Movers and Shakers of Wide Band Gap Semiconductors

Wide Bandgap Technologies – the new norm for 21 century power electronic applications

By Thomas Neyer and Mehrdad Baghaie, ON Semiconductor® Munich

In the last two decades of the last century, researchers and Universities have experimented with several wide bandgap materials, which showed high potential to replace incumbent Silicon material technologies for radio frequency, light emitting, sensoric ond power semiconductor applications. Around the dawn of the new century, Gallium Nitride (GaN) and Silicon Carbide (SiC) has achieved enough maturity and received enough traction to leave other potential alternatives behind to get sufficient attention of industrial manufacturers around the globe.

During the next few years the focus was to investigate material related imperfections, develop customized design, process and testing infrastructure for the new materials and establish a somewhat reproducible passive (Diode) device and several active devices (MosFETs, HEMTs, MesFETs, JFETs or BJTs) which started to find their way into demonstration boards and were able to demonstrate the undisputable advantages wide bandgap materials are bringing to the table. With respect to power semiconductors these comprise the extension of the operating temperature range, increase of current density and up to tenfold reduction of switching losses allowing continuous operation at significant higher frequencies and hence reduced system weight and size of the end application.

For both materials some unique challenges still remain to be worked on:

GaN, perfectly suited to low and medium power, mainly consumer applications, seem to allow a high degree of monolithic integration where one or more power switches, co-packed with driver circuits, with the potential to create power conversion-ICs on a monolithic chip, manufactured in state-of-the art 8-12” mixed signal wafer manufacturing plants. Still, as Gallium is considered a rare, non-toxic metal which might create side effects as unintentional acceptor in Silicon production facilities, strict separation for many manufacturing process steps like dry etching, cleaning or high temperature processes is remain a critical requirement. In addition, GaN is deposited in a MO-CVD Epitaxy process on lattice mismatched carriers like SiC or at larger wafer diameters typically even on Silicon, which instigates film stress and crystal imperfections, which predominantly leads to device instabilities and occasionally to catastrophic failures.

GaN power devices are typically lateral HEMT devices, which take advantage of an intrinsic two dimensional electron gas channel between Source and Drain, gated by schottky type of metals.

SiC on the other hand consists of abundant constituents of silicon and graphite which together make up close to 30% of the earth crust. Growth of industrial scale single crystalline SiC ingots is a well-established and widely available resource in 6”. Early movers have started to evaluate 8” wafers recently and there is hope that within the next 5 years SiC manufacturing will be expending into 8” wafer fabrication lines.

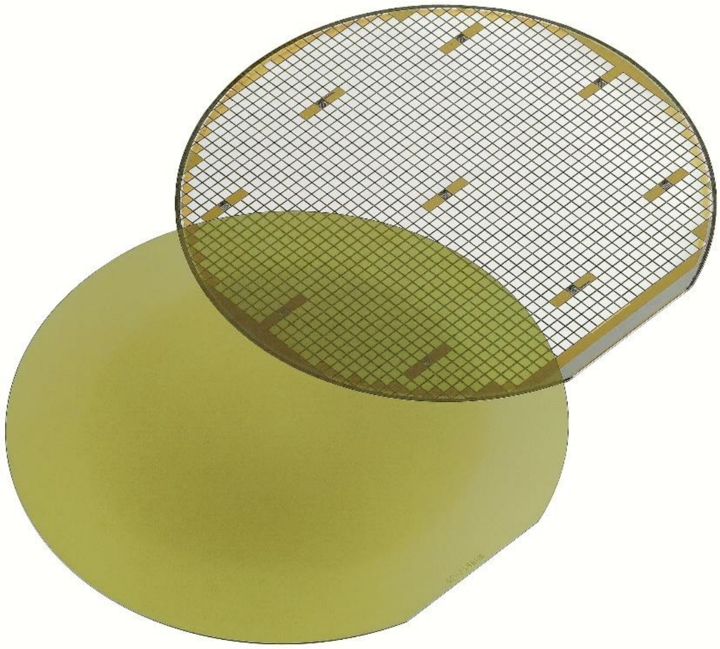

Fig1: SiC maturity on 6” wafers – comparison semitransparent SiC substrate vs completed product wafer

The wide market adoption of SiC Schottky diodes and SiC MosFETs are providing the required scaling effects to reduce manufacturing costs both on high quality substrates, SiC epitaxy and manufacturing processes. Crystal imperfections, eliminated by visual and/or electrical stress testing strongly weights on yields for larger chips sizes. Also, there are several challenges, attributed to low channel mobility, which prevent SiC FETs to be competitive to Silicon FETs in the range between 100 – 600V.

