

Nanoscale Infrared Spectroscopy for Two-Dimensional Electron gas in AlGaN/GaN Heterostructures

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1. Introduction

At the AlGaN/GaN interface, the polarization difference generated by the combined effects of spontaneous and strain-induced piezoelectric polarization in the AlGaN layer leads to the confinement of a two-dimensional electron gas (2DEG) within a narrow region near the interface [1] without the need for intentional doping in either AlGaN or GaN layers. The properties of the 2DEG, including carrier concentration and mobility, significantly impact the performance of AlGaN/GaN high electron mobility transistors and hold promise for enabling and advancing thermal emission control. This study leverages nano-FTIR as a platform for optically characterizing AlGaN/GaN in the nanoscale.

2. Methods

Metal-organic chemical vapor deposition was used to deposit AlGaN layers of varying thicknesses (15 nm, 30 nm and 45 nm) and 2.8 μ m thick GaN layers on sapphire substrates. XRD measurements determined the AlN concentration in the AlGaN layers to be 28.6%. Focused ion beam technique was utilized to prepare a cross-sectional sample of the 45nm thick AlGaN/GaN structure. Second order amplitude (O2A) and phase (O2P) spectra for both cross-sectional and top-view samples were obtained using nano-FTIR.

3. Results and discussion

The measured spectra of O2A exhibit excellent agreement with simulations based on the finite dipole method [2], as demonstrated in Figure 1(a). In the simulations, the 'Bare GaN' response corresponds to a semi-infinite GaN model. The measured O2P of the 45nm thick AlGaN/GaN top-view sample, compared with simulations in Figure 1(b), showed agreement only when a 2DEG layer with carrier concentration of $1.6 \times 10^{13} \text{ cm}^{-2}$ was included in the model. In addition, a visual representation of the 2DEG layer was achieved by conducting a hyperspectral imaging (HSI) on the cross-sectional sample, as shown in Figure 1(c). This approach has the advantage of being able to measure in atmosphere with nanoscale spatial resolution compared to the TEM techniques that have been used to visualize 2DEG so far.

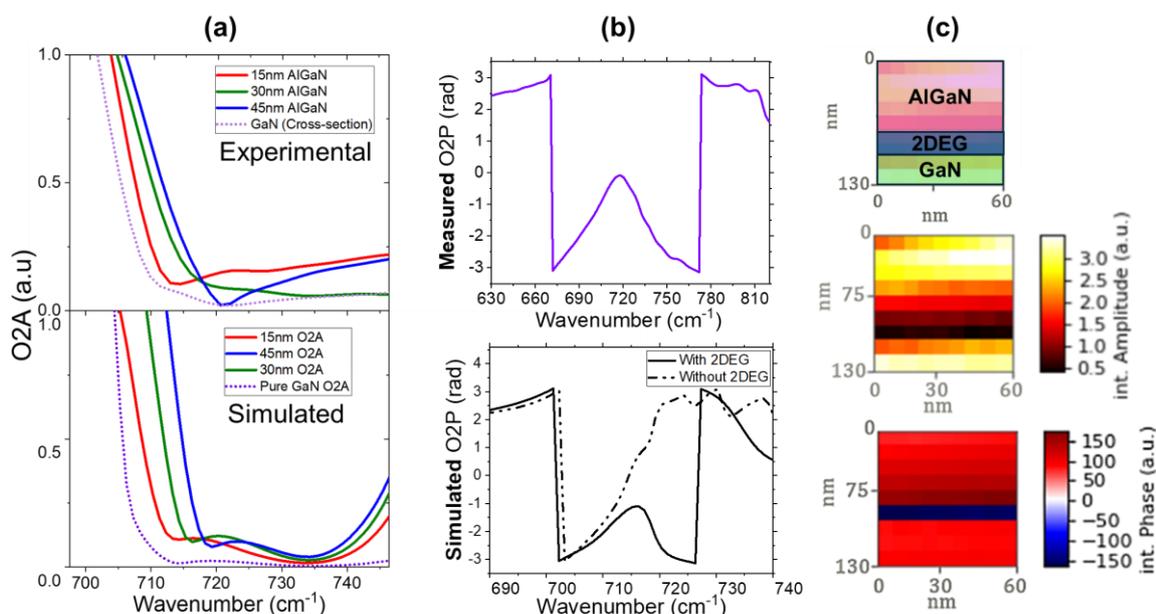


Fig. 1 (a) Measured and simulated nano-FTIR O2A for the AlGaN/GaN samples with different AlGaN thicknesses. (b) Measured and simulated O2P, where the simulated spectra include configurations with and without the 2DEG layer. (c) Schematic and hyperspectral images (integrated amplitude and phase) of the 45 nm cross-sectional sample.

References

[1] O. Ambacher et al., *J. Appl. Phys.* 87, 334 (2000). [2] Vincent, T, et al., <https://arxiv.org/abs/2405.20948> (2024).