Title	Al2O3およびAlTiOの化合物半導体異種材料融合集積技術への応用
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Abstract

Research on applications of Al_2O_3 or AlTiO high-dielectric-constant insulator films to Heterogeneous integration technology

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A narrow-gap compound semiconductor InAs is applicable to high-performance field-effect transistors. In particular, heterogeneous integration (HI) of InAs thin film devices on foreign host substrates is quite important. Previously fabrication and investigation of an InAs/low-k structure was reported, where high-quality InAs thin films are bonded on host low-dielectric-constant (low-k) flexible substrates (FS). The InAs/low-k (InAs/FS) which exhibits high electron mobilities, where the FS has a merit for device applications because of a low parasitic capacitance. However, a serious problem of InAs/FS interface fluctuation affecting electron mobilities and low-frequency noise was founded. Considering these problems, in this work, we investigated an InAs/high-k/low-k structure, where a thin high-k insulator layer between InAs and the low-k FS can be beneficial to suppress the interface fluctuation and to improve the heat release capability, almost keeping the merit of the low parasitic capacitance of the FS. Although TiO_2 as a high-k insulator has one of the highest k, its small band gap is a drawback for the MIS device applications. For the purpose of utilizing TiO_2-based materials, alloy of TiO_2 and Al_2O_3 (AlTiO) has been investigated. However, the composition dependence of the characteristics were not clarified. In this work, we investigated the composition dependence of the electrical properties of AlTiO. Moreover, we employed Al_2O_3/AlN or AlTiO/AlN as a high-k insulator layer and fabricated and investigated the InAs/high-k/low-k (InAs/Al_2O_3/AlN/FS or InAs/AlTiO/AlN/FS).

I fabricated Al_xTi_yO/n-GaAs(001) metal-insulator-metal (MIS) structures, in which Al_xTi_yO were prepared by atomic layer deposition (ALD). Using X-ray photoelectron spectroscopy (XPS), we obtained atomic composition ratios of Al and Ti in the Al_xTi_yO thin films. From XPS electron energy-loss spectroscopy (EELS), the band-gap of the Al_xTi_yO increases with increase in the Al composition. From C-V characteristics of Al_xTi_yO metal-insulator-metal (MIM) strucutures, we obtained dielectric constant of the Al_xTi_yO decreases with increase in the Al composition. Moreover, From the temperature-dependent J-V characteristics of the MIS strucures, we elucidated dominant conduction mechanisms; TE for TiO_2 (x:y=0:1), FN tunneling for Al_2O_3 (x:y=1:0), and PF conduction for other Al_xTi_yO films ($x/(x+y)$=0.47- 0.84). We expect that Al_xTi_yO thin films are useful as high-k dielectric for device processing.

On the other hand, we fabricated an InAs/high-k/low-k structure in comparison with an InAs/low-k structure, where the former and the latter are respectively obtained by bonding of InAs/Al_2O_3/AlN, InAs/AlTiO/AlN and InAs on low-k flexible substrates (FS). The InAs/high-k/low-k exhibits electron mobilities immune to interface fluctuation scattering, whereas this scattering is serious for the InAs/low-k. From room-temperature measurements of the Hall-bar devices, we find that electron sheet concentrations in the InAs/high-k/low-k are significantly higher than those in the InAs/low-k. From energy-dispersive X-ray spectroscopy and EELS for the InAs/Al_2O_3 interface, we consider that the higher electron concentrations can be attributed to natural modulation doping from Al_2O_3 to InAs. Moreover, we fabricated field effect transistor (FET) using the InAs/high-k/low-k structures, where gate insulator is Al_2O_3 or AlTiO. From room-temperature measurements of the FETs, we find that the drain current can be modulated with sufficient thin InAs channel, and also find that the drain current cannot be turn-off sufficiently.

In conclusion, we obtained that intermediate properties of the AlTiO thin film between Al_2O_3 and TiO_2, and the HI device technologies, which can be useful for III-V device processing.

Keywords: Al_xTi_yO, heterogeneous integration, InAs/high-k/low-k, modulation doping, FET