GaN and SiC Power Rectifiers

J. Kim[1], J.W. Johnson[1], S. Nigam[1], B. Luo[1], F. Ren[1], S.J. Pearton[2], J.-I. Chyi[3], S.S. Park[4], Y.J. Park[4], G. Chung[5] and J. Williams[5]

1. Dept. of Chemical Engineering, Univ. of Florida, Gainesville, FL 32611
2. Dept. of Materials Science and Engineering, Univ. of Florida, Gainesville, FL 32611 USA
3. Dept. of Electrical Engineering, National Central University, Chung-Li 32054, TAIWAN
4. Samsung Advanced Institute of Technology, Suwon 440-600, SOUTH KOREA
5. Sterling Semiconductor, Inc., Tempa, FL 33619

There are emerging applications for GaN and SiC electronics in control and switching of electric power in the utilities industry, advanced radar sub-systems, and in the drive-trains of hybrid electric vehicles. A key component of the inverter modules for such applications is the power rectifier. Several groups have reported excellent high breakdown voltage performance from both lateral and mesa geometry GaN, AlGaN and SiC Schottky as well as p-i-n rectifiers. For the SiC Schottky diodes, reverse breakdown voltage and forward current of <1000V and 2A, respectively are commercially available. However, there are still numerous limitations to these GaN rectifiers, including higher reverse leakage current than expected from thermionic emission, high forward turn-on voltages, negative temperature coefficients for reverse breakdown voltage, non-uniformities, and the low thermal conductivity of sapphire. The availability of electrically conductive bulk GaN substrates would allow fabrication of vertical geometry rectifiers with thick drift regions capable of much higher current conduction and superior thermal management, as compared to lateral rectifiers fabricated on insulating substrates. In this work we report, for the first time, the fabrication of edge-terminated, vertically-depleting GaN rectifiers fabricated on novel HVPE-grown bulk GaN templates.

The bulk GaN was grown by hydride vapor phase epitaxy on sapphire substrates and lifted-off by laser heating to produce free-standing ~300 μm thick templates. Chemical mechanical polishing and dry etching were used to smooth as-grown sample, producing a final substrate thickness of ~200 μm. The defect density was ~10^5 cm^{-2}, which is 3-5 orders of magnitude lower than typical heteroepitaxial films on sapphire substrates.

Large-area (~7 mm) and small-area (~50-100 μm) diodes were fabricated in both lateral and vertical geometries with p^+ guard ring edge termination (Fig. 2). The I-V characteristics of a 54 μm vertical diode are given in Fig. 3, illustrating reverse breakdown V_B >150 V and extremely high forward current density J_F >2 kA-cm^{-2}. The specific on-state resistances (R_{ON}) for the three types of rectifiers measured were 3 mΩ-cm^2 for the small-area vertical diodes, 1.7 mΩ-cm^2 for the small-area lateral diodes, and 3.4 Ω-cm^2 for the large-area devices, producing a figure of merit, V_B^2 / R_{ON} of ~8.5 MW-cm^{-2} for small-area devices. This on-state resistance is the lowest reported for any GaN rectifier. The forward turn-on voltage (V_F) was ~1.8 V, roughly half the value for previously reported GaN Schottky rectifiers on heteroepitaxial layers. For the small-area devices, V_F increased with temperature above 100°C. Reverse current was thermally activated with an activation energy of 0.11 ± 0.04 eV, perhaps representing the most prominent surface state giving rise to the current.

Switching performance was analyzed using the reverse recovery current transient waveform, demonstrating nsec switching and minimal stored charge. From these data, we estimate a value of ~15 nsec for the high injection level hole lifetime in our rectifiers. This is within the range of 1-20 nsec for previously reported minority carrier lifetimes in n-GaN.

When placed into context with reported values, these novel bulk GaN rectifiers show significant improvement in forward current density and on-state resistance compared to previously reported devices. In this talk, we will also present the anneal effect on the forward current density.