

ZrO₂ as a High-k Gate Dielectric for Enhancement-mode AlGaIn/GaN MOS HEMTs

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Advanced applications of AlGaIn/GaN high-electron-mobility transistors (HEMTs) in high-power RF and power switching are driving the need for an insulated gate technology. We present here basic and early applied studies of the use of zirconium oxide (ZrO₂) as a high-k, high breakdown gate dielectric for reduced gate leakage and a fully-recessed barrier structure for enhancement-mode operation of AlGaIn/GaN HEMTs. We include the study of GaN surface preparations for dielectric deposition, surface/interface characterization and device operation wherein a world record threshold voltage of +3.99V is achieved.

An optimum GaN surface preparation involving a piranha etch followed by a thermal oxidation of the surface has previously been shown [1] to result in smooth, clean GaN surfaces that exhibit the best electrical performance when ALD high-k dielectrics are deposited thereon. This same preparation is applied to ALD ZrO₂ dielectrics. ZrO₂ films were deposited by atomic layer deposition (ALD) using two different metal precursors [zirconium (IV) tert-butoxide (ZTB) and tetrakis(dimethylamido)zirconium(IV) (TDMAZ)] and water. For the former we also assessed both water and ozone as the oxygen precursor. ZrO₂ films grown by ALD with ZTB were found to be slightly oxygen rich whether ozone or water were used as the oxygen source. However, films grown with ZTB and ozone did have carbon contamination. Films grown with TDMAZ and water were found to be stoichiometric and free of carbon.

Films grown with ZTB and water on optimally prepared surfaces again shown the best electrical performance for the dielectric-semiconductor interface in terms of smoothness, low leakage in forward and reverse bias ($< 10^{-5}$ A cm⁻²) and low hysteresis. Unlike in previous studies with ALD deposited Al₂O₃ and HfO₂, where total trapped charge was in the mid-10¹¹ to low 10¹² cm⁻² range, ZrO₂ films show considerably higher trapped charge densities in the high 10¹² to mid-10¹³ cm⁻² range. The nature of this charge is uncertain at this time but believed to be due to excess oxygen in ZTB deposited films and is directly responsible for a 1.5 – 2 V positive shift in threshold voltage.

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[1] C.R. English, et al., J. Vac. Sci. & Technol. B 32,03D106 (1-17) (2014).