# Cathodoluminescence characterization of thick GaN films grown by HVPE

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Thick GaN layers grown by hydride vapor phase epitaxy was examined. High quality films have been examined by field emission scanning electron microscope (FE-SEM), cathodoluminescence (CL) spectroscopy and imaging. We have carried out spatially resolved studies of film cross-sections and top surfaces, as well as the interface side of GaN layers. The top surface of the films show narrow bound exciton (DBE) emission lines, while the CL spectra near the interface are broad and extend to energies above the band gap. Close to the interface we were able to directly observe a region about 40—m thick containing columnar structures.

Application of GaN in electronic and optoelectronic devices is currently of technological interest[1]. It is therefore important to be able to grow substrates of high quality, suitable for growth of thin multi-layer structures involving GaN. At present, lattice-mismatched substrates such as sapphire and SiC are used, and quality of epitaxial layers are improved by low- temperature buffer layers, but the search continues for large area substrates for GaN homoepitaxy. While a high-pressure growth method is being developed[2], the hydride vapor phase epitaxy (HVPE) at present seems to be the only technique, which is technologically viable and capable of yielding thick, uniform large-area GaN films[3,4]. We report results on low-temperature (80 K) CL of 200 $\mu$m-230 $\mu$m films grown by HVPE. CL studies of GaN grown by other techniques have been reported previously[5,6], but no detailed investigations have been reported for HVPE. For completeness we briefly summarize the results of characterization of other film properties, measured in double crystal x-ray diffraction (DCXRD) and low-temperature photoluminescence (PL).

The films in this study were grown by a modified version of vertical HVPE process described by R. J. Molnar et al.[7]. In this process the Ga precursor is synthesized upper zone in the reactor via a reaction of HCl gas (in an N2 diluent gas) with Ga metal (at 800 °C-900 °C) to form GaCl. This precursor is then transported to the substrate area where it is mixed with NH3 to form GaN (at 1000 °C-1050°C). We were able to achieve growth rates of 115 $\mu$m/h for a HCl flow of 100 ml/min. The DCXRD were measured and the low-temperature PL spectra taken with a 325 nm excitation wavelength of a He-Cd laser generally confirm high quality of the uppermost region of the films. In order to further investigate highly and lightly doped regions we carried out CL spectroscopy and imaging. The CL spectra of films at 80 K were taken in a JSM-6330F FE-SEM with a MONOCL2 CL system by Oxford Instruments.

Fig. 1 shows the FWHM of the (0002) reflection measured for 200 $\mu$m thick films. The narrowest linewidth of 115 arcsec was found for 200 $\mu$m films grown on c-plane sapphire. Fig. 2 shows the PL spectrum of bulk-like 200 $\mu$m thick GaN film. The PL emission is found to be strongly affected by growth conditions. The spectra of samples grown under optimized conditions are typical of good-quality films with low-electron concentration. The FWHM of the DBE lines in the best samples was about 2 meV. A SEM image of one of the cross sections is shown in Fig. 3a together with a panchromatic CL image taken at the same area(Fig. 3b). A bright layer built up from individual columnar structures is clearly visible(Fig. 3b) near the film-substrate interface. These columnar features form a quasi-continuous layer of irregular width. The columns have an average height of about 40 $\mu$m. Fig. 3 shows the cross-section of one of these columns. The CL spectra taken at selected regions are shown in Fig. 4. Our identification of two regions with significant differences in electron concentration such as region A and C(in Fig. 3b) in HVPE films is consistent with other works[8] which report a thickness dependence of electronic properties. Next, we examined top surfaces of GaN films. The films are smooth and flat over most of their area but occasionally they show pits and other surface structure. The SEM images of the films(Fig. 5a) are almost featureless with only a very weak surface pattern. The CL image, on the other hand, shows an irregular pattern reflecting a dense network of dislocations(Fig. 5b). A representative CL spectrum from such regions showing pronounced DBE features is presented in Fig. 6. We also note that the contrast between bright and dark regions in the CL images of these high-quality regions is weak, but sufficient to notice some degree of correlation between topographical features observed in the SEM images and those seen in the CL images.

Thick GaN layers with thickness of 200 $\mu$m have been grown by HVPE. We have carried out a CL investigation of HVPE films grown within the optimized growth window. The top surfaces of the films generally show narrow DBE emission lines and narrow DCXRD lines. GaN film and sapphire interface regions are generally found to be

heavily doped and appear to be closely linked to doping nonuniformities in the interface defective region. The region immediately adjacent to the interface region was found to be strongly n-doped and its low radiative efficiency is explained by structural imperfections leading to strong nonradiative recombination. For the improvement of the HVPE GaN film quality we must concentrate on terminating the columnar defective growth completely.

