AlGaN/GaN HEMTs on AlN substrate for power electronics

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Abstract - GaN high electron mobility transistors (HEMT) are becoming the mainstream for high frequency and power switching applications. On the other hand, Ultra-Wide Band Gap (UWBG) materials such as AlN that has a bandgap of 6.2 eV are attracting attention for pushing the limits of high voltage power devices. In this work, we report on AlGaN/GaN-on-AlN HEMTs using thick and thin GaN channels in comparison with GaN-on-Si HEMTs using a similar thin epi-design.

I. Introduction

GaN HEMTs have changed the scenario from consumer level to advanced power electronic applications by saliently expanding the power competency and reducing the size of devices. Alternatively, aluminium nitride (AlN) based devices delineates the performance of UWBG devices for enhancing device operation in multiple kV's and ultimately making the device smaller and powerful compared to GaN and Si based devices. Here, we demonstrate the potential of AlGaN/GaN-on-AlN HEMT for high voltage power electronic applications.

II. Experimental and Results

The sub-micron thick AlGaN/GaN heterostructures were grown by molecular beam epitaxy (MBE) on bulk AlN and Si substrates. The structure comprises 150 nm AlN nucleation layer, followed by a GaN channel layer, 1 nm thin AlN spacer layer, 19 nm $Al_{0.3}Ga_{0.7}N$ barrier layer and 2nm GaN cap on top (see Fig. 1).

In HEMT processing Ti/Al/Ni/Au for ohmic contact (≈ 0.6Ω.mm) and Ni/Au metal stacks for gates were used. The contacts were processed using double layer optical photolithography followed by inductive coupled plasma (ICP) etching of part of the AlGaN barrier using Cl_2/Ar plasma. The metalization was concluded by evaporation using PLASSYS MEB550S E-beam evaporator followed by lift-off with SVC-14 solvent. Mesa isolation was performed by ICP using Cl_2/Ar plasma succeeded by SiN passivation with deposition by plasma enhanced chemical vapor deposition (PECVD).

From Hall measurements, a high 2DEG density of 10^{13} cm^{-2} or close is observed on all samples. However, the electron mobility is significantly higher (1920 cm^2/V. s) for the thick channel on AlN substrate most probably due to the much better material quality as compared to the similar epilayers grown on Si. It can be pointed out that thinner GaN channel results in lower electron mobility. All transistors are fully functional (see Fig. 2) with low leakage current and on-state currents in agreement with the sheet resistance (Fig. 1). As expected, a drastically higher buffer breakdown is obtained on AlN substrates (Fig. 3) as measured between isolated contacts with multiple kV as compared to about 100V in Si substrate. However, interestingly the thinner channel (50nm) delivers about 10 times higher 3-terminal breakdown voltage (BV) than the 500nm thick channel on AlN substrate (Fig. 3). From the off-state characteristics (Fig. 4), electron injection into Si substrate is clearly confirmed with a high drain leakage while observing a low gate leakage current. In the case of AlN substrates, the gate and drain leakage currents match all the way to the breakdown, reflecting the absence of electron injection into the substrate.

III. Conclusion

As expected, AlGaN/GaN-on-AlN devices increase the breakdown capacity of devices as compared to AlGaN/GaN-on-Si device giving a brief outlook of their benefit for next generation power electronics. Electron injection phenomena is observed with AlGaN/GaN-on-Si device portraying the limitation of the Si substrate, which is exacerbated by the use of a thin buffer. On the other hand, thinner GaN channel grown on AlN delivers superior breakdown voltage. This indicates that the electric field peaks more into the AlN as the space charge region enlarges and thus the device is less prone to the GaN channel layer. The study of even thinner GaN channel structures using the same epi-design is under way in order to elucidate the impact of GaN channel thickness on the overall device breakdown**.**

IV. References

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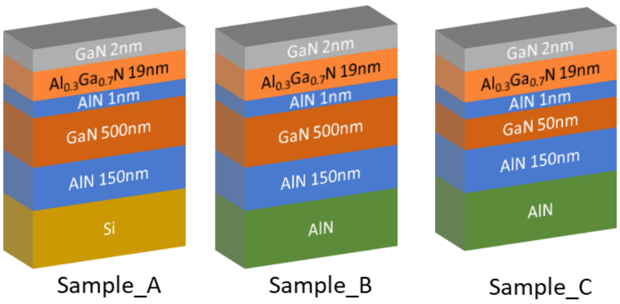

