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# QRVO, MTSI, CREE: Thoughts on GaN

**The International Microwave Symposium (IMS) was held in Philadelphia last week. It may sound like a conference on cooking, but it's actually one of the preeminent gatherings of engineers and scientists in RF semiconductors.** Of particular interest were all the papers, presentations, and hallway conversations about GaN: who's doing what and where it's all going. GaN revenue is becoming material to several of the component and wafer companies we follow as well as a larger part of the revenue growth story over the next two years. Handicapping that growth requires understanding the technology's history, advantages and disadvantages, and end markets.

Having designed cellular power amplifiers during the early days of mobile phones, we are aware of the problems semiconductor technologies face in high-power applications and the reasons behind GaN's slow progress. Decades in the making, GaN power amplifiers are now seeing robust demand at early adopters (like military radar) and finding a home in more cost-sensitive markets (like cellular base stations). GaN's long gestation and wide application, especially for defense, have spawned an industry roster with many names but few big impact players. Its evolution has also led to a convoluted food chain with suppliers competing with their customers at different points in the channel. We have begun a series of technical meetings with several of these companies, and while those meetings are ongoing, we think it beneficial to provide a few insights now on the history and role of some of the largest suppliers: Cree, Qorvo, and MACOM.

## GaN vs. LDMOS

GaN's reason for existence is high power, high frequency RF, which means base stations and radar. There are a few spots in cable and wireline transport systems that could use its help, but for the most part, GaN's home is the big RF amplifiers required for high-frequency transmitters. Little wonder then that its genesis was military-funded research, much of which was conducted at the University of North Carolina at Durham (UNC Durham). The first GaN applications were defense radars, but once scale increased and cost declined, it started appearing in commercial applications.

There are two commercially viable approaches to GaN: (1) using silicon carbide (SiC) wafers and (2) using straight silicon (Si) wafers. In practice SiC accounts for 99% of all GaN devices sold. SiC is much better at conducting heat, making it the best choice for the high-power radars the defense department was developing when GaN began. The facts that SiC wafers are hard as diamonds and significantly more difficult and expensive to grow (lots of energy, lots of time) weren't much of an impediment given the cost of the defense programs they were intended to power. This origin story rooted the GaN family tree firmly in SiC, where it remains today.

GaN's archnemesis and biggest competitor is the incumbent technology: LDMOS.[1] The great strength of LDMOS is its cost: since it's fabricated on Si, it's much less expensive than GaN and thus more widely deployed. GaN is more efficient, can operate at high frequencies, and can handle higher powers, but it can't compete on cost. Therefore SiC-based GaN is good for displacing LDMOS in a system requiring high performance, but it's bad for more cost-conscious applications. This limitations is why GaN has been slow to move into commercial applications like cellular base stations, where LDMOS is heavily entrenched.

The supply chain for GaN is also a bit odd: wafer suppliers compete against their customers in components, and component suppliers compete with internal GaN fabs of some of their module customers. This landscape causes company management to give a lot of mumbled "decline to state" responses when probed on suppliers, competitors, and customers for their SiC wafers or GaN devices. The unconventional supply chain has also resulted in a lot of companies doing a little but only a few doing a lot with these technologies. We're currently developing a formal map of the space, but it's already clear that Cree leads in SiC wafers, Sumitomo in GaN components for bases stations, and Qorvo in GaN for defense. Given the performance advantages GaN brings to high-power military radars, it should come as no surprise that most developed countries are working on the technology for their own defense applications. These additional developments will further dilute the food chain ORG chart but won't likely change the revenue concentration map in our opinion.

## Cree

Like so much of the SiC/GaN world, Cree was born out of UNC Durham by material science students working under Professor Robert Davis, in this case to develop SiC wafers. They formed Cree in 1987 to apply the advantages of SiC to industrial lighting (LEDs) and eventually to high-frequency RF (GaN). At the time there was no such thing as an electric vehicle (EV), but once the EV market showed up it was added to the SiC list. By 2017, the roster of companies producing SiC wafers had grown to about 10 names, but Cree remains the clear market leader. It's the primary source of SiC wafers to the GaN RF industry and counts among its customers the largest manufactures of GaN power devices for both defense and commercial applications. Cree also creates wafers for its own production[2] of EV, lighting, and GaN components. Therefore Cree is both a supplier and competitor in GaN.

