[Gallium Nitride enabling IoT revolution, Cellular 5G to Military Communications, Radars and Jammers]

GaN is a semiconductor material that can amplify high power radio frequency signals efficiently at microwave frequencies to enhance a system's range. Therefore it has become the technology of choice for high-RF power applications that require the transmission of signals over long distances such as EW, radar, base stations and satellite communications.

The adoption of GaN has been advancing significantly over the last five years with several thousand devices been developed and implemented in applications such as radar, satellite communication, counter-IED jammers, 3G/4G base-stations, WIMAX/LTE PAs , CATV modules, and general-purpose applications.

Gallium Nitride has become strategic material. The technology has enabled military radars to operate at much higher frequencies and are used in jammers that allow fighter jets and other aircraft to fly undetected, said Colin Humphreys, a physics professor at Cambridge University. It is no surprise that United states want to stop China and Russia getting hold of gallium nitride technology, which can boost the power and sensitivity of weapons systems while reducing their cost as it requires less electricity.

U.S. earlier blocked a 670 million-euro ($713 million) Chinese bid for German chip equipment maker Aixtron (AIXGn.DE) over concerns of China gaining access to the secrets of producing Gallium nitride, a powdery yellow compound used in light-emitting diodes (LED), radar, antennas and lasers.

The Air Force Research Laboratory (AFRL) demonstrated the ability to grow and place the material on a flexible substrate, enabling the potential to power wearable devices or electronic devices that are not necessarily flat. “We are the first group ever to demonstrate a flexible radio frequency (RF) transistor device based on GaN that actually performs under strain and is flexible, which is quite powerful.” According to AFRL scientists, GaN can be used in future communication systems by optimising just six atoms one ten-thousandth the width of a human hair.

Gallium Nitride Technology

Gallium-nitride is a wonder solid-state material. Gallium nitride (GaN) is a semiconductor commonly used in light-emitting diodes. It is a hard material with a crystal structure, a property that makes it desirable for use in opto applications and high-power devices.

GaN RF transistors offer many times the theoretical maximum output power density of GaAs or silicon transistors, high cut-off frequency and good thermal conductivity. GaN transistors exhibit significant advantages over silicon MOSFET in terms of switching speed and power conversion efficiency as well as in cost versus performance challenge. GaN transistors can operate at higher temperatures, and higher current densities than their SiC counterparts. The switching speed of a GaN power transistor may reach an unbelievable 100V/ns. These properties, make GaN devices well suited for high power, high frequency and wide bandwidth applications in extreme environments.

The advantages of GaN-based devices stems largely from the attractive intrinsic physical properties of the material. The material exhibits wide bandgap, high breakdown voltage, extremely high power density and high gain at microwave frequencies. The raw materials for GaN are available in large quantities. Nitrogen can be taken from the air, and gallium is a waste product in metal working.

GaN monolithic microwave integrated circuit (MMIC) technology performance continues to advance for dual use applications including narrow-band, high-power amplifiers for transmitters, broadband amplifiers for receivers, as well as higher frequency applications such as communication. One company, Check-Cap, has used GaN to develop tiny ingestible capsules to perform internal X-rays. GaN could intensify the power of LiDAR systems in driverless cars. Lidow's company is using it to develop wireless projection of power over long distances, enabling users to charge their phone just by walking into a room, for instance.

By replacing legacy components with GaN transistors, engineers can design electronic systems that are 4x smaller, 4x lighter, that exhibit 4x less energy loss, and are less costly, writes Jim Witham, the CEO of GaN systems. The performance advantages provide customers with a profound array of benefits across markets from the IoT and datacenter servers to industrial equipment, electric vehicles (EVs), and autonomous vehicles.

GaN entering Commercial Applications

The three major applications for GaN are LED, power, and RF. The fourth application showing great potential is GaN sensors. Mercury detection, pH analysis, hydrogen sensing, and DNA and protein sensing are few of the areas being researched with GaN HEMT materials. t stands to reason since many sensors are silicon based and with the emerging need for multiple sensors on a chip, a.k.a., sensor fusion, GaN could open up many new areas for sensor innovation. The possibility of combining power functions, sensors, and optical functions on a small device may not be too far away in the future, write writes Jim Witham, the CEO of GaN systems.

