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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/highk/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 TiO₂ 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 TiO₂-based materials, alloy of TiO₂ and Al₂O₃ (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 Al₂O₃/AlN or AlTiO/AlN as a high-k insulator layer and fabricated and investigated the InAs/high-k/low-k (InAs/Al₂O₃/AlN/FS or InAs/AlTiO/AlN/FS).

I fabricated $Al_x Ti_y O/n$ -GaAs(001) metal-insulator-metal (MIS) structures, in which $Al_x Ti_y O$ were prepared by atomic layer deposition (ALD). Using X-ray photoelectron spectroscopy (XPS), we obtained atomic composition ratios of Al and Ti in the $Al_x Ti_y O$ thin films. From XPS electron energy-loss spectroscopy (EELS), the band-gap of the $Al_x Ti_y O$ increases with increase in the Al composition. From *C-V* characteristics of $Al_x Ti_y O$ metal-insulator-metal (MIM) structures, we obtained dielectric constant of the $Al_x Ti_y O$ decreases with increase in the Al composition. Moreover, From the temperature-dependent *J-V* characteristics of the MIS structures, we elucidated dominant conduction mechanisms; TE for TiO₂ (*x*:*y*=0:1), FN tunneling for Al_2O_3 (*x*:*y*=1:0), and PF conduction for other $Al_x Ti_y O$ films (x/(x + y)=0.47- 0.84). We expect that $Al_x Ti_y O$ 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/Al₂O₃/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-kare significantly higher than those in the InAs/low-k. From energy-dispersive X-ray spectroscopy and EELS for the InAs/Al₂O₃ interface, we consider that the higher electron concentrations can be attributed to natural modulation doping from Al₂O₃ to InAs. Moreover, we fabricated field effect transistor (FET) using the InAs/high-k/low-k structures, where gate insulator is Al₂O₃ 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: $Al_x Ti_y O$, heterogeneous integration, InAs/high-k/low-k, modulation doping, FET