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Suppression of gate leakage and enhancement of breakdown voltage using Al_2O_3 nano particles as gate dielectric for AlGaN/GaN MOS-HEMTs

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Introduction

GaN based wide band gap semiconductors are excellent candidate for high power, low noise and high frequency operations. This is due to their superior electronic properties such as high mobility, high breakdown field, saturated electron drift velocity and 2DEG channel induced by spontaneous polarization. One of the major factors that limit the performance and reliability of GaN high electron mobility transistors (HEMTs) to be finally commercialized for rf high-power applications is their relatively high gate leakage.

The gate leakage reduces the breakdown voltage and the power added efficiency while increasing the noise figure [1]. One of the effective ways to reduce the gate leakage is by using a good insulating layer as gate dielectric for AlGaN/GaN HEMTs. GaN metal-insulator-semiconductor HEMTs using a thin dielectric film as gate insulator is one of the effective solutions to reduce the high gate leakage and improve the device performance [2]. Over the past year SiO_2, Si_3N_4, Sc_2O_3, Ga_2O_3, Al_2O_3, HfO_2 etc were used as gate dielectrics. Among these dielectrics Al_2O_3 is found to be attractive insulating material due to its larger band gap (~9 eV) and high dielectric constant (~10) [3].

Device fabrication

Our Al_2O_3 nano particle (NP) based MOS-HEMT started with mesa isolation using BCl_3 plasma based reactive ion etching (RIE). Devices were passivated using 100 nm electron beam evaporated SiO_2. Ohmic patterns were performed using conventional photolithography followed by metallization of Ti/Al/Ni/Au (20/80/12/40 nm). The Ohmic contacts were annealed at 850 °C using Infra-red lamp annealing for 30 s in N_2 ambient. Gate lithography was performed to define a layer of Al_2O_3 NPs under the Schottky gate. A 10 nm Aluminum layer was evaporated by filament heating technique at the patterned gate region. A base pressure of $7x10^{-5}$ Pascal was maintained in the chamber and the evaporation rate was maintained as low as 0.1 nm/sec. The samples were oxidized/annealed at 600°C for 15 minutes at a constant oxygen flow rate. This way of oxidizing Al layer specially under gate electrode do not require any further wet or dry etching at the source drain contacts. Gate lithography was performed for the second time to define metallic Schottky gate over the insulating Al_2O_3 NPs layer for MOS-HEMT. Gate metals Pd/Ti/Au (40/20/60 nm) was deposited followed by lift off. Fig. 1. Shows the schematic representation of MOS-HEMT.

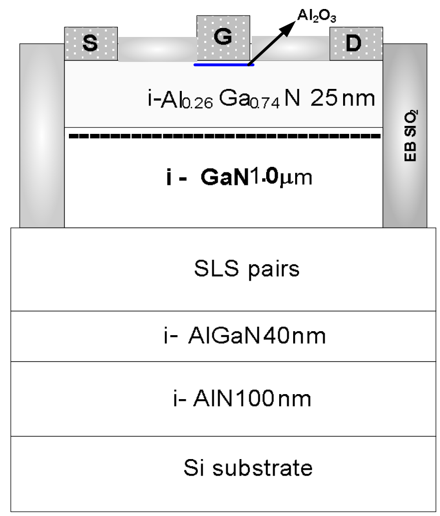

Fig. 1. Schematic representation of MOS-HEMT

Results and Discussion

The Al_2O_3 layer was analyzed using XPS. We observed that the oxidative annealing at 600° C has oxidized the deposited Al layer into Al_2O_3. The metallic main peak of Al was not observed and the Al2*p* peak appeared at a higher binding energy of 74.7 eV corresponding to Al_2O_3. The higher binding energy of Al2*p* peak indicated stoichiometric insulator layer comprising of Al_2O_3 [4]. The XPS spectrum of Al2*p* is shown in Fig. 2.

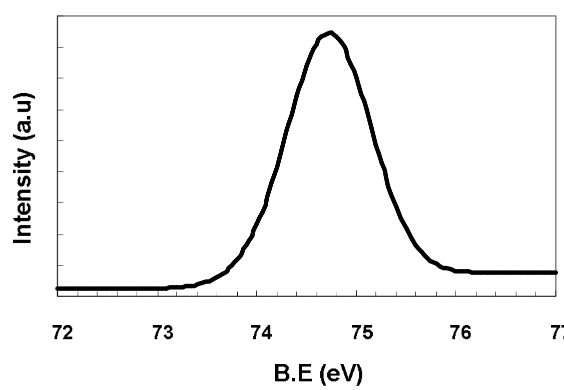

Fig. 2. Core level spectrum of Al2*p*

Further morphological analyses were carried out using AFM (Fig. 3.). AFM measurements confirmed the presence of Al_2O_3 nano particles over AlGaN surface. The diameter of each particle was around 45 ± 2 nm. The

RMS value and P-V distance obtained from AFM analysis were 1.5 nm and 15 nm respectively. The I_{dmax} for HEMT and MOS-HEMT are 593 mA/mm and 425 mA/mm respectively. Both HEMT and MOS-HEMT exhibited good pinch off features at threshold voltage of -2.1 and -2.8 V respectively. The measured transconductance (g_m) for HEMT and MOS–HEMT were 124 and 121 mS/mm respectively.

