GaN Based Power Devices: Cost-Effective Revolutionary Performance

A novel gallium nitride (GaN) based power device platform promises to deliver figure-of-merit (FOM) performance that is at least an order of magnitude better than existing silicon MOSFETs. **Michael A. Briere, Executive Scientific Consultant, ACOO Enterprises LLC, under exclusive contract to International Rectifier Corp.. USA**

Some 30 years ago, International Rectifier introduced the first commercially viable silicon MOSFETs, called HEXFETs, to enable rapid adoption of switch mode power supplies (SMPS) over then dominant linear supplies which used bipolar devices. Since that time, this Si based technology platform has continued to evolve to satisfactorily serve myriad markets. But silicon MOSFETs have now approached a performance plateau, while cost of advancements has increased dramatically. Concurrently, next generation and emerging applications are demanding further substantial leaps in power conversion performance.

Hence, to meet the new requirements of forthcoming applications, new materials and transistor structures are needed to fill this gap. Although, silicon carbide (SiC) FETs have emerged on the scene in the past 10 years to address these issues, they suffer from significant cost premiums due to limited quality material supply, as well as the intrinsic cost structure of the material. Additionally, SiC based technology is not scalable.

Envisioning such a need, IR scientists and engineers have developed a revolutionary gallium nitride (GaN) based power device technology platform that promises to deliver performance that is at least 10 times better than existing silicon devices to enable dramatic reductions in energy consumption in end applications.

In fact, over five years of device R&D has resulted in a proprietary GaN-on-silicon epitaxial process and device fabrication technology that heralds a new era in power conversion. IR expects the potential impact of the new GaN based device technology platform to be at least as significant as the introduction of HEXFETs some three decades ago. Referred to as GaNpowIR, the company plans to offer a broad range of commercially viable products (20 to 1200V) supporting discrete as well as circuit solutions (modules and chipsets).

Benefits of GaN

Structurally, bulk GaN substrates have been prohibitively high-priced, requiring the use of hetero-epitaxial films. However, major substrates used for GaN epitaxy until now, such as SiC or sapphire, have also been relatively expensive. While silicon was a very attractive low cost alternative, it remained difficult because of defects and deformations due to intrinsic mismatch in lattice constants and thermal expansion coefficients. Recently, solutions to these epitaxial process difficulties have been developed. This program has leveraged the extensive experience in GaN epitaxy and devices that has been achieved through the efforts of a wide community of investigators, focused mainly in the fields of GaN RF devices and LEDs. This hetero-epitaxial process allows for volume deposition of GaN based material on low cost silicon wafers, costing about 100 times less than SiC.

As shown in Figure 1, the basic current GaN-on-Si based device structure is a HEMT, based on the presence of a two dimensional electron gas (2DEG) spontaneously formed by the intimacy of a thin layer of AlGaN on a high quality GaN surface. Ohmic

