AlGaN/GaN HEMTs Employing Multiple Al_2O_3/Ga_2O_3 stacks

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Summary

We have successfully fabricated AlGaN/GaN HEMTs employing new gae insulator of multiple Al_2O_3/Ga_2O_3 stacks in order to increase the breakdown voltage and positive shift of V_{TH}. (High Electron Mobility Transistors) employing multiple Al_2O_3/Ga_2O_3 stacks by rf sputtering have been proposed and fabricated. AlGaN/GaN HEMT employing 10 nm thick-Al_2O_3/Ga_2O_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_2O_3/Ga_2O_3 is -1.4 V while that of the conventional HEMT is -2 V because of charge accumulation in Al_2O_3/Ga_2O_3 stacks. The AlGaN/GaN HEMT employing Al_2O_3/Ga_2O_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_2O_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 [1]. In order to improve reverse blocking characteristics of AlGaN/GaN HEMTs various methods such as surface passivation and field plate structure have been reported [2]. 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_2O_3 and Ga_2O_3 are may be a 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_2O_3/GaN and Ga_2O_3/GaN [3-4]. 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_2O_3/Ga_2O_3 stacks. The Al_2O_3/Ga_2O_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_2O_3/Ga_2O_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-Orgarnic Chemical Vapor Deposition). The ohmic contact, Ti/Al/Ni/Au (20/80/20/100 nm), was formed by lift-off and it was annealed at 880 ^{o}C for 40 sec. Prior to Al_2O_3/Ga_2O_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_2O_3/Ga_2O_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_2O_3/Ga_2O_3 stacks. We have also fabricated the conventional HEMT and one employing Al_2O_3 only for comparison.

Experimental Results

Fig. 2 shows the drain leakage current of the proposed devices. The drain leakage (when V_{GS}= -10 V V_{DS}= 100 V) of the AlGaN/GaN HEMT employing Al_2O_3 stacks, HEMT employing Al_2O_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_2O_3/Ga_2O_3 stacks is 1100 V while that of the conventional HEMT and HEMT employing Al_2O_3 only are 380 V and 1050 V respectively (determined by the leakage current of 1 mA/mm). Al_2O_3 suppresses the leakage current by passivating the surface on the AlGaN/GaN HEMT and inreases breakdown voltage. Moreover, The reverse blocking characteristics of the HEMT employing Al_2O_3 stacks are rather improved due to the electron accumulation in Al_2O_3/Ga_2O_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_2O_3/Ga_2O_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 increament. The AlGaN/GaN HEMT employing Al_2O_3/Ga_2O_3 stacks showed the increased output current by hole accumulation at forward bias. The V_{TH} of the AlGaN/GaN HEMT employing Al_2O_3 only from -2 V to -2.2 V (determined by the 1 mA/mm) while that of the AlGaN/GaN HEMT employing Al_2O_3/Ga_2O_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_2O_3/Ga_2O_3 stacks indicates the formation of MIS structure and an additional charge accumulation under the gate. Also, the AlGaN/GaN HEMT employing Al_2O_3/Ga_2O_3 stacks show a large hysterysis 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 Al_2O_3/Ga_2O_3 stacks by rf sputtering in order to increase breakdown voltage and shift the V_{TH} in positive direction.

References

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[4] C. Ostermaier, et. Al., “Interface characterization of ALD deposited Al_2O_3on GaN by CV method”, phys. stat. sol. (c) 5, No. 6, 1992– 1994,2008.

Figures

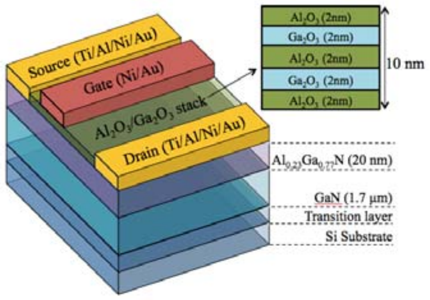

Figure 1: Systematic structure of the fabricated devices

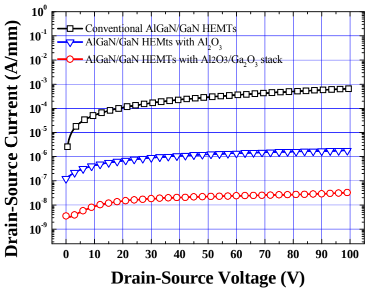

Figure 2: Drain leakage current

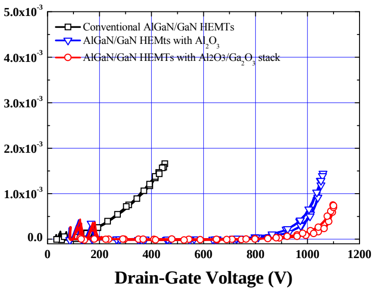

Figure 3: Breakdown voltage

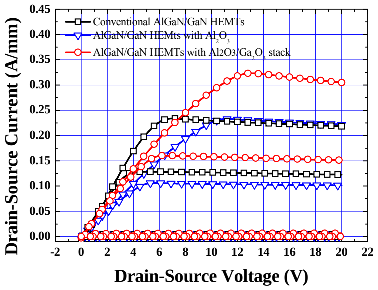

Figure 4: Output characteristics

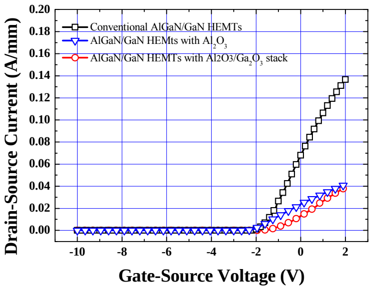

Figure 5: Transfer curve

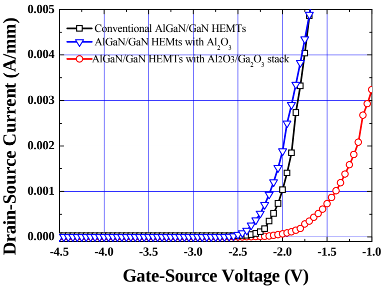

Figure 6: Expanded transfer curve

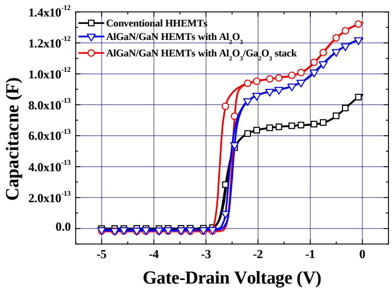

Figure 7: Capacitance-voltage curve

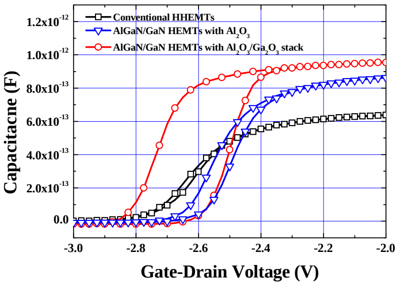

Figure 8: Capacitance-voltage curve

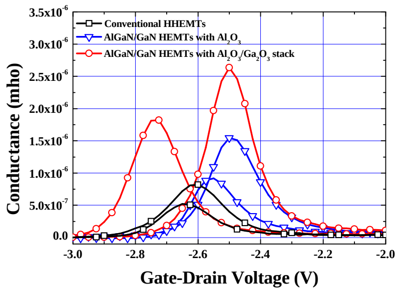

Figure 9: Conductance (channel modulation)