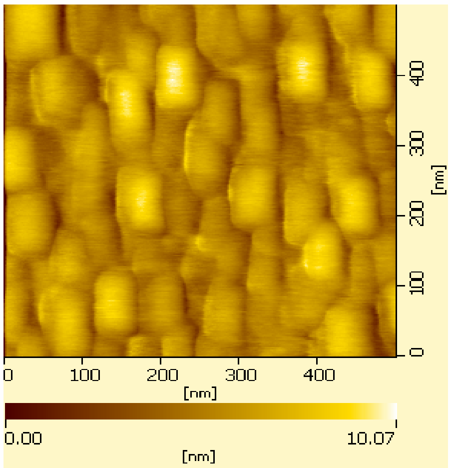

Fig. 3. AFM image of Al_2O_3 NP layer

The presence of Al_2O_3 NPs layer encouraged us to study the leakage phenomena and its influence on the breakdown voltage. Interestingly we observed that gate leakage was reduced by three orders for MOS-HEMT when compared with conventional HEMT from our two terminal reverse leakage measurements. The results are shown in Fig. 4.

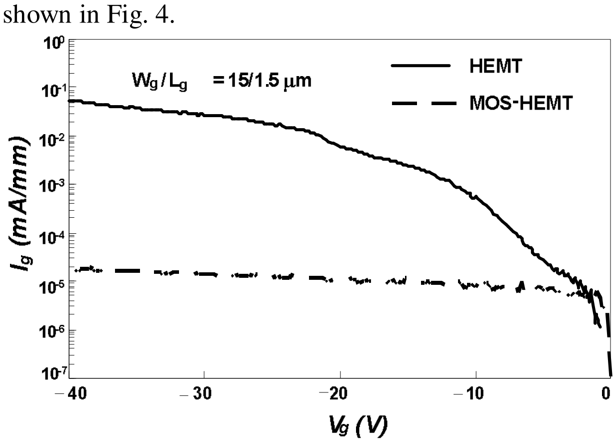

Fig. 4. Comparison of two terminal gate leakage with device dimension $W_g/L_g/L_{gd}$ =15/1.5/3 µm

Three terminal breakdown measurements (*off state*) were carried out by keeping V_g at a sub threshold voltage of -5 *V* and increasing the V_{DS}. For conventional HEMT the breakdown voltage was 185 V which is due to the high gate leakage where as in the case of MOS-HEMT the gate leakage was suppressed by three orders of magnitude which accompanies a high breakdown voltage of 207 V. Fig. 5 shows the comparison of three terminal (off state) *BV* measurements performed on HEMT and MOS-HEMT.

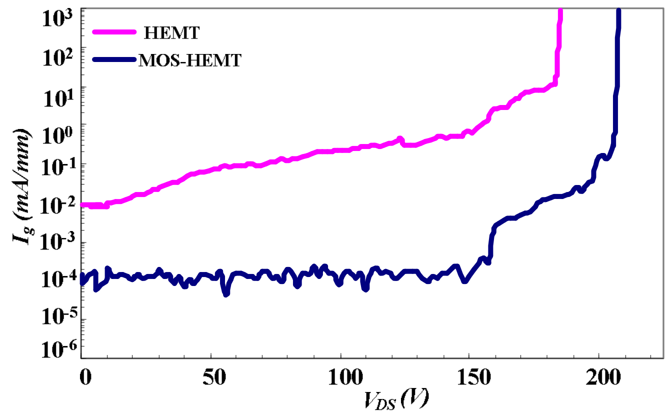

Fig. 5. Comparison of three terminal (*off state*) *BV* measurements. $W_g/L_g/L_{sd}/L_{gd}$ = 200/2/10/4 µm.

Conclusion

We have demonstrated for the first time Al_2O_3 NPs as insulator layer for AlGaN/GaN MOS-HEMT. This technique seems to be process compatible and cost effective compared to other conventional techniques for dielectrics. Morphological characterizations were carried out using AFM and SEM to characterize the newly formed Al_2O_3 NPs. The mechanism of formation of Al_2O_3 NPs can be explained on the phenomena of diffusion of oxygen molecules to the deposited Al layer. We observe the initial Al layer thickness; oxygen flow rate and oxidation/annealing temperature highly influencing the formation of Al_2O_3 NPs.

Moreover from device point of view the gate leakage was reduced by three orders and breakdown voltage was increased considerably. Al_2O_3 NPs as insulator layer seem to be promising in the near future for AlGaN/GaN MOS-HEMTs for high power and low noise applications.

Acknowledgements

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References

[1]. Y. Q. Wu, T.Shen, P.D. Ye, G. D Wilk, Appl. Phys. Letts, **90**, (2007), 143504.

[2]. Z.H. Liu, G.I. Ng, S.Arulkumaran, Y. K. T. Maung, K. L. Teo, S.C. Foo and V. Sahmuganathan., Appl. Phys. Letts, **95**, (2009), 223501.

[3]. S. Taking, A. Banerjee, H. Zhou, Z. Li, A.Z. Khokhar, R. Oxland, I. McGregor, S. Bentley, F. Rahman, I. Thayne, A. M. Dabiran, A. M. Wowchak, B. CuI and E.Wasige, Electrons. Letts, **46,** (2010), 4

[4] Z.W Zhao., B.K.Tay, G.Q .Yua, D.H.C Chua, S.P Lau, L.K.Cheah, Thin Solid films , (**447),** 2004, 14**.**

[5] W.Wang, J. Derluyn, M. Germain, Leys .M, S. Degroote, Schreurs. D, Borghs.G, Jap. J. Appl. Phys., **4**, 2006, L224.