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*Partners from RF to Light*

# GaN Manifesto

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# The Path to Mainstream GaN Commercialization in RF and Microwave Applications

The RF and microwave industry is on the cusp of a major technology transition. This tectonic shift will be felt far and wide, impacting our industry and others in profound ways for decades to come.

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 apparent.

Reaching mass-market adoption, however, will require a much more mature supply chain and ecosystem than the one that exists today for GaN. To fully appreciate the path that we're on – and to understand what needs to happen to bring GaN into the mainstream – consider the parallels to the path Gallium Arsenide (GaAs) traveled two decades ago.

Twenty years ago GaAs was in a formative stage that's similar to where GaN is now. It was an emerging technology, the economics of which were skewed toward government funding and applications that could afford performance at any cost. As much as 50% of GaN revenues today are attributable to government programs, not commercial production. ***Just as GaAs went from esoteric technology to high-volume market mainstay, GaN is now poised to do the same.***

For GaAs, the catalyst for mainstream adoption was the explosion in consumer demand for handsets, which drove strong economies of scale. Compound semiconductor companies like ANADIGICS, RFMD and Skyworks led the industry toward the establishment of robust, reliable and scalable GaAs supply chains. They invested hundreds of millions of dollars in large-scale GaAs fabs, and made the technology transition from boutique to commercial mainstay.

In parallel, smaller GaAs fabs evolved with a capital structure and operations model to support low volume, high diversity businesses and niche process variants for performance optimization. Without exposure to consumer technology transitions and capacity underutilization, these "capital-lite" fabs are right-sized for programs that need supply continuity over decades of production.

## The Revolution has Begun

The consolidation that we've begun seeing in the compound semiconductor industry is a direct consequence of GaAs being replaced in handsets by silicon-based technologies such as CMOS and SOI. The transition began with up-down converters, progressed to switches and now threatens high-power GaAs amplifiers. Silicon industry powerhouses like Qualcomm and Broadcom have announced initiatives to supplant the majority of GaAs production leveraging economies of scale that dwarf even the largest GaAs factory.

The same will hold true for high performance applications that find value in GaN. The advent of GaN on Silicon (Si) substrates promises to deliver the industry's highest compound semiconductor performance, with a cost structure that leverages economies of scale much like those displacing GaAs in handsets.

***At maturity, we believe that GaN on Si will benefit from silicon cost structures that are 3X lower than today's highest volume GaAs and 100X lower cost than today's GaN on SiC technology.***

## Into the Mainstream

GaN is today 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.

1) Regarding the maturation of GaN technology, ***GaN on Si has demonstrated minimally 8X the raw power density of incumbent GaAs technology while boosting efficiency from mid-40s to as much as 70%. GaN on Si performance has now matched that of much more expensive GaN on SiC substrates.***

2) Establishing a reliable and stable supply chain entails two key steps in the manufacturing chain. The first lies in establishing a cost-effective and scalable supply of GaN materials; namely, epitaxial wafers (epi). The second involves processing those wafers through high-volume silicon fabs.

In both cases, the economics of GaN on Si technology will be driven by power conversion applications, which command unit volumes that are orders of magnitude greater than RF and microwave demand. ***Put in perspective, a full year's production for the entire RF and microwave industry can be serviced in a few weeks by a single 8" silicon factory that's built to service the power conversion market.***

MACOM recently announced an agreement with IQE, the world's premier supplier of GaAs epi, who will scale high-volume, cost-effective supply of GaN materials for cost sensitive, high-volume applications. IQE has the operational experience, competence and capital structure to scale production of GaN materials.

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As we saw with GaAs, we expect a bifurcation in the GaN supply chain for low volume applications. Cost-sensitive applications will go the path of 8" 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, including GaN on SiC.

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. 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 thus prohibitive for mainstream commercial use.***

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 transition in handsets. Such factories can support a high diversity of relatively low-volume programs, and their capital structure can ensure long-term supply without facing consolidation as handset production transitions to silicon.

## Breaking the Barriers

One of the last remaining barriers to GaN adoption will be removed as the cost structure of GaN intersects and drops below that of GaAs. Once cost parity is achieved, better performing technologies always displace incumbents in the highest performance applications.

MACOM has assumed a leadership role in driving the commercialization of GaN into mainstream applications. MACOM offers the RF and microwave industry's only portfolio of both GaN on Si and GaN on SiC products spanning plastic, ceramic and pallet options for pulsed and continuous wave applications. MACOM is thus firmly established as a leader across all GaN variants and end-market requirements.

In terms of supply chain, MACOM's recently announced collaboration with IQE will drive capacity and economies of scale for mass market 8" silicon cost structures.

***In this manner, MACOM is taking a leadership role in breaking the final technology and commercialization barriers to mainstream GaN adoption. In doing so, we're building a sustainable technology and supply chain model which will be viable for decades to come.***

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