Extended Abstracts of the 2007 International Conference on Solid State Devices and Materials, Tsukuba, 2007, pp. 164-165

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First Operation of AlGaN Channel High Electron Mobility Transistors with Sufficiently Low Resistive Source/Drain Contact formed by Si Ion Implantation

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1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) are strong candidates for future high-power and high-frequency applications[1,2]. This is because GaN-based wide bandgap semiconductors have not only superior material properties compared to silicon or GaAs, such as high breakdown field and a high electron saturation velocity, but also a high-density two-dimensional electron gas induced in the AlGaN/GaN hetero-structures due to the polarization effects even if AlGaN barrier layer is consisted of unintentionally-doped layer. The trend of such devices is now progressing for much higher-power applications. In order to operate in much higher-power region, increasing the breakdown voltage is simple strategy and applying the materials with higher breakdown field (E_c) to the channel layer is the one of the effective method. Higher aluminum mole fractional AlGaN is the available material in order to increase the breakdown voltage without decrease of the drain current density, because the E_c of AlN which has about twice large of energy bandgap comparing to that of GaN is about four times larger than that of GaN, and the electron saturation velocity of AlN is almost as same as that of GaN. For realizing of such hetero-structures, however, we may use much higher aluminum mole fractional AlGaN as the barrier layer which will increase the contact resistance significantly, so that a breakthrough technology is necessary for the AlGaN channel HEMTs.

Recently we have reported that Si ion implantation technique was very effective to realize superior ohmic contact for the HEMTs with GaN channel[3]. In this paper, we fabricated the HEMTs with AlGaN channel, where the Si ion implantation technique was used to form sufficiently low resistive contact, and demonstrated the transistor operation for the first time.

2. Experimental

Figure 1 shows the cross sectional structure of the fabricated HEMTs with AlGaN channel layer. The AlGaN/AlGaN epitaxial layers were grown on a sapphire substrate with a thin low-temperature GaN (LT-GaN) buffer layer by the metalorganic chemical vapor deposition technique. The aluminum mole fraction in barrier layer and channel layer were 40% and 20%, respectively. Both barrier layer and channel layer were unintentionally doped.

The fabrication process started with selective Si ions implantation into the source/drain region. ^{28}Si ions were implanted with energy of 50 keV at dose concentration of 1 x 10^{15} cm^{-2} at room temperature, and subsequently implanted Si ions were activated by rapid thermal annealing at 1150 ^{O}C for 5 min in an environment of flowing nitrogen. During the Si ions implantation and activation annealing, the wafer was capped by 30nm thick of SiN layer deposited by plasma-enhanced chemical vapor deposition. After removing the SiN cap layer in a HF solution, the Ti/Al source/drain ohmic contacts were formed, and device isolation was performed by Zn ion implantation[4]. Lastly Ni/Au Schottky gate contact was formed. All electrodes were defined by the conventional photolithography and liftoff technique, and the all metals were deposited by an electron beam evaporation system.

The current-voltage (I-V) and capacitance-voltage (C-V) characterization were carried out at room temperature using an Agilent 4156C parameter analyzer and a HP4284 LCR meter.

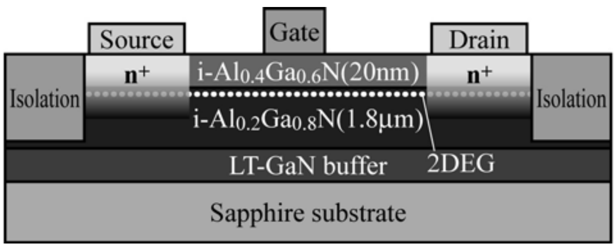

Fig.1 Schematic structure of HEMTs with AlGaN channel layer

3. Results and discussion

3.1. Formation of two-dimensional electron gas

Figure 2 shows the depth profile of carrier concentration calculated form C-V characteristics of Schottky diode fabricated on same wafer.

The carrier concentration rapidly increased around 20 nm of depth corresponding to the AlGaN barrier layer thickness. This result indicated that the two-dimensional electron gas was formed at the AlGaN/AlGaN hetero interface. The sheet carrier concentration calculated from the integration of this carrier concentration was 6.9 x 10^{12} cm^{-2}.

