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Citation
Zhou, Hong; Lou, Xiabing; Chabak, Kelson D.; Gordon, R.G.; Ye, Peide D. 2015. AlGaN/GaN MOSHEMT on Si Substrate with High on/off Ratio and High Off-state Breakdown Voltage Enabled by Atomic Layer Epitaxial MgCaO as Gate Dielectric. 46th IEEE Semiconductor Interface Specialists Conference, Arlington, VA, December 2-5, 2015.

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AlGaN/GaN MOSHEMT on Si Substrate with High on/off Ratio and High Off-state Breakdown Voltage Enabled by Atomic Layer Epitaxial MgCaO as Gate Dielectric

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AlGaN/GaN high-electron-mobility-transistors (HEMTs) on Si substrates have attracted more and more attention in the area of high voltage power switches due to their lower-cost substrates, large substrate diameters and their ability to integrate with silicon processes [1-3]. Conventional Schottky gate HEMTs suffer from relatively high gate leakage currents which limit maximum forward gate bias swing and off-state performance. Metal-oxide-semiconductor HEMTs (MOSHEMTs) are proposed with a thin oxide layer in between gate and barrier to solve the aforementioned problems [4]. A good oxide must have a sufficiently large barrier height and high interface quality. In this work, we incorporate epitaxial $Mg_{0.25}Ca_{0.75}O$ gate dielectric deposited by atomic layer deposition (ALD) into the GaN MOSHEMT process yielding improved device performance.

Fig. 1 shows schematic view of an AlGaN/GaN MOSHEMT on a Si (111) substrate with sheet resistance (R_{sh}) ~ 450 Ω/□. Device fabrication started with mesa isolation by Cl_2/BCl_3 etching to a depth of 150 nm. Then, Ohmic contacts were formed by depositing Ti/Al/Ni/Au (20/100/40/50 nm) followed by 775 °C rapid thermal anneal in N_2 atmosphere, yielding a contact resistance (R_c) of 0.35 Ω·mm. A 4 nm epitaxial $Mg_{0.25}Ca_{0.75}O$ dielectric capped with 2 nm of amorphous Al_2O_3 was then deposited by ALD. The growth temperature of MgCaO was 310 °C, using bis(*N,N'*-di-*tert*-butylacetamidinato)calcium, bis(*N,N'*-di-*sec*-butylacetamidinato) magnesium, and water vapor as precursors [5]. Single crystalline MgCaO offers an advantageous band offset, a good interface, and good lattice matching to GaN alloys [6]. Finally, Ni/Au (30/50 nm) was deposited as the gate metal followed by a lift-off process. All of the lithography processes were carried out using a MJB3 mask aligner lithography system. Devices have a gate width (W) of 100 µm and gate length (L_g) of 1, 2, 4, 8, 20, and 40 µm.

Fig. 3 shows the well-behaved DC output I_{ds}-V_{ds} characteristics of a GaN MOSHEMT. The device has an L_g=1 µm and source to drain spacing (L_{sd}) of 4.2 µm. Due to a 6 nm thick gate oxide, a high gate bias (V_{gs}) of 3 V can be applied, yielding a maximum drain current ($I_{ds,max}$) of 700 mA/mm. Fig. 4 is the I_{ds}-V_{gs} transfer characteristic measurement of the same device. Impressively, a high on/off ratio of 10^{10} is achieved with subthreshold swing (SS) of 65 mV/dec at V_{ds}=5 V. Traditional HEMT devices are not able to have such a high on/off ratio because of their large gate leakage currents in the off-state. The oxide of the MOSHEMT suppresses this leakage, yielding large on/off ratios. In addition, benefiting from the lattice matching and good interface between MgCaO and GaN,[5] the GaN MOSHEMT also demonstrates a negligible hysteresis (50 mV) as shown in Fig. 5. Fig. 6 shows the I_{ds}-V_{gs} and g_m-V_{gs} plot at the linear region. Peak transconductance ($g_{m,max}$) of 160 mS/mm and threshold voltage (V_T) of -2.2 V are observed at V_{ds}=5 V. The off-state breakdown/leakage characteristics of a MOSHEMT are shown in Fig.7. This device has a W/L_g=100 µm/1 µm and L_{gs}=L_{gd}=1.6 µm. The device is operated at the pinch-off region with V_{gs}=-3.5 V and V_s=0 V. It can be observed that the breakdown voltage is 150 V even with a short L_{gd}=1.6 µm. The breakdown voltage, which is a critical figure of merit for power switch, is expected to increase with the increase of L_{gd} and drain-gate region engineering. Scaling metrics of GaN MOSHEMTs are also studied as shown in Fig. 8 and Fig. 9. The I_{ds} and g_{max} are found to increase when the L_g is scaled. SS and drain induced barrier lowering (DIBL) are found to be slightly influenced by the L_g, and V_T shows roll-off behavior when L_g=1 µm.

