Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp204-205

Crystal growth of InAs/AlGaSb heterostructures by molecular beam epitaxy and fabrication of InAs HFETs using Ni/Au alloy ohmic metal

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Abstract

The growth of InAs/AlGaSb heterostructures by molecular beam epitaxy and characterization of antimonide-based composite-channel InAs HFETs are reported. Antimonide-based compound semiconductors, such as those of InAs combined with AlGaSb, are candidates for high-speed, low-power digital applications. InAs/AlGaSb HFETs utilizing high-k (HfO_2) gate insulator were fabricated using Ni/Au ohmic metallization. A transconductance g_m of 450 mS/mm and maximum drain current density I_d of 600 mA/mm were obtained for the HFET with gate length of 2 μm.

1. Introduction

Improved operation speed performance in silicon devices has been achieved by miniaturization. However, consequent increasing leakage current is a serious problem, especially in terms of standby power consumption. The introduction of high-k metal gate technology, which resolved the gate leakage issue, is one of the most important recent innovations in CMOS technology. In addition, the introduction of new alternative materials in place of silicon is becoming important. III-V compound semiconductors with high electron velocity and high electron mobility have thus been attracting much attention. Antimonide-based compound semiconductors especially are candidates for high-speed and low-power digital applications [1].

In this paper, we report the growth of InAs/AlGaSb heterostructures by molecular beam epitaxy (MBE), and characterization of InAs HFETs using an Ni/Au ohmic contact with low contact resistance. To achieve a low density of interfacial defects between the high-k gate insulator and semiconductor, the interface between hafnium oxide (HfO_2) and GaSb upper layer pre-treated with hydrochloric acid (HCl) has been characterized.

2. MBE growth of InAs/AlGaSb heterostructure

Figure 1 shows a schematic cross-section of an InAs/AlGaSb heterostructure grown on semi-insulating substrates by molecular beam epitaxy (MBE) [2]. A 200-nm-thick AlGaSb and 8-nm-thick-AlSb bottom barrier layer, a 15-nm-thick InAs channel layer, a 15-nm-thick AlGaSb upper barrier layer, and a 10-nm-thick GaSb cap layer were grown on AlGaSb and superlattice buffer layers. Hall effect measurements using the van der Pauw method showed an electron mobility of 22,000 cm^2/Vs, electron density of 2.1×10^{12} cm^{-2}, and sheet resistance of 135 Ω/square at 300 K.

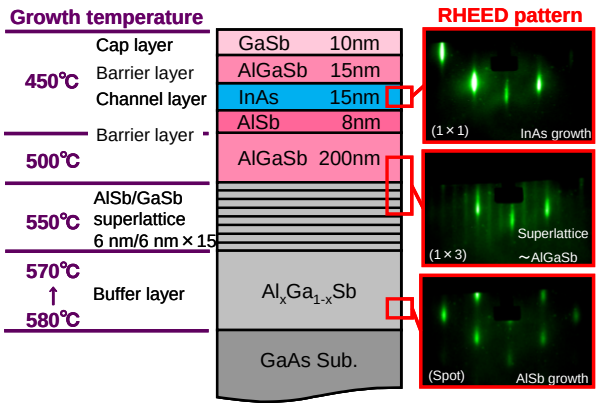

Fig. 1 Cross-sectional schematic view of an InAs/AlGaSb heterostructure and the growth conditions used. RHEED patterns from the buffer layer, superlattice layer, and InAs channel layer are also shown.

3. Fabrication of InAs/AlGaSb HFET with Ni/Au ohmic contact

Figure 2 shows a schematic diagram of an InAs HFET made using the heterostructure. The HFET was defined by photolithography and wet chemical etching. Ni/Au ohmic metal contacts and Ti/Au gate metal were deposited by electron beam evaporation. HfO_2 high-k gate insulators were also deposited by electron beam evaporation. The HFET has a gate length of 2 μm and a gate width of 50 μm.

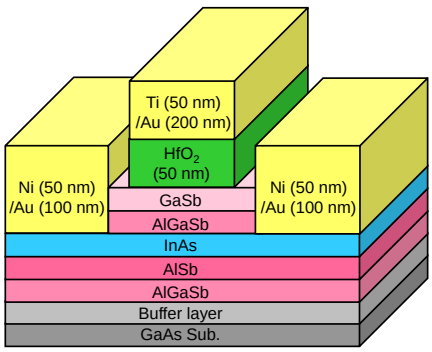

Fig. 2 Schematic diagram of fabricated InAs HFET with Ni/Au ohmic contact.