Historically, Cree's dual status hasn't been a problem because the GaN industry spent the best part of the last 20 years as an R&D project in material science. That changed about five years ago when GaN started showing up first in electronic warfare products for the U.S. military and then in power amplifiers (PAs) for cellular base stations. The rise of 5G is expected to generate another big increase in demand: the higher frequencies and higher peak-to-average power ratio required for 5G bands will bring into sharp relief the performance advantage of GaN over LDMOS. The stage could be set for conflict between Cree and leading GaN customers (such as Qorvo or Sumitomo), especially if Cree's SiC wafer capacity can't keep pace with secular demand. That problem was one of the biggest facing the company when Greg Lowe (former head of TXN's High Performance Analog group) took the helm in September 2017. Currently Cree is addressing the issue by moving from 150mm to 300mm wafers, but should that move fail to keep pace with demand, the company would have to acquire or build another fab, given it is "at the walls" in the existing facility. So, while competing with its customers isn't a problem for Cree today, it could certainly become one if the company under-ships SiC wafers to fuel its own GaN growth.

## Qorvo

Qorvo is the largest supplier of GaN products for defense applications and recently began addressing mobile cellular applications. Because military systems have stringent performance requirements, only SiC-based GaN will suffice. Like Cree, Qorvo is both supplier and competitor to several of its largest customers, all of which are major defense contractors with their own GaN fabs. However, these fabs are typically used for R&D and product development and aren't configured or scaled for volume production. Therefore it's common for a firm to build the first units of a large contract using its own fab but switch to Qorvo for volume production. (For example, Raytheon took such an approach in 2013 with its win of the Navy Next Generation Jammer.) Qorvo has greater GaN capacity than the internal fabs of all its defense customers combined, giving it a material cost advantage which its defense customers leverage when bidding for contracts against their competitors.

Qorvo's GaN came from Triquint, which was one of the three original R&D centers for U.S. government research contracts on the technology. To speed development and eliminate duplication, the Defense Advanced Research Projects Agency[3] assigned each company different frequency spectrum over which to develop GaN. Triquint got the high frequencies, Raytheon got the low, and Cree got all wide-bandwidth systems. This division pushed each firm into different applications, some of which see higher native demand than others. And since Triquint was already supplying RF components to cell phone OEMs, it enjoyed an advantage in scale that neither Cree nor Raytheon could match. That is still the case today and is one of the primary reasons Qorvo's Industrial and Defense Product Group (IDP) is the favored supplier for GaN into defense applications. From a slow start, GaN has grown to become one of the two big drivers[4] fueling IDP's +25% y/y revenue growth. This trend will almost certainly accelerate as the technology continues to infiltrate radar, communications, and electronic warfare systems, many of which are decades old and due for upgrades.

## MACOM

Unlike with military systems, commercial applications (such as cellular base stations) require more of a balance between cost and performance. Compared to military systems, commercial applications have less demanding performance standards but more stringent cost requirements. This trade off hasn't stopped network systems OEMs from using GaN-on-SiC in base station PAs, but the growth curve has been more gradual, partly due to the atrophy in demand for cellular base stations after the build-out of 4G. So while GaN would probably have done materially better had it arrived five years earlier, it is now taking share of a declining market, making the cost issue that much more acute. This situation is the reason MACOM is optimistic about the prospects of its GaN-on-silicon efforts.

Unique among its peers, MACOM is growing GaN-on-Si wafers instead of SiC. The drawback of this approach is Si's inability to move as much heat away from the power device, thereby limiting power and efficiency levels well below what can be achieved using SiC. This limitation makes Si a non-starter for high-power radar applications, but most 4G base stations don't require anywhere close to those power levels, and the MiMo requirements for 5G (if it ever gets deployed) will call for even less power per amplifier. Meanwhile Si's cost savings are significant. The base material isn't the only factor impacting cost, but it's certainly a big one: a 4-inch wafer is $70 for Si compared to $400 for SiC. So GaN-on-Si could be a game changer if it could achieve the performance and reliability requirements for cellular applications.

MACOM's GaN-on-Si technology came from its 2014 acquisition of Nitronex. Like Cree, Nitronex was born out of academic research in North Carolina, but with a focus on GaN-on-Si rather than silicon carbide. It was the late 1990s, and Cree had already established an arrangement with Davis that gave the company extensive (if not exclusive) IP rights to SiC technology. To avoid this tie up, a group of students focused on GaN-on-Si research ultimately formed Nitronex in 1999. After many years and copious VC and defense department resources, Nitronex sold nearly 1.5M GaN Si power devices into military handheld radios, the transmit power for which is vastly lower than the radar systems GaN SiC sells into. Since acquiring Nitronex, MACOM has worked to improve performance and raise power levels to better address the cellular base station market. About 18 months ago it began engineering qualification tests for two major network systems OEMs, and it has since qualified for new designs at both.