In conclusion, we have demonstrated high performance AlGaN/GaN MOSHEMTs on Si substrate with high on/off ratio and high off-state breakdown voltage with epitaxial MgCaO gate dielectric. The lattice-matched MgCaO provides high quality interface and an appropriate electron barrier height, which makes it feasible to be applied to future GaN power switch applications.

The work at Purdue is supported by AFOSR and the work at Harvard is supported by the ONR.

References: [1] B. De Jaeger et al., *Proc. ISPSD,* pp. 49-52, 2012. [2] P. Moens et al., *Pròc. ISPSD*, pp. 374-377, 2014. [3] N. Ikeda et al., *Proc. of the IEEE,* Vol. 98, No. 7, pp. 1151-1161, 2010. [4] P. D. Ye et al., *Appl. Phys. Lett.*, vol. 86, pp. 063561, 2005. [5] X. B. Lou et al., CSW, 2015. [6] H. Zhou et al., DRC, 2015.

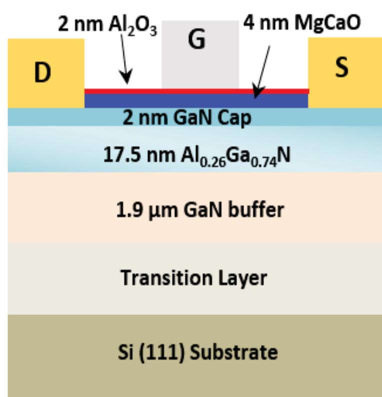

Fig. 1 Schematic view of an AlGaN/GaN MOSHEMT

- Sample Solvent Clean:
  Acetone, Methanol, and IPA each 5 mins
- Mesa Isolation Etch:
  BCl_3/Cl_2 dry etching with depth ~150 nm
- Ohmic Contact Formation:
  Ti/Al/Ni/Au (20/100/40/50 nm) deposition
  RTA annealing @775 ℃ for 30 s in N_2
- ALD deposition:
  BOE/$NH_3 \cdot H_2O$ pretreatment
  $MgCaO/Al_2O_3$ (4/2 nm) deposition
- Gate Formation by Ni/Au (30/50 nm) deposition

Fig. 2 Device fabrication process steps of AlGaN/GaN MOSHEMTs

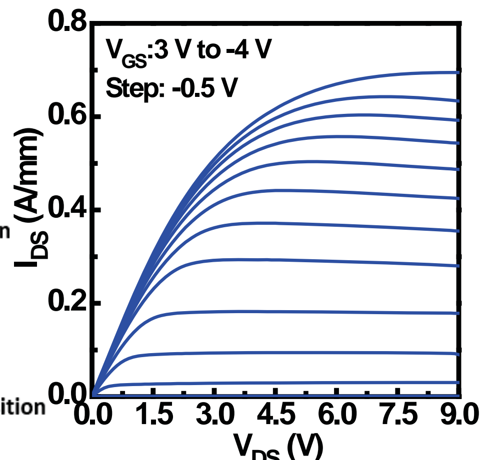

Fig. 3 Output characteristics of an AlGaN/GaN MOSHEMT with L_g=1 µm and L_{SD}=4.2 µm.

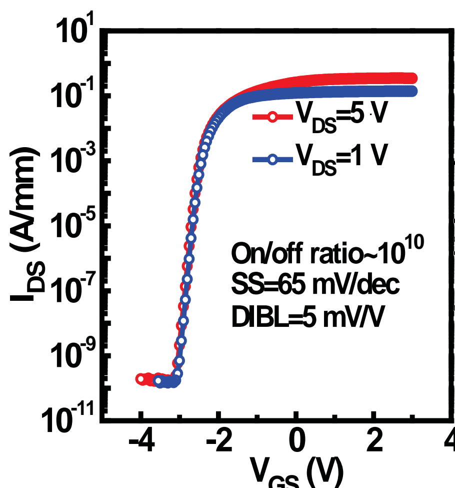

Fig. 4 I_{ds}-V_{gs} transfer characteristics with on/off ratio of 10^{10} and low SS=65 mV/dec.

