Sub-Micron thick Step-Graded AlGaN Buffer on Silicon with a Buffer Breakdown Field Higher Than 6 MV/cm

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GaN based High Electron Mobility Transistors (HEMTs) have drawn great attention due to their potential for high power millimeter-wave applications [1, 2]. Usually, thick buffer layers (several µm) are used to minimize growth defect/dislocation density due to the large lattice mismatch between GaN and the substrate. However, thick buffer layers degrade the thermal dissipation and increase the epi-wafer cost. Recent results proved that AlGaN/GaN HEMTs with sub-micron total thickness grown on Silicon Carbide (SiC) can show competitive DC and RF characteristics [3]. However, the use of Silicon (Si) substrate would further decrease the cost although more challenging to achieve due to the large thermal expansion mismatch between GaN and Si potentially leading to cracks. **In this work, we demonstrate the successful fabrication of sub-micron thick AlGaN/GaN HEMT epilayers grown on Si (111) substrate delivering a record vertical buffer breakdown field > 6 MV/cm. Fully functional transistors with promising off-state breakdown voltage have been fabricated.**

Two different AlN nucleation layer (NL) with thickness 1 (t_1) << thickness 2 (t_2) have been grown by ammonia-Molecular Beam Epitaxy on 8-inch Si(111) substrates followed by step-graded $Al_xGa_{1-x}N$ buffer layers ($Al_{0.60}Ga_{0.40}N$ /$Al_{0.30}Ga_{0.70}N$/ $Al_{0.08}Ga_{0.92}N$), a 170 nm thick GaN channel layer, 1 nm thick AlN spacer and 14 nm thick $Al_{0.32}Ga_{0.68}N$ barrier capped with 1 nm GaN layer (Fig. 1). The total stack thickness is less than 650 nm for the AlN NL t_1 and the second structure has also a total thickness below 1 µm. The source/drain ohmic contacts were achieved by partially etching the AlGaN barrier prior to a Ti/Al/Ni/Au metal stack deposition and annealed at 825°C. A mesa etching (150 nm depth) has been used to realize the isolation step. Then, Ni/Au gates of 3 µm length were deposited. Finally, the devices were passivated before Ti/Au pads deposition. As expected from the XRD data, the structure having a thicker AlN nucleation layer exhibits a higher mobility. The 2DEG properties have been measured by Hall effect measurements and showed a charge density of 1.1×10^{13} cm^{-2} and 1.3×10^{13} cm^{-2} with an electron mobility of 1050 $cm^2/V.s$ and 1530 $cm^2/V.s$ for AlN NL t_1 and t_2, respectively.Vertical BV measurements on isolated ohmic contacts have been measured (Fig. 1). A leakage current below 1 mA/cm^2 is observed up to 400 V and 200 V with a hard BV at 500 V and 375 V for the AlN NL t_1 and t_2, respectively. This results in a remarkable vertical buffer breakdown field > 6 MV/cm for AlN NL t_1. To better understand the origin of this result, we performed a decomposition study of the structure with AlN NL t_1 by etching several samples down to the different epilayers: channel, $Al_{0.08}Ga_{0.92}N$, $Al_{0.30}Ga_{0.70}N$, $Al_{0.60}Ga_{0.40}N$ and Si(111) substrate (Fig. 2). The vertical BV of the decomposed structure shows that the remarkable vertical breakdown field is clearly attributed to the insertion of Al-rich AlGaN in the buffer layers combined with an optimized AlN NL offering outstanding breakdown strength of about 15 MV/cm. The 3-terminal off-state BV has been measured at V_{GS} = - 6 V for various gate to drain distance for AlN NL t_1 and t_2 (Fig. 3). A leakage current well below 100 µA/mm up to 200 V regardless of the gate to drain distance is observed for AlN NL t_1 while AlN NL t_2 transistors deliver 2 orders of magnitude higher leakage current even at low bias. Moreover, DC characteristics shows fully functional transistors with low off-state leakage current (Fig. 4).

These results confirm that AlN buffer layers play a decisive role and surprisingly, it is shown that it can be advantageous to reduce the thickness of the AlN buffer layer in order to improve the breakdown voltage and to reduce leakage current.

