AlGaN channel high electron mobility transistors on bulk AlN substrate

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Nowadays, AlGaN/GaN HEMTs have become the sailor of the next generation of power devices delivering promising electrical performance as compared to conventional silicon based power devices. Novel HEMTs based on the $Al_xGa_{1-x}N$ channel are becoming the subject of interest for pushing the performance of power devices beyond the limitations of GaN devices [1]. In this work, we report on the first electrical operation of AlGaN channel HEMTs grown on bulk AlN substrate. The $Al_{0.23}Ga_{0.77}N$ channel HEMT showed remarkable transistor breakdown voltage > 2100V for large gate-drain spacing. In contrast, a significantly lower breakdown voltage is observed in HEMT-on-AlN using various GaN channel thicknesses. Lastly, we show a short-term robustness test comparison of GaN and AlGaN channel devices under a high electric field.

The $Al_{0.60}Ga_{0.40}N$ /$Al_{0.23}Ga_{0.77}N$ and $Al_{0.30}Ga_{0.70}N$ /GaN heterostructures were grown by ammonia source MBE on 2″ bulk AlN substrates. The three different heterostructures were realized with 200nm GaN channel (Sample_A), 100nm GaN channel (Sample_B), and 500nm thick AlGaN channel. The active area of devices was mesa isolated down to the bulk AlN. MIS (Metal Insulator Semiconductor)-HEMTs devices were fabricated by deposition of 30nm PECVD SiN before e-beam evaporation of 3µm Ni/Au gates, with a 2×50 µm width. The DC transfer characteristics of HEMTs show fully functional devices with low-off state leakage current (about 1µA/mm) and good on-state performance (see Fig.2). The output DC characteristics yield a maximum drain current of I_d=900 mA/mm for Sample_A, I_d=173 mA/mm for Sample_B, and I_d=280 mA/mm for Sample_C as shown in Fig. 3. This concurs with the sheet resistances but it is limited by the non-optimized ohmic contacts. Buffer breakdown characteristics reveals an excellent quality of AlN substrate showing a breakdown field up to 9MV/cm for low contact spacing and a buffer breakdown voltage as high as 3600V for a contact spacing of 31 µm defined at 1 µA/mm. The high voltage characteristics of $Al_{0.23}Ga_{0.77}N$ channel transistors outperform GaN channel devices with an off-state breakdown voltage of 2189 V for GD = 40µm against less than 500 V, respectively. A robustness test comprises 20 times 1500V off-state sweeps realized on Sample_B and Sample_C in order to evaluate their performance under a high electric field. For GaN channel device the off state, leakage current increases by two folds after stress while AlGaN channel device showed no change in leakage current. The threshold voltage shift is ascribed to trapping effects.

References

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[2] J. Mehta, I. Abid, T.H. Ngo, Y. Cordier, F. Medjdoub, 44th Workshop on Compound Semiconductor Devices and Integrated Circuits, WOCSDICE 2021.