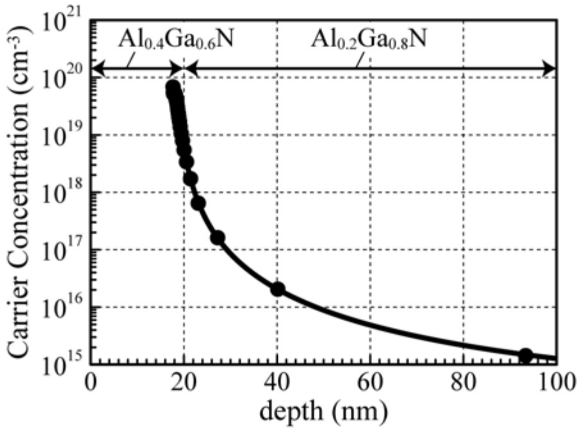

Fig.2 Depth profile of the carrier concentration calculated from the C-V characteristics.

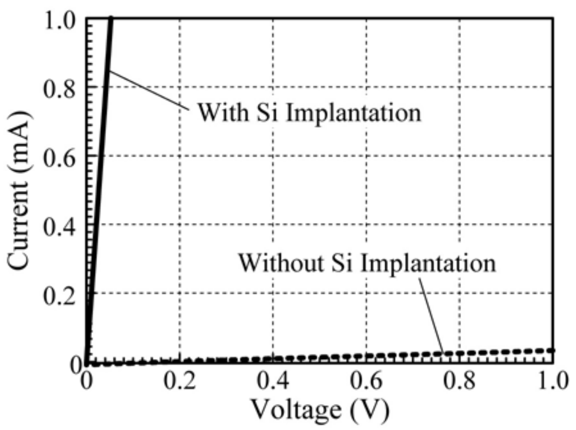

Fig.3 I-V curves of the CTLM pattern with and without Si ion implantation.

3.2. Si ion implantation for Ohmic contact

Figure 3 shows the I-V curves of the circular transfer length method (CTLM) pattern spaced 4μm with and without Si ion implantation. In the sample without Si ion implantation, the contact resistance was so high that we could not calculate it from CTLM, because the AlGaN barrier layer was not only unintentionally doped but also the aluminum mole fraction was higher comparing to the conventional barrier layer of AlGaN/GaN structure. On the other hand, in the sample with Si ion implantation, we could realize the low ohmic contact resistance of 1.2×10^{-3} Ωcm^2 led from the CTLM. As a result Si ion implantation technique was very effective to obtain sufficiently low contact resistance to operate the transistor with this AlGaN/AlGaN hetero-structure.

3.3. Characteristics of AlGaN/AlGaN HEMT

Figure 4 shows the drain current-drain voltage curves of the AlGaN channel HEMT applied the Si ion implantation technique for source/drain ohmic contact. The gate length and the gate width of the measured sample were 1μm and 50μm, respectively. We could confirm the transistor operation in the HEMTs with AlGaN channel layer and obtained the maximum drain current density of 0.13 A/mm at the gate voltage of 2 V.

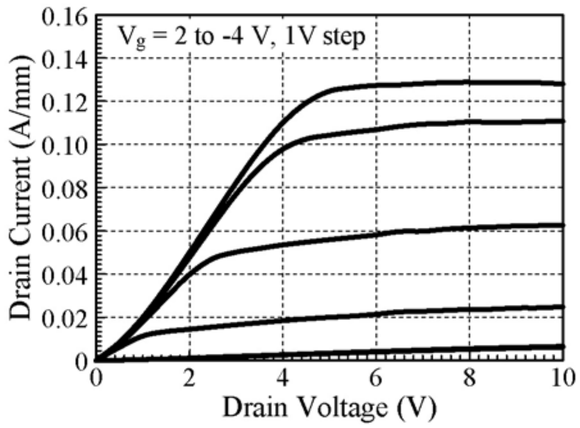

Fig.4 Drain current-drain voltage curves of the sample applied Si ion implantation for source/drain ohmic contact.

4. Conclusions

We realized low resistive contact by applying the Si ion implantation technique for the source/drain formation and demonstrated a transistor operation in the HEMTs with AlGaN channel layer for the first time. This remarkable result is very promising for increasing the breakdown voltage without the decrease of drain current, and thus much higher-power operation of HEMTs should be realized.

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