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Confocal Photoluminescence and Cathodoluminescence Studies of AlGaN

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ABSTRACT

$Al_xGa_{1-x}N$ films grown by MOCVD on sapphire and SiC substrates have been investigated by spatially resolved confocal photoluminescence microscopy and cathodoluminescence spectroscopy and mapping. The sample on SiC has a rougher topography, but it is much more uniform in emission intensity and wavelength than the sample on sapphire.

1. INTRODUCTION

$Al_xGa_{1-x}N$ films are of particular interest for ultraviolet (UV) lasers and light-emitting diodes, because of the large, direct, composition-dependent bandgap of these materials. However, problems of low luminescence efficiency and high defect densities remain to be solved for $Al_xGa_{1-x}N$. Similar problems with $In_xGa_{1-x}N$ films have been overcome, which has allowed these materials to be used successfully in blue and near-UV lasers. High luminescence quantum efficiency in $In_xGa_{1-x}N$ has been attributed to composition fluctuations, and resulting excitation localization, induced by doping or by lattice mismatch strains [1]. Choice of substrate material is critical for lattice mismatch strains and for minimizing nonradiative defects. We have used confocal photoluminescence (PL) microscopy and cathodoluminescence (CL) to investigate effects of substrate choice, either sapphire or SiC, on MOCVD-grown $Al_xGa_{1-x}N$ films.

2. EXPERIMENTAL TECHNIQUES

Photoluminescence mapping has often been used to characterize homogeneity of luminescence from semiconductor structures in the visible and with spatial resolution of ~1μm. Better resolution should be possible for photoluminescence mapping in the UV, but no sub-micron mapping results have been reported. The best spatial resolution for PL mapping reported for GaN is ~2.5μm [2]. In this paper we report higher spatial resolution PL mapping results obtained using a custom built confocal luminescence microscope. This instrument is shown schematically in figure 1. A He-Cd laser, together with a single mode optical fiber and polarization control device, provides 325nm optical excitation. The excitation is focused on the surface of the sample by a microscope objective with NA=0.55. The resulting spot size is diffraction limited to less than 1μm. The optical system has a long working distance, good UV transmission, and no detectable UV emission. The sample can be cooled to approximately 10K in a cryostat mounted on a high-precision two-dimensional translation stage.

Luminescence is collected in the backward direction by the same microscope objective, and it is focused onto the entrance slit of a monochromator. The fiber output, the excited sample volume, and the monochromator slit are located on conjugated focal planes, so the whole assembly works as a confocal luminescence microscope. The dispersed spectra are recorded using a back-thinned, UV-sensitive, cooled CCD camera. A spectral range of 30nm can be acquired in 0.1s with a 0.03nm resolution, so many spectra can be collected in a short time while step scanning an area on the sample surface. Each spectrum is analyzed in terms of total intensity, average emission wavelength, and emission peak width. Very small emission wavelength shifts can be detected, corresponding to local composition changes as small as Δx = 0.0002.

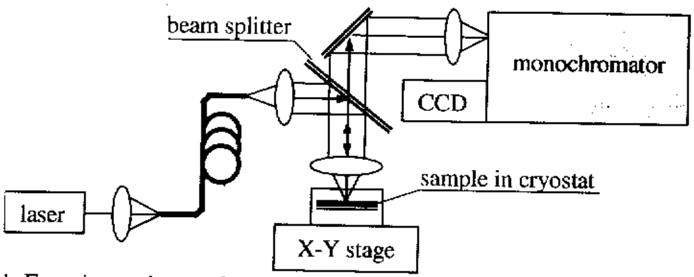

Figure 1. Experimental setup for confocal photoluminescence spectroscopy.

To complement the PL mapping experiments, we have used room temperature cathodoluminescence (CL). CL experiments were carried out in a JSM-6400 JEOL SEM equipped with an Oxford Instruments CF302 CL detection system and SPEX spectrometer. CL was generated by a 10keV, 16nA electron beam, and CL was collected by a parabolic mirror positioned over the sample. The luminescence was collimated and focused onto the entrance slit of the monochromator, and was detected by a cooled Hamamatsu GaAs photomultiplier tube. The CL signal can be used to measure luminescence wavelength spectra at selected locations determined by the position of the electron beam, or it can be used to produce monochromatic luminescence intensity maps. Secondary electron (SE) and CL images can be collected simultaneously.