The IoT and 5G applications generate massive amounts of data, driving the need for increased data storage and processing, which requires more power supplies and servers. GaN devices reduce power consumption and increase power supply density, saving customers operating costs and allowing more servers in the same rack. The same holds true for the automotive ADAS and autonomously driven vehicle space where automotive manufacturers are building datacenters to manage the 10X explosion in data generated by these vehicles. EV and HEV systems are undergoing extensive electrification, which increases semiconductor demand 3x to 4x more than vehicles currently require, writes Jim Witham.

The emerging IoT revolution would have trends as car-to-car (C2C) or machine-to-machine (M2M) communication – cars and machines need to communicate in high speed with each other. The real-time radio communication is necessary for visions such as Industry 4.0 or autonomous driving. Maximum data rates of 10 gigabits per second are needed and thus targeted. From 2020 the 5G mobile standard is aiming to transmit data rapidly and energy-efficiently. For that purpose companies like Fraunhofer is developing new power amplifiers based on the semiconductor gallium nitride.

Wireless power transfer is an emerging application with a direct tie to sensors. This is a perfect method to supply power to these sensing devices. Then there are robot and drone applications that are just starting to take off; these will also leverage the advantages of wireless power transfer and charging.

Another emerging application for GaN is artificial intelligence and machine learning. These applications use microprocessors, GPUs and memory in their high-performance computing (HPC) that require higher power, in the order of 500 W in the same volume that currently delivers only 200 W. GaN transistors provide a path for designers to increase power density without adding volume or weight.

Power Electronics

GaN is quickly capturing market share in the power amplifier function. CATV became the earliest market segment to experience widespread GaN adoption.

GaN is the perfect replacement material for silicon in medium-voltage power applications. GaN offers advanced features in terms of power efficiency at high voltages, high reliability, and flexibility in power rectification, power factor correction, and power amplification.

Currently, there are various traditional, above-normal voltage power applications in several application segments, such as power distribution systems, industrial systems, heavy electrical systems, turbines, heavy machinery, advanced industrial control systems, electromechanical computing/computer systems, and others.

"Moreover several new power applications (clean-tech) such as high-voltage direct current (HVDC), smart grid power systems, wind turbines, wind power systems, solar power systems, and electric & hybrid electric vehicles. Due to the expanding size of the above-mentioned applications, there is a rising demand for suitable (such as GaN based) power semiconductor devices," reports Marketsandmarkets.

Wireless Charging

GaN allow designers to use wireless charging in a wider range of products without having to redesign the antennas. Energous, the developer of WattUp, just announced a new GaN based, high-power Near Field WattUp transmitter reference design. It is capable of charging devices with up to 10 watts of energy. In doing so, it increases the amount of power delivered to receiving devices, while also eliminating connectors and charging contacts for a much wider variety of devices. The solution includes a GaN-based 5-10W RF receiver IC and a GaN-based 10-15W RF power amplifier (PA).

Another company leveraging GaN technology is Solace Power. It uses a technology called Resonant Capacitive Coupling (RC2). The firm has demonstrated capacitive resonance to deliver power to flying drones that can be charged several inches above the charging pad on moving automobiles, increasing total time in the air and reducing human interaction. The demo uses EPC's GaN FETs working at 13.56 MHz. Compared to silicon devices that can handle the same power levels, these FETs are five to 10 times smaller.

5G Cellular / WIMAX

Scheduled for commercial launch in 2020, 5G is expected to offer significant advantages, including higher capacity and efficiency, lower latency, and ubiquitous connectivity. The new cellular network standard will enable the live transmission of high-quality video.

The base stations are an important component in the cellular network. They are the bottleneck through which all data must pass. The researchers are developing power amplifiers that are able to send more data more quickly and above all more efficiently through the cellular network. "New power amplifiers provide the necessary radio frequencies over which the data is transmitted", Quay explains. As a first step, additional radio frequencies of up to 6 gigahertz are freed up for 5G. Currently, LTE is limited to 2.7 gigahertz.

