Commercially Viable 600 V GaN on Si based Power Device Development

A wide variety of power electronic applications can benefit from GaN

Demonstration of commercially viable 600 V GaN-on-Si power devices involves first and foremost the demonstrated ability to grow AlxGayN alloy based epitaxy on standard thickness silicon substrates. In addition to the ability to manufacture these devices in high volume silicon factories, alongside existing silicon devices, the long term reliability of the GaN based devices must also be demonstrated.

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Once these pre-requisites are satisfactorily established, the revolutionary enabling benefits of GaN based power devices can be taken advantage of in a wide variety of power electronic applications. The current status of the development and current performance of the required 600 V rated GaN on Si based devices at International Rectifier are discussed.

Introduction

It has been well documented that the advent of high voltage GaN based power devices provides unprecedented opportunities to reduce both conduction (Rdson) and switching losses (Qsw) in a wide variety of power conversion circuits [1]. The combination of hetero-epitaxy using silicon substrates and device fabrication alongside silicon CMOS products in high volume factories provides the necessary cost structure to compete commercially with silicon based alternatives.

The capability to grow thick crack free AlxGayN alloys on standard thickness silicon substrates in manufacturing volumes has often been underestimated either as an essential element to commercialization of GaN based power devices or as a significant technological hurdle when moving from non-commercially viable substrates such as SiC. In the ranking of required capabilities to successfully compete in the commercialization of GaN based power devices, such capability, together with supporting intellectual property should be considered the most important. As such, International Rectifier is among the very few institutions which have demonstrated such capability. As an example, IR has previously demonstrated the manufacturability of up to 5 um thick AlxGayN alloy epitaxy on standard thickness 150 mm Si substrates [2]. In addition the volume manufacturability of low distortion (bow = 15+/-10 um) crack free GaN on Si epitaxy for 2.25 um thick films on standard thickness (725 um) 200 mm diameter silicon substrates is demonstrated in Figure 1 for over 20 multi-wafer batches. These results are made possible through the use of IR's proprietary compositionally graded transition layer III-N on Si epitaxial technology [2]. Another essential requirement for commercialization is the ability to produce devices alongside the incumbent high volume silicon based power devices. Such capability has also previously been demonstrated by IR.

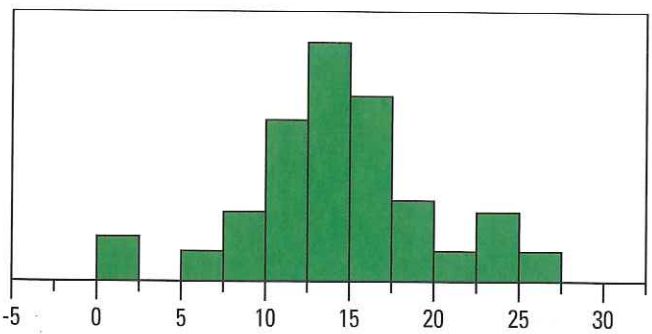

Figure 1: Measured distribution of final wafer bow for over 20 multi-wafer process runs producing more than 60 crack free 2.25 um thick AlGaN alloys based hetero-epitaxy on 200 mm standard thickness (725 um) silicon substrate.

It is often stated that development of an enhancement mode GaN based high electron mobility transistor (HEMT) is an essential element of commercialization. This is not a valid assertion. Besides the opportunity to use depletion mode, normally on devices, in a majority of power electronic circuits (e.g. using dc enable switch based topologies), several topologies, such as ac-ac converters used for motor drive, actually are superior when implemented with the inherently bi-directional capable depletion mode GaN based HEMT devices. In addition, the inherent instability of the two dimensional electron gas to positive applied fields which collapse the built in barrier potential of the AlGaN barrier layer (in AlGaN-GaN HEMTs) presents a severe crippling restriction of gate drive to any enhancement mode barrier based 2DEG device, through the limitation of applied overdrive gate voltage above threshold. Therefore, in the cases where normally off behavior is preferred, the cascoded configuration, using a low voltage MOSFET is recommended. In addition to providing a well established and reliable gate drive interface for external circuits, this approach has many advantages not found in an enhancement mode GaN based power device [3].

In addition to inherent and revolutionary integratability, the lateral GaN based (HEMTs) exhibit advantages of significantly lower terminal capacitances, several times lower specific source-drain resistance and essentially zero reverse recovery charge compared to either silicon based superjunction FETs or IGBT alternatives. It has been shown that the often feared current handling capability limitation associated with the lateral nature of the HEMTs can be effectively addressed through the use of front side solderable devices and dual sided surface mount packaging techniques. Current handling densities of more than 500 A /cm² at 150°C are demonstrated with large

(Wg = 330 mm, AA = 8 mm^2) 600 V rated devices capable of processing more than 80 A at room temperature [4,5].

Early long term reliability results for 600 V rated devices, which have previously been shown to exhibit negligible dynamic Rdson [6], under accelerated stress conditions of 480 V drain to source reverse bias for 5000 hrs at 150°C are presented in Figures 2 and 3; demonstrating the production readiness of IR's GaNpowIR® technology platform.

