Evidence for Inquest

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The information below was gathered in order to put some perspective on gallium nitride technology.

In my career I was involved in gallium nitride HEMT for the past ten years. I don't have a deep theoretical knowledge how gallium nitride HEMTs are produced, my expertise more practical: is in how to apply its breakthrough performance to greatly increase the performance of existing RF systems, and use it in new ways to enable systems that were previously not possible.

History of GaN development

The US government paid for the early development of gallium nitride. One program alone, Darpa's Wide Bandgap Semiconductor for RF Applications (WBGS-RF) invested $100M over 2002-2008. Here is a quote from the WBGS-II program solicitation on FedBizOpps website:[i]

"Awards totaling approximately $75 to $110 million over four years are expected to be made during the first half of calendar year 2005. Multiple awards are anticipated."

In the article *The DARPA Wide Band Gap Semiconductors for RF Applications (WBGS-RF) Program: Phase II Results, Mark Rosker1 et al, GaasMantech 2009*[ii]. Mark Rosker tells how the key to meeting the goals was in the device epi layer (the so-called "recipe"). Rosker was the Darpa program manager for this project.

> *"Key to achieving Phase II's goals and surpassing what had been previously achieved for stable devices was the systematic investigation of the role of the device epi-layer design and device fabrication methods on performance and reliability. New analytical models developed in the program assist with understanding device stability [2]. Improvements in PAE and gain were achieved through careful design of the buffer layer and reduction of gate current leakage. The role of buffer layer doping and the barrier strain and thickness were carefully investigated to balance the requirements for high power density and stable operation. In addition, the teams investigated various back barriers to increase carrier confinement."*

Darpa's mission is as follows, according to Fifty years of Innovation and Discovery, By Dr. Richard Van Atta:

> *DARPA's primary mission is to foster advanced technologies and systems that create "revolutionary" advantages for the U.S. military. Consistent with this mission, DARPA is independent from the military services and pursues higher-risk research and development (R&D) projects with the aim of achieving higher-payoff results than those obtained from more*

incremental R&D. Thus, DARPA program managers are encouraged to challenge existing approaches and to seek results rather than just explore ideas. Hence, in addition to supporting technology and component development, DARPA has funded the integration of large-scale "systems of systems" in order to demonstrate what we call today "disruptive capabilities."

Underlying this "high-risk – high-payoff" motif of DARPA is a set of operational and organizational characteristics including: relatively small size; a lean, non-bureaucratic structure; a focus on potentially change-state technologies; and a highly flexible and adaptive research program. What is important to understand at the outset is that in contrast to the then-existing defense research environment, ARPA was designed to be manifestly different. It did not have labs. It did not focus on existing military requirements. It was separate from any other operational or organizational elements. It was explicitly chartered to be different, so it could do fundamentally different things than had been done by the military service R&D organizations.

Darpa tends to publish a lot of results (but not details), which broadcasts what is possible to everyone. The IEEE provides a worldwide professional forum where gallium nitride these results are published; perhaps 90% of the details of a recipe that IME was developing can be obtained from professional journals.

All of Darpa's efforts (and there are many) started out as GaN on silicon-carbide. Silicon carbide is an expensive material and is available only in four inch wafers. Silicon is available in much larger format, even up to 18 inches in commercial fabs.

What is the significance of GaN?

The article "GaN Revolution: After Long Germination, Industry Readies High-Power Chips", Defense News, Feb. 28, 2011, Dave Majumdar[iii], talks to the capabilities of GaN for improving the range of military radar and cell phone base stations

"Generally speaking, GaN power amplifiers are particularly useful for high-output or high-frequency devices such as cell-phone base stations, jammers, tactical radios, satellite-communications stations, power-distribution systems, and military radar systems, Rosker said.

Colin Whelan, a Raytheon engineer who works on GaN technology, said a GaN-based active electronically scanned array radar could search five times the volume as a similarly sized GaAs-based radar, or at a 50 percent greater range. You could even halve the size of the radar and still deliver greater performance.

