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Oxide-free InAs(111)A interface in metal-oxide-semiconductor structure with very low density of states prepared by anodic oxidation

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In this letter, we present structural, compositional, and electrical characteristics of anodic oxide layer-based metal-oxide-semiconductor (MOS) capacitors on n-type InAs(111)A, along with the effect of a thin fluorinated interfacial passivation layer. Electrochemical oxidation in acid electrolyte with addition of fluorine (NH_4F) led to the formation of oxygen free well-ordered wide gap fluorinated interfacial layer at InAs(111)A with the fixed charge (Q_{fix}) and density of interface states (D_{it}) in the range of $(4–6) \times 10^{10}\,cm^{-2}$ and $(2–12) \times 10^{10}\,eV^{-1}\,cm^{-2}$, respectively. We found that MOS capacitors showed excellent capacitance-voltage characteristics with very small frequency dispersion ($<1\%$ and $<15\,mV$). Fluorinated interfacial layer consists of crystalline isostructural compound with the InAs substrate, which remains intact with the atomic smoothness and sharpness that explain unpinned behavior of the Fermi level. *© 2014 AIP Publishing LLC*.
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As the performance of thermovision matrixes and metal-oxide-semiconductor field-effect transistors (MOSFETs) becomes more in demand, a narrow gap and high mobility channel materials have been widely studied.[1] InAs substrate has a great potential to challenge the high performance requirement due to its narrow direct gap and high mobility in comparison with Si substrate. Moreover, the presence of downward band bending and the formation of 2D electron gas at InAs surfaces and interfaces,[2–4] in contrast with almost all other III-V semiconductors, where electron depletion is generally observed for n-type material, make this material very attractive for various applications.

Unlike SiO_2 on the Si substrate, there were no stable native dielectrics on III-V compound semiconductors from the viewpoints of high-quality interface and thermodynamic stability. For this reason, the surface passivation is a crucial process for device fabrication based on III-V semiconductors. There have been a variety of attempts to provide high quality interface and to prevent Fermi level pinning issues. A great effort has been made in finding a proper dielectric and deposition method to improve the performance of the devices. For the formation of high-quality interface on InAs, various interface passivation layers (IPL) such as Ge,[5] BeO,[6] $LaLuO_3$,[7] Al_2O_3,[8] HfO_2,[9] and different chemical treatment[10–12] were considered. The atomic layer deposited (ALD) Al_2O_3 and HfO_2 have demonstrated the most acceptable IPL characteristics due to their high dielectric constants and interface quality. However, defect interface density is still high $D_{it} > (2–5) \times 10^{11}\,eV^{-1}\,cm^{-2}$.

The alternative method of the InAs surfaces passivation consists in the formation of thin (5–15 nm) fluorinated anodic layer (FAL) formed in alkaline electrolyte. This method allowed one to reduce the density of interface states and to fabricate the thermovision camera with the high-contrast images of two-dimensional thermal patterns with the resolution up to 7 mK for medical and scientific application with hybrid infrared (IR) focal plane arrays based on the matrix of indium oxide (In_2O_3)/SiO_2/FAL/InAs structures.[13] It was found that addition of fluorine in electrolyte led to the partial replacement of oxygen by fluorine atoms in the oxide layer and, as a result, to the reduction of both fixed (built-in) charge and density of surface states of Au/FAL/InAs MOS structures.[14,15] On the other hand, it is well known that the thermodynamic instability of oxygen containing compounds of group Vth element on III-V semiconductor interface causes the instability of parameters of devices based on MOS structures.

In this paper, we realized an idea of complete oxygen replacement by fluorine atoms during the anodic oxidation process in an anhydrous acid electrolyte with high concentration of fluorine (NH_4F) in order to form the wide gap InF_3 insulator at the FAL/InAs(111)A interface with a very low D_{it}. The electrical characteristics of InAs MOS-structures with a thin (5–15 nm) anodic layer with different content of NH_4F as the gate dielectric were studied by capacitance-voltage (C-V) and conductance-voltage (G-V) characteristics. High-resolution transmission electron microscopy (HRTEM) and atomic force microscopy (AFM) were used to examine the FAL/InAs interface structure and morphology. The chemical state characterization technique was employed to investigate the bonding properties using X-ray photoelectron spectroscopy (XPS).

The experiments were performed on InAs epitaxial layers in order to avoid possible influence of structural defects, which are present near the surfaces of commercial substrates prepared by mechanical and chemo-mechanical polishing. We used InAs layers grown by gas-phase epitaxy on conventional

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