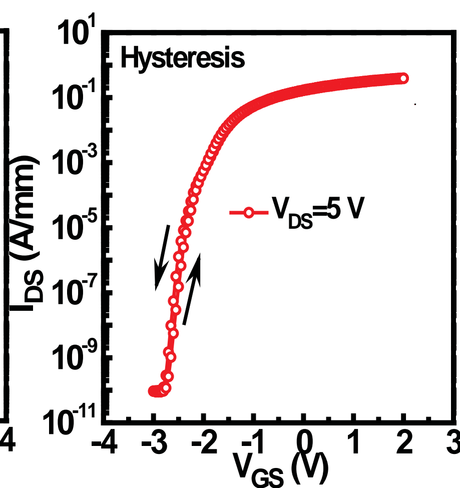

Fig. 5 I_{ds}-V_{gs} hysteresis measurement at V_{ds}=5 V.

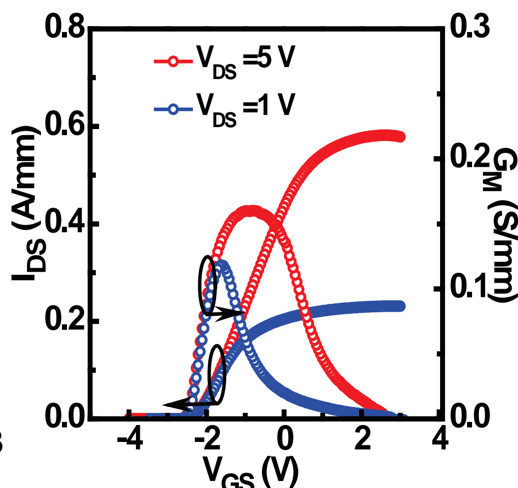

Fig. 6 I_{ds}-V_{gs} and g_m-V_{gs} of the same device in the linear region plot.

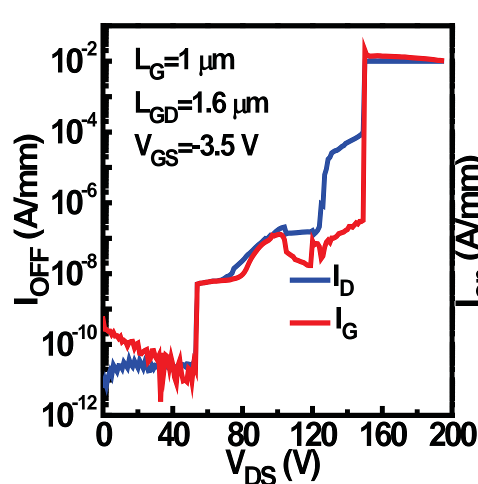

Fig. 7 Three-terminal off-state breakdown measurement with L_g=1 µm and L_{gd}=1.6 µm.

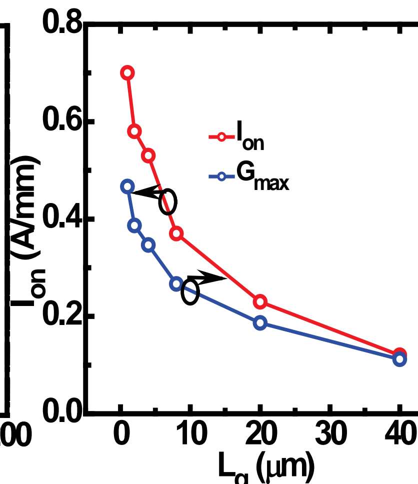

Fig. 8 I_{on} and G_{max} scaling metrics of GaN MOSHEMTs.

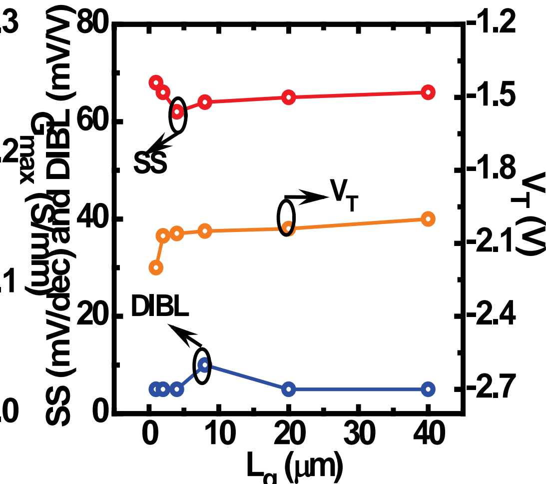

Fig. 9 SS, DIBL and V_T scaling metrics of GaN MOSHEMTs.