The article also touches on the struggle to make the process reliable:

Rosker said the road to a practical GaN-based chip was not easy. Early chips degraded into uselessness in less than a week, and for no discernable (sic) *reason.*

"There were plenty of theories about what the problem was, no real clear understanding of what caused the physical degradation," Rosker said.

Through an effort led by DARPA, the underlying problem was largely corrected, yet the exact nature of the degradation, though basically understood, is still debated, Rosker said."

GaN was first targeted for military applications because it cost so much. In GaAs GaN War Debunked[iv], Balistreri states(as of 2010) cost was prohibiting GaN from commercial systems.

...the first application of GaN technology was in defense systems where cost was not as prominent a factor as performance. In commercial applications, acceptable performance is assumed and cost becomes the driver, which currently makes GaN less competitive than GaAs for many applications, regardless of the latter's technical merits.

What has changed since 2010, is that GaN-on-silicon is showing performance almost as good as GaN on SiC, but is far less expensive. Darpa did NOT see this coming. GaN on silicon was pioneered by a US company called Nitronex, which was recently sold by the original investors; it failed to capture substantial market share.[v]

Eight inch silicon wafers cost a few dollars and yield 400% more area compared to four-inch silicon carbide wafers that were pioneered by Darpa. Soon, all cell base stations will be replaced with GaN transmitters using GaN-on-Si technology, which will be less expensive and more powerful than the GaAs transmitters that are used today. This upgrade represents billions of dollars of business, a market that is far greater than the military use of GaN.

The advantage of GaN for cellular infrastructure is discussed in "How Something You've Never Heard Of Is Changing Your World, John C. Zolper, Ph.D, August 12th, 2012, TechCrunch[vi]

"RFHIC Corp of Suwon, South Korea, which makes GaN-based radio frequency and microwave components for telecommunications and broadcasting industries, estimates U.S. carriers could save approximately $2 billion per year by using GaN technology for their wireless infrastructures. Large carriers, including Sprint, have already launched GaN-powered towers in several markets."

In "Military Spending and GaN Adoption Driving RF Power Semiconductor Markets"[vii] , Zolper claims that that GaN has two significant markets, wireless infrastructure and military:

"Other than wireless infrastructure, the vertical market showing the strongest uptick in the RF power semiconductor business has been the military, which Wilson describes as being now "a very significant market." While the producers of these devices are located in the major industrialized countries, the military market is now so global that equipment buyers can come from anywhere."

Why is the specification on Shane's computer a concern?

If you read the export restrictions on microwave power transistors, the US starts restrictions at 3.2 GHz at a power level of 60 watts. See Commerce Control List Supplement No. 1 to Part 774 Category 3, Export Administration Regulations Bureau of Industry and Security December 7, 2012[viii]

b.3. Discrete microwave transistors having any of the following:
b.3.a. Rated for operation at frequencies exceeding 3.2 GHz up to and including 6.8 GHz and having an average output power greater than 60W (47.8 dBm);

The specification calls for a 150 watt transistor at 3 GHz. Such a transistor would output close to 150 watts at 3.2 GHz. The way the specification was written it seems like it was deliberately trying to skirt the export law.

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[i] https://www.fbo.gov/index?tab=core&s=opportunity&mode=form&id=dfd64a58dd4de51db5a85884bd4deed8

[ii] http://www.gaasmantech.org/Digests/2009/2009%20Papers/002.pdf

[iii] http://www.defensenews.com/article/20110228/DEFFEAT01/102280305/GaN-Revolution
[iviv] http://www.triquint.com/products/tech-library/docs/articles/GaAs%20Vs%20GaN%20War%20Debunked%20MPDigest%20September%202010.pdf
[v] http://www.businesswire.com/news/home/20120626005493/en/Gaas-Labs-Acquires-Leader-Gallium-Nitride-RF
[vi] http://techcrunch.com/2012/08/12/how-something-youve-never-heard-of-is-changing-your-world/

[viivii] http://www.abiresearch.com/press/military-spending-and-gan-adoption-driving-rf-powe

[viii] http://www.bis.doc.gov/policiesandregulations/ear/ccl3.pdf