The Status of GaN based Power Device Development at International Rectifier

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Abstract

A review is presented of the current status of GaN based device development at International Rectifier. Several fundamental technological barriers to the achievement of a commercially viable device platform are discussed. The characteristics of the resulting GaN based devices are compared to those of state of the art silicon alternatives from 20 to 600 V. The relative performance of GaN based devices to best in class silicon incumbents in a variety of circuit topologies from high frequency dc-dc point of load to class-D audio and offline ac-dc converters are presented.

INTRODUCTION

A sustained engineering effort extending more than 8 years at International Rectifier has resulted in the development of commercially viable GaN based power devices rated for operation between 20 and 600 V. This technology platform, referred to as GaNpowIR ™ is based on the use of hetero-epitaxial III-N films on large diameter silicon substrates with device processing using standard high volume silicon fabrication facilities. This has required the resolution of several key technological obstacles which are further enumerated here. The availability of substantially better performance-to-cost power devices than are possible using the incumbent silicon based technology will enable a revolutionary transformation in the power conversion field.

TECHNOLOGICAL OBSTACLES OVERCOME

Though many of the technological challenges are the same for all commercially viable GaN based power devices, the emphasis varies depending on the device performance requirement. For instance, the need to produce reproducibly low contact resistance is important for 600 V devices, but is critical for competitive 20 V devices, where the contact resistance can represent 30 % of the overall device resistance. The development of low voltage GaN based power devices required the manufacturable fabrication of gold free contacts with specific resistance consistently less than 0.3 ohm-mm. This was accomplished using standard Al based interconnect technology commonly used in silicon device fabrication, together with standard Al-Ti ohmic metallurgy used for GaN based HEMTs [1]. Likewise, the development of epitaxial processes to provide crack free, low warpage/bow starting material for device fabrication is difficult for 20 V devices at about 2 um of epitaxy, but it is very complex for 600 V or higher material with over 4.5 um of total epitaxy. In order to facilitate high mechanical wafer fabrication yields, as well as uniform photo-lithograhic yields, it was determined that the maximum acceptable wafer bow is about -25 microns. In addition, total wafer warpage needs to be kept below 60 microns. This was accomplished through the use of a proprietary III-N transition and buffer layer technology on 150 and more recently 200 mm diameter silicon wafers of standard thickness. The use of a proprietary insulated gate construction has enabled the reduction of gate leakages to less than 10 pA/ mm of gate periphery, well below the common 1-1000 uA/mm most often reported for Schottky or even p-n gate devices. This insulated gate construction has also resulted in the complete elimination of the often cited " reverse piezo-electric effect" found for Schottky gate structures. High voltage device drain leakage through the epitaxial layer to the substrate or between drain and source terminals has been reduced to less than 1 nA/mm of gate periphery at the rated voltage of 600 V. Long term stability has been demonstrated for over 10 Million device hours under stress for low voltage devices. A high density, high voltage capable backend interconnect was developed to support 600 V rated devices.

DEVICE PERFORMANCE

As previously reported [1,2] low voltage GaN based power devices were successfully developed to achieve operational performance in excess of the best in class silicon based devices and have enabled power conversion circuits to provide better efficiency and density than other wise possible. Here it will be shown that for mid voltage (100 V) and high voltage (600 V) devices, even more glaring performance advantages are found for first generation GaN based devices over the silicon incumbents. A factor of 4 improvement in conduction loss * switching loss performance (or Ron* Qsw) has been found for 100 V GaN vs. best in class uni-polar silicon MOSFETs, as well as for 600 V GaN switches vs best in class superjunction MOSFETs and vs 600 V Insulated Gate Bipolar Transistors (IGBTS). It is shown that GaN based rectifiers perform comparable to silicon carbide diodes, at a substantially reduced production cost.

Application Performance

The performance of low voltage GaN based power devices is demonstrated in world class point of load buck circuits operating at 5 to 10 MHz from 12 V to 1.8 V with 88 and 84 % peak efficiency respectively. Mid voltage 100 V devices are shown to provide far superior performance in class D audio circuitry in terms of efficiency, density and total harmonic distortion compared to best in class silicon based devices. High voltage, 600 V, devices are shown to substantially out-perform state of the art silicon based devices in a wide variety of circuits, including a power-factor-correction boost (150 Vin to 450 Vout) converter and a 400 kHz, 300Vin to 30 Vout buck converter. In all cases, robust GaN based device operation is demonstrated with significantly improved efficiency and density compared best in class silicon based devices.

Conclusions

A commercially viable GaN based power device technology platform has been developed at International Rectifier. The resulting devices outperform state of the art silicon based alternatives from 20 to 600 V in terms of inherent device characteristics as well as in circuit behavior.

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References

[1] M.A. Briere, *GaN on Si Based Power Devices: An Opportunity to Significantly Impact Global Energy Consumption,* Proceeding of the 2010 CS MANTECH Conference Technical Digest, February 2010.

[2] M.A. Briere, IEDM 2010, December 2010

Acronyms

HEMT : High Electron Mobility Transistor
Ron : Specific On-Resistance
Qsw : Charge associated with device Switching