**AlGaN/GaN HEMTs Employing Multiple Al$_2$O$_3$/Ga$_2$O$_3$ stacks**

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**Summary**

We have successfully fabricated AlGaN/GaN HEMTs employing new gate insulator of multiple Al$_2$O$_3$/Ga$_2$O$_3$ stacks in order to increase the breakdown voltage and positive shift of $V_{TH}$. (High Electron Mobility Transistors) employing multiple Al$_2$O$_3$/Ga$_2$O$_3$ stacks by rf sputtering have been proposed and fabricated. AlGaN/GaN HEMT employing 10 nm thick-Al$_2$O$_3$/Ga$_2$O$_3$ stacks shows a high breakdown voltage of 1100 V and drain leakage current of 33 nA/mm while those of the conventional HEMT are 380 V and 654 μA/mm respectively. The $V_{TH}$ of the proposed device employing Al$_2$O$_3$/Ga$_2$O$_3$ is -1.4 V while that of the conventional HEMT is -2 V because of charge accumulation in Al$_2$O$_3$/Ga$_2$O$_3$ stacks. The AlGaN/GaN HEMT employing Al$_2$O$_3$/Ga$_2$O$_3$ stacks has a larger capacitance and hysteresis which induce increase of output current and positive shift of $V_{TH}$ than that of conventional HEMT and HEMT employing Al$_2$O$_3$ only.

**Background**

AlGaN/GaN HEMTs have a considerable attention for high power applications due to wide bandgap properties such as a high critical electric field and a low intrinsic carrier concentration. Also they exhibit a very low on resistance and a fast switching speed due to the 2DEG (2 Dimensional Electron Gas) induced by piezoelectric polarization. However, the soft breakdown characteristics caused by the surface traps on AlGaN layer may be critical issue of AlGaN/GaN HEMTs. In order to improve reverse blocking characteristics of AlGaN/GaN HEMTs various methods such as surface passivation and field plate structure have been reported. MIS Structure is effective for suppression of the gate leakage current induced by a thermionic emission into the lowered Schottky barrier because of the surface traps. SiO$_2$ layer have been widely used for gate insulator of AlGaN/GaN MIS-HEMT. However, the low dielectric constant of SiO$_2$ (3.9) causes the large negative shift of $V_{TH}$.

Al$_2$O$_3$ and Ga$_2$O$_3$ are may be good candidates as a gate insulator of AlGaN/GaN HEMTs due to their high dielectric constant exceeding 10 and a good interface characteristics of Al$_2$O$_3$/GaN and Ga$_2$O$_3$/GaN. And they can be simply deposited by rf sputtering with excellent uniformity for mass product. The purpose of our paper to report the AlGaN/GaN HEMTs employing the new gate insulator of multiple Al$_2$O$_3$/Ga$_2$O$_3$ stacks. The Al$_2$O$_3$/Ga$_2$O$_3$ stacks successfully suppress the surface leakage current and increase the breakdown voltage of AlGaN/GaN HEMT with positive shift of $V_{TH}$ and increase of output current by accumulating electron/hole in Al$_2$O$_3$/Ga$_2$O$_3$ stacks.

**Device Structure and Fabrication**

The systematic structure of the proposed device is shown in Fig. 1. GaN cap (4 nm)/Al$_0.23$Ga$_{0.77}$N barrier (20 nm)/GaN buffer (1.7 μm)/Transition layer were grown on Si (111) substrate by MOCVD (Metal-Organic Chemical Vapor Deposition). The ohmic contact, Ti/Al/Ni/Au (20/80/20/100 nm), was formed by liftoff and it was annealed at 880 °C for 40 sec. Prior to Al$_2$O$_3$/Ga$_2$O$_3$ sputtering, we performed BOE (30:1) cleaning for 30 sec in order to remove a native oxide of the GaN. The 10 nm thick-Al$_2$O$_3$/Ga$_2$O$_3$ stacks was sputtered at power of 50 W at room temperature under Ar ambient (3 mTorr). The thickness of one layer was 2 nm (5 layers). Finally, Schottky contact, Ni/Au (30/150 nm), was formed on Al$_2$O$_3$/Ga$_2$O$_3$ stacks. We have also fabricated the conventional HEMT and one employing Al$_2$O$_3$ only for comparison.

**Experimental Results**

Fig. 2 shows the drain leakage current of the proposed devices. The drain leakage (when $V_{DS}$= -10 V $V_{DS}$= 100 V) of the AlGaN/GaN HEMT employing Al$_2$O$_3$ stacks, HEMT employing Al$_2$O$_3$ only and conventional one are 33 nA/mm, 1.8 μA/mm and 654 μA/mm respectively. The breakdown voltage of the proposed HEMT employing Al$_2$O$_3$/Ga$_2$O$_3$ stacks is 1100 V while that of the conventional HEMT and HEMT employing Al$_2$O$_3$ only are 380 V and 1050 V respectively (determined by the leakage current of 1 mA/mm). Al$_2$O$_3$ suppresses the leakage current by passivating the surface on the AlGaN/GaN HEMT and increases breakdown voltage. Moreover, The reverse blocking characteristics of the HEMT employing Al$_2$O$_3$ stacks are rather improved due to the electron accumulation in Al$_2$O$_3$/Ga$_2$O$_3$ stacks. The depletion region underneath gate is extended by the accumulated electron at reverse bias. The discontinuity of energy band and interface trap at Al$_2$O$_3$/Ga$_2$O$_3$ stacks may induce charge accumulation.

Output characteristics (Figure. 4) are measured with sweeping $V_{GS}$ from 2 V to -4 V at -2 V increment. The AlGaN/GaN HEMT employing Al$_2$O$_3$/Ga$_2$O$_3$ stacks showed the increased output current by hole accumulation at forward bias. The $V_{TH}$ of the AlGaN/GaN HEMT employing Al$_2$O$_3$ only from -2 V to -2.2 V (determined by the 1 mA/mm) while that of the AlGaN/GaN HEMT employing Al$_2$O$_3$/Ga$_2$O$_3$ stacks is -1.4 V. It indicates that the electron accumulation under gate extends the depletion region into vertical direction (Figure. 5-6).

Charge accumulation of the fabricated devices is investigated by CV measurement (Fig. 7-9). The large capacitance of the AlGaN/GaN HEMT employing Al$_2$O$_3$/Ga$_2$O$_3$ stacks indicates the formation of MIS structure and an additional charge accumulation under the gate. Also, the AlGaN/GaN HEMT employing Al$_2$O$_3$/Ga$_2$O$_3$ stacks show a large hysteresis and a high...
peak value of conductance which cause the positive shift of \( V_{TH} \) and increase of output current.

We have successfully fabricated the AlGaN/GaN HEMT employing the new gate insulator of multiple \( \text{Al}_2\text{O}_3/\text{Ga}_2\text{O}_3 \) stacks by rf sputtering in order to increase breakdown voltage and shift the \( V_{TH} \) in positive direction.

**References**


2. M. Sugimoto, et. al., “A Study of MIS –AlGaN/GaN HEMTs with SiO\textsubscript{2} Films as Gate Insulator”, Proceedings of the 17\textsuperscript{th} ISPSD, 2005


**Figures**

1. Systematic structure of the fabricated devices

2. Drain leakage current

3. Breakdown voltage

4. Output characteristics

5. Transfer curve

6. Expanded transfer curve

7. Capacitance-voltage curve

8. Capacitance-voltage curve

9. Conductance (channel modulation)