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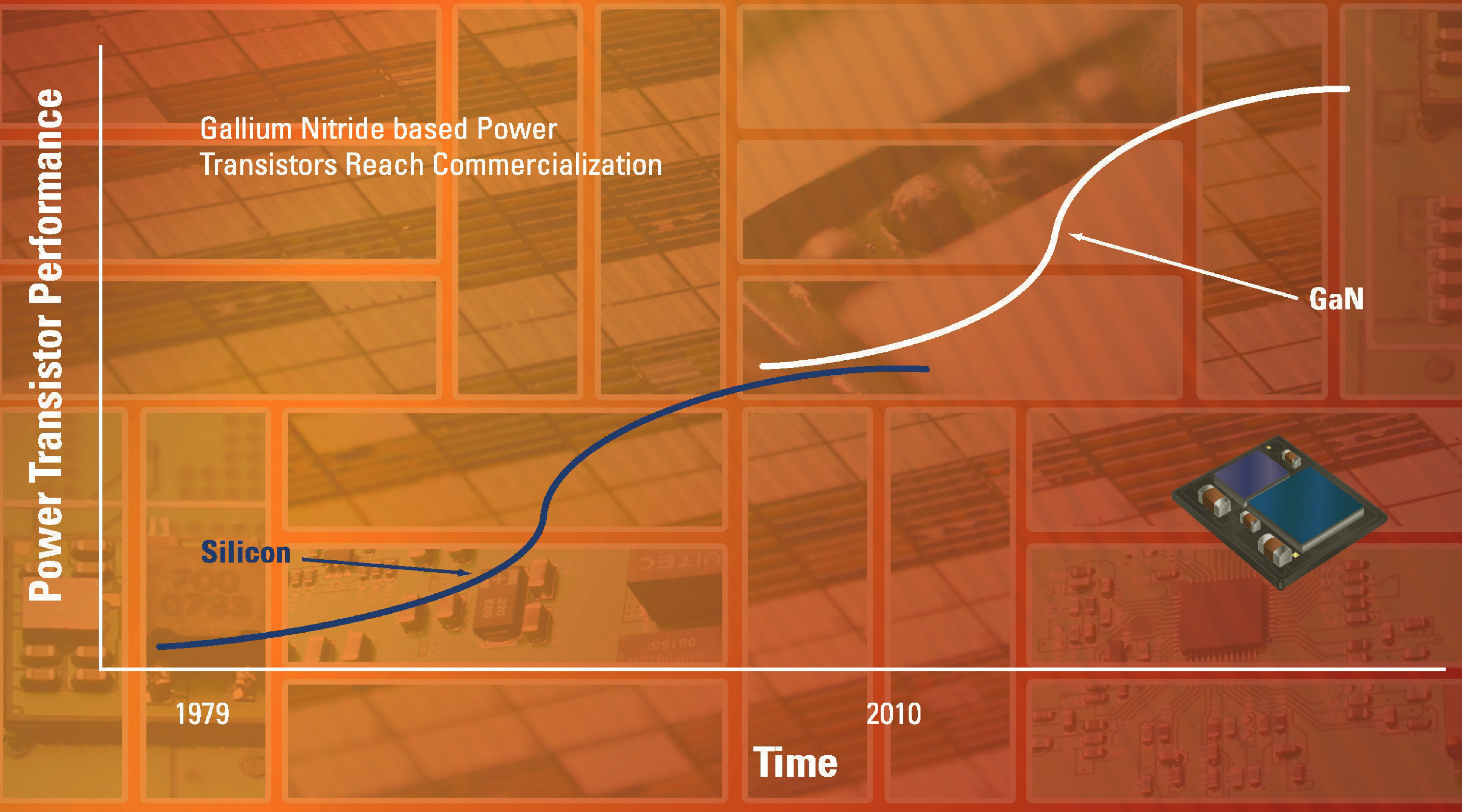

GaN-based power devices can herald a new regime in power electronics

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Commercialisation of GaN-based Power Devices

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Significant advances in the performance/cost figures of merit (FOMs) for power devices (e.g. Rdson*cost or Ron* Qsw*cost) are required in order to improve the power delivery system FOM of efficiency*density/cost. The reduction of total system costs can be substantially enabled by intelligent power electronics which optimise performance/cost. In turn this will promote wide spread adoption of more efficient working loads, leading to a potential reduction in worldwide energy consumption by some 25 %.

