the technology transitions that have affected the cellular handset market.
How are the Two Flavors Maturing?

GaN on Si has demonstrated minimally 8X the raw power density of incumbent GaAs technology while boosting efficiency to as much as 70% [2]. GaN on Si performance has now matched that of much more expensive GaN on SiC substrates.

GaN on SiC has been produced mainly by boutique 3-inch and 100mm compound semiconductor fabs. The main volume application to date for compound semiconductors has been cellular handsets, which today are under attack from CMOS due to cost efficiencies. Therefore SiC-based GaN has no clear viable roadmap to large diameter, high volume production facilities which can drive cost for consumer markets.

The use of GaN on Si, on the other hand, allows vendors to move to larger diameter fabs with typical volumes greater than 5,000 8-inch wafer starts per week. Here CMOS process control typically enables line yields that are above 98%. Due to the extreme high volume of the end markets that CMOS is addressing, balancing yield and cost dynamics is critical, driving a level of operational discipline that’s extremely rare to find in the III-V industry.

At full maturity, we expect that the GaN on Si cost structure in mainstream silicon fabs will be reduced significantly from today’s GaN on SiC structure. As shown in the adjoining figure, scaling GaN from small diameter GaN development fabs to 200mm silicon fabs achieves an almost 10X reduction in cost. This cost advantage is further multiplied by the very high volume of a CMOS facility. To achieve significant GaN volumes at 8”, RF demand will be augmented with the volume GaN on Si production that will be driven by the DC power market. This market may be as much as 10X larger than the RF and microwave market. With upwards of 95% of GaN unit volume going forward tied to GaN on Si, both the DC power and RF domains will likely be serviced by the same 8-inch silicon fabs.
Figure 2: Relative cost of GaN on silicon vs GaN on SiC.

GaN is the Path Forward
GaN on Si and GaN on SiC occupy their own distinct place in today’s RF and microwave domain. The economic and performance efficiencies that are enabled by GaN on Si have been realized, and will drive significant market penetration and growth in our industry.

References:
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2. Internal MACOM calculations and projections based on presentation by Bo Cui, ECE, University of Waterloo, referencing “Silicon VLSI Technology: Fundamentals, Practice, and Modeling” by James D. Plummer, Michael Deal, Peter D. Griffin

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Dr. Douglas J. Carlson received his ScB in Electronic Material from Brown University in 1983 and his ScD in Electronic Materials from the Massachusetts Institute of Technology in 1989. Dr. Carlson subsequently served on the research staffs of MIT and Bell Laboratory, Murray Hill, NJ. His research focus was on fabrication and characterization of semiconductors and superconductors for microwave applications. In 1990, Dr. Carlson joined MACOM in its Advanced Semiconductor Division. In his career at MACOM he has held engineering, operations and product management positions. Dr. Carlson’s current position is Director of Aerospace and Defense Strategy. In this role, Dr. Carlson is focused on advanced technology development and specifically is pioneering the application of commercial manufacturing practices for phased array radar. Dr. Carlson has published over 40 articles in peer-reviewed journals. He has authored numerous invited papers and invited presentations on the topics of advanced semiconductors, packaging, low cost manufacturing and phased array radar.
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