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Characterization of GaN/AlGaN epitaxial layers grown by metalorganic chemical vapour deposition for high electron mobility transistor applications

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Abstract. GaN and AlGaN epitaxial layers are grown by a metalorganic chemical vapour deposition (MOCVD) system. The crystalline quality of these epitaxially grown layers is studied by different characterization techniques. PL measurements indicate band edge emission peak at 363.8 nm and 312 nm for GaN and AlGaN layers respectively. High resolution XRD (HRXRD) peaks show FWHM of 272 and 296 arcsec for the (0 0 0 2) plane of GaN and GaN in GaN/AlGaN respectively. For GaN buffer layer, the Hall mobility is 346 cm^2/V-s and carrier concentration is $4.5 \times 10^{16}/\text{cm}^3$. AFM studies on GaN buffer layer show a dislocation density of $2 \times 10^8/\text{cm}^2$ by wet etching in hot phosphoric acid. The refractive indices of GaN buffer layer on sapphire at 633 nm are 2.3544 and 2.1515 for TE and TM modes respectively.

Keywords. Gallium nitride; aluminium gallium nitride; high electron mobility transistors; metalorganic chemical vapour deposition; photoluminescence; high resolution X-ray diffraction.

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1. Introduction

GaN compound semiconductor is a promising candidate for high power and high frequency electronic devices. The performance level of GaN/AlGaN HEMT devices has increased rapidly over the last few years. Reliability, performance and lifetime combination of these devices are much higher than other devices. Output power densities of 30 W/mm [1] for GaN/AlGaN HEMT devices and GaN/AlGaN amplifier with 550 W at 3.5 GHz [2] are reported. Fujitsu reported that GaN/AlGaN HEMT devices might operate for more than 100 years at 200°C [3].

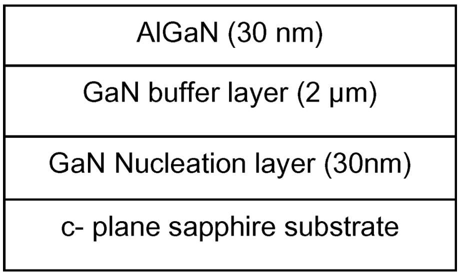

Figure 1. GaN/AlGaN HEMT structure.

Epitaxial growth of GaN and AlGaN layers faces many problems. Due to lack of the native substrate, GaN epitaxial layers are generally grown on sapphire or SiC substrate with lattice and thermal mismatch. Growth of GaN epitaxial layers on such substrates, by using a low-temperature nucleation layer demonstrated a good crystal quality [4]. Remarkable improvement in epitaxial material quality is reported by introducing annealing of the GaN layer in nitrogen [5], Fe doping [6], delta doping [7,8], etc. The quality of epitaxial growth of GaN is further studied by using low-cost Si substrates [9] and also on diamond substrates [10].

In this work, GaN and AlGaN epitaxial layers were grown on sapphire substrates by the metalorganic chemical vapour deposition (MOCVD) system at CEERI. The quality of each grown layer is characterized by PL, XRD, Hall Effect and AFM.

2. Experimental

GaN and AlGaN epitaxial layers were grown by MOCVD system ($3 \times 2''$ closed coupled showerhead, M/s Thomas Swan Scientific Equipment Ltd, U.K.) on $2''$ *c*-plane sapphire substrates.

Trimethyl gallium and trimethyl aluminum were used as precursors for gallium and aluminum respectively. Ammonia gas was used as the source gas for nitrogen. Hydrogen was used as a carrier gas. Growth of epitaxial layers was monitored by *in-situ* interferometeric technique.

The characterization of GaN and AlGaN layers was carried out by using photoluminescence (PL) mapping system (Model RPM 2000, Accent Optics), high resolution XRD (HRXRD) system (CN 1518 BI, Rikagu), AFM (Nanoink) and Prism Coupler (2010, Metricon). Dislocation densities in the GaN epitaxial layers were obtained by etching the sample in hot phosphoric acid.

3. Results and discussion

The schematic of GaN and AlGaN epitaxial layers grown in this study by MOCVD is shown in figure 1. The details of the growth process can be found elsewhere [11].

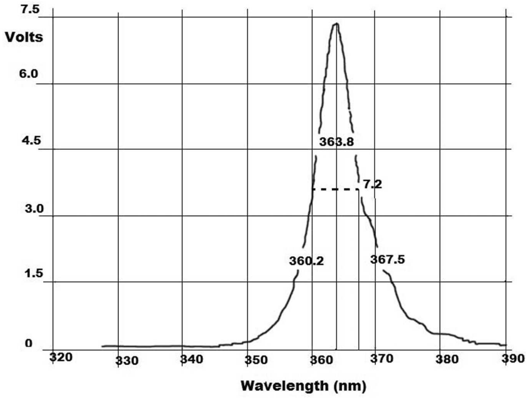

Figure 2. PL spectral curve of GaN buffer on sapphire.