3. SAMPLES

We have studied $Al_xGa_{1-x}N$ films grown by MOCVD at Pennsylvania State University. Nominal compositions, layer thicknesses, substrate types, and x-ray rocking curve widths are given in Table 1.

Both samples were deposited in a cold-wall vertical axisymmetric reactor at a nominal reactor pressure of 100Torr. Purified H_2 carrier gas and trimethylaluminum, trimethylgallium, and ammonia precursors were used. C-axis sapphire substrate was degreased in acetone, followed by isopropanol, deionized (DI) water rinse, and blown dry with N_2. As-received 6H-SiC (0001) substrates were degreased the same way, followed by a 10min dip in 10% hydrofluoric acid solution, DI water rinse, and blown dry with N_2. Both sapphire and SiC substrates were held at ~1100°C for 10min in flowing hydrogen prior to deposition. Samples on

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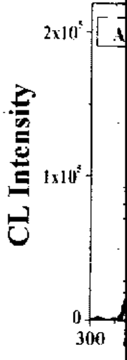

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sapphire consisted of an AlN buffer layer grown at ~500°C and then annealed at ~1100°C prior to epilayer growth at the same temperature. For samples on SiC substrate, the AlN buffer layer was grown at ~1100°C.

Table 1. Parameters of the investigated structures.

Sample	Nominal x	Thickness	Buffer layer	Substrate	Rocking curve width
$Al_xGa_{1-x}N$	0.1	4.0 μm	7.5 nm AlN	sapphire	780 arcsec
$Al_xGa_{1-x}N$	0.1	1.0 μm	60 nm AlN	SiC	560 arcsec

4. RESULTS

CL wavelength scans at room temperature are shown in figure 2. Each spectrum contains a narrow near band edge emission (NBE) peak, and a broad, deep level peak at a longer wavelength. NBE luminescence from the sample on sapphire was more intense than that from the sample on SiC, which had stronger emission from deep levels. The NBE peak from the sample on sapphire had a shoulder at a shorter wavelength, which was resolved into a separate peak in low-temperature PL measurements (figure 5).

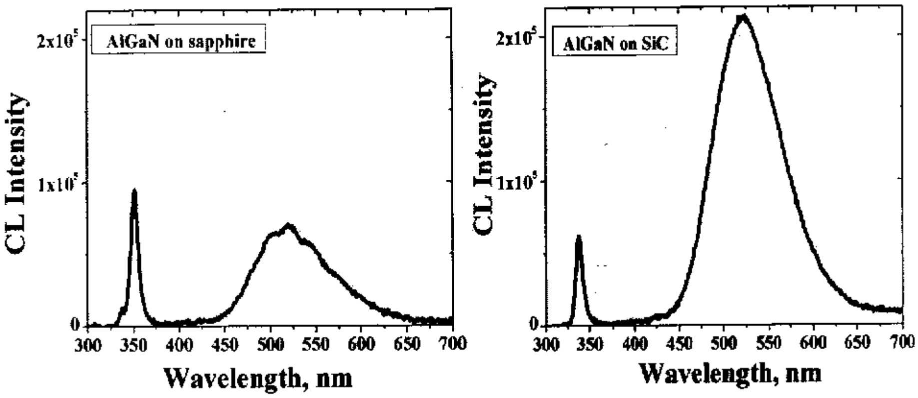

Figure 2. CL wavelength scans from samples on sapphire and SiC substrates.

Monochromatic CL intensity images acquired from the NBE luminescence, presented in figures 3 and 4, show that luminescence from the sample on SiC is more uniform than luminescence from the sample on sapphire. This is more apparent from the line scans, which indicate the amount of change of luminescence between different areas. This result is somewhat surprising considering the rougher surface of the film grown on SiC, which can be seen by comparing the SE micrographs in figures 3 and 4 along with line scan profiles.