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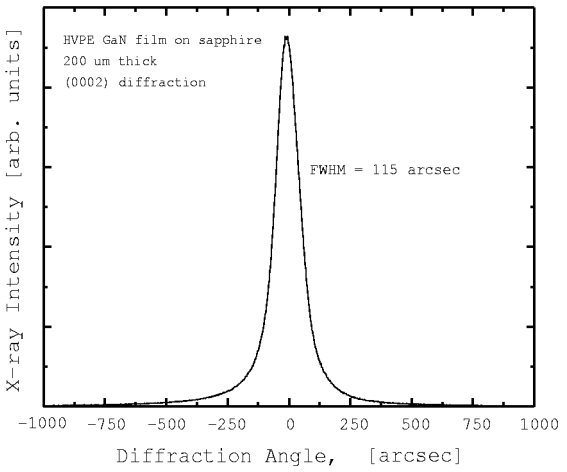


Fig. 1 Kim et al

FIG. 1. X-ray rocking curve of the HVPE GaN films on sapphire.

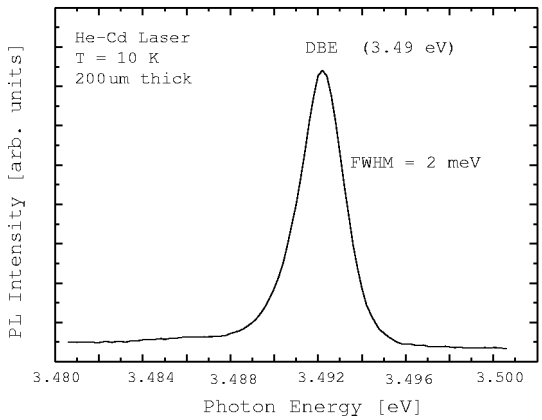


Fig. 2 Kim et al

FIG. 2. PL spectrum of the HVPE GaN films on sapphire.

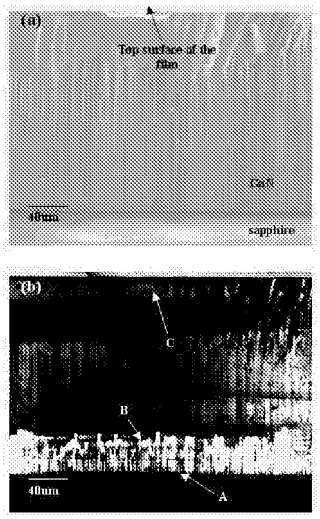


Fig. 3 Kim et al.

FIG. 3. (a) A secondary electron image of the cross section of the HVPE GaN films; (b) a panchromatic CL image of the same region.

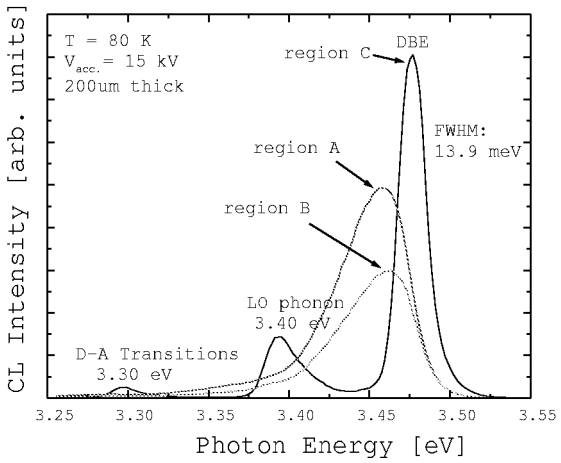


Fig. 4 Kim et al.

FIG. 4. The CL spectra of selected regions in Fig. 3: (a) region A; (b) region B; (c) top region of the film.

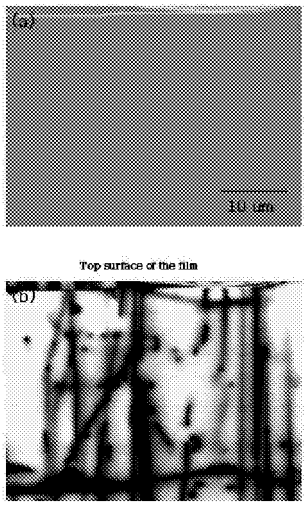


Fig. 5 Kim et al.

FIG. 5. (a) A secondary electron image of the top surface of the GaN films on sapphire, (b) a panchromatic CL image of the top surface of the GaN films on sapphire showing the dislocations.

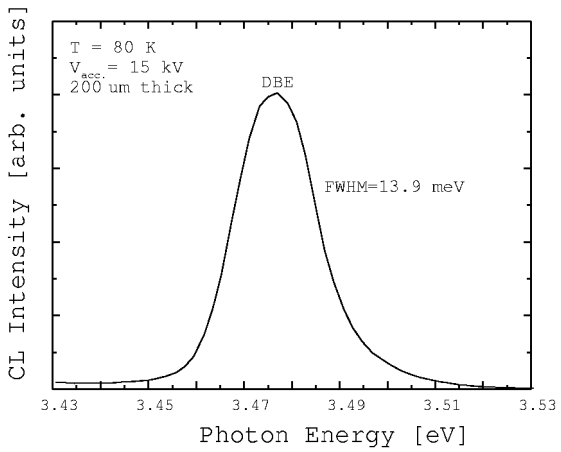


Fig. 6 Kim et al.

FIG. 6. The CL spectrum of the top film surface.