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Novel quaternary AlInGaN/GaN HFET grown by MOCVD on sapphire substrate

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1. Introduction

The high performance of AlGaN/GaN HFET is primarily due to the existence of high mobility two-dimensional electron gas (2DEG) at the heterointerface, which are created by large conduction band offset, the strong piezoelectric and spontaneous polarization effect in the heterostructure [1]. Further improvement of HFET performance can be expected by increasing Al content of AlGaN barrier layer. However, with further increase of Al content, the increasing lattice mismatch between AlGaN and GaN will decrease the critical thickness of a fully strained AlGaN barrier and result in uncontrolled local relaxation at the heterointerface via generation of misfit dislocation and cracks. To solve the problem, quaternary AlInGaN was proposed [2, 3] to replace AlGaN as barrier because of following two advantages. First, quaternary can allow the independent adjustment for bandgap and lattice constant, by which the built-in strain can be controlled below the critical value before the occurrence of relaxation. Second, larger polarization may be expected in quaternary AlInGaN barrier via significant Al incorporation (mainly increasing spontaneous polarization) because theoretical research predicted that the spontaneous polarization was as large as the piezoelectric polarization in wurtzite group-III nitrides increasing from GaN over InN to AlN. So far, there is very few report available [4] concerning the research of AlInGaN/GaN HFET. In this work, the properties dependence of undoped quaternary AlInGaN/GaN HFET on Al mole fraction had been studied. Enhancement mode AlInGaN HFET was demonstrated.

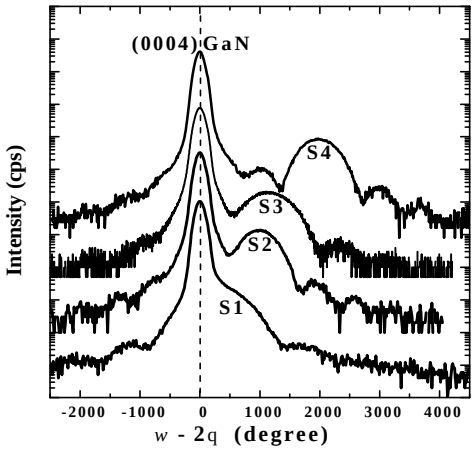

Fig. 1 XRD *w-2?* scan of four AlInGaN/GaN heterostructures.

2. Experiment

The undoped quaternary AlInGaN/GaN heterostructures were grown by Taiyo Nippon Sanso SR2000 metal organic chemical vapor deposition system on c-plane sapphire substrate. After the growth of 1.3 μm of undoped GaN, about 30 nm thick undoped AlInGaN was deposited. In this study, four samples of $Al_xIn_{0.02}Ga_{0.98-x}N$ were grown with a constant In mole fraction (2%) and different x value (10, 16, 22 and 30%). Hereinafter, the four heterostructure samples are referred as to S1, S2, S3 and S4, respectively, with increasing the Al mole fraction. Pseudomorphic growth of four AlInGaN barrier layers was confirmed by XRD asymmetrical reciprocal lattice mappings. Figure 1 showed the XRD *w-2q* scan for four HFET structures, from which we believed that the tensile strain in AlInGaN epilayer increased with Al mole fraction. Room temperature Hall measurement revealed that the materials exhibited n type properties. The plot of mobility and sheet carrier density as a function of Al mole fraction was shown in Fig.2. It can be seen that the mobility decreased when Al mole fraction is larger than 16%.

The device isolation was accomplished by mesa dry etching down to i-GaN by BCl_3 plasma reactive ion etching. Then, 100-nm-thick SiO_2 passivation layer was deposited by electron beam evaporation. The Ti/Al/Ni/Au (15/70/12/40 nm) and Pd/Ti/Au (40/20/60 nm) were used as Ohmic contact and Schottky gate contact, respectively.

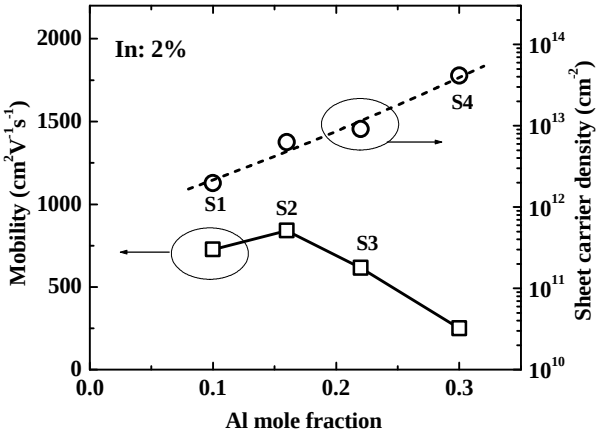

Fig.2 The plot of mobility and sheet carrier density as a function of Al mole fraction.