In the RF field, in the near term, GaN will see the highest growth in cellular infrastructure applications. GaN's bandwidth, power, and efficiency advantages provide compelling drivers for adoption in macro base stations and small cells. It will further penetrate cellular infrastructure, providing solutions for point-to-point communications. The largest potential market for commercial applications is power amplifier (PA) for base stations, and for new standards appearing at higher frequencies like WIMAX.

“Higher frequencies mean faster data transmission, but unfortunately also less available power for the transmitters”, says Quay. For this reason, the scientists are manufacturing transistors and microchips that are only a few square millimeters in size out of the semiconductor material gallium nitride (GaN). “Due to its special crystal structure, the same voltages can be applied at even higher frequencies, leading to a better power and efficiency performance”, says says Dr. Rüdiger Quay of the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg (Germany).

Millimeter Wave systems

Millimeter wave systems are also around the corner, the research efforts in wireless communications on 5G at 60 GHz and commercial implementation of automotive FMCW radar at 77 GHz are driving forces. Northrop Grumman has showcased Ka-band GaN MMIC with high power and linear performance.

The benefit to military designs would be twofold: the use of these commercial technologies for future communications systems and autonomous vehicle operations; and the impact on lower price component technologies resulting from commercial use

Optoelectronics

GaN has played a major role in the development of modern light-emitting diodes and is today used in back-illuminated liquid-crystal displays in devices ranging from mobile phones to TV screens. It has been very successful in the LED market, where GaN-on-sapphire or GaN-on SiC-based LEDs are currently being produced in high volume, at very low prices. Its wide band gap of 3.4 eV affords it special properties for applications in optoelectronic applications.

GaN is the substrate that makes violet (405 nm) laser diodes possible, without use of nonlinear optical frequency-doubling. GaN-based violet laser diodes are used to read Blu-ray Discs where the shorter wavelength of the light allows higher data-storage densities..

GaN looks set to further revolutionize electronics and optoelectronics with the recent demonstration of an electrically pumped "inversionless" polariton laser operating at room temperature made from a bulk GaN-based microcavity diode.

Military Applications

The simultaneous combination of high frequency, wide bandwidth, high power capabilities and high temperature operation make GaN a natural fit for military applications. GaN on silicon carbide (SiC) is being successfully applied in the military domain today, in applications such as broadband electronic warfare jammers and radar systems, while GaN on silicon (Si) has been successfully deployed in military communications.

Anti-IED

Military was the early user of GaN for Electronic Warfare applications, Anti-IED (improvised explosive devices) systems used GaN based Power Amplifiers to generate broadband microwave noise to disrupt and jam RF signals used to detonate the IEDs. Cree and Sumitomo were early suppliers of GaN on SiC devices for the IED jammers that were used in Iraq and Afghanistan.

US has identified this anti-IED capability as central to its future battle plans due to increasing threat of asymmetric warfare in future conflicts. The technology was also used in military communications; Nitronex shipped around a million GaN on Si devices for the Falcon multi-band tactical radio.

The older power amplifiers designs based on vacuum tubes, TWTs, klystrons, and older semiconductor technologies are being upgraded to Gallium Nitride (GaN) based solid state power amplifiers.

Satellites: GaN Based 50 Watt X-Band SSPB/BUC for Tactical Mobile Military Applications

Advantech Wireless, has released Gallium Nitride (GaN) Technology based 50 Watt X-Band Solid State Power Block/Block UpConverter (SSPB/BUC) for Tactical Mobile Military Applications. The new 50W BUC will allow higher output power, and higher data rates for mission critical, bandwidth hungry operations in challenging mobile military environment.

“These units are designed for extreme low weight Satcom on the Move (SOTM), man packs, and flyaway applications, where weight and energy efficiency is the driving factor," mentioned Cristi Damian, VP Business Development at Advantech Wireless.

