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# AlGaN channel high electron mobility transistors on bulk AlN substrate

J. Mehta<sup>1,\*</sup>, I. Abid<sup>1</sup>, R. Elwaradi<sup>2</sup>, Y. Cordier<sup>2</sup>, F. Medjdoub<sup>1</sup>

<sup>1</sup>*IEMN, CNRS, Université de Lille, 59650 Villeneuve d'Ascq, France.*

<sup>2</sup>*Université Côte d'Azur, CNRS, CRHEA, rue Bernard Grégory, 06560 Valbonne, France.*

\*email: [jashrinku.mehta@univ-lille.fr](mailto:jashrinku.mehta@univ-lille.fr)

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  $\text{Al}_x\text{Ga}_{1-x}\text{N}$  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  $\text{Al}_{0.23}\text{Ga}_{0.77}\text{N}$  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  $\text{Al}_{0.60}\text{Ga}_{0.40}\text{N}/\text{Al}_{0.23}\text{Ga}_{0.77}\text{N}$  and  $\text{Al}_{0.30}\text{Ga}_{0.70}\text{N}/\text{GaN}$  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 3 $\mu\text{m}$  Ni/Au gates, with a 2 $\times$ 50  $\mu\text{m}$  width. The DC transfer characteristics of HEMTs show fully functional devices with low-off state leakage current (about 1 $\mu\text{A}/\text{mm}$ ) 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  $\mu\text{m}$  defined at 1  $\mu\text{A}/\text{mm}$ . The high voltage characteristics of  $\text{Al}_{0.23}\text{Ga}_{0.77}\text{N}$  channel transistors outperform GaN channel devices with an off-state breakdown voltage of 2189 V for  $\text{GD} = 40\mu\text{m}$  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, 44<sup>th</sup> Workshop on Compound Semiconductor Devices and Integrated Circuits, WOCSDICE 2021.

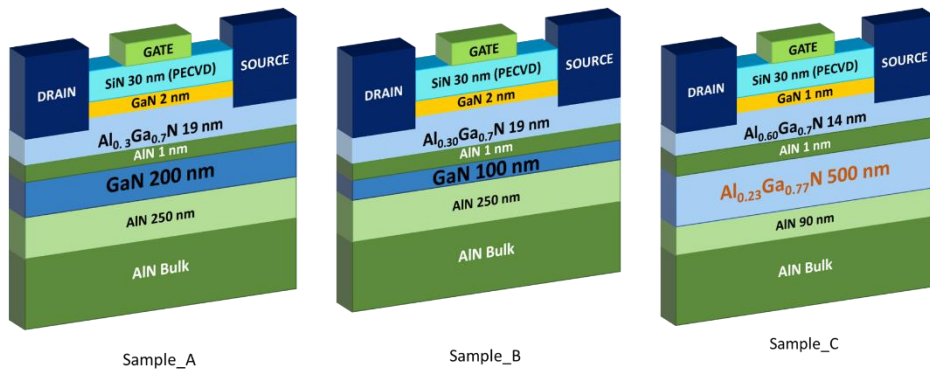


Fig. 1 Schematic diagram of GaN and AlGa channel HEMTs

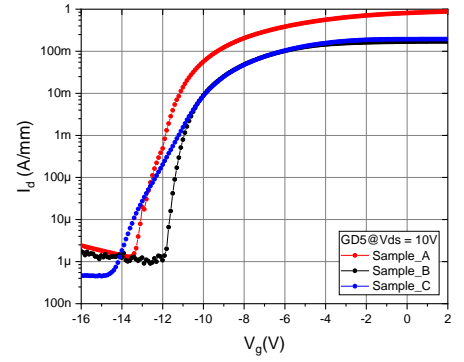


Fig. 2  $I_d$ - $V_g$  characteristics

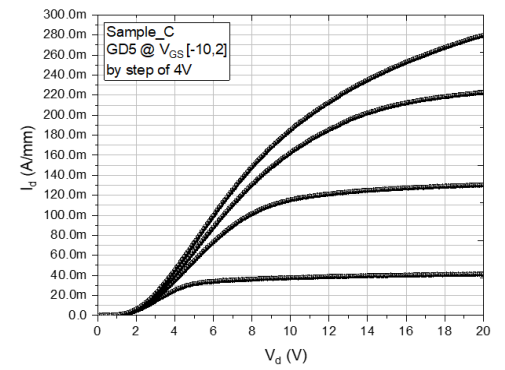
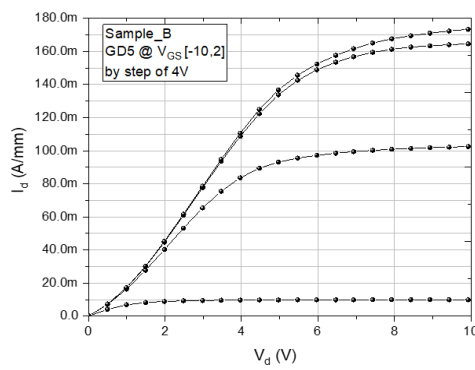
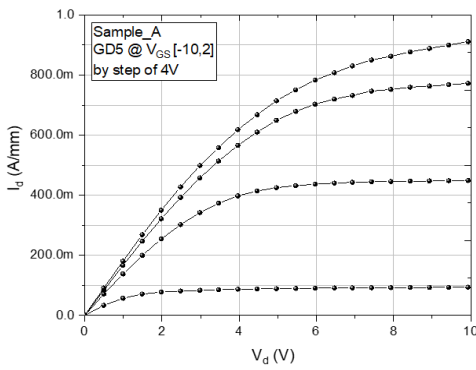