Leaders in the market have realized the importance of a vertical supply chain to manufacture GaN and SiC products. Building manufacturing competence under a single roof which includes, crystal growth, wafering and polishing, epitaxy, device manufacturing and packaging expertise, including optimized modules and packages, which take fast transients and thermal capabilities or limitations of wide band-gap devices (WBG) into consideration, allows for lowest cost and highest yields and reliability. ON Semiconductor® was the first to transition SiC mass production to 6” factories in 2015 and since then expanded the portfolio from Diodes to MosFETs over several voltage classes and package line-ups. ON Semiconductor® has continuously invested into this strategy and 2020 denotes the year where internally manufactured substrates are being introduced to mass production. With this accomplishment, ON Semiconductor® has established SiC manufacturing footprints in Asia, Europe and US and has high flexibility to source from several location, which proves advantageous considering pandemic lockdown scenario or trade disputes between major suppliers and markets. A very similar approach applies to ON Semiconductor®s GaN supply chain, where the goal is to establish a global 8” manufacturing footprint.

With a wide and competitive product portfolio and a global supply chain in place, the new focus is moving towards product customization to enable game changing applications. Have initially drop-in replacements of Silicon Diodes, IGBTs and Superjunction MosFETs prepared the market of WBG technologies, there is plenty of more potential in tailoring electrical performance to selective topologies to continue to drive power efficiency, extend driving range, reduce weight, size and component counts and enable novel, breakthrough end-applications in industrial, automotive and consumer fields.

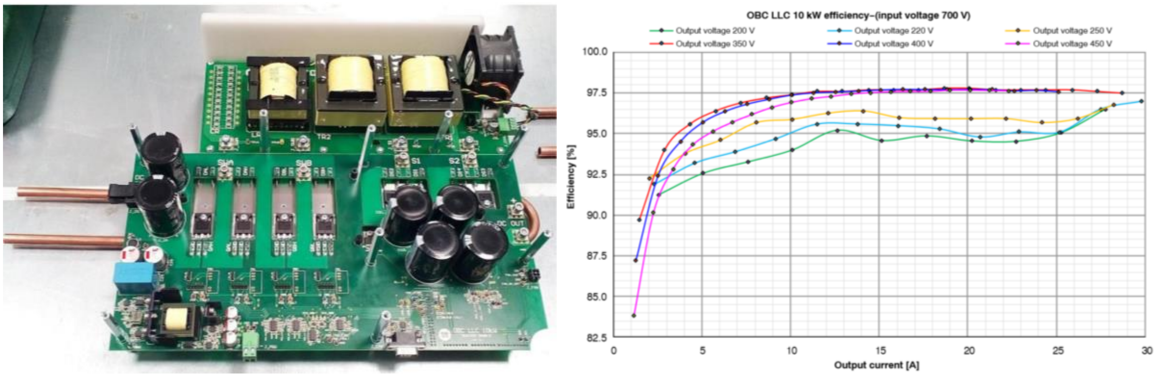

Fig2. Highest efficiency On-Board-Charger system using 1200V SiC MosFETs both in PFC and LLC stage reaching highest power density and lowest weight. Reference design made available through https://www.onsemi.com/products/wide-bandgap

A critical element to enable rapid design-in cycles are accurate spice models which include thermal performance and calibrated package parasitics, available for virtually all popular simulator platforms, as well as quick sampling support, application notes, customized SiC and GaN driver ICs and world-wide support infrastructure.

The upcoming 10 years will bear witness to another historic shakeup, where GaN and SiC based power semiconductors will drive radical inventions in power electronic packaging integration and applications. In the course of this process, Silicon devices will be nearly eradicated from power switching nodes but will continue to find refuge in highly integrated power ICs and lower voltage regimes.