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Power up: The rise of GaN as an alternative to GaAS for enhanced power and efficiency.

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The semiconductor compound gallium arsenide (GaAs) has been used to manufacture monolithic microwave integrated circuits (MMICs) since they were first developed in the mid-1980s. MMICs use compound semiconductors to enhance data communications in radio frequency (RF) systems across the microwave and mmWave frequency spectrum.

GaAs was chosen as an alternative to silicon in integrated circuits because of its improved performance at higher frequencies. Silicon-based devices experience greater losses at high frequencies and can deliver less power than their compound semiconductor counterparts. GaAs is now well-established in commercial and military applications and is used extensively in RF devices ranging from consumer electronics such as smartphones to radar systems.

The emergence of GaN as an alternative to GaAs

In the push to meet even more demanding performance requirements, often driven by the needs of the defence sector, gallium nitride (GaN) emerged as an alternative to GaAs. It offers greater power density, efficiency and operating temperature all properties of GaN’s wide bandgap.

GaN has been around for almost three decades, but the lengthy processes of research, trialling and development mean that it has only more recently become established as a viable alternative to GaAs at higher frequencies. Crucially, the cost of fabrication using GaN has now been reduced to commercially acceptable levels, as a result of scaling up small prototype devices onto bigger wafer sizes. GaN is now fabricated on the same wafer sizes as GaAs, meaning the costs of the two technologies are more comparable. That gives device manufacturers the opportunity to embrace GaN MMICs to achieve the power and efficiency gains required for cost sensitive applications.

What is the optimum frequency range for GaN?

GaN crystals can be grown on a variety of substrates, including silicon carbide (SiC) and silicon (Si). It offers particularly enhanced performance at frequencies between 6GHz and 80GHz, depending on the substrate used. (see Figure 1).

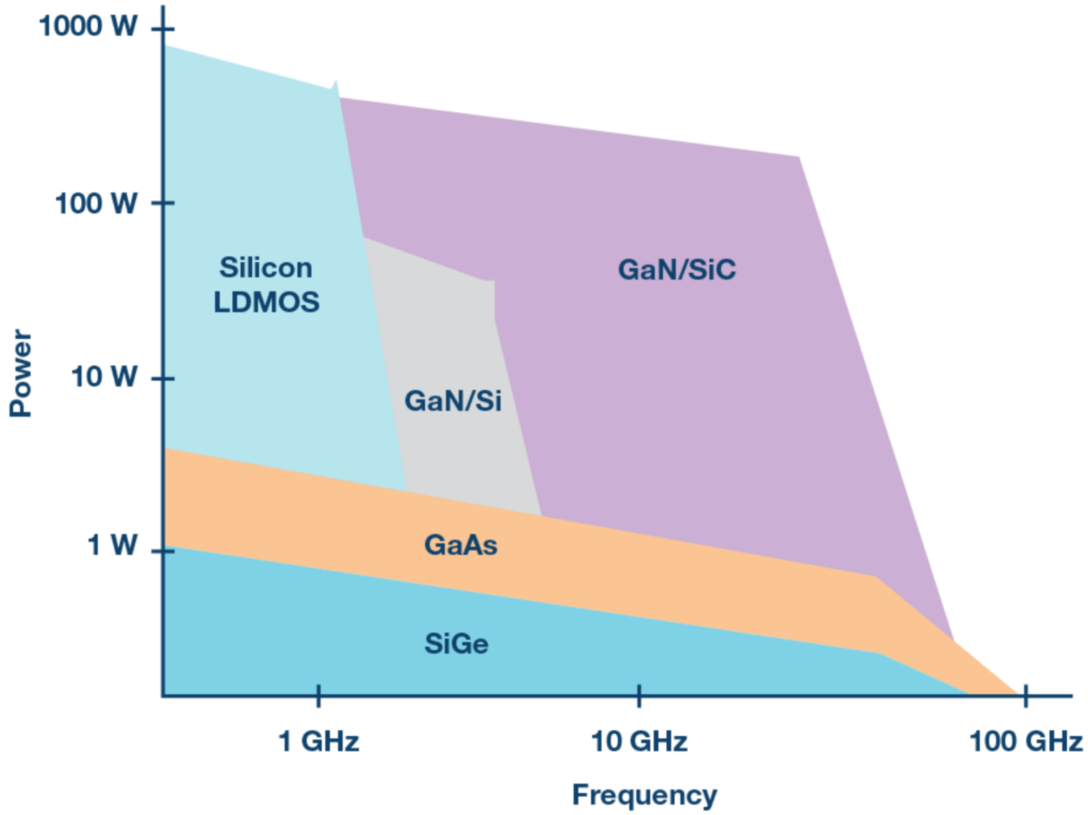

Figure 1: Compound semiconductor power and frequency range.

The frequency breakpoints between semiconductor materials are changing all the time, as new processes are developed. For example, developments to shrink node sizes are enabling higher frequencies to be reached with a given semiconductor compound. This development process is ongoing with silicon. GaN MMICs are now very stable at lower frequencies, but advances are still being made in the very high frequency range. GaN doesn't have the wide frequency range of GaAS, but with node sizes shrinking to the level of 90 nanometres, GaN is starting to be used at E-band (71-86GHz) and even at W-band (92-114GHz) – the emerging frontier of GaN-based devices.