Fig. 3  $I_d$ - $V_d$  characteristics of Sample\_A (left), Sample\_B (middle) and Sample\_C (right) for gate-drain spacing of  $5\ \mu\text{m}$ .

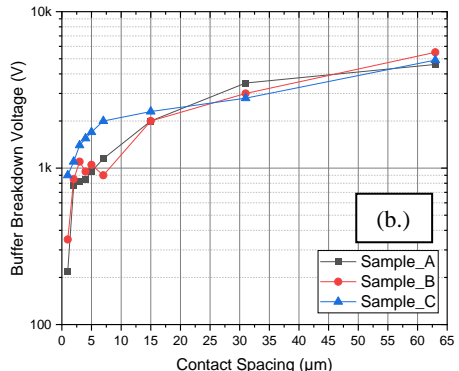
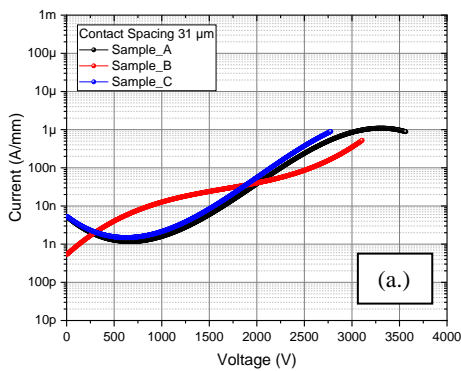


Fig. 4 (a.) Buffer breakdown characteristics for  $31\ \mu\text{m}$  contact spacing, (b.) buffer breakdown voltage vs two terminal contact spacing (right)

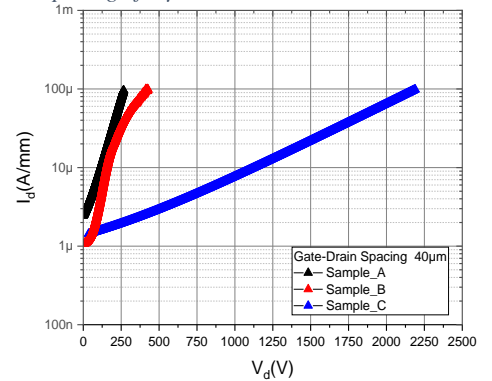


Fig. 5 (a.) Transistor Breakdown I-V characteristics for transistor with  $40\ \mu\text{m}$  gate-drain spacing

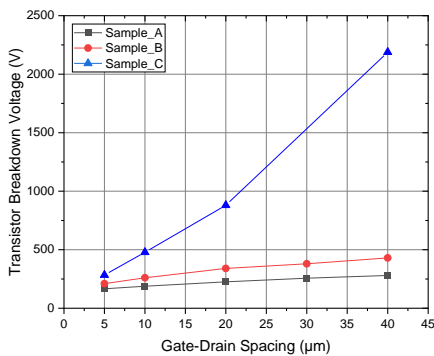


Fig. 5 (b.) Transistor Breakdown Voltage realised at  $100\ \mu\text{A/mm}$  leakage current vs gate-drain spacing

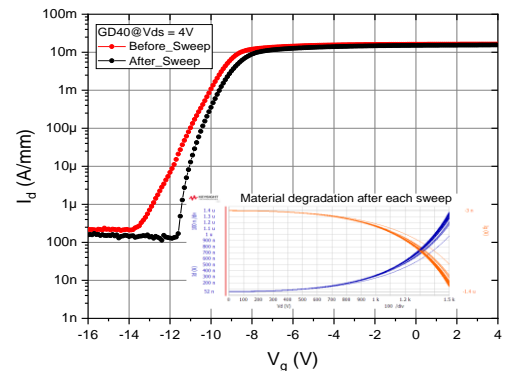
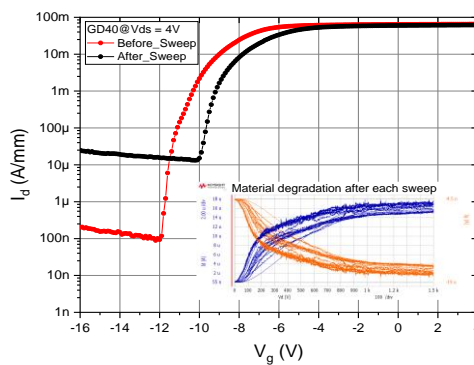


Fig. 6  $I_d$ - $V_g$  characteristics of Sample\_B (left) and Sample\_C (right)