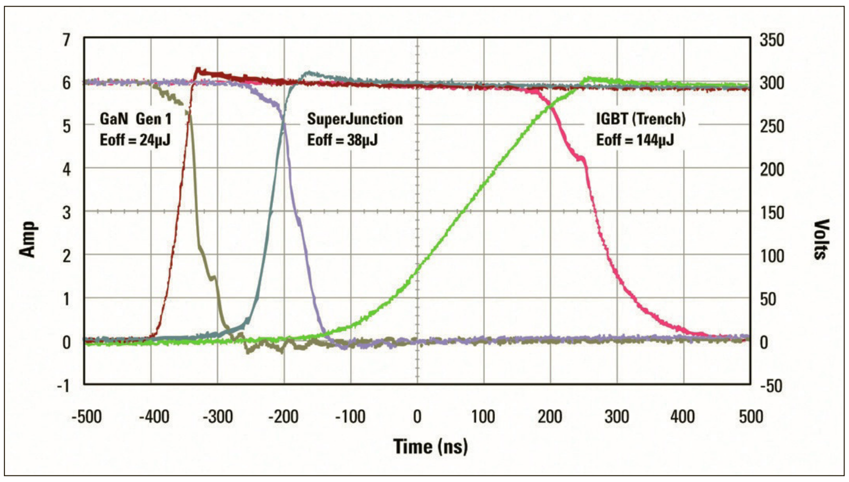

Figure 2: Turn off waveforms for 600 V rated IR GaNPowIR HEMT, superjunction and IGBT devices. The measured Eoff are 24 uJ, 38 uJ and 144 uJ, respectively.

As silicon-based power device technology approaches maturity, it becomes increasingly expen-sive to achieve even modest improvements in the device FOMs. It is estimated that less than a factor of two improvements will be economically feasible to achieve for 30V FETs, with perhaps a factor of five possible for 600 – 1200V silicon IGBTs. Necessary further advances in power device performance must be achieved through the use of alternative materials. One of the most promising alternatives to silicon is gallium nitride-based power devices. Even though the basic GaN HEMT transistor was first invented nearly 20 years ago by M. Asif Khan, significant development efforts on practical power devices using GaN-on-Si technology have been fairly recent, predominantly in the past five to seven years. GaN-based power devices are expected to improve rapidly over the next 10 to 20 years. In fact, it is expected that an order of magnitude in improvement in the key device performance FOMs will be achieved over the next five years.

In order to provide a compelling alternative to silicon-based devices, the new GaN-based devices must achieve certain performance characteristics expected in today's power electronic marketplace. The first amongst these is cost. Cost effective GaN-based power devices require the use of large diameter (at least 150 mm dia) silicon substrates for hetero-epitaxy, as well as device fabrication compatible with high volume silicon CMOS factories. International Rectifier has achieved these requirements in a high volume, high performance and high reliability plat-form known as GaNpowIR.

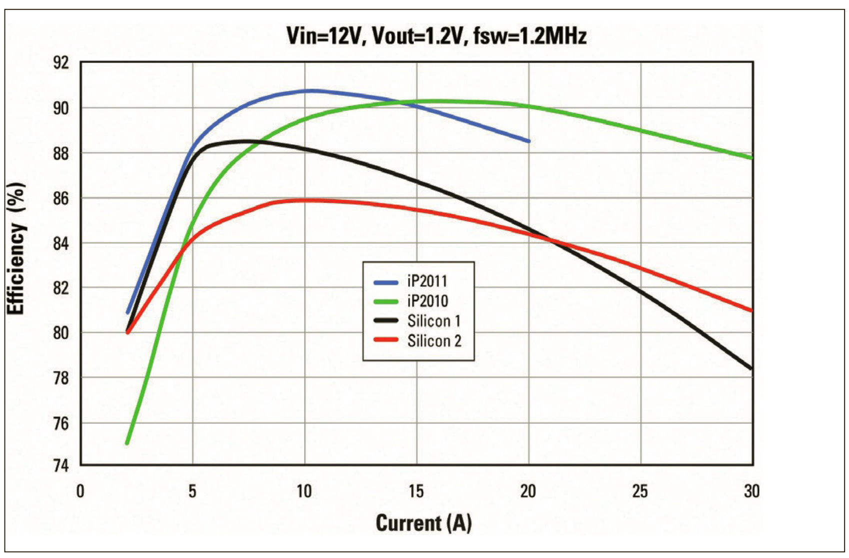

Figure 1: Measured power conversion efficiency for initial GaNpowIR product,iP2010, a 12 Vin to 1.2 Vout POL converter power stage operating at 1.2 MHz compared to two silicon based alternatives

