Field characteristics of electron mobility and velocity in InAs/AlGaSb HFETs with high-k gate insulators

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Abstract. We report on the fabrication and characterization of InAs/AlGaSb heterojunction field-effect transistors (HFETs) with high-k gate insulators. These HFETs have been operated with a maximum extrinsic transconductance of 180 mS/mm at room temperature. The use of an 80-nm-thick Al_2O_3 gate insulator greatly lowered the gate leakage. The leakage current density was three orders of magnitude lower compared with other experimental studies of Shottky gate InAs HFETs. In addition, we evaluated the electron motility and drift velocity by increasing the field strength.

Keywords: Indium arsenide, heterojunction field-effect transistors (HFET's), high-k material, gate current
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INTRODUCTION

The antimonide-based semiconductors, such as InAs combined with GaSb, AlSb and similar alloys, are compounds whose heterostructures have conduction band offsets that permit great flexibility in their band-gap engineering [1]. Additionally, the low-dimensional electrons in these nano-structures [2] are attracting interest because of their low effective mass and subsequent strong confinement in the quantum well. InAs/AlGaSb heterostructures have several advantages: high electron mobility, high electron drift velocity that are suitable for the production of high-speed heterostructure field-effect transistors (HFETs) [3, 4]. On the other hand, a technical issue for this material system is an enhanced gate leakage due to the elevated charge generated by impact ionization and through the Shottky junction. Recently, an Al_2O_3 insulator has been used as a high-k gate dielectric material able to control the FET leakage current [5]. In this paper, we demonstrate the performance of InAs/AlGaSb HFETs into which we have inserted a high-k gate dielectric insulator, and discuss the attendant field characteristics of electron mobility and velocity.

DEVICE FABRICATION

Figure 1 shows the schematic diagram of an InAs/AlSb HFET and its energy band structure.

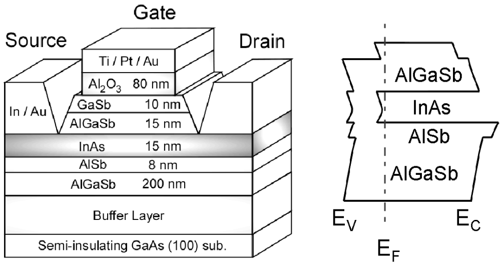

FIGURE 1. Schematic diagram of InAs/AlGaSb HFET structure and energy band structure.

The epitaxial layers were grown by molecular beam epitaxy (MBE) on a semi-insulating GaAs substrate. To improve the crystal quality of the InAs channel, we grew an un-doped 1.5 μm thick AlSb buffer as a buffer layer. Device isolation was accomplished by wet-chemical etching with a phosphoric acid-based etchant consisting of H_3PO_4, H_2O_2 and H_2O in a volume ratio of 1:1:100. Mesa isolation was carried out down to the middle of the bottom AlGaSb barrier, and the etched area was filled with a SiO_2 insulator deposited by electron beam evaporation. Next, the ohmic contact patterns were defined by photolithography, and the In/Au (20 nm/100 nm) ohmic layers were deposited by thermal evaporation. The gate metal (Ti/Au) and Al_2O_3 gate insulator were deposited by electron beam evaporation. In the end, the thicknesses of the gate metal and the Al_2O_3 were 100 nm and 80 nm, respectively. Hall measurements at 300 K revealed that

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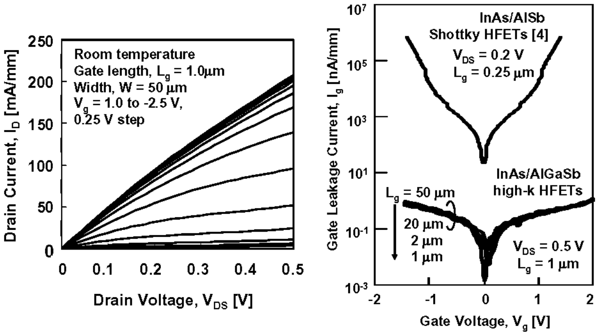
the electron mobility of an as-grown wafer reached 22,000 cm^2/Vs and exhibited a sheet carrier density of 1.88 x 10^{12} cm^{-2}.

RESULTS AND DISCUSSION

The high-k gate InAs HFET characteristics measured at 300 K are shown in Fig. 2 (a). The gate voltage was varied from -2.5 to +1.0 V in 0.25 V steps. We demonstrated the operation of a 1-μm gate device with a 80-nm-thick Al_2O_3 insulator at room temperature, and a peak extrinsic transconductance, g_m was 180 mS/mm. Using the measured values for contact resistance and sheet resistance, we obtained a peak intrinsic g_m of 205 mS/mm (V_{DS} = 0.5 V).

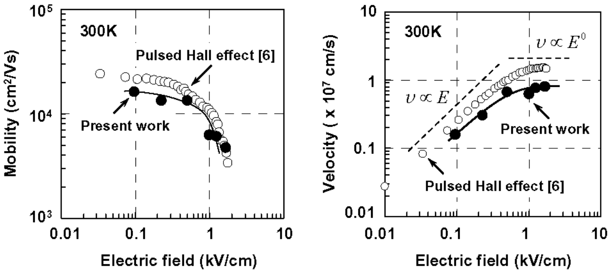


(a) (b)

FIGURE 2. (a) Drain V_{DS}-I_D characteristics of an 1-μm gate device measured at room temperature, and (b) gate leakage current characteristics for different gate lengths.

Figure 2 (b) shows that the gate leakage current densities were greatly decreased by inserting the Al_2O_3 gate insulator. We achieved a maximum gate current of less than 1 nA/mm at room temperature. In comparison with other results, regardless of gate length, we found that the gate current density of the InAs high-k gate HFET was three orders of magnitude lower than that of the InAs/AlSb Shottky gate HFET [4]. Evidently, this insulating layer significantly suppresses the leakage current in InAs HFETs.

We also estimated the field-effect mobility. Figure 3 (a) shows the mobility-field characteristics. The field effect mobility was affected by the lateral electric fields. With increases in the electronic field, the field effect motilities decreased from 16,300 cm^2/Vs at 0.1 kV/cm to 4800 cm^2/Vs at 1.7 kV/cm. The electron mobility in the InAs high-k FET tends to decrease with the field in a similar manner to that seen in the pulsed Hall-effect [6]. Next, we evaluated the drift velocity v. Electrons are accelerated according to the relation $v = \mu E$, where μ and E are the electron mobility and the lateral electric fields, respectively. Up to field strength of 0.8 kV/cm, the velocity rose in proportion to the electric field. However, above 1.0 kV/cm, the mobility decreased, and the velocity saturated at 8.0 x 10^6 cm/s. Taking into account the contact resistance, we noted that the velocity reached the high value of 1.05 x 10^7 cm/s at 1.7 kV/cm. Although the reason for the degradation of the velocity is not clear at the present, these results showing velocity suppression at high field strength are in good agreement with those reported for the pulsed Hall measurements [6]. This comparison of field effect characteristics clearly demonstrates the advantages of InAs/AlGaSb heterostructures for high-speed applications.



(a) (b)

FIGURE 3. (a) Electron mobility as a function of field, and (b) velocity-field characteristics of high-k HFETs.

CONCLUSION

We fabricated and characterized InAs/AlGaSb HFETs with a high-k gate insulator. In room temperature FET operations, the gate leakage was greatly reduced by the introduction of an 80-nm-thick Al_2O_3 gate insulator. The field effect mobility and drift velocity in high-k InAs HFETs were evaluated from FET characteristics, and these results were found to be useful for HFETs using high-k insulators.

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