Software Defined Radios

Broadband radios (portable, man-pack, mobile, and base station) demand ever wider operating bandwidths and are incorporating data and video capabilities in addition to two-way voice. The "network-centric" operations also demand broad bandwidth, "smart" and agile communications devices to stitch together all the information sources into a coherent network

Software-Defined Radio (SDR) architectures are playing an increasingly important role in emerging radio configurations with requirements for supporting multi-band and multi-standard operation. They will be reconfigurable by software which allows improved spectral efficiency and faster deployment of new standards.

Wide bandwidth and linearity requirements are critical to the ability of the SDR to adapt to multiple bands, modulation formats, and radio standards. For systems like the JTRS, power amplifiers need to operate over multi-decade bandwidth covering VHF, UHF, and L-bands, and need to be highly efficient and compact, especially when the amplifier is used in a handheld or mobile unit.

By using a single wideband PA instead of individual narrowband amplifiers for each band, significant cost savings are obtained through reduced component count. GaN HEMT devices with high breakdown voltage and high power density capability offer several advantages for broadband high power amplifiers. They can provide cost effective solutions that reduce system size and complexity while addressing the need for wideband power with efficiencies exceeding typical solutions used today.

Further advances in GaN technology and packaged Power ICs will provide future-proof solutions able to meet linearity requirements of more complex modulation waveforms envisioned with next generation multi-band, multi-standard portable and mobile SDRs.

GaN is also attractive for LNA (low noise amplifiers) due to its excellent electrical robustness (high maximal field), which should simplify the system integration and improve overall performance

GaN’s usage continues to expand in the military market. Its low sensitivity to ionizing radiation making it a suitable material for solar cell arrays for satellites. Military and space applications could also benefit as devices have shown stability in radiation environments.

AESA Radars

Next-generation radar systems are critical to providing situational awareness of the entire networked battlefield. Active electronically scanned array (AESA) radar systems operating in bands from UHF to X-band can produce very high-pulsed powers for surveillance applications or multiple simultaneous beams for shorter distance targeting and acquisition applications.

They contain a number of solid-state transmit/receive (T/R) modules that are combined at the antenna input. This array architecture enables simultaneous functions ranging from radar surveillance and fire control to jamming and advanced data link communications. Multifunction AESA versatility also enables dramatic improvements in target tracking, they allow for high-precision, multi-target tracking spanning both short- and long-range threats. The maturity, production ability and low risk of the GaN-based Radar Modular Assemblies are underpinning development of next generation radar system.

The Navy has awarded Raytheon a $92 million contract to develop a new Enterprise Air Surveillance Radar (EASR) for the Navy’s new Ford-class carrier eet and big deck amphibious warships. The EASR will provide simultaneous anti-air and anti-surface warfare capabilities, along with electronic protection and air traffic control functionality, to the Gerald R. Ford-class carriers — starting with John F. Kennedy — and the planned LHA-8 amphibious warship.

The system replaces existing AN/SPS-48 and AN/SPS-49 air search radars and will take the form of an active electronically scanned array (AESA), also known as an active phased array radar. The system is based on Raytheon’s gallium nitride (GaN) semiconductor technology. Radio frequency amplifiers made with GaN are five times more powerful than the ones in radars using traditional semiconductors, the company reported.

By leveraging the advances already being made in the SPY-6 program, the new system "will enable the war fighters to conduct their mission with greater operational efficiency," according to Dave Washburn, Raytheon enterprise air surveillance radar program director."It will have the ability to execute the mission under modern threats in a challenged electronic environment," Washburn said. The system has built-in "electronic protection capabilities … to be able to counter electronic attacks. The threat space is continually evolving and radar needs to be able to perform in that evolving threat space. It has to cut through clutter, interference, jamming."

GaN-Based AESAs Enable U.S. Navy's Next-Generation Jammer

Raytheon engineers will incorporate the first demonstrator of this technology into the Next Generation Jammer (NGJ) program led by the Raytheon Space and Airborne Systems segment in McKinney, Texas. The NGJ is scheduled for low-rate initial production in 2018.