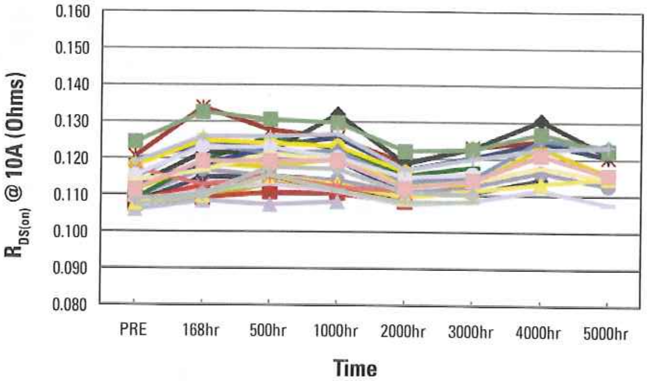

Figure 2: Source-drain resistance, Rdson of 600 V rated cascode switch for a population of representative cascoded GaN-on-Si based HEMT devices with Wg = 120 mm, under a drain bias of 480 V and 0 gate bias for 5000 hrs at 150°C.

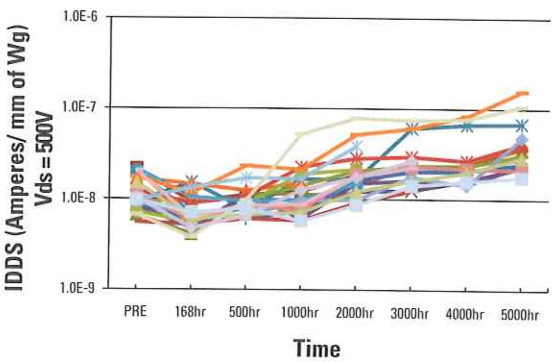

Figure 3: Source to drain leakage, Idss, current measured with 500 V drain bias and 0V gate bias of 600 V rated cascode switch for a population of representative cascoded GaN-on-Si based HEMT devices with Wg = 120 mm, under a drain bias of 480 V and 0 gate bias for 5000 hrs at 150°C.

The performance of these 600 V rated GaN-on-Si based devices in several widely used power topologies such as point of load dc-dc or ac-dc conversion have previously been presented [1]. One of the most wide-spread applications for 600 V rated devices is in the inverter drive circuitry for motors. It is therefore important to assess the value provided by GaN based power devices in motor drive applications. Figure 4 shows the dramatic improvement in power loss in a nominally 400 W motor drive inverter circuit, using state - of - the - art silicon based IGBTs or first generation 600 V GaN based cascaded switches. As can be seen the conduction losses are reduced by a factor of 6, while at the same time, the switching losses are reduced by a factor of 2. This remarkable result is based on the 4-10 x (depending on load current) improvement in the VceonxEsw (or RdsonxQsw) in the performance figure of merit of the GaN based devices over the silicon based IGBTs previously reported [6]. Such improvements in power handling capability allow for the related increase in the inverter power density of a factor of more than 10. In this instance, taking into account that the GaN based inverter does not require the heat sink of the silicon based inverters, the power processing volume density is increased by more than 100. Such revolutionary simultaneous improvements in power processing efficiency and density are examples of the potential of GaN based power devices to transform power electronics.

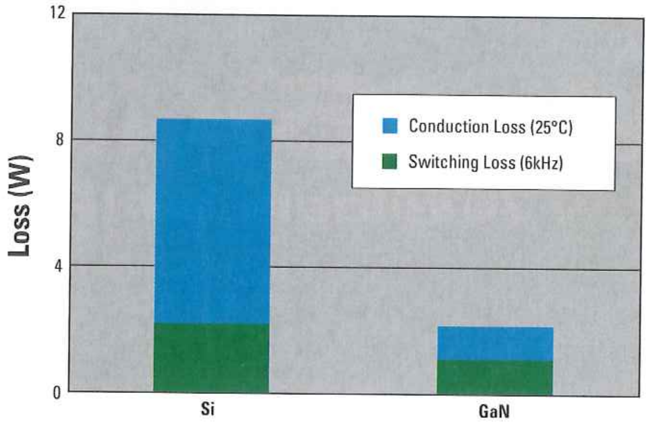

Figure 4: Measured conversion efficiency for nominally 400 W motor drive inverter, using either IR's GaNpowIR® based devices or state - of - the - art silicon based IGBTs and diodes.
Test Condition: IC = 1.5A, Vbus = 300V, Output voltage = 160V, Output Power = 415W, Tcase=150C.

Conclusion

The readiness of 600 V GaN-on-Si based power devices fabricated using International Rectifiers GaNpowIR® technology platform for large scale production is demonstrated. The combined improvement in power efficiency and density for these high power applications is nothing short of revolutionary.

Acknowledgment:

The author would like to thank the entire International Rectifier GaN Technology development team for their continued efforts in bringing this platform to commercial realization.

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