Electrical properties of InAlP native oxides for GaAs-based MOS applications

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Past explorations of native oxides in the GaAs material system have failed to produce an adequate insulator possessing low leakage currents, high breakdown fields, and low interface trap densities as required for MOS device applications. Recent studies on in-situ deposition of $Ga_2O_3(Gd_2O_3)$ from $Gd_3Ga_5O_{12}$ have yielded promising results.[1] Native oxides formed via wet thermal oxidation of AlGaAs have thus far shown unacceptably high leakage currents and Fermi-level pinning due to residual As.[2,3] We report here our observations of the significantly better electrical characteristics of wet-thermal native oxides of the As-free material, $In_{0.485}Al_{0.515}P$ (lattice-matched to GaAs). 50 nm thick InAlP films grown by MOCVD on GaAs are surface-oxidized in water vapor at a temperature of 500 °C with oxidation times between 30 and 120 min. In all cases, as can be seen in Table I, leakage current densities in the 10^{-10} A/cm^2 range are measured (at 5 V), about 3 orders of magnitude smaller than our best leakage in laterally-oxidized $Al_{0.98}Ga_{0.02}As$ films. Breakdown fields for InAlP native oxides are approximately 7 MV/cm -- about 2 times higher than our AlGaAs oxides, and similar to those reported for $Ga_2O_3(Gd_2O_3)$.[1]

Low frequency (quasi-static) capacitance-voltage (C-V) studies, useful for observation of inversion layer formation, have not been feasible in earlier investigations of AlGaAs native oxides because of their high leakage currents.[3] With the much lower leakage levels obtained from the InAlP native oxides, quasi-static C-V measurements can be performed. High-frequency (1 MHz) and quasi-static C-V measurements were performed on capacitors with areas ranging from 3600 to 115,200 μm^2. When illuminated with the light of a microscope to generate the required electron-hole pairs, many of our InAlP oxide samples show clear signs of an inversion layer (see Fig. 1), characteristic of a clean interface and possibly unpinned Fermi level.

Under dark-box measurement conditions, none of our InAlP oxide samples show evidence of an inversion layer. However, the need for optical generation of electron-hole pairs (EHPs) does not necessarily imply the presence of traps as the thermal generation rates are quite low here due to the larger energy gap of GaAs. It is not uncommon in other wide-bandgap systems (e.g., in GaN MOS research)[4] to need light to generate carriers. In addition, comparative quasi-static C-V studies show that the apparent inversion layer formation is dependent on oxidation time. With incomplete InAlP oxidation at t_{ox}=30 min, only partial inversion is observed, presumably because of the lower optical generation rate of EHPs with our illumination source in the higher energy gap $In_{0.485}Al_{0.515}P$ (E_g=2.33 eV). For full oxidation near t_{ox}=60 min (Fig. 1), a strong reverse bias increase in capacitance is observed (corresponding to hole accumulation and inversion layer formation). At t_{ox}=90 min, the degree of inversion is reduced and, at t_{ox}=120 min, the inversion layer does not develop at all, which we attribute to increasing overoxidation into the GaAs substrate. High frequency measurements are consistent with quasi-static behavior, as a flat inversion region occurs for samples oxidized for 60 min. For other times, sloping inversion regions indicate varying degrees of deep depletion. Other samples containing a 10 nm InGaP oxidation barrier layer below the InAlP show similar behavior, but with less reduction of inversion at t_{ox}=90 min.

Details will also be reported on variable-angle spectroscopic ellipsometry (VASE) and transmission electron microscopy (TEM) studies presently being performed and analyzed to further elucidate precisely where the inversion layer is occurring within the oxidized InAlP/GaAs and InAlP/InGaP/GaAs heterostructures.

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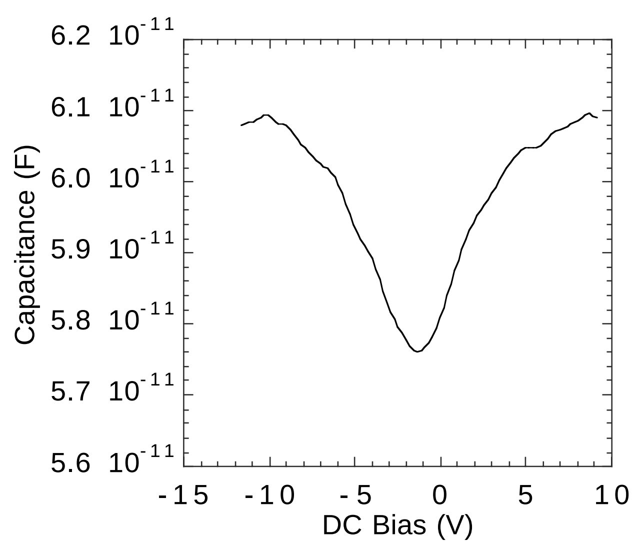

Figure 1. Quasi-static capacitance vs. DC bias for oxidized InAlP/GaAs. Oxidation was carried out in water vapor in a furnace set at 500 °C for 60 min.

Table 1. Electrical data of studied structures after wet-thermal oxidation.

Original Structure	$J_{Leakage}$ (A/cm^2)	$E_{Breakdown}$ (MV/cm)	ε_r	D_{it} (10^{12}/cm^2/eV)
500 Å $Al_{0.98}Ga_{0.02}As$	4.9e-7	3.75	4.66	2.3
500 Å $In_{0.485}Al_{0.515}P$	6.2e-10	6.35	6.57	1.1
500 Å $In_{0.485}Al_{0.515}P$/100 Å $In_{0.485}Ga_{0.515}P$	2.2e-10	6.33	5.77	1.3