	R_{sh} [Ω/□]	Electron mobility [cm²/V.s]	N_S [cm^{-2}]
Sample A	800	950	8×10^{12}
Sample B	330	1920	1.0×10^{13}
Sample C	1700	460	8×10^{12}

Fig. 1: Schematic cross section and 2DEG properties AlGaN/GaN-on-Si and -on-AlN HEMTs

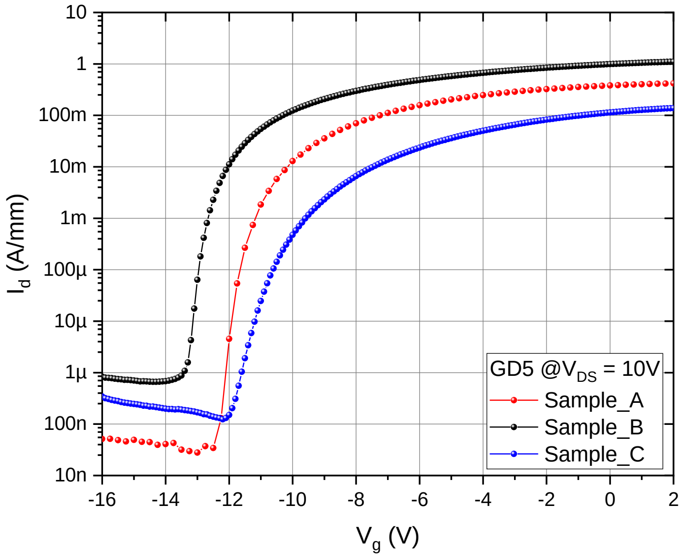

Fig. 2: I_d-V_g characteristics of AlGaN/GaN-on-Si and AlGaN/GaN-on-AlN HEMTs

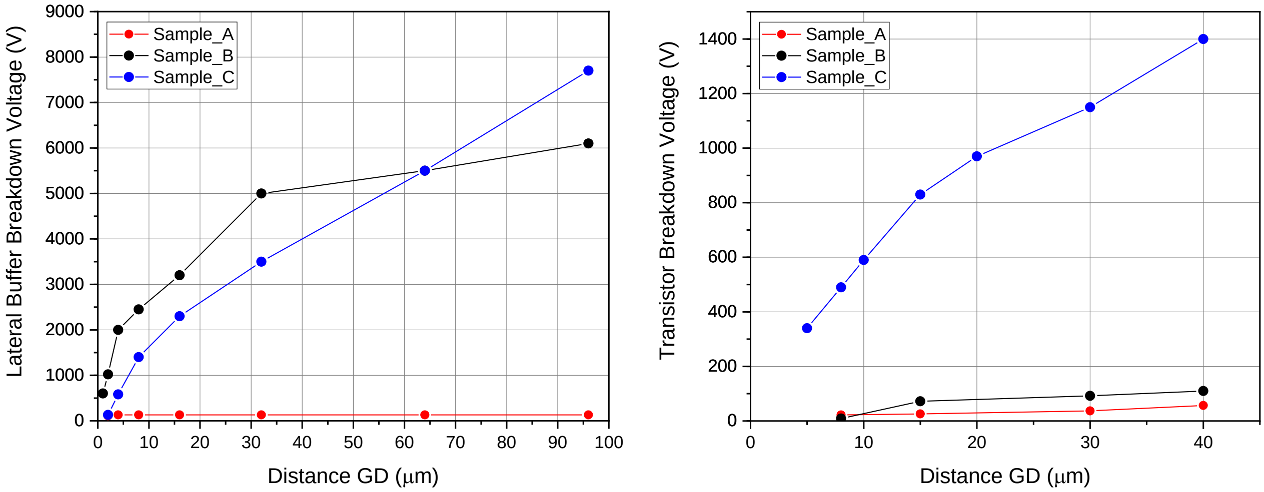

Fig. 3: Lateral buffer breakdown and 3-terminal transistor breakdown voltage of AlGaN/GaN-on-Si and AlGaN/GaN-on-AlN HEMTs vs. Gate-Drain distances (GD)

