High Power Developments Emphasize Semiconductor Materials

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Microwave and RF power device news has been dominated recently by advances in semiconductor materials. Each new material has performance capabilities that give it advantages in one or more areas such as frequency, efficiency, linearity, reliability or thermal performance.

In this report, we present the descriptions of several materials from the companies that are manufacturing and marketing devices that use those materials. While these comments are marketing-driven, taken together, they provide a picture of these various areas of technology, and identify key performance features of each. This information was obtained from Web sites and other information that the companies have made public.

Cree (SiC and GaN)

Silicon Carbide (SiC)—The physical and electronic properties of SiC make it the foremost semiconductor material for short wavelength optoelectronic, high temperature, radiation resistant, and high-power/high-frequency electronic devices. Electronic devices formed in SiC can operate at extremely high temperatures without suffering from intrinsic conduction effects because of the wide energy bandgap. Also, this property allows SiC to emit and detect short wavelength light which makes the fabrication of blue light emitting diodes and nearly solar blind UV photodetectors possible.

SiC can withstand a voltage gradient (or electric field) over eight times greater than Si or GaAs without undergoing avalanche breakdown. This high breakdown electric field enables the fabrication of very high-voltage, high-power devices. Additionally, it allows the devices to be placed very close together, providing high device packing density for integrated circuits. At room temperature, SiC has a higher thermal conductivity than any metal. This property enables SiC devices to operate at extremely high power levels.

SiC devices can operate at high frequencies (RF and microwave) because of the high saturated electron drift velocity of SiC. SiC has several intrinsic advantages that enable broadband amplifiers for UHF, L Band and S Band applications. These properties include: high thermal conductivity, high breakdown electric field, high saturated electron drift velocity and high power density (power per unit gate periphery). These features make SiC MESFET an attractive power FET for multi-octave to decade bandwidth power amplifiers.

Gallium Nitride (GaN)—Cree Materials synthesizes GaN substrates using a hydride vapor phase epitaxy (HVPE)-based method. During the HVPE process, HCl reacts with molten Ga to form GaCl, which in turn reacts with NH3 to form GaN. The large growth rate enables the growth of self-supporting wafer thicknesses in a convenient time period.

GaN HEMT devices are now being used to demonstrate amplifier efficiencies far in excess of what can be shown in other technologies. This is achieved by either using their inherently good linearity, or by using Class E circuit topologies that were not possible at these high frequencies and power levels using Si or GaAs. In the broad area of power switching devices, there are a myriad of drivers and requirements, and there are many different attributes of SiC power devices that attract attention ranging from high temperature operation, high frequency operation, or extreme power levels that are not attainable any other way. However, the one underlying theme in virtually every application is higher efficiency.

GaN HEMT devices provide a very high ratio of peak current (I_{MAX}) to output capacitance, similar to GaAs PHEMTs. The major difference, however, is the significantly higher breakdown voltage associated with GaN HEMTs. Typical breakdown voltages are greater than 100 volts, enabling high power, high efficiency switch-mode operation at 2 GHz and beyond.

Nitronex (GaN)

Only gallium nitride delivers the power, efficiency and linearity required for 2.5G and 3G wireless base stations. Nitronex grows the highest-quality GaN ever—resulting in 100,000 less defects relative to other growth techniques. Using its patented SIGANTIC process, those crystals are deposited on large-area silicon wafers, the most prevalent and inexpensive substrate available. The result is the highest performing/lowest cost power transistor in the history of the RF semiconductor industry.

For decades, researchers around the globe have struggled to grow high-quality GaN crystals. Unlike silicon, gallium arsenide, silicon carbide and indium phosphide, only GaN can manage both high speeds and high signal purity at high power.

Following recent breakthroughs in crystal growth research (using large-area silicon substrates), GaN components are now rapidly becoming a commercial reality. And nowhere do its high-performance/low-cost advantages

hold more promise than in wireless communications.

Delivering wholesale improvements in RF transmission signal processing, GaN is a III-V compound semiconductor material with a very wide bandgap and a correspondingly high bandgap voltage of 3.4 V. GaN's physical nature includes: high thermal conductivity, high melting temperature, low dielectric constant and high breakdown voltage. This translates to fundamental performance advances in the area of high power, high frequency power transistors for RF transmission applications covering the 1-50 GHz band.