High voltage devices

One challenge to commercial viability for GaN-based power devices has been unacceptably high leakage current levels (i.e. Amperes). Through the combined use of a proprietary insulated gate construction and improved III-Nitride epitaxial film quality, low device leakage behaviour has been obtained. Gate and drain-source leakages for low voltage (30V) devices of < 10pA/mm of gate width have been achieved. The resulting ratio of Ion/Ioff of > 1010 is many orders of magnitude better than reported elsewhere for GaN based devices. Such results are also achievable for high voltage devices where the drain leakage current at breakdown for a 100 mm wide device, capable of saturation currents of greater than 20A (Vg=0V), is < 50nA/mm at 600V at a gate voltage of -10V. Another challenge for the realisation of commercially viable low voltage GaN devices is the effective conduction of the source-drain current from the internal to the external device terminals. This has been accomplished through the use a flip-chip die, eliminating wire bonding and minimizing other package related parasitics. In addition to issues in placement and handling, there are several performance issues that must be addressed to fully realise the advantages of such GaN-based flip chip power devices. The spreading resistance of the substrate used to interpose the device in the application circuit can represent a 20 to 50% addition to the intrin-sic (die) device FOM. Parasitic inductance in the substrate layout can produce undesirable ring-ing. An integrated approach which optimises the power switch interface with the application board, as well as the gate driver and minimises parasitic related behaviour is provided by Inter-national Rectifier's iPowIR product platform. An optimised driver also provides for achieving the maximum performance benefits afforded by the GaN based power devices, through intelli-gent deadtime control. For these reasons, the first GaNpowIR product is the iP 2010, a fully in-tegrated and perform-ance optimised solution. The target of a useable FOM of 30 mohm*nC for this first generation technology platform as packaged in the iP2010 has been achieved.

Conversion Efficiency

The first product release to production on the IR GaNpowIR technology platform is a 30 A ca-pable 12V buck converter power stage product. It incorporates the control and synchronous rec-tifying switches together with the intelligent gate driver in a low parasitic LGA package. Figure 1 shows the measured power conversion efficiency for this first generation GaN product and a lower current derivative, the 2011, compared to competitive silicon-based solutions at 1.2 MHz. Here it can be seen that the GaN-based power devices provide up to 8% improved conversion efficiency over state of the art silicon FETs. In addition, by enabling high efficiency (>90 % peak) at 1.2MHz, this GaN-based power solution also enables high density as well improved transient response per phase. Further improvements in LV GaN based power devices (e.g. RonQsw < 5 mohmnC, compared to 45mohmnC for state of the art silicon-based devices) will allow for truly revolutionary performance of efficient (85 to 90%) single stage power conver-sion (e.g. 12V to 1.2V) at > 50MHz frequencies, eliminating much of the output filter compo-nents, significantly reducing costs, and shrinking the converter size by more than a factor of ten. The resulting simultaneous improvement in power conversion density, efficiency and cost represents the true value of GaN based power device development for LV applications.

Turn-off behaviour

Similarly, for many high voltage applications, the Vceon*(Eoff+Eon) FOM is a determinant value proposition. As in the case of silicon carbide based power device, GaN based HEMT de-vices operate with majority carriers, making the reverse recovery switching times and associated losses far lower than the alternatives provided by silicon-based, superjunction and bipolar devices. Figure 2 shows a comparison in turn-off

