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Ultra-thin gate dielectrics for leakage current suppression in vertically-scaled GaN MIS-HEMTs

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GaN high-electron-mobility transistor (HEMT) transistor technology is beginning to gain traction in the power switching and amplifier markets. While commercial GaN products are available now, there is still a large, on-going research effort to push the switching speeds and power handling capabilities of HEMTs towards theoretical limits. One issue that routinely prohibits novel GaN devices from achieving their maximum electrical performance potential is gate leakage current.

Off-state gate leakage current is undesirable for a number of reasons. In addition to contributing to large stand-by power dissipation values, gate leakage current causes a device to have a soft breakdown character that limits the operating voltage range of the transistor. As GaN transistor heterostructures are vertically-scaled to maintain device aspect ratio and support shorter gate length, the electric fields in close proximity to the gate increase and exacerbate the leakage problem. As a method of suppressing gate leakage current in scaled devices, we have investigated the use of several types of gate insulators and have evaluated the resulting device dc and RF electrical performance. Atomic layer deposition (ALD) Al_2O_3, HfO_2, Ta_2O_5, and TiO_2 have been applied to several different Ga-polar and N-polar GaN devices and have been shown to reduce gate leakage current compared to Schottky-gate reference devices.

As an alternative to ALD for deposition of the gate dielectric, we have also investigated the use of ultra-thin (1 - 6 nm) molecular-beam epitaxy (MBE) grown silicon nitride (SiN) on vertically-scaled 2.3 nm $In_{0.17}Al_{0.83}N$/1 nm AlN/GaN HEMTs on SiC. The thin layers of MBE SiN were deposited at 575 °C prior to any device fabrication. RF devices with gate lengths ranging from 65 nm to 1 µm and source-drain spacing of 3 µm were fabricated using standard processing methods. Electrical characterization of these insulated-gate devices showed excellent suppression of gate leakage current. Figure 2 shows that reverse-biased gate leakage current was consistently low for all thicknesses of SiN used in this study. The benefit of the reduced gate leakage current was evident in the excellent off-state breakdown behavior, shown for a 65 nm device in Figure 3. With a breakdown voltage of 82 V and an extrinsic f_T/f_{max} = 118/208 GHz, this device had a high f_T x V_{BK} product, greater than 9 THz-V.

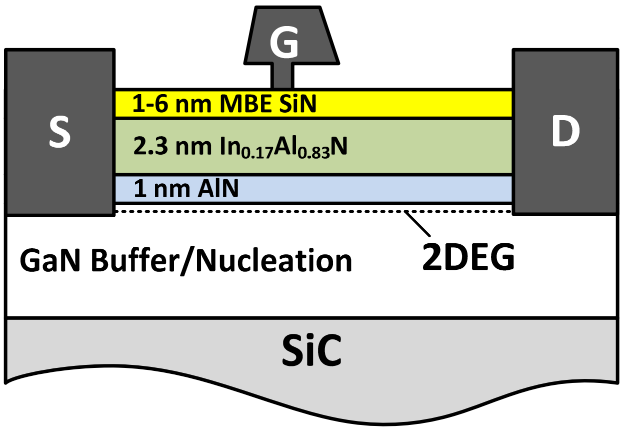

Figure 1 – Schematic of an MBE SiN insulated T-gate $In_{0.17}Al_{0.83}N$/AlN/GaN HEMT used in this study.

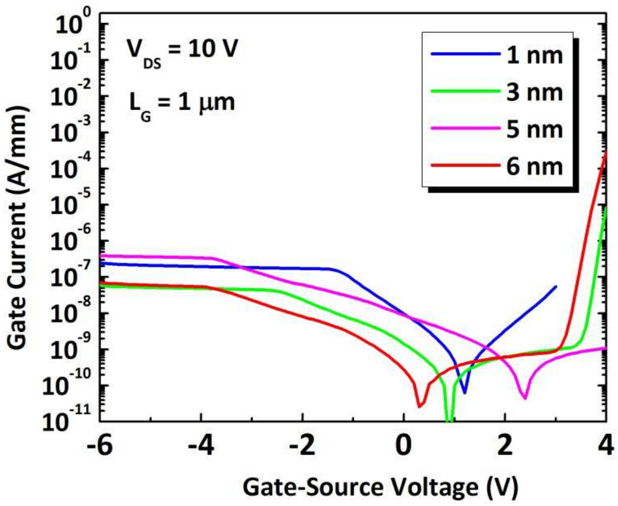

Figure 2 – Gate current characteristics for 1 µm gate-length MIS-HEMTs with various thicknesses of MBE SiN gate insulator.

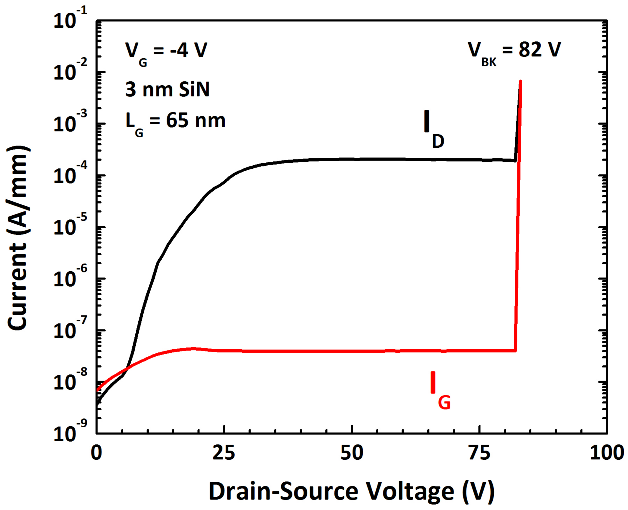

Figure 3 – Off-state breakdown characteristics for 65 nm T-gate MIS-HEMT with 3 nm MBE SiN gate insulator.

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