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Comparison of AlGaN/GaN insulated gate heterostructure field-effect transistors with ultra-thin Al_2O_3/Si_3N_4 bilayer and with Si_3N_4 single layer

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1. Introduction

High electron mobility transistors(HEMT) based on AlGaN/GaN heterostructure are very promising for high-power high-frequency applications.[1–3] Metal-insulator-semiconductor(MIS) based HEMT structures employing SiO_2 or Si_3N_4 have been developed recently to suppress the large gate current leakage in nitrides-base HEMT, but using thick insulators(around 10 nm), combined with their low dielectric constants, give rise to very large tranconductance loss in those MISFET structures.[4,5] A novel MIS structure using bilayer Al_2O_3/Si_3N_4 insulator has been proposed.[6,7] In this work, MISFET with ultrthin Al_2O_3/Si_3N_4 bilayer was developed, and compared with the widely used Si_3N_4 insulator based MISFET.

2. Experiment

AlGaN/GaN HEMT structures were grown on sapphire(0001) substrates using a metalorganic vapor phase epitaxy(MOVPE) system with stainless steel vertical reactor at a pressure of 300 Torr. 2 μm thick undoped GaN layer was grown at 1000°C, followed by 20 nm $Al_{0.3}Ga_{0.7}N$ barrier layer consisted of 5 nm undoped space layer, 11 nm Si-doped layer and 4 nm undoped layer for schottcky contact. Two dimensional electron gas sheet density of 1×10^{13} cm^{-2} with mobility of 1100 $cm^2/V{\cdot}s$ at room temperature has been obtained by Hall measurement

A Cl_2 based ECR process was done to etch the mesas pattern with the height of 120 nm. Source-drain ohmic contacts were obtained by annealing at 800°C in nitrogen ambient for 30 seconds after e-beam evaporation of Ti/Al/Ti/Au (20 nm/80 nm/40 nm/200 nm) metals. Typical contact resistances measured by TLM measurements yield contact resistances between 0.3 to 0.5 Ωmm. Insulators were deposited at room temperature using ECR-plasma system prior to gate fabrication. Ultra-thin Al_2O_3/Si_3N_4 (1 nm/0.5 nm) bilayer or 10nm of the widely used Si_3N_4 single layer was used as insulator. Ni/Au (40 nm/200 nm) metals was deposited as the gate contact with 1.5 μm of length and 20 μm of width.

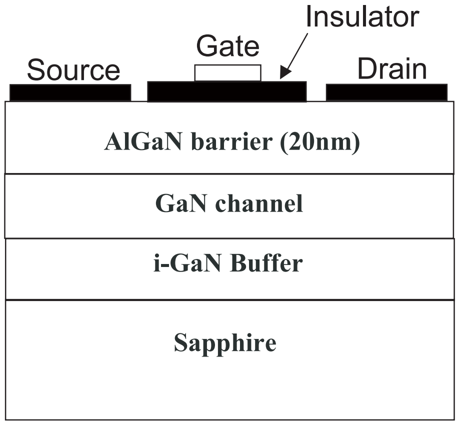

Fig. 1. Schematic cross-section of AlGaN/GaN MISFET

3. Results and discussion

As shown in fig.2 both MISFETs show very good current-voltage characteristics. MISFET with 10 nm