References

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Supplementary information

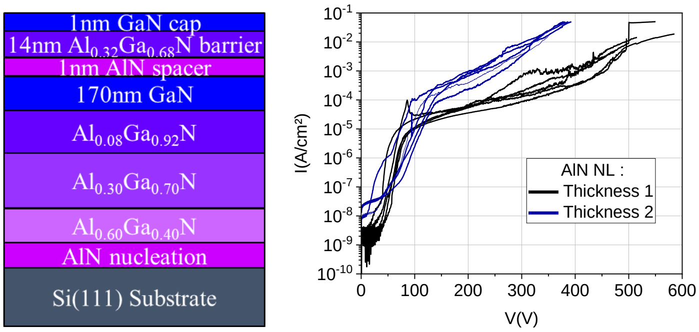
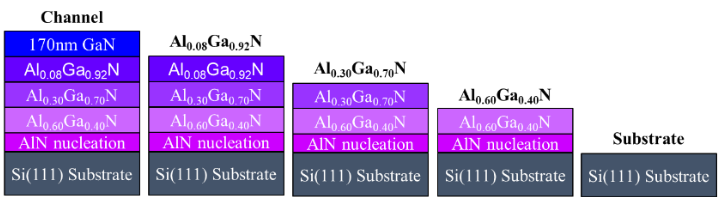


Figure 1: Schematic cross section of the AlGaN/GaN HEMTs (left) and vertical breakdown characteristics of the sub-micron GaN-on-Si HEMT with AlN NL thickness1 and 2 (right).

Channel	$Al_{0.08}Ga_{0.92}N$	$Al_{0.30}Ga_{0.70}N$	$Al_{0.60}Ga_{0.40}N$	
6.3	9.6	12.1	15.8	Breakdown Field (MV/cm)



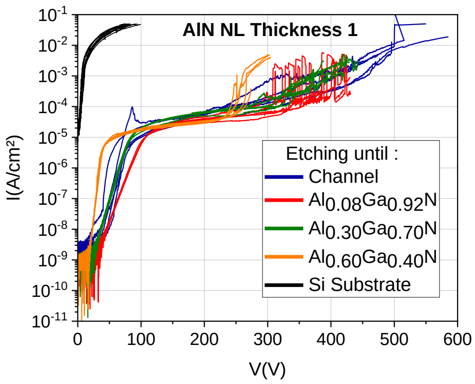


Figure 2: Vertical breakdown and breakdown field characteristics of the decomposed step-graded $Al_xGa_{1-x}N$ buffer and the Si(111) substrate.

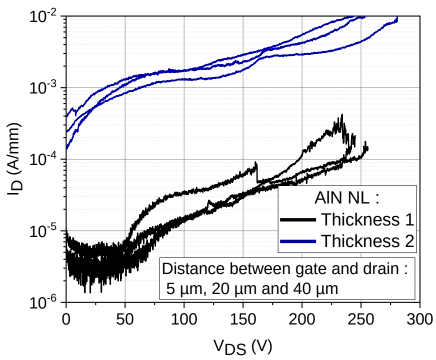


Figure 3: Three-terminal off-state breakdown voltage characteristics of sub-micron thick 2×50 µm AlGaN/GaN HEMTs with AlN NL thickness 1 and 2 for various gate to drain distance.

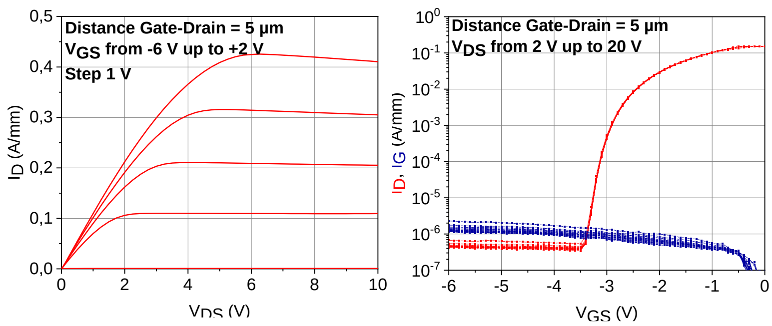


Figure 4: Output characteristics (left) and transfer characteristics (right) of a sub-micron thick 2×50 µm AlGaN/GaN HEMT with AlN NL thickness 1 for a gate to drain distance of 5 µm.