

Growth of Thin InAlP Native Oxides for GaAs Metal-Oxide-Semiconductor Devices

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In an earlier reported study [1] on the scaling of In_{0.485}Al_{0.515}P wet thermal native oxides towards thicknesses suitable for use in GaAs metal-oxide-semiconductor (MOS) devices, we observed that thin 7 nm oxide films showed Schottky-diode-like behavior with relatively large leakage current densities for capacitors of $J_L \sim 4 \times 10^{-2}$ A/cm² at a field of 1 MV/cm. Attributing this to thin spots in the oxide, we here report a 400,000X reduction in the leakage (to $J_L \sim 1 \times 10^{-7}$ A/cm² at 1 MV/cm) for similar MOS capacitors fabricated with improved processing from the same MOCVD-grown heterostructure. This leakage now compares favorably to the 9×10^{-8} A/cm² value at 1 MV/cm achieved for an 8-nm-thick Al₂O₃ film grown by atomic layer deposition for a GaAs MOSFET device [2]. In this work, we present further data from transmission electron microscopy and variable-angle spectroscopic ellipsometry (VASE) measurements on the growth kinetics of device-quality InAlP native oxide films. In particular, a diffusion marker experiment has been used to establish for the first time the inward growth of InAlP native oxide, key to achieving an electrically clean oxide/semiconductor interface. Using e-beam lithography, 177 nm wide, 4 nm thick Cr lines spaced 2 μ m apart were deposited on an InAlP surface. Following oxidation, the Cr marker was left on the outer surface, as verified by energy-dispersive x-ray spectroscopy (EDXS), confirming that oxidation must proceed primarily by inward diffusion of O to the oxide/InAlP interface where new oxide is produced (rather than by outward transport of the semiconductor elements In, Al and P to the outer oxide surface). This is unlike the reported oxidation of GaAs or AlGaAs, and allows preexisting surface impurities to remain on the outer oxide surface and thus not contaminate the interface causing interface states. This observation is consistent with demonstrations via capacitance-voltage characteristics that the Fermi level at InAlP oxide/GaAs interfaces is unpinned [3], making them suitable for MOS devices. We have recently reported GaAs channel MOSFET devices employing an \sim 11 nm InAlP native oxide as the gate dielectric with microwave frequency performance ($f_t = 13.7$ GHz, $f_{max} = 37.6$ GHz) [4]. Using VASE thickness measurements presented here, the growth kinetics for wet oxidation of InAlP at temperatures of 420-500 °C are fit to the Deal-Grove linear-parabolic oxide growth law to yield diffusive and reactive growth mechanism activation energies of 1.52 and 1.16 eV/molecule, respectively. However, the oxide growth rate is predominantly reaction-rate limited (linear growth kinetics) for oxide thicknesses up to \sim 40 nm with an oxidation rate of 0.21-0.25 nm/min at 440 °C.

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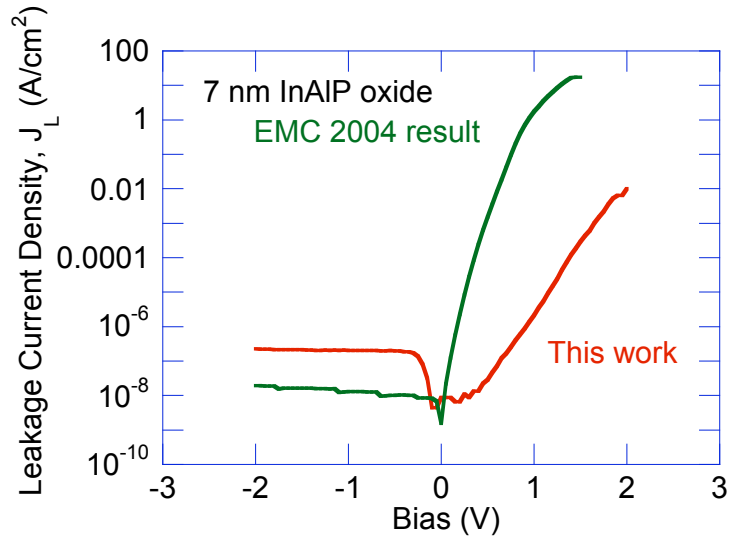


Fig. 1 Comparison of leakage of 7 nm InAlP oxide of same heterostructure from 2004 and with improved processing showing 400,000X reduction in leakage (at 1 MV/cm)

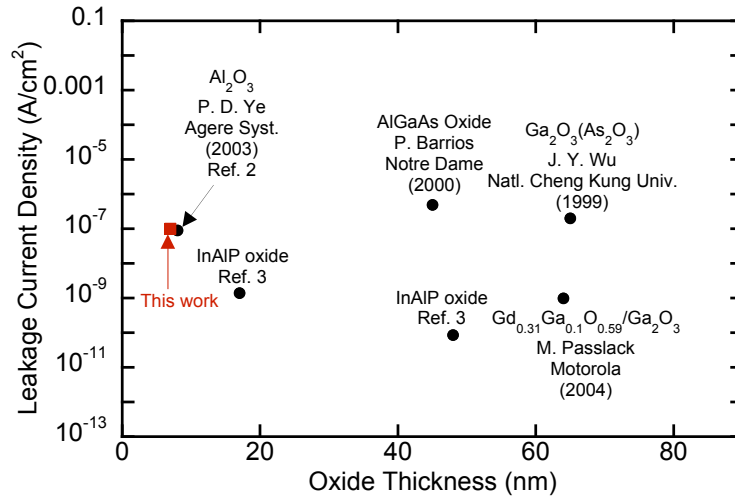


Fig. 2. Comparison of InAlP native oxide leakage with other GaAs MOS candidate oxides (cited in Table 1 of Ref. 3)

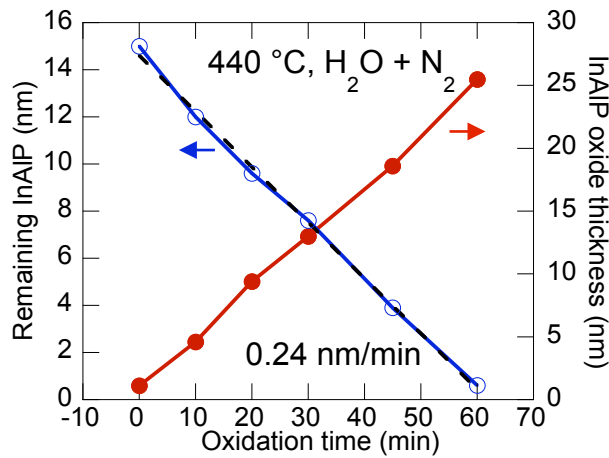


Fig. 3. VASE data showing oxidation rate of 15 nm InAlP layer in MOSFET structure of Ref. 4. Linear growth rate of ~ 0.24 nm/min observed for n+ InAlP at 440 °C in water vapor.