Extended Abstracts of the 2003 International Conference on Solid State Devices and Materials, Tokyo, 2003, pp. 138-139

F-2-4

The improvement of DC performance in AlGaN/GaN HFET with isoelectronic Al doped channel

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1. Introduction

III-V nitride materials have been investigated for the various optical and electronic devices.[1] Especially, the AlGaN/GaN heterostructure has high breakdown field strength ($1\sim3\times10^{6}$ V/cm), high saturation velocity for electron, and high sheet charge densities in excess of $\sim10^{13}/cm^{2}$ due to high conduction band offset and high piezo-electricity.[2] Thus, AlGaN/GaN heterostructure field effect transistors (HFETs) have been considered to be one of the most promising candidates for their potentially superior performance in high power and high frequency electronic devices.[3] Since the lattice mismatch between GaN and sapphire for substrate is about 13.9 %, a number of dislocations and various point defects, such as vacancies and anti sites, should be produced into the GaN layer, leading to the increase of threshold current and current collapse of the devices. The extensive improvement of the HFET performance has been achieved by optimizing the crystal quality in AlGaN/GaN heterostructure and fabrication processing.[4] In the previously reported results, the isoelectronic doping improved the crystalline quality of the III-V and II-VI semiconductors due to reducing the unintensional doping concentration, deep levels, and dislocation densities.[5,6] These effects of isoelectronic doping on semiconductor could improve the electrical and optical performance of the devices. We have already reported that point-defect-related electron scattering and non-radiative centers can be significantly reduced by incorporating only a small amount of Al into GaN, thereby improving the electrical and optical properties of GaN films.[7]

In this letter, we report the improvement of device performance using Al isoelectronic doping. the 0.8 μm gate-length AlGaN/GaN HFETs with Al doped channel were fabricated on sapphire substrate.

2. Experimental details

The isoelectronic Al doped channel AlGaN/GaN heterostructure and conventional structure used in this work were grown on a (0001) sapphire substrate using metal organic chemical vapor deposition. For the Al-doped channel structure, the Al-doped GaN channel layer with a thickness of 700 Å was grown on the semi-insulating undoped GaN, followed by the growth of 250-Å-thick undoped AlGaN layer. The conventional HFET structure consisted of a 250 Å undoped AlGaN layer grown on the undoped GaN buffer layer with a thickness of 2.5 μm. The Al composition in AlGaN was determined to be 42 % from XRD measurements. Figure 1 (a) and (b) show the schematic cross-sectional diagram of conventional and Al-doped channel heterostructure, respectively.

In the fabrication of AlGaN/GaN HFET, an active region was defined by Cl_2 based inductively coupled plasma (ICP) methods. For the ohmic contact, Ta/Ti/Al /Ni/Au metals were deposited in sequence by electron beam evaporation, followed by annealing at 850 ^{o}C for 10 s in N_2 ambient. The specific contact resistivity was evaluated to be $4.2 \times 10^{-7}\,\Omega cm^{2}$. After fabrication of ohmic contact, the gate electrode with 0.8 μm gate length and 50 μm gate width was patterned using photolithography, followed by deposition of Pt (500 Å)/Au (2000 Å) using e-beam evaporator.

3. Results and discussion

The sheet carrier density and 2DEG mobility as a function of temperature of conventional and Al-doped structure were summarized in Table 1. The 2DEG mobility of Al-doped structure increased by 18 % for 300 K and 43 % for 77 K compared with that of conventional structure, respectively. These results might be due to the decease of point defects strongly related with the electron scattering center through the Al incorporation at the Al-doped GaN layer.

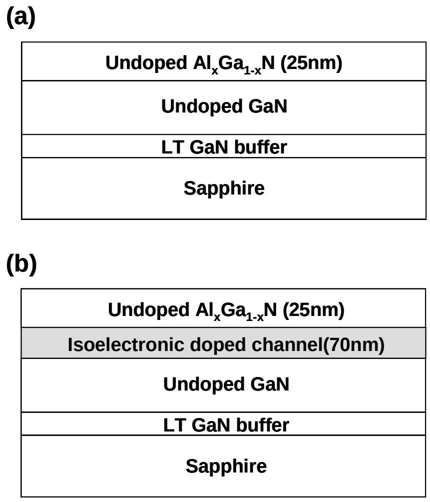

Fig. 1 Schematic cross sectional view of heterosturcutre: a) conventional structure, b) isoelectronic Al doped structure.

Table 1 Electrical properties of conventional and Al-doped structure.