"We have only scratched the surface when it comes to harnessing the game changing power that gallium nitride technology can bring to military applications," says Colin Whelan, vice president of advanced technology in Raytheon's Integrated Defense Systems business unit.

U.S. Navy has commissioned a $279.4-million contract to enhance the jamming features of the EA-18G Growler airframe to maintain air superiority in the modern battlespace when adversaries employ latest radar technologies. The contract called for standoff jamming technology that brings next-generation jamming assets to the U.S. Navy. Raytheon, which was awarded the contract, will implement a highly efficient AESA-based (actively electronically steered array) jamming system with powerful and wideband gallium-nitride (GaN) technology.

The array modules include electronics that use GaN high-power amplifiers (HPAs). Those amplifiers drive the power signals through the circulators and apertures to the array elements. The AESAs can therefore form high-energy RF beams with advanced signal capability that can be steered by a highly advanced and rapidly reprogrammable computer.

“Due to the nature of it being an AESA, you can form many beams or a super beam with a lot of energy. It is agile, so you can dart from one system to another system on the ground almost instantaneously,” says Andy Lowery, the NGJ chief engineer for Raytheon.

GaN challenges

Despite undeniable performance advantageous for power applications and widespread usage in military applications, commercial adoption of the technology for RF applications has been much slower than expected.

The major challenges to more widespread GaN adoption have been reliability and price. Many of the early reliability challenges of GaN have been solved and GaN today demonstrates, via RF life test, a mean time to failure (MTTF) of greater than1 million hours at a junction temperature above 200°C.

However in applications below 3.5GHz, GaN-on-SiC is not cost-effective enough versus Si-LDMOS. The Low volumes, the cost of the SiC wafers, coupled with wafer diameters in the 2″ – 4″ range all contribute to GaN devices being many times more expensive than competitive technologies like GaAs and LDMOS.

In 2013, RFMD introduced the first 6-inch GaN-on-SiC wafers for RF power transistors and M/A-COM technology introduced a line of GaN devices in plastic packaging. Companies like TriQuint, Cree and UMS continue to expand their GaN product and process portfolios. Developments like these and ongoing process improvements will continue to reduce the cost of GaN devices.

Officials of the U.S. Air Force Research Laboratory and the Office of the Secretary of Defense have awarded a $14.9 million contract for the Raytheon Integrated Defense Systems segment in Tewksbury, Mass., to enhance GaN semiconductor manufacturing, Raytheon announced. The pact follows a previous GaN Title III contract, which Raytheon completed in 2013, and aims to increase the performance, yield, and reliability of Raytheon GaN based, wideband, monolithic, microwave -integrated circuits (MMICs) and circulator components.

Conclusion

GaN-based electronics (not pure GaN) has the potential to drastically cut energy consumption, not only in consumer applications but even for power transmission utilities. MIT spinout Cambridge Electronics Inc’s claim their transistors have at least one-tenth the resistance of such silicon-based transistors. This allows for much higher energy efficiency, and orders-of-magnitude faster switching frequency. This has huge implications not only for energy usage of power electronics systems, but their physical size and stability.

When doped with a suitable transition metal such as manganese, GaN is a promising spintronics material (magnetic semiconductors). GaN packaging options are an essential part of the equation, while Plastic-packaged high-power GaN enables designers to adopt conventional surface-mount manufacturing approaches and their associated manufacturing efficiencies. GaN on ceramic remains the packaging option of choice for devices that must be hermetically sealed to ensure reliable operation in environmentally challenging conditions. Ceramic-packaged GaN devices also can manage much greater power-dissipation levels than plastic-packaged alternatives available today.

The challenge to the industry is to be able to deliver components at a cost effective price. Further penetration into commercial markets will place significant demands on the manufacturing infrastructure for GaN—from device fabrication to packaging. The entire supply chain reaching from the availability of Silicon Carbide (SiC) substrates for the epitaxial growth of gallium nitride, to the industrial manufacturing of High Electron Mobility Transistors (HEMT) will have to adjust to increased market demand.

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