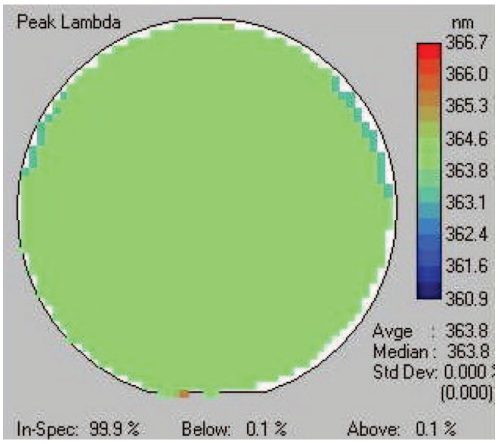

Figure 3. Peak lambda of GaN.

The PL spectral curve for GaN buffer layer on sapphire substrates is shown in figure 2. The band edge emission peak at room temperature for GaN is obtained at 363.8 nm (3.41 eV) and peak FWHM is 7.2 nm. The spectral mappings for $2''$ wafer obtained by photoluminescence mapping system for peak lambda of GaN and FWHM are shown in figures 3 and 4 respectively. The peak lambda of GaN for spectral mapping is uniform throughout the $2''$ wafer. FWHM varies from 7.1 to 7.7 nm.

Aluminum concentration mapping in GaN/AlGaN on sapphire substrate is shown in figure 5. The band edge emission peak is obtained at 312 nm (3.94 eV), which corresponds to 31% of Al in AlGaN. This measurement was a result of interpolation of peak lambda of GaN, AlN and AlGaN. The FWHM of the peak is 11.3 nm. This slight increase in FWHM is due to alloy disorder in quantum well. The mapping of Al concentration varies from 29 to 32% throughout the $2''$ wafer.

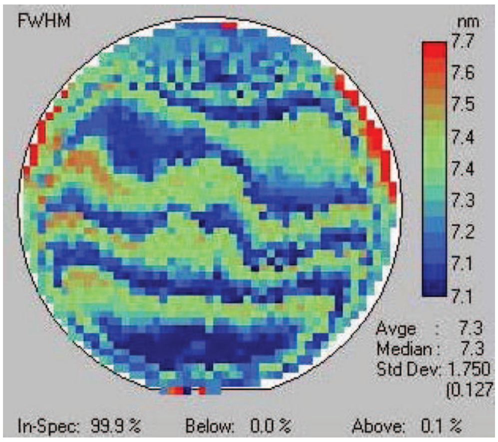

Figure 4. FWHM for PL of GaN.

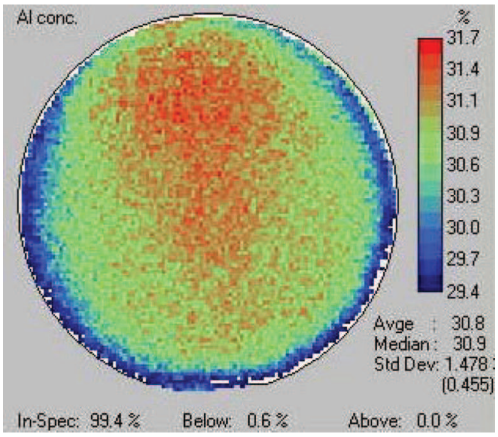

Figure 5. Al concentration in AlGaN layer.

High resolution XRD of GaN buffer layer shows a sharp peak at 34.8° (2θ) due to GaN (0 0 0 2) lattice planes. The calculated lattice constant (c) for GaN (0 0 0 2) is 5.15 Å, which is approximately equal to the reported value of 5.125 for wurtzite GaN. The FWHM of GaN (0 0 0 2) HRXRD peak is 272 arcsec as shown in figure 6. The FWHM of GaN for GaN/AlGaN for (0 0 0 2) peak is 296 arcsec as shown in figure 6. This broadening of GaN peak indicates the increase in dislocation density in GaN buffer layer.

Hall measurement on GaN buffer layer shows a mobility (μ_{H}) of 346 cm^2/V-s and carrier concentration (n_{H}) of $4.5 \times 10^{16}/\mathrm{cm}^3$, at room temperature. This order of carrier concentration is generally needed in high power HEMT devices.