How much traction GaN Si will have in this market remains to be seen, especially given it's head-to-head competition against GaN SiC. Several quarters of happy talk about revenue and qualifications success have not translated to material revenue, but that result is probably related to the decline in secular demand which systems OEMS are wrestling with each quarter. In its most recent report, MACOM highlighted production orders in three programs but was reticent to commit to revenue or growth forecasts, so the jury is still out on whether GaN-on-Si can meet the needs of cellular network OEMs and thus successfully displace GaN SiC in those sockets.

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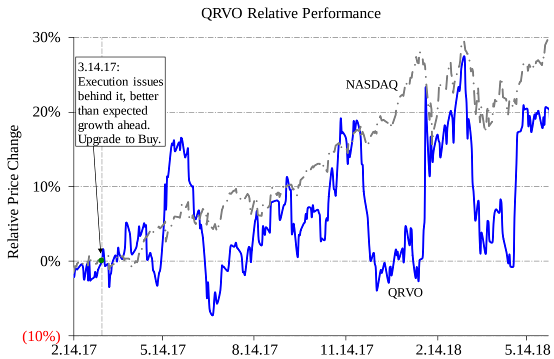


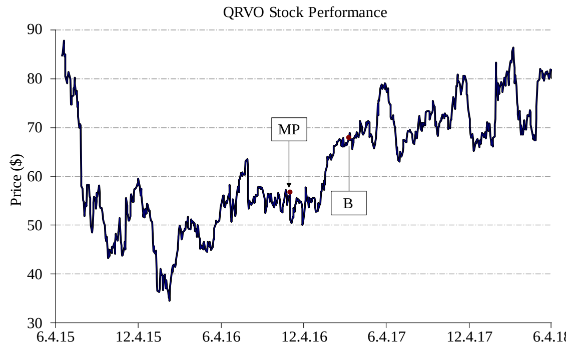


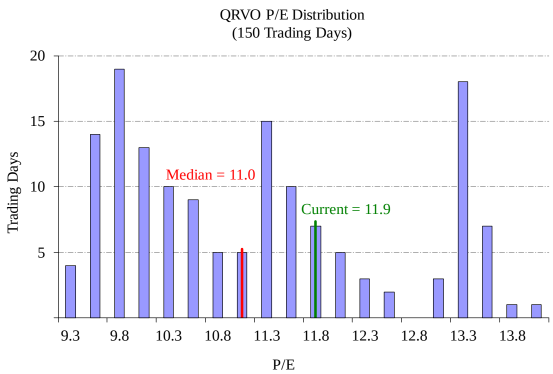


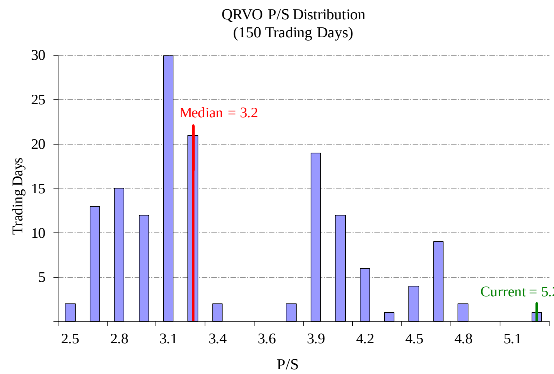


Charter Equity Research does not formally cover Cree or Macom and therefore is not including valuation charts related to those two stocks.

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**Endnotes**

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[1] LDMOS: Laterally Diffused Metal Oxide Semiconductor. LDMOS refers to a specific type of device but it has also become a shorthand way of referring to relatively inexpensive silicon RF power transistors used primarily for high power amplifiers (10s to 100s of watts) in cellular base stations. The technology is also widely used in defense radars.
[2] Cree fabricates high power MOSFETS on SiC wafers for power control applications in electric vehicles. It also fabricates LEDs on SiC for industrial and commercial lighting and GaN transistor for high-power RF amplifiers.
[3] Defense Advanced Research Projects Agency: DAPRA. Launched in 1958, DARPA funds research with the purpose of maintaining the United States' technological superiority through risky but potentially groundbreaking innovations. DARPA received $2.9B in federal funding in 2017, and over $3.1B in 2018.
[4] IDP's +20% y/y revenue growth is primarily being driven by demand for GaN and WiFi products.