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Gate Leakage Reduction Mechanism of AlGaN/GaN MIS-HFETs

Daigo Kikuta, Ryohei Takaki, Junya Matsuda, Masaya Okada, Xin Wei[1], Jin-Ping Ao, and Yasuo Ohno

Dept. of Electrical and Electronic Eng., The University of Tokushima, Tokushima 770-8506, Japan
Phone: +81-88-656-9690 Fax: +81-88-656-9060 E-mail: kikuta@ee.tokushima-u.ac.jp
[1]Satellite Venture Business Laboratory, The University of Tokushima, Tokushima 770-8506, Japan

1. Introduction

AlGaN/GaN metal-insulator-semiconductor (MIS) heterostructure field-effect transistors (HFETs) using various insulators have shown extremely low gate leakage and good dc and RF performances, such as with SiO_2 [1,2], Si_3N_4 [3,4], Al_2O_3 [5], and Sc_2O_3 [6]. We have also fabricated MIS-HFETs using e-beam evaporation SiO_2 and obtained low gate leakage and good dc characteristics [7]. From ac performances, however, it is estimated that the low gate leakage is not by the insulator, but caused by increased resistance of AlGaN layer after the SiO_2 deposition [7]. To investigate the leakage current reduction mechanism for AlGaN layer, we made MIS-HFETs with metal layer between the AlGaN and the insulator (MIMFET), together with standard MIS-HFET (MISFET) and conventional HFET (HFET) for comparison.

2. Device Preparations and Electrical Performances

Schematic cross section of the MIMFET is shown in Fig. 1. After device isolation and ohmic contacts formation, 50-nm-thick Ni layer was formed on AlGaN layer by lift-off technique with the same mask of gate for a half area of the wafer. Then, 100-nm-thick SiO_2 was deposited by e-beam evaporation. A part of the oxide was etched-off for ohmic contact through-holes and to form the Schottky gate for conventional HFETs. Then, Ni/Au was deposited for the gate electrode with lift-off technique.

Figure 2 shows I_D-V_G characteristics for the FETs with gate length and width of 100 µm and 200 µm, respectively. Drain current of the MISFET is modulated by gate bias similar to the conventional HFET, but that of the MIMFET cannot be controlled. Figure 3 shows I_G-V_G characteristics of the three types of FETs. Low leakage currents are obtained in MISFET and MIMFET. In particular, only MISFET at negative gate voltages has much lower leakage current. This suggests that the leakage through AlGaN layer is reduced when and only when the surface is covered with insulator and the gate voltage is negative.

Figure 4 shows transconductance-frequency (g_m-f) characteristics of the FETs from 20 Hz to 1 MHz. At low frequencies, transconductances for the MISFET and the MIMFET are those estimated from the dc performances; finite value and zero, respectively. As the frequency increases, both transconductances converge at a certain value that conforms to the capacitance values measured at 1 MHz.

We propose an equivalent circuit model of MISFET and MIMFET gate operations. Since both insulator and AlGaN layer have finite leakage, those layers are expressed as a capacitor with a resistor connected in parallel. The capacitor and resistor for the two layers are connected at the interface as shown as the inset in Fig. 4. Then, the drain current should be proportional to the charge variation at the 2DEG (two-dimensional electron gas) node of the model circuit. The charge is modulated by the potential of interface node ($V_{interface}$). At high frequencies, $V_{interface}$ is defined by through solely capacitive coupling, but it is defined by the ratio of resistors at low frequencies. The measured results indicate that $R_{SiO2} << R_{AlGaN}$ for the MISFET, but $R_{SiO2} >> R_{AlGaN}$ for the MIMFET. Thus, the AlGaN layer leakage is much different between the MISFET and the MIMFET.

3. Leakage Characteristics through AlGaN Layer

To obtain the actual current-voltage characteristics of AlGaN layer and insulator from I_G-V_G characteristics, voltage across the AlGaN layer is estimated. Here, it is assumed that the same AlGaN layer voltage gives the same drain current. Comparing I_D-V_G characteristics of MISFET or MIMFET with those of HFET, voltages across the AlGaN layer and insulator are separately determined. The obtained I-V characteristics for AlGaN layer are shown in Fig. 5. The data for 100-nm-thick CVD SiO_2 measured on different wafers are also included. Though the current can be measured only in a small voltage region for MIMFET, it is clear that the AlGaN layer leakage current for metal deposited samples is several orders of magnitude higher than those for oxide coated ones. For positive gate voltages, however, current increases abruptly at around 1 V even for the oxide coated AlGaN layers. The oxide I-V characteristics are shown in Fig. 6. As expected from the transconductance measurement, leakage current through the e-beam evaporated oxide is higher than that through the AlGaN layer.