Fujitsu (GaN)

Fujitsu Laboratories Ltd. has developed a new high-reliability technology for high power gallium nitride (GaN) high electron-mobility transistors (HEMT). The new technology enables the transistors to operate at the high temperature of 200 degrees Celsius for more than one million hours, equivalent to over 100 years, under pinch-off condition with a drain voltage of 50 volts (50V). Fujitsu is targeting the high-speed wireless communications market, such as for satellite communication (VSATs), cellular base stations, WiMAX(3) base stations, and other high-speed wireless communications infrastructure.

In order for GaN HEMTs to be used as high power, high voltage-endurance devices, they must maintain high reliability. Fujitsu analyzed and discovered that in GaN HEMTs a correlation exists between gate leakage current and reliability. Furthermore, they observed that the increase in gate leakage current depends on the quality of crystal and the structure of GaN HEMTs. Fujitsu has improved crystal quality and optimized the layer structure to mitigate the electric field in a gallium-nitride HEMT structure with few surface traps by using a proprietary n-type GaN cap layer.

RF Micro Devices (GaN)

High power density, high voltage operation, higher reliability, and broadband performance are some of the intrinsic benefits to products developed utilizing Gallium Nitride (GaN) technology. RFMD is pursuing the development of GaN transistors for various high-volume commercial and defense oriented applications requiring greater performance than economically attainable with traditional GaAs technology. Through the utilization of this dedicated GaN capability, RFMD's vertically integrated development structure provides material processing, device fabrication and MMIC design expertise.

Vitesse Semiconductor (InP)

Vitesse Semiconductor Corp. now offers indium phosphide (InP) HBT foundry services through MOSIS, a provider of low-cost prototyping and small-volume production services for IC (and optical IC) development. By working directly with MOSIS, customers will have access to Vitesse's proprietary InP VIP-1 technology. The VIP-1 process includes high performance SHBT devices with other active and passive devices and multiple levels of metal interconnect.

The VIP-1 process offers circuit designers the benefits of both high-speed and high-voltage operation suitable for digital, analog, and RF circuits at 10 GHz or higher. The process uses four-inch diameter semi-insulating substrates. The key active device is a SHBT, characterized by f_T = 150 GHz, F_{MAX} = 150 GHz (at I_C = 1 mA/µm), and BV_{CEO} in excess of 4.5V. The process also includes resistors and capacitors, and three layers of metal interconnect.

The silicon-like interconnect and volume manufacturing capability is suitable for many applications requiring the performance or optoelectronic properties of InP, such as high-voltage drivers, high-frequency amplifiers, high-speed DACs and ADCs, adaptive RF electronics, automotive radar, low loss waveguides and optical components such as photodetectors.

To demonstrate the abilities of the process, Vitesse produced the industry's most complex InP integrated circuit, a 40 Gbps 16:1 MUX with integrated PRBS 231-1 generator, which contains close to 5000 HBTs. Vitesse will continue to advance the uses of InP technology through the development of the next generation process: VIP-2, a dual HBT InP process with f_T = 300 GHz and BV_{CEO} in excess of 10V.

Other Technologies

Carbon Nanotubes—These nanoscale structures of carbon atoms have two potential applications: thermal conduction and very small transistors. While the transistors (FETs) are likely to have greater application in memory and other high-density applications, the high thermal conductivity of carbon nanotubes has resulted in numerous experiments in thermal enhancement of power devices of all types, including RF and microwave. This application area has a realistic chance in the near-term for production.

Silicon-on-Insulator—SOI works by placing a thin, insulating layer, such as silicon oxide or glass, between a thin layer of silicon and the silicon substrate. This process helps reduce the amount of electrical charge that the transistor has to move during a switching operation, thus making it faster and using less energy. SOI also offers the opportunity to enjoy the benefit of low noise and high-quality passives.

In 2006, Freescale Semiconductor reported "strained silicon-on-insulator" (sSOI) technology, where a layer of silicon is placed over a substrate of silicon germanium (SiGe). The atoms in the silicon stretch to align with those of the silicon germanium, which are naturally farther apart. Straining the silicon in this way allows the electrons to move 70 percent faster, which results in sSOI's big performance increases and reduced power consumption.

RF CMOS—RF CMOS is currently used for low cost, low power wireless devices such as keyless entry, Bluetooth™ and ZigBee®. Although power levels may not be considered "high power," advanced research is targeting microwave and mm-wave frequencies, where RF CMOS may provide alternatives to more expensive III-V semiconductor technologies, leveraging CMOS' capability for small geometry processing, sometimes combined with SOI techniques for improved dielectric properties.