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Experimental band alignment of Ta$_2$Os/GaN for MIS-HEMT applications

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1. Introduction

GaN Metal Insulator Semiconductor High Electron Mobility Transistors (MIS-HEMTs) have been used extensively for high frequency, high power and low noise applications [1,2]. A layer of GaOx can be formed on the GaN surface by reaction with oxygen even at room temperature. Surface-related defect states associated with the GaOx layer result in large leakage current and severe current collapse at high frequency, inhibiting device performance. Recently, the insertion of a dielectric layer for surface passivation has been reported to mitigate the issues above [1,3,4]. Ta$_2$Os of a dielectric layer for surface passivation has been extensively for high frequency, high power and low noise applications [1,2]. A layer of GaOx can be prepared using the techniques X-ray Photoelectron Spectroscopy (XPS) and Variable Angle Spectroscopic Ellipsometry (VASE). Note that only theoretical values of the valence (VBM) for GaN substrate (Fig. 4a), $\delta$OXIDE of Ta 4f CL and VBM for Ta$_2$Os bulk sample (Fig. 4b), and $\delta$INT of Ga 3d and Ta 4f CLs for interfacial Ta$_2$Os sample (Fig. 4c). The value of VBO from the data in Fig. 4 is $0.71 \pm 0.2$ eV, which with the band gap extracted by VASE gives $\delta = 0.35 \pm 0.2$ eV, illustrated schematically in Fig. 5.

4. Conclusion

This paper experimentally demonstrates the band alignment of Ta$_2$Os prepared by RF sputtering on ex-situ HCl treated GaN surface. The HCl treatment is carried out to minimize C and O contaminants on the GaN surface. The VBO of Ta$_2$Os/GaN is found to be $0.71 \pm 0.2$ eV from the XPS and Kraut’s method, while CBO is derived using the band gaps of GaN (3.34 eV) and Ta$_2$Os (4.4 eV) and found to be $0.35 \pm 0.2$ eV. The results have importance for developing future GaN based MIS-HEMTs.

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References:
Fig. 1: (a) Background subtracted O 1s CL XPS peaks from different cleaning treatments. The HCl treatment shows the lowest intensity. (b) Cl 2p CL XPS spectrum of the GaN surface cleaned by HCl treatment.

Fig. 2: VASE data for the GaN sample (circle) and the best multiple-layer model (red line) in the wavelength range of 240–1700 nm; ∆ fit at: (a) 60°, (b) 65°, (c) 70°, (d) Ψ fit at the three SE angles (60°–75°).

Fig. 3: Photon energy dependence of parametric dielectric function, ε₁ and ε₂, for (a) as-received GaN substrate and (b) 10 nm (nominal) RF magnetron sputtered Ta₂O₅.

Fig. 4: The XPS spectra of: (a) Ga 3d CL for GaN substrate. The spectrum is fitted by 7 components. (b) Ta 4f CL for bulk Ta₂O₅ sample. The inset in (a)–(b) show the VBM estimation from valence band leading edge linear fitting. (c) The XPS spectrum of Ga 3d and Ta 4f CLs for interfacial Ta₂O₅/GaN sample showing the difference between the CLs.

Fig. 5: Band diagrams of experimentally derived band alignment for the Ta₂O₅/GaN interface; (left) Kraut’s method for VBO measurement, and (right) CBO derived using band gap energies by VASE.