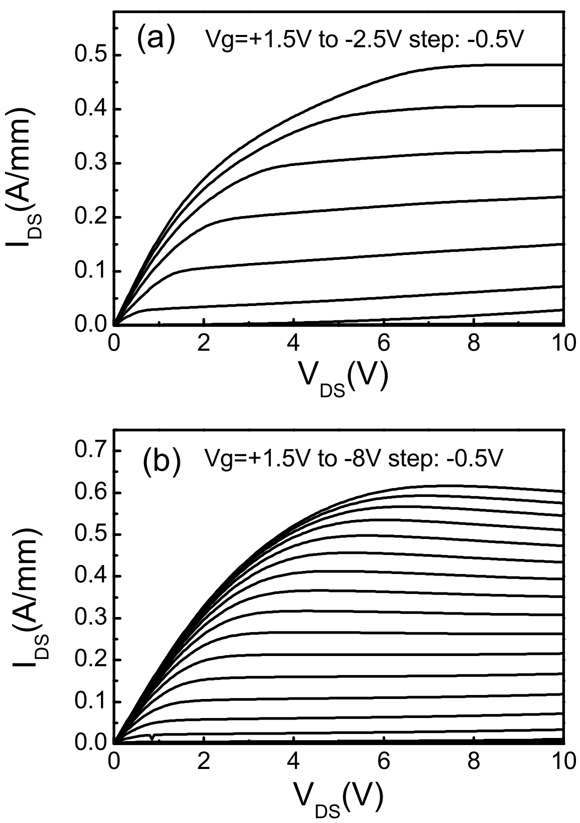

Fig. 2. Current-voltage curves of MISFETs with (a) ultra-thin Al_2O_3/Si_3N_4(1 nm/0.5 nm) bilayer or (b) 10 nm of the widely used Si_3N_4 single layer.

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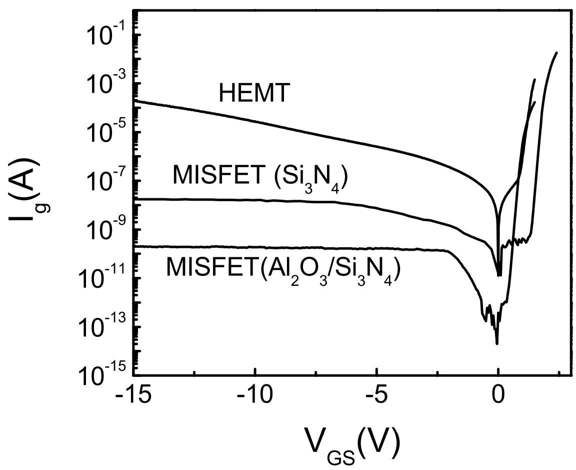

Fig. 3. Gate-source current ver gate-source voltage for HEMT and two MISFET structures.

Si_3N_4 shows higher I_{DS} current by up to 20% due to thicker insulator with higher flat band voltage, and its threshold voltage is around -6.8 V, much lower than -2.5 V of MISFET with 1 nm/0.5 nm of Al_2O_3/Si_3N_4 bilayer.

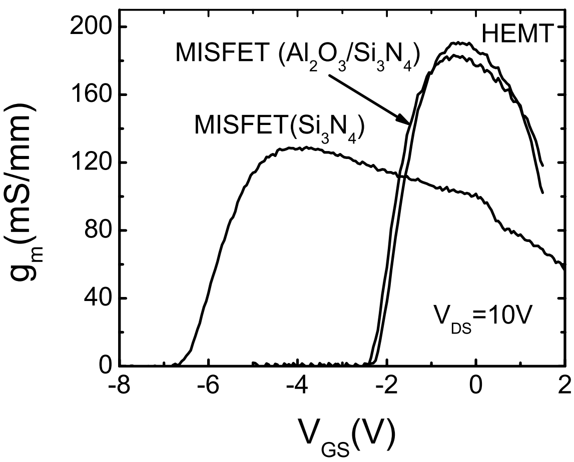

Fig. 4. Transcondutance ver gate-source voltage for HEMT and two MISFET structures

Fig.3 indicates the V_{gs} dependence of the gate-source current for three samples. Under reverse condition conventional HEMT without insulator shows very high current leakage, which, however, was suppressed substantially, by more than four orders of magnitude, using MIS structures. Ultra-thin Al_2O_3/Si_3N_4 displays much better suppression effect than much thicker Si_3N_4 single layer because of the higher conduction band offset between nitrides and Al_2O_3.[7]

Fig.4 shows the gate-source dependence of tranconductance. MISFET with 10 nm thick Si_3N_4 exhibits very strong reduction in transconductance, for example, up to 40% reduction in maximum transconductance, because of the smaller dielectric constant and larger separation between gate and channel. On the other hand MISFET with ultrathin Al_2O_3/Si_3N_4 shows very small loss of less than 10% in transconductance due to the ultra-thin insulator with higher dielectric constant.

4. Conclusions

We have compared the MISFET structures with ultra-thin Al_2O_3/Si_3N_4(1 nm/0.5 nm) and with 10 nm Si_3N_4. Higher drain-source current was obtained using thick Si_3N_4, however MISFET with Al_2O_3/Si_3N_4 exhibits much lower gate current leakage under reverse conduction and much higher transconductance due to the employment of ultrthin bilayer with large dielectric constant and the large conduction band offset between Al_2O_3 and nitrides. The works in this paper demonstrate that Al_2O_3/Si_3N_4 bilayer insulator is a superior candidate for nitrides-base MISFET devices.

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