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Electric- Field-Driven Degradation in Off-State Step-Stressed HfO_2/AlGaN/GaN Metal-Oxide-Semiconductor HFETs

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1. Introduction

Recently, AlGaN/GaN heterojunction field-effect transistors (HFETs) attract lots of attentions for use in high power applications because of their high critical electric field, high two-dimensional electron gas (2DEG) channel density and high mobility [1,2]. For power switching applications, normally-off operation is necessary to simplify the design of circuit and to reduce standby power consumption. In order to fabricate normally-off device with low gate leakage current, recessed Metal-Oxide-Semiconductor HFETs (MOS-HFETs) are widely used [3]. The Reliability of conventional AlGaN/GaN HFETs has been investigated for years, however, that of MOS-HFET is not proven yet [4-5].

In this paper, degradation mechanism of MOS-HFET was investigated to evaluate the reliability of MOS-HFET. The stress condition as step-stressed reverse gate voltage was set to measure the DC and AC response of MOS-HFET device. With the various gate recess length, the effect of E-field driven degradation was discussed.

2. Experimental

$Al_{0.25}Ga_{0.75}N$/AlN/GaN (30/1/3000 nm) HFET structure was grown by metal-organic chemical vapor deposition (MOCVD) system on 6-inch Si (111) substrate. MESA isolation was performed and Ti/Al/Pd/Au ohmic contacts were used as source and drain. To fabricate normally-off device, gate recess process was carried out by using inductively coupled plasma-reactive ion etch (ICP-RIE) with Cl_2/N_2 gas mixture. HfO_2 100 nm was deposited as a gate dielectric and passivation layer. The gate length was 3 μm and recessed lengths were 0.5 (sample A) and 1 μm (sample B) to investigate the relationship between electric field and reliability of MOS-HFET.

Step-stress experiments were conducted to study the reliability of MOS-HFET. Time-dependent step-stress of reverse gate bias is known to be an effective method for evaluating trap formation on a device [4]. The step-stresses were applied from 0 to -100V for 1minute per each stress voltage to generate high vertical fields through the barrier. Moreover, the dynamic on-resistances were measured for each sample in order to figure out the permanent damage caused by the reverse-bias stress.

3. Results and discussion

Fig.1 shows the schematic diagram of fabricated MOS-HFET device. The gate recess length of each sample is 0.5μm (sample A) and 1.0μm (sample B), respectively. Due to the geometry of the gate, sample A would receive larger electric field on vertical component than sample B. This structural difference between two samples would change the electric-field, resulting on the different stress conditions.

In order to investigate the degradation mechanism in MOS-HFET, the step-stress test on the gate was performed. Fig.2 shows the change of DC characteristics of sample A before and after step-stress experiment. The degradation of maximum drain current, on-resistance and off-state current in reverse gate bias were noticed after step-stress.

The resistance measurement after each stress step was performed to understand the effect of stress (Fig.3). While the sample B only shows gradual increase of resistance, the slope of resistance of the sample A abruptly increases at critical voltage, V_G=-55V.

AC response measurement was performed after 1 hour-recovery time and it could be the origin of permanent degradation. In Fig.4, the increment of dynamic on-resistance with drain voltage of sample A is higher than that of sample B. It is believed that the electrical trap, or dislocation in AlGaN barrier, was induced by reverse-biased stress [4].

The major mechanism of the degradation such as critical voltage and permanent degradation could be understood with the reverse piezoelectric effect theory which is similar to in case of HFET structure [4]. Therefore, the reverse piezoelectric effect that is caused by vertical electric field and dislocation plays an important role in the degradation process. The interesting fact is that the degradation was linearly increased as the stress voltage increases which was not reported in HFET structure. This difference could be originated from the existence of gate oxide and it should be studied in future.

4. Conclusion

The electrical degradation of HfO_2/AlGaN/GaN HFET under high reverse gate voltage conditions was investigated, to understand the mechanism of degradation in MOS-HFET. By increasing the vertical electric field, abrupt change of

maximum drain current at V_G= -55V and increment of dynamic on-resistance were observed. It is believed that the degradation of MOS-HFET could be explained by reverse piezoelectric effect and transient degradation came from the failure of gate oxide in MOS-HFET. Understanding the degradation mechanisms of MOS-HFET would be helpful to fabricate of reliable AlGaN/GaN MOS-HFET and will be presented in detail.