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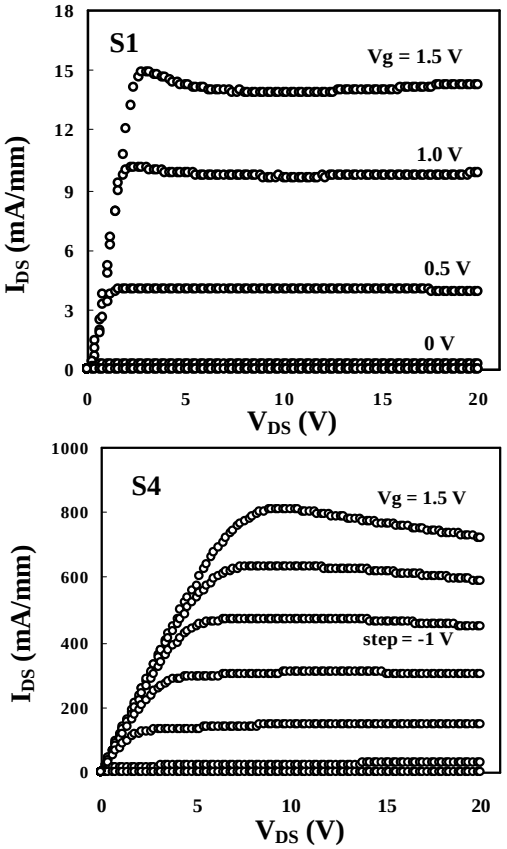

Fig. 3 The plot of I_{DS} versus V_{DS} for sample S1 and S4.

3. Result and discussion

All the Q-HFET exhibited good pinch off characteristics, in which the plot of drain current (I_{DS}) versus drain-source voltage (V_{DS}) characteristics at different values of gate-source voltage (Vg) for S1 and S4 were shown in Fig.3. The maximum drain current (I_{dmax}) of about 15 and 810 mA/mm were obtained with the peak extrinsic transconductance (g_{mmax}) of 9 and 123 mS/mm for S1 and S4, respectively. As shown in Fig.3, the HFET of S1 was pinched off at zero volt, which indicated that enhancement mode (normally off) HFET was fabricated. It was also found that a decrease in threshold voltage (V_{th}) down to about -6 V correlated with the increase in Al mole fraction (see Fig.4), which was accompanied by an increase in g_{mmax} and I_{dmax}.

We believe that such Al mole fraction dependent HFET properties are due to their unique material characteristics exhibited by Hall measurement. As shown in Fig.2, the carrier sheet density increased with Al mole fraction, which is mainly due to the density increase in 2DEG caused by the enhancement of conduction band offset and polarization (both piezoelectric and spontaneous) in the AlInGaN. Another reason is assigned to the increased background doping (from 10^{16} to 10^{18} cm^{-3}) [5] in AlInGaN barrier layers with increase of Al mole fraction, which may be attributed to the native defects or impurities. Thus, the decreased mobilities in high Al samples (see Fig.2) can be explained in terms of the scattering from the defects or impuities.

The realization of normally off HFET in S1 is due to the less sheet carrier density and higher Schottky barrier, which resulted in a longer depletion region and made the conduction channel fully depleted at zero bias. Further details will be presented on the conference.

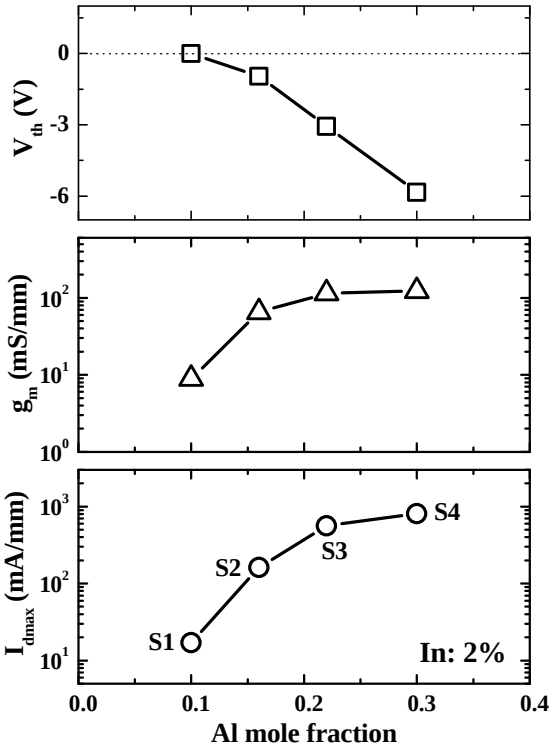

Fig.4 The plot of V_{th}, g_m and I_{dmax} as a function of Al mole fraction.

3. Conclusion

In this work, the properties dependence of undoped quaternary AlInGaN/GaN HFET on Al mole fraction had been studied. It was found the threshold voltage of HFET can be adjusted by changing the Al mole fraction in AlInGaN barrier layer. Enhancement mode AlInGaN HFET was demonstrated.

References

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