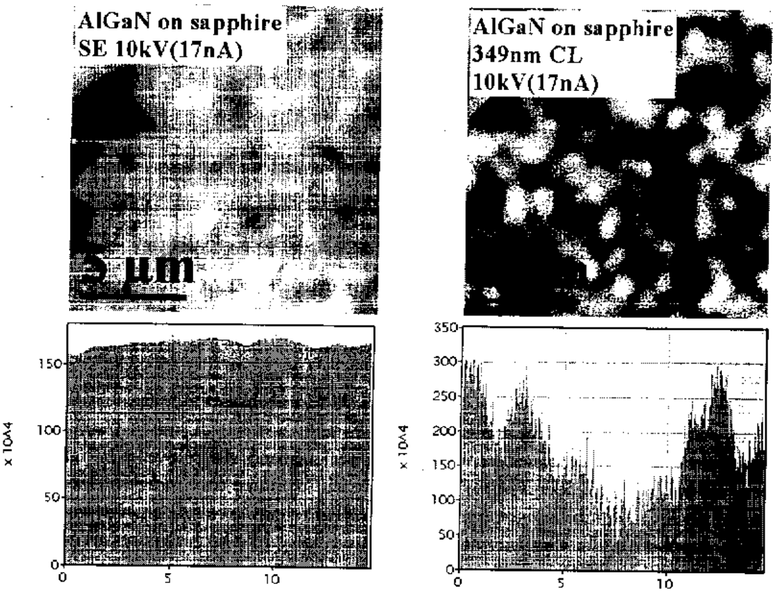

Figure 3. SE and CL micrographs and line scan profiles for the sample on sapphire.

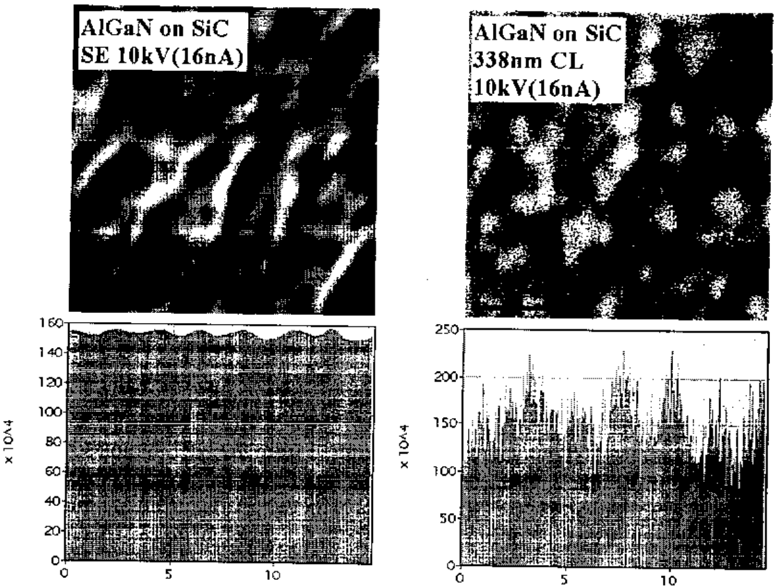

Figure 4. SE and CL micrographs and line scan profiles for the sample on SiC.

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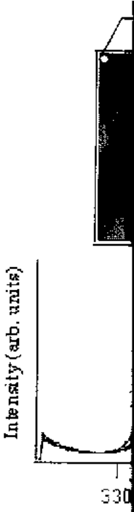

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Low-temperature NBE PL spectra obtained from several locations on the two samples are shown in figures 5 and 6. For the sample on sapphire these spectra, in figure 5, consist of two distinct peaks about 14nm apart with widths of about 3nm, which we attribute to excitons and to shallow impurities. G. Coli et al. have reported NBE PL spectra with two overlapping components for $Al_xGa_{1-x}N$ films on sapphire [3]. They attributed the shorter wavelength component to loosely localized excitons. The NBE PL spectrum for the sample on SiC, in figure 6, consists of a single, asymmetric peak of about 7nm width.