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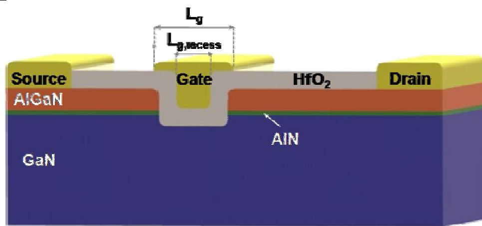

Figure 1. The schematic diagram of fabricated MOS-HFET device

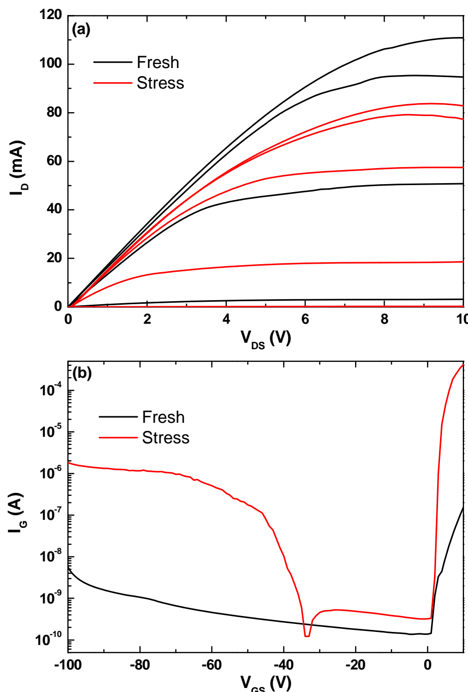

Figure 2. (a)I_D-V_D and (b)I_G-V_G(OFF) of MOS-HFET device before and after the degradation due to step-stress test.

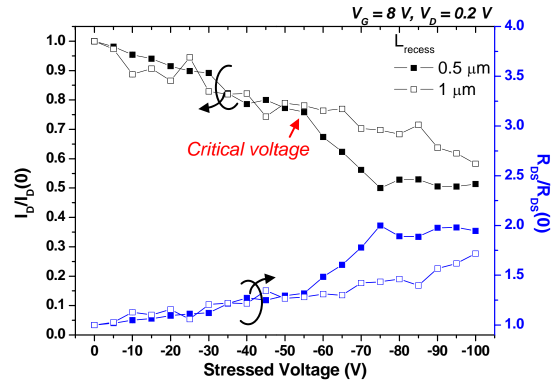

Figure 3. Plot of $I_{DMax}/I_{DMax}(0)$ vs step-stress condition. The step-stress starts with -10V and the duration time is 1 minute. The stress gets stronger by 10V in reverse direction for each step. After applying the each stress step, the resistance was measure by I_D-V_D measurement when V_G=+8V.

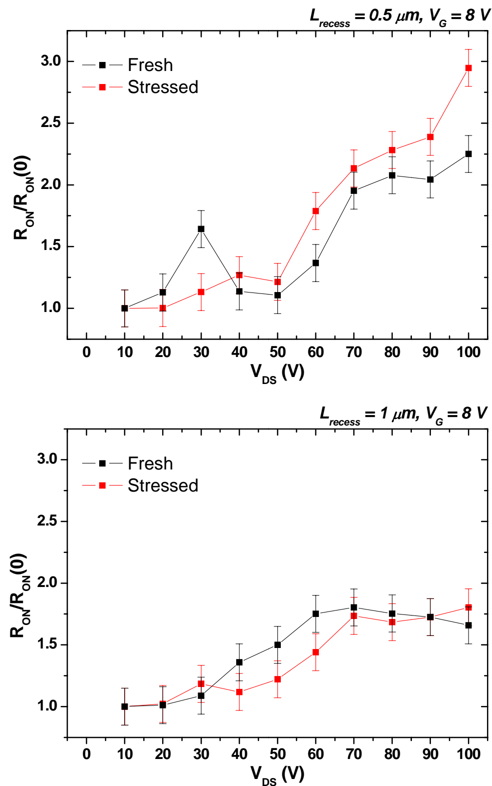

Figure 4. Measurement result of dynamic on-resistance for the sample containing gate recess length of (a) 0.5μm and (b) 1.0μm. The red rectangular points present the stressed sample when the black points mean the fresh sample.