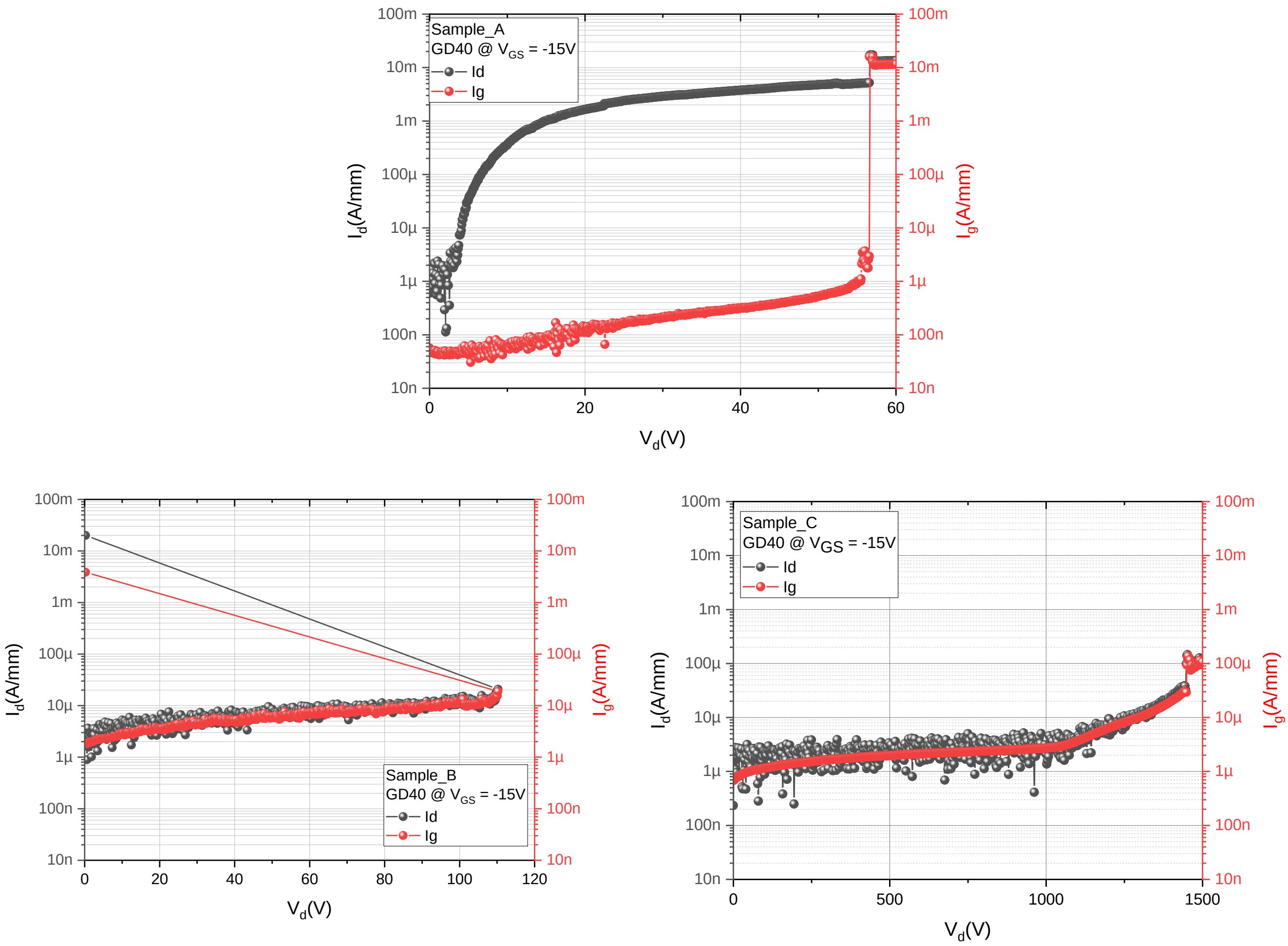

Fig. 4: Off-state leakage current characteristics of AlGaN/GaN-on-Si and AlGaN/GaN-on-AlN HEMTs