Advanced EELS spectroscopy characterization of AlGaN/GaN materials

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Background incl. aims
The combination of STEM with electron energy-loss spectroscopy (EELS) and Electron-Loss Near-Edge Structure (ELNES) has gained great interest in the microelectronics industry. Indeed, ELNES can provide additional information on local atomic and electronic structures of materials compared to the already commonly used XEDS method for chemical quantification. This project intends to investigate High-Electron Mobility Transistor (HEMT) devices based on AlxGa(1-x)N semiconductors for high-power and high-frequency applications.

Methods
The HEMT device presented in this work [See Fig.1 (a) and (b)] is composed of a GaN channel and an AlGaN barrier structure separated by a few-nanometer AlN spacer grown to improve the performance of the 2-Dimensional Electron Gas (2DEG) formed at the interface [2]. The wider bandgap and stronger polarization of AlN compared to AlGaN provides higher breakdown fields and enhances the electron mobility and sheet density in the 2DEG while limiting alloy scattering. Due to significant lattice mismatch between GaN and Si, an AlN nucleation layer is grown first on 300 mm Si wafers. Successive AlxGa(1-x)N buffer layers with decreasing amounts of Al are then needed to accommodate stress in the structure. This buffer stack allows the growth of an ideally crack-free GaN channel as shown in Fig. 1 (a), assuring optimal electron mobility in the device. Layers are grown using MOCVD deposition method on Si (111) wafers. The main goal of this project is to investigate the comportment of materials in this device, especially at the active AlGaN/AlN/GaN interface through EELS analysis with “ultimate” resolution. TEM experiments are performed on a probe Cs-corrected JEOL Neo-ARM 200F equipped with a Cold-FEG and a GIF (Gatan Image Filter) Continuum spectrometer.

Results
Preliminary work has been conducted to investigate the variation of the plasmon peak in the low-loss region (≈ 10-30 eV) along the buffer stack which demonstrated a linear dependency between the plasmon energy peak (Ep), and the fraction of Al in the ternary alloys, xAl [Fig. 2 (a)]. Likewise, the acquisition of the N K-edge ELNES structure along the buffer layer stack has been conducted at 200 kV, highlighting the transition between layers [Fig.2 (b)]. The most significant difference is observed for the first 3 peaks of the spectra (≈ 400-410 eV) where the first and third peaks gradually gain in intensity over the second as the AlN mole fraction increases in the ternary alloys. According to literature [3], these peaks should result from N-cation anti-bonding interactions and the intensity re-distributions is mostly due to the valence d-electrons of the GaN. These experimental N K-edges are consistent with calculated wurtzite AlxGa(1-x)N spectra obtained in the previous studies [4,5].

Conclusion
Based on these first results, additional work has been carried out to optimize TEM sample preparation for EELS analysis, especially using Plasma-FIB Xe and PIPS II Ar ion polishing to successfully prevent Ga implantation experienced with standard Ga FIB thinning as illustrated by Fig.3 (a) and (b). Further experiments will be performed to investigate electron beam irradiation as well as the contribution of lower acceleration voltage (i.e. 80 and 60 kV) on the N K-edge ELNES analysis.

Graphic:

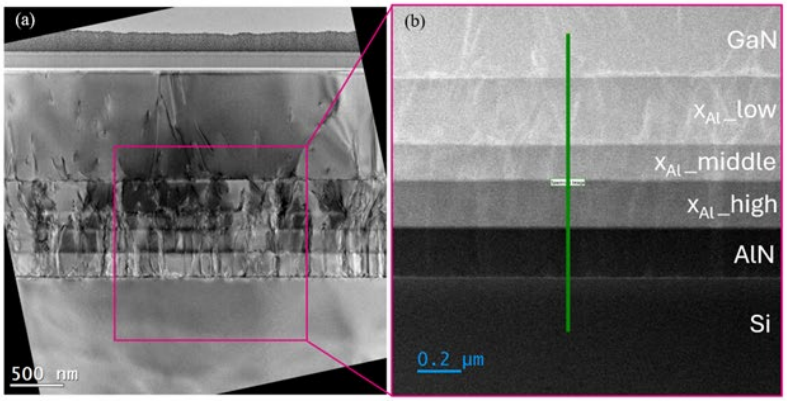

Figure 1. (a) TEM micrograph of HEMT device, (b) STEM-HAADF image of the $Al_xGa_{1-x}N$ buffer layer stack

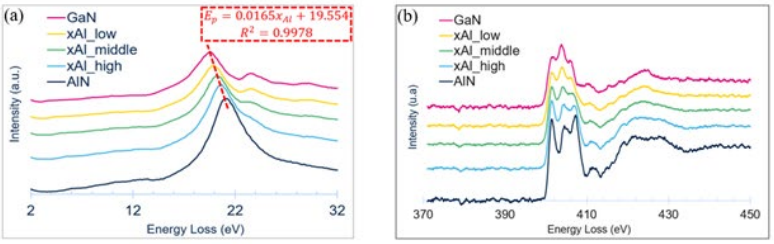

Figure 2. (a) plasmon peak analysis along $Al_xGa_{1-x}N$ buffer layer stack and linear dependency of the Ep depending on AlN mole fraction xAl (b) ELNES spectra of N K edge in GaN, $Al_xGa_{1-x}N$ buffer layers and AlN nucleation layer.

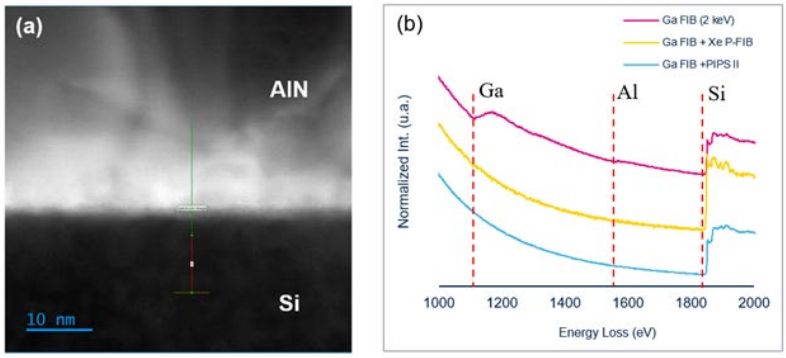

Figure 3. (a) STEM-HAADF image of the Si substrate and AlN nucleation layer interface (b) EELS spectra highlighting the presence of Ga and Al in Si substrate for the Ga FIB prepared sample whereas neither Ga nor Al is observed after Xe P-FIB or PIPS II polishing.

Keywords:

EELS, ELNES, AlGaN/AlN/GaN, HEMT

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