4. Conclusion

From these experimental results, it can be concluded that the resistance of AlGaN layer is much increased by depositing insulating films on the surface. The possible mechanism is that the electron concentration at the AlGaN surface is different due to the difference in the pinning levels for the metals and the insulators. At negative gate voltages, electrons will jump or tunnel from the surface to the 2DEG channel. Pinning level difference of 0.3eV will give

5 orders of magnitude different current at room temperature. On the other hand, at positive gate voltage, electrons will spill over from 2DEG channel, so the leakage current may be similar even for different surface structures.

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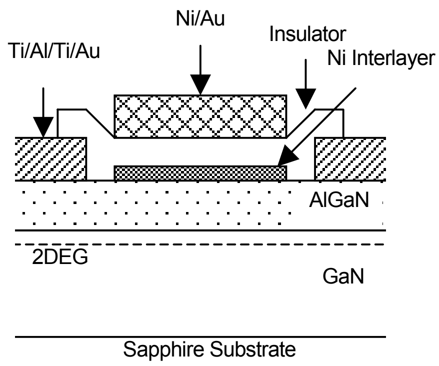

Fig. 1. Schematic cross section of the MIMFET

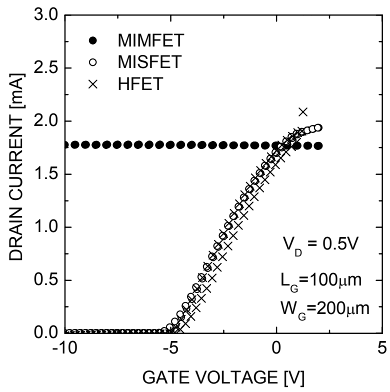

Fig. 2. Drain current-gate voltage characteristics of MIMFET, MISFET and HFET at $V_D = 0.5$ V.

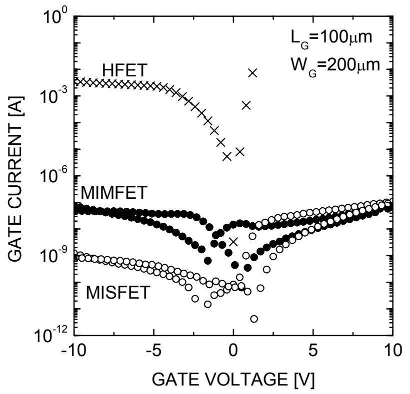

Fig. 3. Gate current-gate voltage characteristics of MIMFET, MISFET and HFET. Gate length and width are 100 μm and 200 μm, respectively.

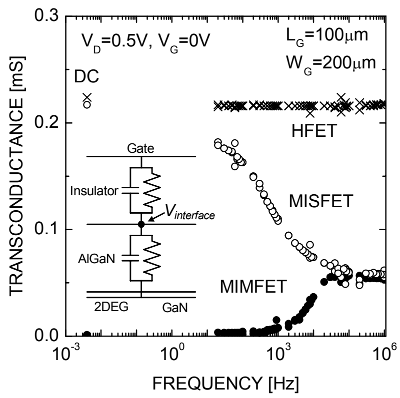

Fig. 4. Transconductance characteristics of the FETs. Drain and gate voltage are 0.5 V and 0 V, respectively. The inset is the equivalent circuit model of the MISFET or MIMFET gate structure.

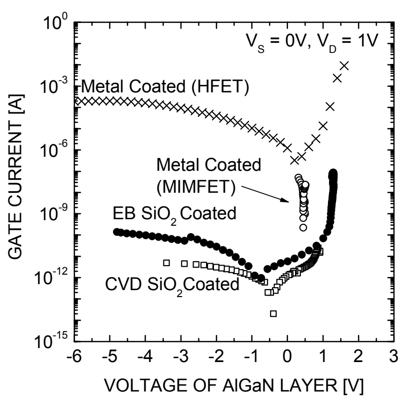

Fig. 5. *I-V* characteristics of AlGaN layers estimated from I_G-V_G characteristics where, that of HFET is used as reference.

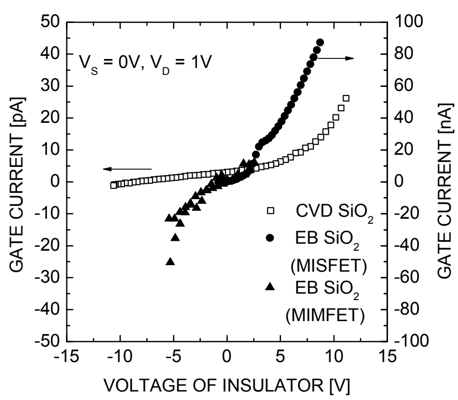

Fig. 6. *I-V* characteristics for the oxide layers estimated by the same method used in Fig. 5.