GaN Metal–insulator-semiconductor Field Effect Transistor Based on GaN/AlGaN/GaN Double Heterojunctions

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III-N is the most promising material for high-temperature, high-power electronic devices. There have been many researches on GaN-based metal semiconductor FET (MESFETs). For many applications, metal-insulator-semiconductor technology is desirable since it would provide high DC input impedance, large gate voltage swings, normally-off operation with high source-drain blocking voltage, and high temperature operation as a result of reduced gate leakage comparing to that of a conventional metal semiconductor FET (MESFET). However, for a semiconductor with a wide energy gap, the generation of minority carries in the deep depletion region of the MIS capacitor would be extremely slow. In a GaN MIS capacitor it would be about 10^{11} year[1]. Therefore, Obtaining an inverted channel would be very difficult in a GaN MISFET with a conventional device structure, and could not work under enhancement mode.

In this paper, we demonstrated an enhancement mode GaN-based MISFETs based on the piezoelectric of GaN/AlGaN/GaN double heterojunction .The device structure is illustrated in fig.1.

The device structure was grown on sapphire substrates using light-radiation heating low-pressure metalorganic chemical vapor deposition (LRH/LP-MOCVD)[2]. The MISFET structure employed in this study includes, from the bottom, 30-nm GaN buffer layer, 1.4-μm GaN, 50-nm $Al_{0.4}Ga_{0.6}N$, 100-nm GaN. Trimethygallium(TMG) and trimethaluminium(TMA) were used as the gallium and aluminum precursor. Ammonia(NH_3) was used as a nitrogen precursor and H_2 as the carrier gas. All layers are undoped. Finally, 100-nm SiO_2 layer was deposited on the surface of the top GaN by PECVD. The devices have gate lengths of 6 μm and 10 μm and a gate width of 100 μm. The Al was evaporated on the top GaN layer and annealed at 500 ºC for 20 minutes in nitrogen for ohmic contacts. Then, the Al was evaporated on gate SiO_2 layer for gate contact.

It had been known that the piezoelectric effect induced by lattice-mismatch-induced strain is very important in a III-V nitride heterojunction structure. Bykhovski *et.al.*[3] have detailed study the piezoelectric properties on a GaN/AlN/GaN structure, and demonstrated that the strain-induced electric fields can shift the flat ban voltage and produce an accumulation region on one side and a depletion region on the other side of AlN. The electric fields direction depends on the type of atomic plane at the heterointerface (Ga or N). The band bending induced by piezoelectric field is shown in fig.2. Recently, Ramvall *et.al.*[4] have reported the carrier distribution on a MOCVD-grown GaN/$Al_{0.14}Ga_{0.86}N$/GaN double heterojunction structure. Their experimental results clearly revealed the depletion region on the top GaN layer and the electric field (E_p) directions, which prove that there will be a hole well around the interface same as fig.2. This field will strongly affect the band bending.

Fig.3 shows a DC output characteristic of the device. This figure shows a very good output and pinch-off characteristics of a device with a gate length of 6 μm. The transconductance is 0.6 mS/mm and the maximum drain-source current is 5 mA/mm. The gate leakage current is lower than 10^{-6} A at a gate voltage of -10 V, and the gate breakdown voltage is higher than 20 V.

High-frequency (1MHz) capacitance-voltage (C-V) measurements were also performed on the sample with the same structure as our device. The C-V characteristics are shown in fig.4. In this figure, the MIS capacitance on GaN/AlGaN/GaN reaches a minimum value, while that on a single 1.2-μm GaN layer runs in deep depletion as expected. The saturation at a minimum value of the C-V curve confirmed the presence of a *p*-channel in the device structure.

In conclusion, an enhancement mode GaN-based MISFET on a GaN/AlGaN/GaN double heterojunction with PECVD-grown SiO_2 as gate insulator was firstly demonstrated. The DC measurements show this device has a good output and pinch-off characteristic and a transconductance of 0.6 mS/mm with a maximum drain-source current of 5 mA/mm. The presence of *p*-channel is due to the strongly asymmetric band bending and carriers distribution induced by the strain-induced piezoelectric field.

ACKNOWLEDGEMENT

This work was supported by Project of High technology Research & Development of China, Project of Fundamental Research of China and MOTOROLA(China Inc.) Semiconductor Scholarship.