Power and efficiency benefits of GaN

At frequencies between 6GHz and 80GHz, GaN offers valuable benefits over GaAs. Firstly, it offers significantly greater power density. For the same-sized device, GaN offers around six to eight times the power of GaAs. It means GaN can be used to achieve the same power as GaAs within a much smaller die area. The other major advantage of GaN is efficiency. At lower frequencies, GaN is around twice as efficient as GaAs. GaN is also easier to match over wide bandwidths when compared to GaAs.

These benefits make GaN the ideal choice when size, weight and power (SWAP) are critically important, as they are in many defence, space and aerospace applications.

GaN as a drop-in replacement for GaAs

There are opportunities to replace GaAs MMICs directly with GaN MMICs in some RF systems. When it's important to retain the existing size and dimensions of a device, GaN MMICs can be used to boost power and efficiency. Such applications include military radar systems, jammers and electronic countermeasure systems, in which greater power means greater range. There are huge benefits to increasing the reach of these assets, meaning a wider area can be covered by a single asset and enabling operatives to be located further away from potential threats.

Exchanging GaAs for GaN MMICs within existing devices, the power and efficiency of hardware can be significantly enhanced, without the need to re-engineer the housing or structure of the overall module. That is especially important for RF systems that are housed in fixed locations, such as in the nose cone of an aircraft, inside ground-based radar stations, or on-board military vehicles or ships. Replacing GaAs MMICs with GaN alternatives here is an effective way to deliver major upgrades to these devices within their pre-defined footprints.

GaN is also beginning to displace GaAs in telecommunications base stations. Here, the efficiency gains achieved by GaN can significantly reduce running costs. These facilities consume a huge amount of electricity to power both the RF devices they house and the air-conditioning systems required to cool them. Energy efficiency is a major concern for the telecoms industry, particularly since new 5G base stations consume up to twice the energy of 4G stations. Any technology that can improve energy efficiency is highly prized in this sector.

Developing smaller GaN-specific modules
Alongside developments that enable GaN to be used as a drop-in replacement for GaAs, there is a drive to develop GaN-specific products, particularly at the higher end of its frequency range. Here, the greater power density of GaN enables module size, weight and an overall system cost to be reduced – producing the same power from a smaller device. The improved efficiency of these products means they require smaller heatsinks, which means less metalwork, and smaller power supplies. It means that designing modules specifically for GaN MMICs creates overall system improvements, in addition to the performance improvements derived directly from GaN.

There are challenges associated with developing smaller modules with greater power density. One of which is overheating, since the same amount of heat needs to be dissipated in a smaller area. Dissipating heat requires advanced process engineering expertise to ensure devices perform optimally for their expected lifespan. That relies on getting the details right in the choice of die-attach materials such as epoxies or sintering materials. In addition to the material selection, process engineering controls are necessary to define curing recipes and dispense patterns to ensure good adhesion, sheer strength and to avoid voiding, which is key cause of reduced lifetime and device failure.

Advanced packaging systems, such as plastic encapsulation, are an important feature of GaN-based devices, where low cost and low weight are critical. This is particularly important on military aircraft or drones, where the increasing number of sensors on-board, allied with a limited power supply, means that reducing the weight and improving the efficiency of devices is critically important.

One application at the frontier of GaN developments is space communications. The incumbent technology used within ground stations to power the data transmission up to near space is the travelling wave tube. Used to amplify RF signals, travelling wave tubes are the highest power consuming element in the system. Filtronic's range of Cerus Solid state Power Amplifiers (SSPAs) are now a viable alternative to travelling wave tubes, and has already developed a GaAs version that leads the market. To fully displace the incumbent technology, we are working to develop GaN systems that could deliver a fourfold increase in power at E-band frequencies.

Building UK semiconductor capabilities

Some of the best-quality GaN developments today are happening in Asia, where semiconductor expertise and resources are well established. This is where the vast majority of the low node size silicon fabricators are based.

There is a desire in the UK to move semiconductor fabrication closer to home, motivated to a large extent by geopolitical instability. Developing this sovereign capability is important to the UK economy and security – so much so that the government has developed a National Semiconductor Strategy to encourage investment with £1B to be invested in the next 10 years.

Within the UK we already have much of the underlying technology required, including production facilities for epitaxial (EPI) wafers. These base wafers are currently shipped to fabricators in Asia to be processed into MMICs. That is the missing piece of the UK jigsaw with only small scale R&D facilities. While the UK may never be a major player in low-node silicon fabrication, due to the high cost of setting up fabrication plants, there is a significant opportunity to develop niche processes, like GaN fabrication. This could benefit sectors like defence, which require relatively small numbers of wafers per year. With the right investment, the UK could develop boutique, leading-edge operations in high-quality GaN production to meet UK demand.

End-to-end design and development expertise

Filtronic is keen to see a thriving supply chain ecosystem developed in the UK, enabling the development of GaN-based devices entirely within the country. We are already working at the cutting-edge of developments in applications for GaN MMICs.

Our end-to-end capabilities mean we can support GaN projects from the very beginning, designing MMICs for integration into packages customised for specific applications. We have the process engineering expertise to ensure devices are integrated in optimal ways within a product, and we have the system design expertise to turn products into modules and subsystems. We understand every step of the design chain and have the capabilities to produce complex, precision-manufactured GaN-based devices to the highest standards.

If you are looking to develop higher-power RF applications, please get in touch with Filtronic to discuss the possibilities of GaN MMICs.