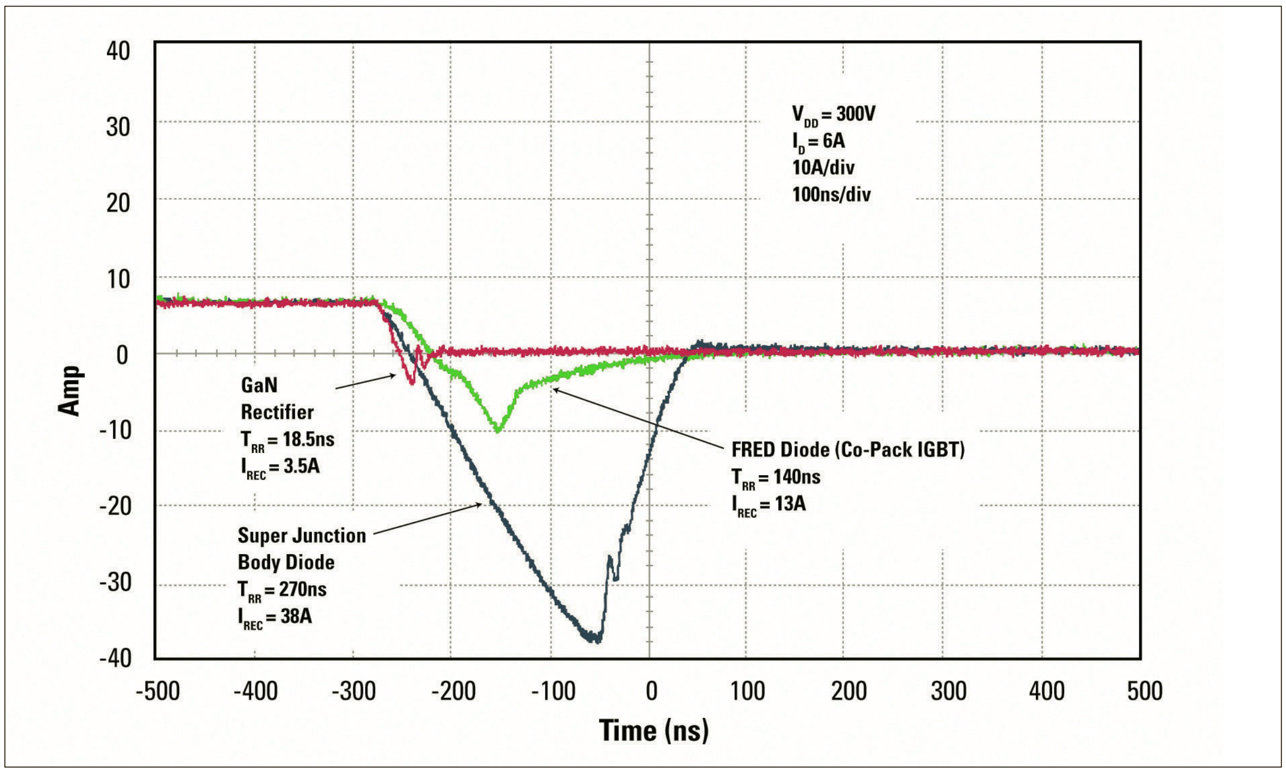

Figure 3: Reverse recovery characteristics of 600 V rated GaN based rectifiers compared to state of the art silicon based fast recovery diodes and superjunction FET body diodes. The Trr values are 18.5, 140 and 270 ns respectively. The Irr values are 3.5, 13 and 38 A respectively.

behaviour for early IR GaNpowIR 600V rated devices, best in class superjunction FETs and IGBTs. As can be seen, the GaN-based devices represent more than a factor of 5 reductions in Eoff compared to state of the art fast IGBTs and nearly a factor of 2 compared to superjunction devices. Together with significant improvements in Rdson (e.g. 5 to 10 times), it is clear that GaN-based power devices provide superior perform-ance compared to silicon-based alternatives.Figure 3 shows the benefits of GaN-based rectifiers over silicon-based fast recovery diodes as well as compared to the recovery characteristics of super-junction body diodes. As can be seen, the GaN-based rectifiers exhibit negligible reverse recovery inertia compared to silicon alternatives. This characteristic provides the opportunity for low cost alternatives to expensive SiC based diodes in the near future. It is anticipated that IR will release its 600 V GaN based power device technology platform to production by the end of 2011. The first products will include normally off power switches as well as rectifiers for use in applications such as PFC AC-DC converters, motor drives, solar inverters and lighting.

Finally, the stability of device in-circuit performance is a prerequisite to commercialisation. The stability of all critical FOMs for the GaNpowIR technology platform is excellent under acceler-ated conditions for > 6000 hrs. In fact, over 4,000,000 device hrs of reliability testing has shown performance in line with silicon based device specifications.

Perhaps even more importantly, the IR GaNpowIR technology platform represents a cost effective platform for true power integrated circuits, incorporating a range of voltage capable devices with best in class performance. This will allow system on a chip integration, such as complete AC-LV DC conversion and high power monolithic inverters for motor drives and power distri-bution. More than the replacement of silicon discrete devices with GaN-based devices; this plat-form opens a new era for integrated power conversion.

Conclusion

There are many challenges to the commercialisation of GaN-based power devices. Chief amongst these is cost, performance and reliability. Significant technical efforts are required to overcome these barriers. It is for these reasons that International Rectifier has developed its GaNpowIR technology platform using GaN-on Si hetero-epitaxy and device fabrication process-ing that can be performed in a standard modern silicon CMOS manufacturing line with little modification to equipment or process discipline. It is this approach that allows this technology platform to provide power devices with compellingly superior performance/cost FOMs com-pared to silicon which will promote widespread adoption. The first commercially viable GaN based power device platform has been released to production, overcoming several significant barriers, particularly cost.

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