4. Reduction of contact resistance using Ni/Au stack metallization systems

A rapid thermal annealing process was performed in the temperature range of 200°C to 300°C. The annealing conditions were optimized to achieve a reduction in contact resistance between Ni/Au and the InAs layer. Contact resistance was measured using transmission line model measurements (TLM). Figure 3 shows the alloying temperature dependence of the contact resistance. Ni/Au metal was incorporated in the InAs by annealing under a nitrogen atmosphere at 250°C for 1 min, and lower contact resistance of 0.024 Ωmm was achieved at 300°C. There is a tendency for the contact resistance to be reduced with increasing alloying temperature.

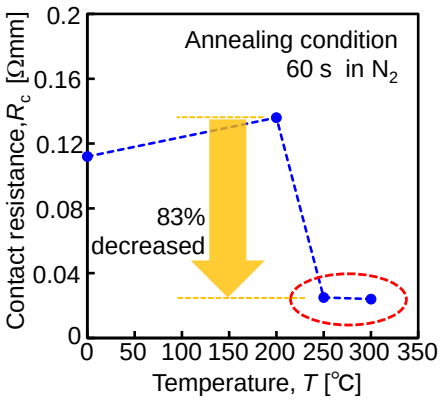

Fig. 3 Contact resistance of the Ni/Au alloy for different annealing temperatures.

5. Treatment with hydrochloric acid for removal of native oxides

The surfaces of III-V materials have native oxides from exposure to the atmosphere or chemically generated oxides from wet chemical treatment. As a result, transconductance and current density in the characteristics of a transistor are reduced by the formation of native oxide films. Many methods have been reported to reduce native oxides and to improve the interfacial layer of MOS structures [3,4]. In this study, we attempted to improve the interfacial properties of high-k/GaSb using HfO_2 as the dielectric. In order to remove the native oxide film on a GaSb surface, the GaSb/AlGaSb surface was cleaned using hydrochloric acid with an upper barrier layer prior to formation of a gate insulating film. Treatment was carried out for 60 seconds with 14% HCl and the surface was washed with pure water for 5 seconds. Figure 4 shows XPS of the Sb 3d core level signals for the GaSb treated with the solutions. The Sb-Ga bond in GaSb has a binding energy of 529.5 eV, and the Sb-O bond has a binding energy of 532.0 eV. The peaks of Sb-O in the XPS spectra were significantly changed in intensity with surface treatment using the HCl solution. These results show that it is possible to reduce the natural oxide film on the GaSb surface by hydrochloric acid treatment. In addition to the heat treatment of the ohmic contact, we carried out fabrication of a HFET by a combination of hydrochloric acid treatments.

Figure 5 shows the I_d-V_{ds} characteristics of the fabricated InAs/AlGaSb HFETs with the high-k gate insulator, measured at 300 K. The dashed plots show the I_d-V_{ds} characteristics of the HFET using the heat treatment process, and the solid lines are those of using hydrochloric acid and the heat treatment process. The extrinsic transconductance g_m = 330 mS/mm was found for the 300°C heat treatment. By using hydrochloric acid and heat treatment, a transconductance of g_m = 450 mS/mm at V_{ds} = 0.6 V for the fabricated HFET was obtained.

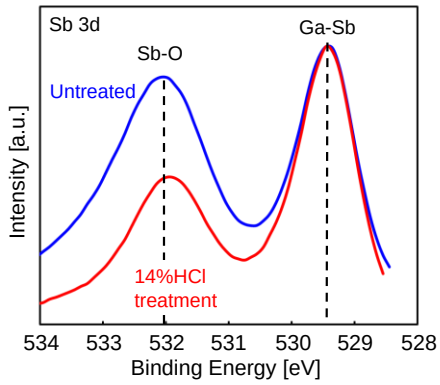

Fig. 4 Sb 3d XPS spectrum for untreated and 14% HCl treatment.

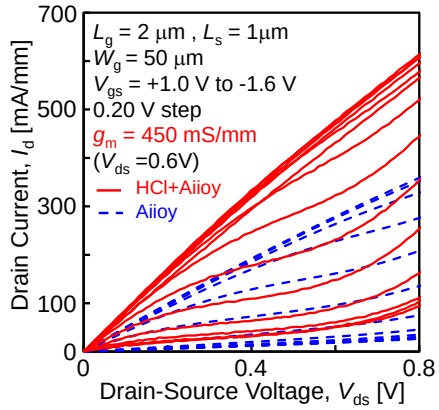

Fig. 5 I_d–V_{ds} characteristics of a fabricated InAs/AlGaSb HFET with HCl treatment and alloying process.

6. Summary

InAs/AlGaSb heterostructures were grown by MBE. Low contact resistance was obtained by Ni/Au ohmic metal annealed at 300°C in N_2 for 60 seconds. The native oxide on the GaSb surface was reduced effectively using a hydrochloric acid treatment. Transconductance of 450 mS/mm for the HFET with gate length of 2 μm was obtained.

References

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