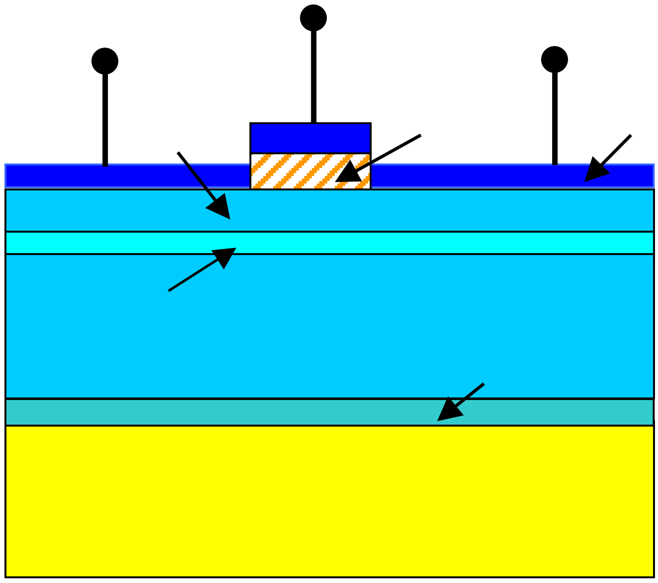
References

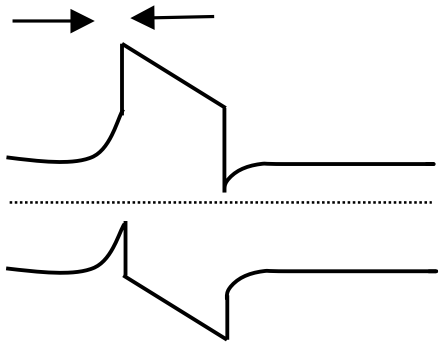
[1] H.C.Casey,Jr., G.G.Fountain, R.G.Alley, B.P.Keller, and Steven P.DenBarrs, *Appl. Phys. Lett.* vol **68**, pp. 1850-1852, 1996.

[2] B.Shen, Y.G.Zhou, Z.Z.Chen, P.Chen, R.Zhang, Y.Shi, Y.D.Zheng, W.Tang and W.Park, *Appl. phys. A*, **68**, pp. 593-596, 1999.

[3] A.Bykhovski, B.Gelmont, and M.Shur, *J. Appl. Phys.* vol **74**, pp. 6734-6739, 1993.

[4] P.Ramvall, Y.Aoyagi, A.Kuramata, P.Hacke, and K.Horino, *Appl. Phys. Lett.* vol **74**, 3866-3868, 1999.





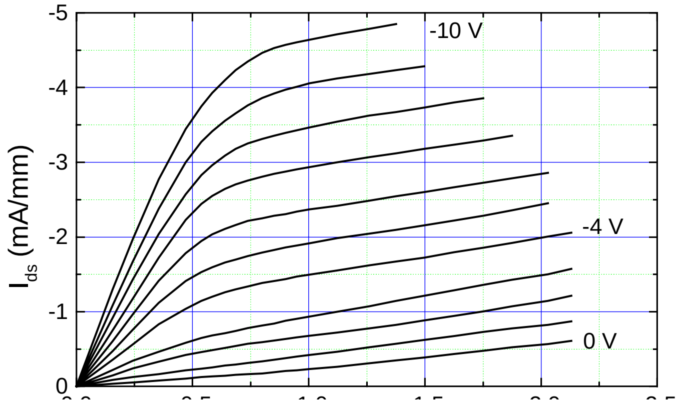


Fig.3 The output characteristic of a device with a gate length of 6 μm. This figure shows a very good output and pinch-off characteristics with a transconductance of 0.6

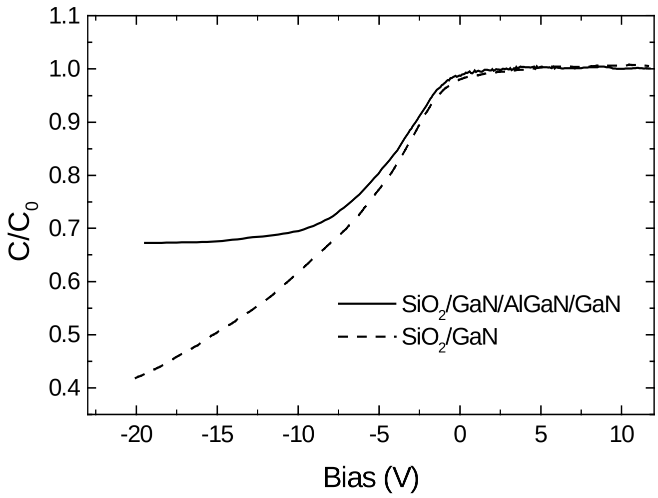


Fig.4 The MIS capacitance of on a GaN/AlGaN/GaN structure and on a single 1.2-μm GaN layer