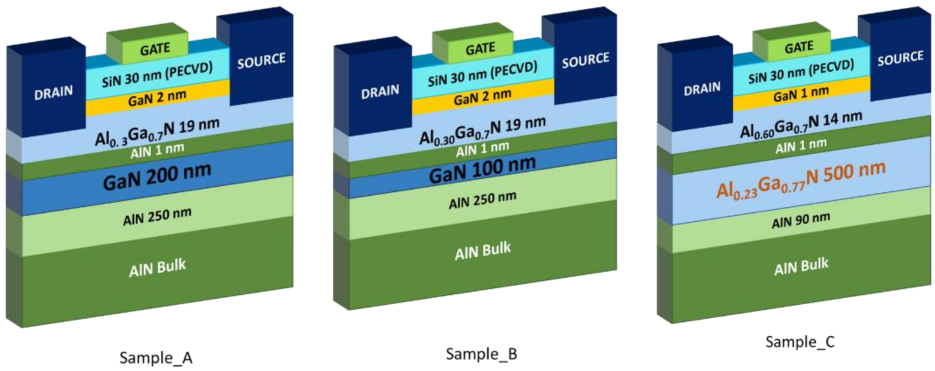

Fig. 1 Schematic diagram of GaN and AlGaN channel HEMTs

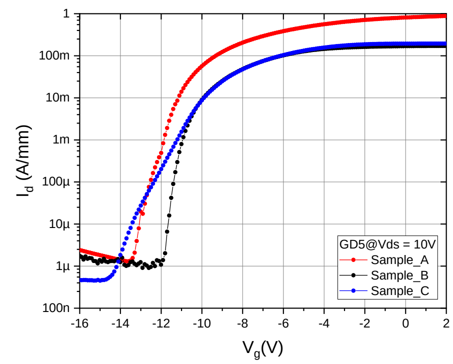

Fig. 2 I_d-V_g characteristics

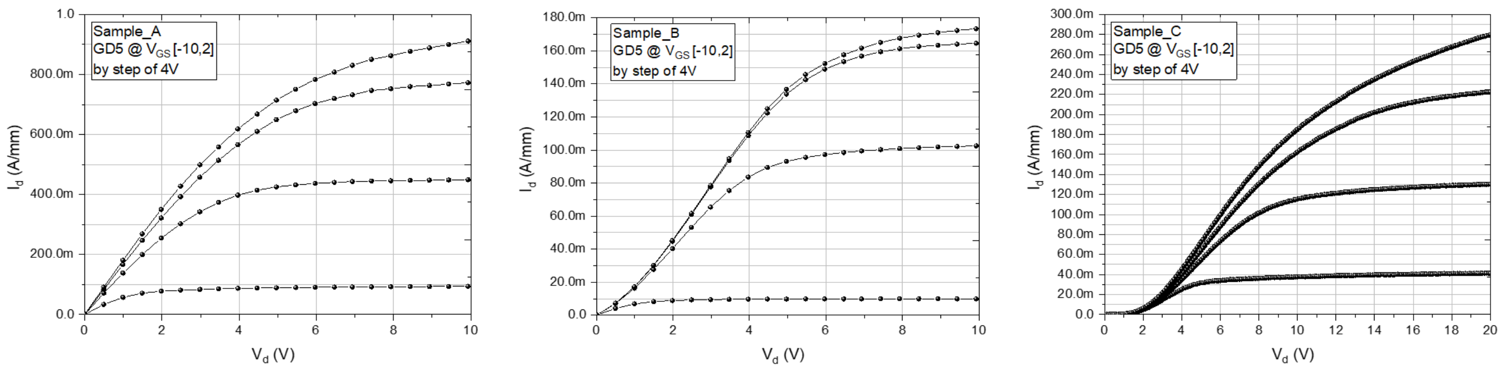

Fig. 3 I_d-V_d characteristics of Sample_A (left), Sample_B (middle) and Sample_C (right) for gate-drain spacing of 5 µm.

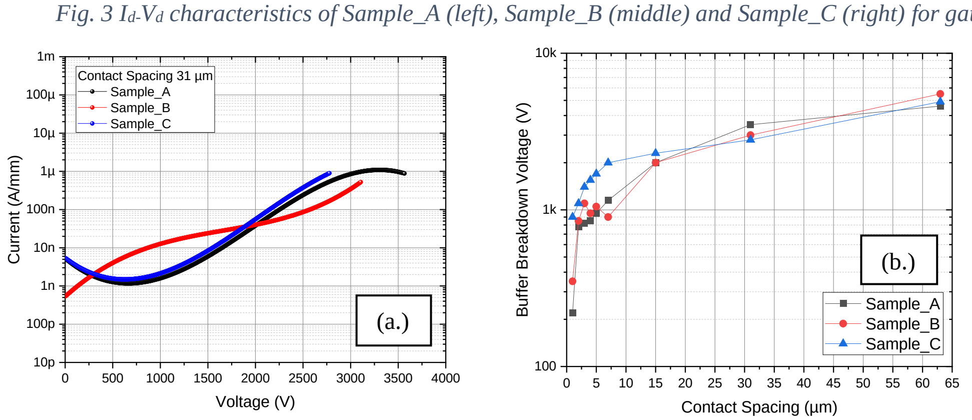

Fig. 4 (a.) Buffer breakdown characteristics for 31µm contact spacing , (b.) buffer breakdown voltage vs two terminal contact spacing (right)

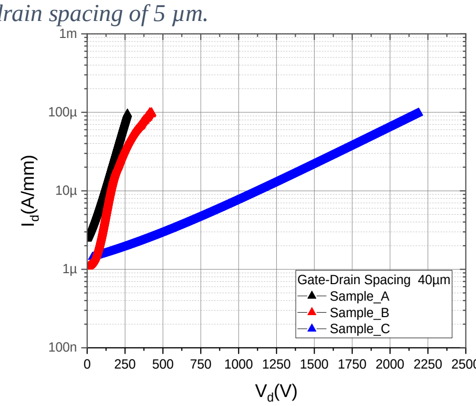

Fig. 5 (a.)Transistor Breakdown I-V characteristics for transistor with 40µm gate-

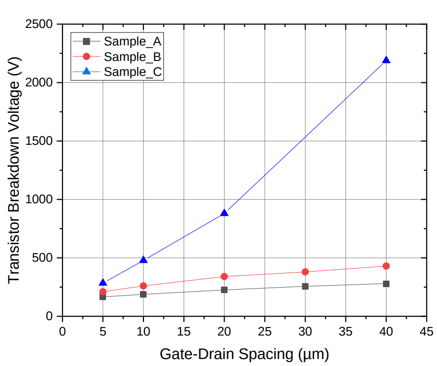

Fig. 5 (b.) Transistor Breakdown Voltage realised at 100µA/mm leakage current vs gate-drain spacing

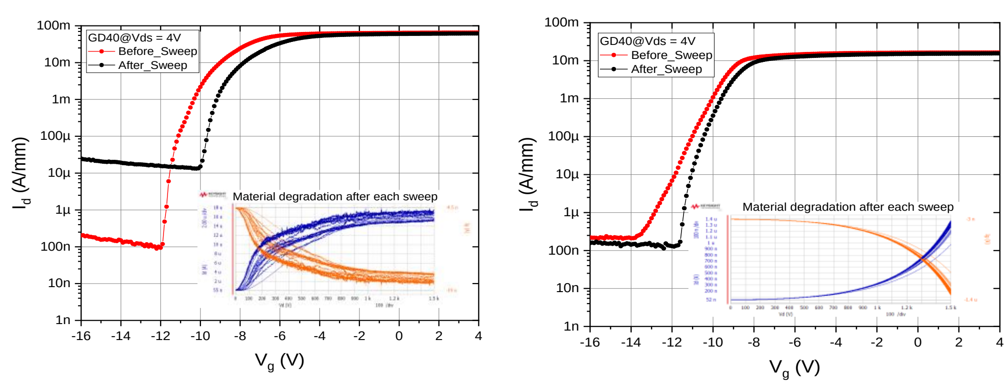

Fig. 6 I_d-V_g characteristics of Sample_B (left) and Sample_C (right)