High-indium-content InGaAs metal-oxide-semiconductor capacitor with amorphous La Al O 3 gate dielectric

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Citation: Applied Physics Letters 91, 093509 (2007); doi: 10.1063/1.2776846
View online: http://dx.doi.org/10.1063/1.2776846
View Table of Contents: http://scitation.aip.org/content/aip/journal/apl/91/9?ver=pdfcov
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High-indium-content InGaAs metal-oxide-semiconductor capacitor with amorphous LaAlO$_3$ gate dielectric

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(Received 5 June 2007; accepted 7 August 2007; published online 29 August 2007)

The structure and electrical properties of LaAlO$_3$/n-In$_{0.53}$Ga$_{0.47}$As metal-oxide-semiconductor capacitors deposited by molecular-beam epitaxy were investigated. Transmission electron microscopy revealed a sharp interface between the dielectric and InGaAs. Postdeposition annealing at 440–500 °C significantly reduced the capacitive equivalent thickness and frequency dispersion. A hysteresis of 15 mV–0.1 V, a dielectric permittivity of 17±1, and a dielectric strength of ~4.3 MV/cm were measured. Additionally, a high loss in the parallel conductance and gate-bias independence in the inversion region was observed, implying the fast generation rate of minority carriers in In$_{0.53}$Ga$_{0.47}$As. © 2007 American Institute of Physics. [DOI: 10.1063/1.2776846]

Due to limits to scaling of silicon, the use of alternative III-V compound semiconductor channels such as In$_{3.5}$Ga$_{0.7}$As and InSb in complementary metal-oxide-semiconductor (MOS) devices is becoming attractive due to their higher electron mobilities and smaller band gaps. It is surmised that integration of a high quality gate dielectric may help reduce gate leakage and improve $I_{on}/I_{off}$ ratio in such devices. Recently In$_{0.5}$Ga$_{0.5}$As devices with various high dielectric constant (high-$k$) insulators showing superior electrical properties have been demonstrated. In this letter we describe the physical and electrical characteristics of thin amorphous lanthanum aluminate (LaAlO$_3$) deposited on In$_{0.53}$Ga$_{0.47}$As.

Silicon-doped In$_{0.53}$Ga$_{0.47}$As layers were grown on (001) InP substrates in a GEN II molecular-beam epitaxy (MBE) system at the University of Oklahoma. To minimize the dielectric/III-V layer interface defect density, the InGaAs samples were capped with arsenic and shipped in a vacuum container to Penn State University. The cap was desorbed in a Veeco 930 MBE system in the absence of arsenic overpressure. Amorphous LaAlO$_3$ was then deposited as described elsewhere. Reflection high-energy electron diffraction showed the LaAlO$_3$ to be amorphous. Tungsten (W) was evaporated ex situ either as deposited or postdeposition annealed (PDA) dielectric film to form the gate electrode and subsequently a MOS capacitor (MOSCAP). Evaporated indium or Ni–Ge–Au alloy formed Ohmic contact.

The structural integrity, dielectric physical thickness ($t_{oxide}$) and electrical characteristics in MOSCAPs were determined by cross-sectional high-resolution transmission electron microscopy (HRTEM), spectroscopic ellipsometry, capacitance-voltage (C-V), and current density–voltage (J-V) measurements. The LaAlO$_3$ film stoichiometry was established by medium energy ion scattering (MEIS) technique and Rutherford backscattering spectrometry. The absence of an interfacial layer (IL) between amorphous LaAlO$_3$/Si has been previously noted. A comprehensive thermodynamic analysis of the stability of binary oxides in contact with III-V semiconductors indicates no expected reactions between La$_2$O$_3$ or Al$_2$O$_3$ with GaAs or InAs and thus from a zeroth-order bond strength argument, LaAlO$_3$ is expected to be stable in contact with InGaAs. HRTEM image (Fig. 1) shows no distinct IL between InGaAs/LaAlO$_3$/W interfaces following a 500 °C PDA (or 440 °C, not shown)

![HRTEM image of a W/LaAlO$_3$/n-In$_{0.53}$Ga$_{0.47}$As MOS capacitor after a PDA in nitrogen ambient at 500 °C (5 min). As-deposited (not shown) and annealed (at 440 or 500 °C) LaAlO$_3$ are amorphous. (b) High angle annular dark-field scanning TEM (HAADF-STEM) reveals an abrupt interface between the LaAlO$_3$ and InGaAs. (c) The cross-sectional compositional information as obtained by electron energy loss spectroscopy (EELS) and energy dispersive x-ray spectroscopy is overlayed on the HAADF-STEM micrograph of the sample. Humps seen in the dielectric film composition are an artifact of the nonuniformity of the sample thickness in cross section.](image-url)

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In summary, we observed encouraging physical and electrical characteristics such as reasonably low frequency dispersion, low leakage current density, high dielectric constant, band offsets $>1$ eV, and absence of an interfacial layer in amorphous LaAlO$_3$/In$_{0.53}$Ga$_{0.47}$As MOSCAPs comparing well with LaAlO$_3$/Si devices. Additionally, gate-bias independent conductance loss was noted in inversion, implying a fast generation rate of minority carriers in n-In$_{0.53}$Ga$_{0.47}$As.

The authors acknowledge Intel for financial support and Stanford Nanofabrication Facility of NNIN (supported by the National Science Foundation under Grant No. ECS-9731293).