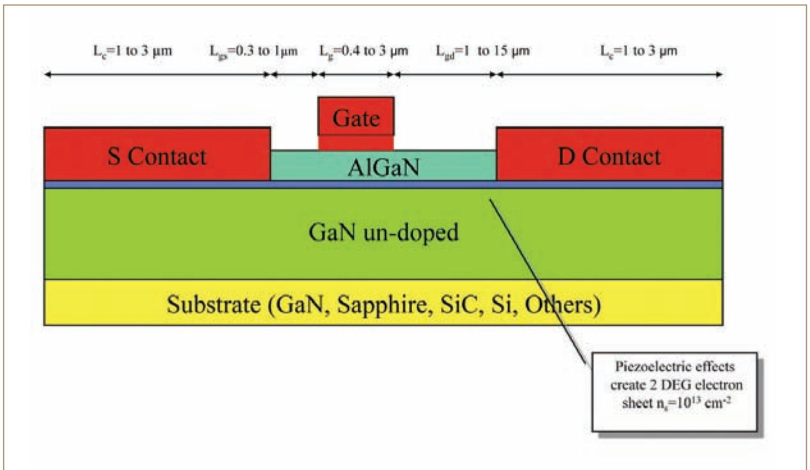


Figure 1: Basic GaN based device structure is HEMT

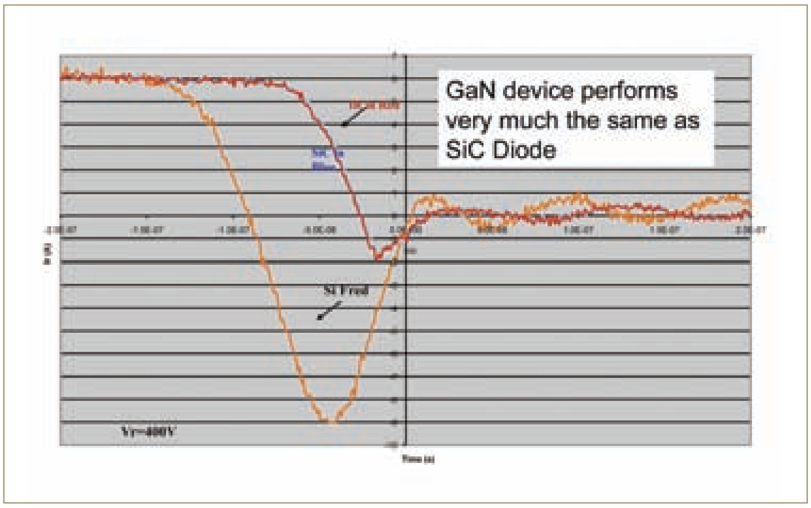


Figure 2: **Reverse Recovery (Q_{rr}) performance for GaN device is same as SiC diode**

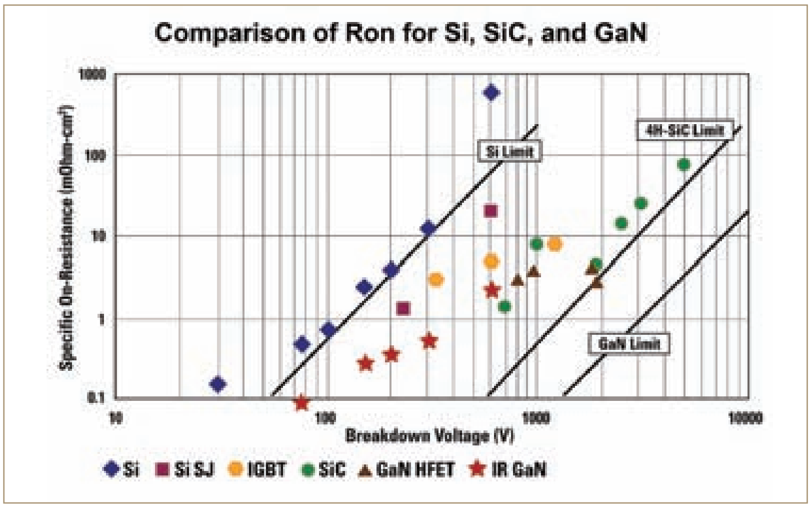


Figure 3: **Comparing specific on-resistance of IR's GaN-on-Si based HEMTs with silicon and SiC power MOSFETs**

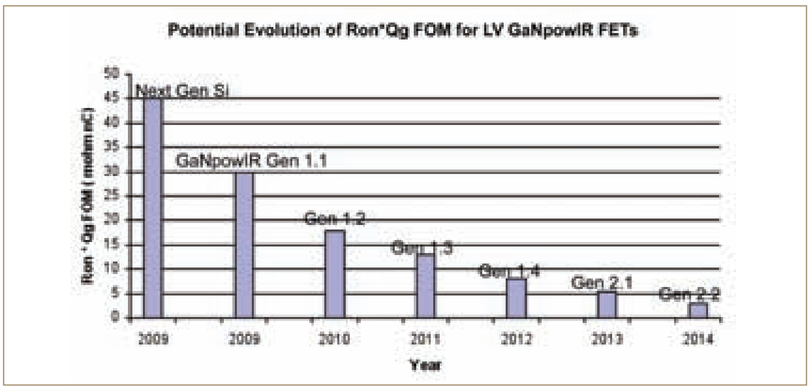
contacts are made to the 2DEG, typically using Ti/Al based metallurgy. An insulated or rectifying metal gate structure is formed between the ohmic contacts and provides for the field induced modulation of the 2DEG. It is clear then that the native nature of this device structure is a JFET with a high electron mobility channel and conducts in the absence of applied voltage (normally on). Several techniques have been developed to provide a built-in modification of the 2DEG under the gated region, providing for normally off behaviour.