Compositional non-uniformity can be estimated from PL maps of average emission wavelength as shown in figures 5 and 6, if the wavelength shifts are attributed to composition differences rather than to strain differences. Darker areas in the maps correspond to shorter wavelengths, and brighter areas correspond to longer wavelengths. For the sample on sapphire, PL maps from each of the two peaks, in figure 5, are similar. Spatial non-uniformities are on the length scale of about 5μm. The magnitude of these non-uniformities from the exciton-related peak at ~332nm is ~0.3nm , which indicates local Al fluctuations of about $\Delta x = 0.002$ [4] if the wavelength differences are attributed solely to composition differences.

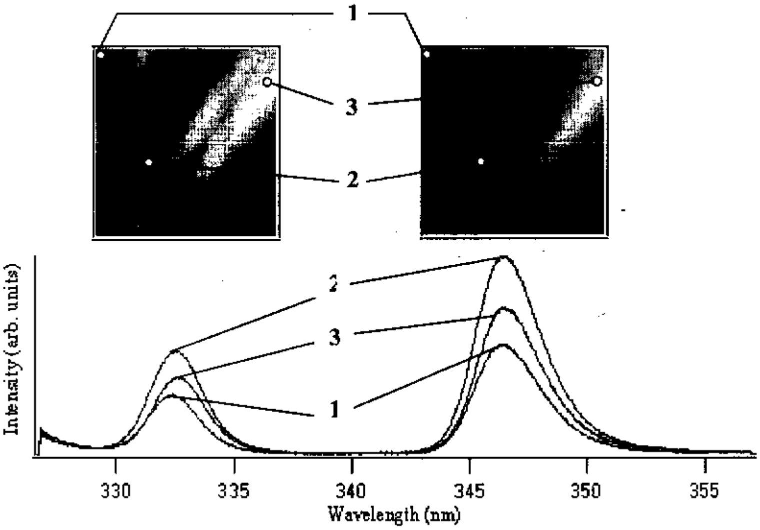

Figure 5. NBE PL spectra for three locations on the sample on sapphire and PL maps (60μm × 60μm) of the average emission wavelength.

NBE PL from the sample on SiC was much more uniform, as seen from PL spectra and the 50μm × 60μm PL map of the average emission wavelength in figure 6. The magnitude of the wavelength fluctuations for this sample did not exceed 0.1nm, which would correspond to $\Delta x = 0.0006$ [4]. Therefore, fluctuations of Al content, and/or fluctuations in strain, for the film grown on SiC are much smaller than for the film grown on sapphire. The length scale of these fluctuations was of the order of 20μm. Bergman et al. [4] have reported room temperature PL and Raman measurements for $Al_xGa_{1-x}N$ ($x = 0.12 - 0.70$) films on SiC indicating somewhat larger composition fluctuations, in the range $\Delta x = 0.002$ to 0.004.

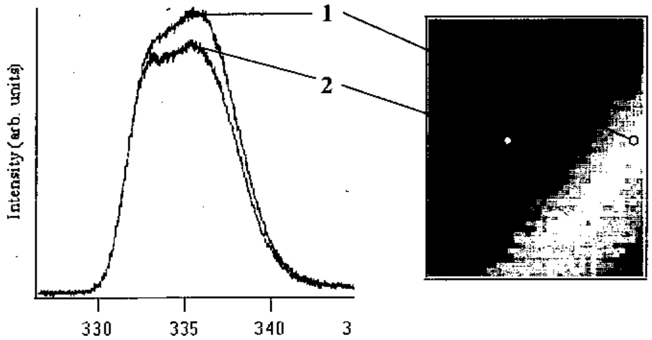

Figure 6. NBE PL spectra for two different locations on the sample on SiC and PL map (50μm × 60μm) of the average emission wavelength.

5. CONCLUSIONS

Spatially resolved PL and CL show differences between $Al_xGa_{1-x}N$ MOCVD-grown samples on sapphire and SiC substrates. Although the sample on SiC has a rougher topography, it exhibits much smaller fluctuations in the emission intensity and wavelength compared to the sample on sapphire. X-ray rocking curves also indicate that the film on sapphire has poorer crystal quality than the film on SiC.

ACKNOWLEDGEMENTS

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