Dislocation density of GaN buffer layer is calculated by etching the sample in hot phosphoric acid at 240°C for 200 s. The total etch pit density of $2 \times 10^8/\mathrm{cm}^2$ is obtained by AFM. The AFM image for an area of 17.6 $\mu\mathrm{m}^2$ shown in figure 7

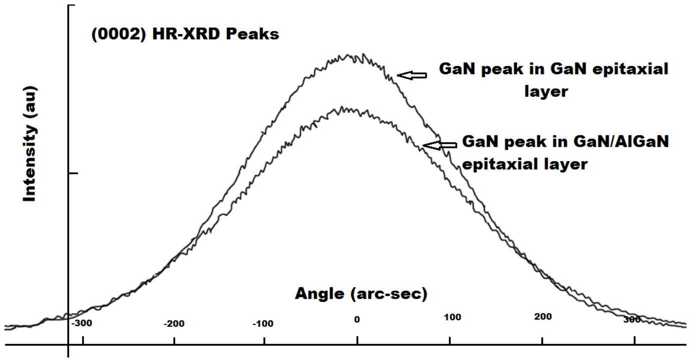

Figure 6. HRXRD of AlGaN and GaN layers.

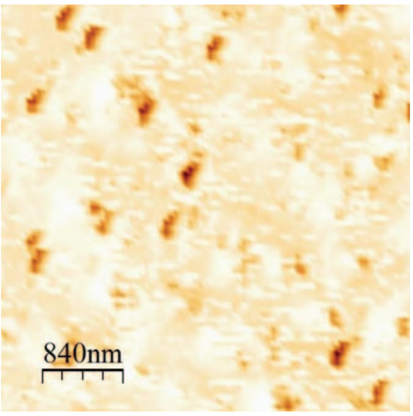

Figure 7. AFM image of etched GaN surface.

indicates that there are three types of pit depths – small, medium and large, which correlate with screw (= 1.02×10^8), edge (= 5.11×10^7) and mixed (= 4.54×10^7) types of dislocations. The dislocation density measured by this method is in good agreement with the dislocation density measured by Keller *et al* [12] and Kozawa *et al* [13] by TEM.

The refractive index of GaN buffer layer on sapphire substrate measured by Prism Coupler is shown in figure 8. The refractive indices at 633 nm are 2.3544 for the TE (ordinary) mode and 2.1515 for the TM (extraordinary) mode. The refractive index for TE mode is close to the calculated value by Barker and Ilegems [14] at 633 nm. No experimental data on extraordinary refractive index at 633 nm is reported for GaN.

4. Conclusions

In conclusion, GaN and AlGaN epitaxial layers are successfully grown by MOCVD on *c*-plane sapphire substrate and characterized by PL, XRD, Hall Effect and AFM.

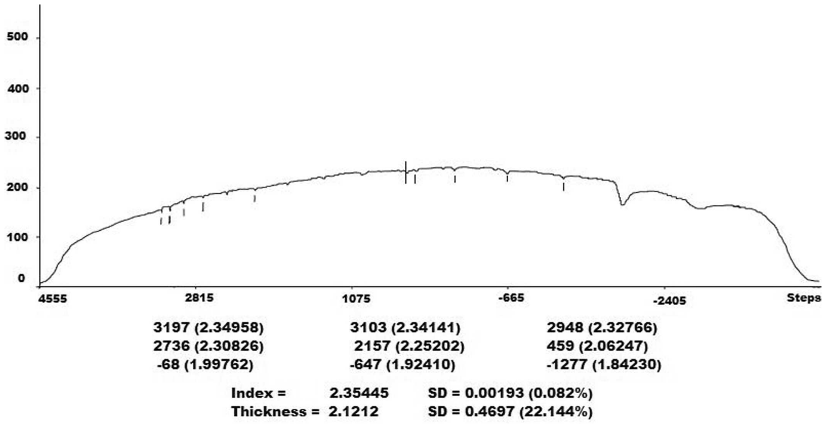

Figure 8. Plot for GaN buffer layer on sapphire by prism coupler.

PL measurement shows band edge emission peak at 363.8 and 312 nm respectively for GaN and AlGaN layers. Increase in PL peak width is due to alloy disorder. HRXRD peak shows FWHM of 272 and 296 arcsec for 0 0 0 2 plane for GaN and GaN in GaN/AlGaN respectively. Hall mobility for GaN buffer layer is 346 cm^2/V-s and carrier concentration is $4.5 \times 10^{16}/\mathrm{cm}^3$. Dislocation density of GaN buffer layer, $2 \times 10^8/\mathrm{cm}^2$, was measured by AFM after wet etching. The refractive indices of GaN buffer layer at 633 nm is 2.3544 for TE mode and 2.1515 for TM mode. This data demonstrate the quality achieved for GaN and AlGaN epitaxial layers grown by MOCVD.

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