Internal studies show that GaN based power devices can offer performance that is comparable to SiC but at much lower cost. Prototype tests conducted show that reverse recovery (Q_{rr}) characteristics for high voltage GaN diode function is same as for commercially available SiC diodes, both being significantly better than state of the art silicon fast recovery diodes (FRED) (Figure 2).

A combination of high electron mobility and higher bandgap provides GaN with a significant reduction on device specific on-resistance $R_{DS(on)}$ for a given reverse hold-off voltage capability than both SiC and silicon devices, as shown in the calculated material limit curves for (non-highly compensated) unipolar devices in Figure 3. Also shown are representative, best case, published measured results for the three materials, as well as for highly compensated (SJ) and bipolar (IGBT) device structures in Si. Results from the early development of GaNpowIR platform are also shown (IR GaN). It is clear that an order of magnitude improvement in specific on-resistance can be achieved for GaN based devices over silicon counterparts, even at the early stages of GaN power device development.

Since GaN based power devices achieve a combination low gate

Figure 4: **Potential evolution of $R_{(on)} * Q_g$ FOM for low voltage GaNpowIR HEMTs**



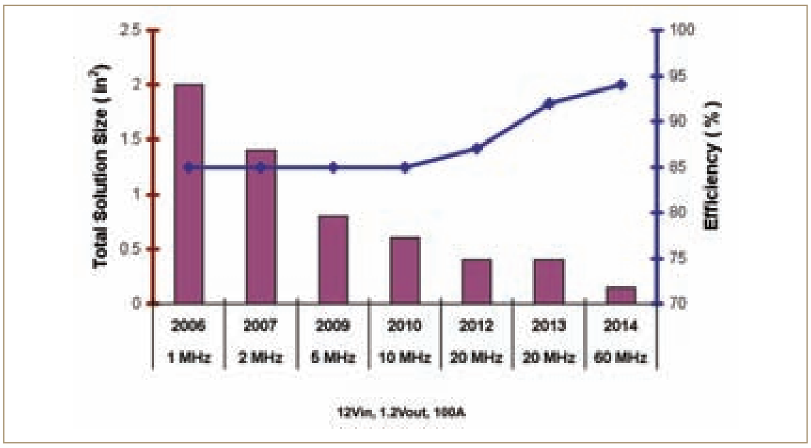


Figure 5: Projected evolution of size and power conversion efficiency for a 100A, 12 to 1V converter (including output filter), corresponding to improvements of the power switch FOM, $R_{(on)}$ * Q_g

capacitance and low on-resistance, it permits much higher frequency switching converters than competing silicon transistors. Results based on device modeling indicate that $R_{(on)}$* Q_g figure of merit (FOM) for first generation GaNpowIR HEMTs, to be introduced in 2009, is 33% lower than that of state of the art silicon MOSFETs. On going engineering efforts are expected to provide further significant improvements in the next few years. Figure 4 shows that $R_{(on)}$* Q_g for GaNpowIR devices is expected to be as low as 13mΩ-nC by 2011, representing a 50% improvement over GaN based devices introduced in 2009.

By 2014, the $R_{(on)}$* Q_g FOM for GaNpowIR is expected to be below 5mΩ-nC, an order of magnitude improvement over state of the art Si based devices available in 2009.

Figure 5 depicts the expected effect of the improvements in $R_{(on)}$* Q_g FOM of the power switch on the size and efficiency of a DC/DC converter, including the output filter. Current state of the art converters perform 12 to 1V conversion efficiently up to 2MHz. The GaNpowIR technology platform is expected to enable efficient power conversion to greater than 50MHz in the near future.

GaN roadmap

IR's GaN based power device roadmap anticipates that initial prototypes will switch efficiently at 4 to 5MHz, with commercial products introduced over the next few years will support switching frequencies of 10 to 60MHz.

While products for general availability are expected to be released by the end of 2009, several prototypes of power conversion solution using the new GaN based power devices will be demonstrated at the Electronica 2008 trade show in Munich, Germany.