Layer sturcuture		conventional structure	isoelectronic doped structuree
2DEG mobility	300K	1280	1510
(cm^2/Vs)	77K	3390	4870
Sheet concentration	300K	1.2	1.1
($10^{13}/cm^2$)	77K	1.1	1.0

The AlGaN/GaN HFETs with Pt/Au gate electrode were fabricated in this study with the dual gate structure. The gate length and gate width were 0.8 μm and 2×25 μm, respectively. The spacing from source to drain was 3.6 μm. Figure 2 shows the drain *I-V* characteristics of two kinds HFET structure. In conventional structure, the drain saturation current, I_{dss}, and on-state resistance, R_{on}, were investigated to be 266.6 mA/mm and 0.0049 Ωmm, respectively. In Al isoelectronic doped structure, the I_{dss} increased by 50 % compared with conventional structure, and the R_{on} was observed to be 0.0030 Ωmm. Figure 3 display the drain current and extrinsic transconductance (g_m) as a function of gate bias. During the measurement, the drain bias was maintained by 3 V. The threshold voltages were measured by -2.8 and -3.1 V for the conventional and Al doped structure, respectively. The maximum drain current (I_{max}) was evaluated by 700.61 mA/mm at the gate bias 2.5 V and the $g_{m,max}$ was 192.22 mS/mm with conventional structure. However, the I_{max} and $g_{m,max}$ of Al doped structure were measured by 908.48 mA/mm and 231.83 mS/mm, respectively. This significant increase of the performance corresponding to 22.9 % for I_{max} and 17 % for $g_{m,max}$ might be due to a consequence of higher mobility and higher carrier concentration in this device.

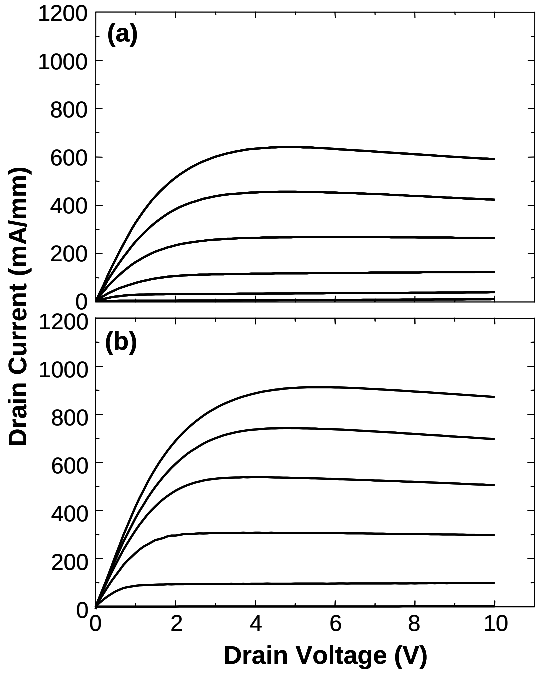

Fig. 2 Drain *I-V* characteristics of AlGaN/GaN HFET: a) conventional structure, b) Al-doped structure. (V_{gs}= 2~-3V step 1V)

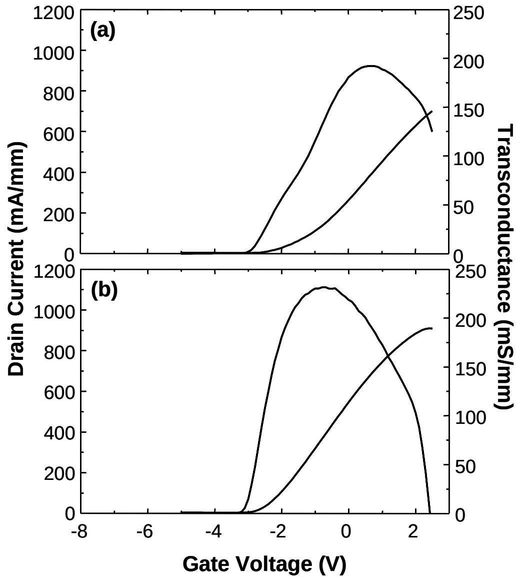

Fig. 3 Transconductance vs. gate voltage characteristics of (a) conventional structure, and (b) Al-doped structure. (V_{ds}=3V)

In conclusion, we have investigated the effect of isoelectronic Al-doping on AlGaN/GaN heterostructure and demonstrated the HFET with new structure. In Al doped structure, the 2DEG mobility significantly increased and the performances of the HFET corresponding to I_{max} and $g_{m,max}$ were dramatically improved by 22.9 % and 17 % compared with conventional structure, respectively. These improved results originated from the compensation of point defects associated with screw dislocation by the incorporation of Al in the channel layer.

Acknowledgment

This work was performed through project for "National Research Laboratory" sponsored by the Korea Institute of Science and Technology Evaluation and Planning (KISTEP).

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