The successful development of short wavelength light emitting diodes and the most recent realization of nitride semiconductor lasers have stimulated great interests in the applications of this material for blue and ultraviolet optoelectronic devices. Epitaxial films grown by chemical vapor deposition or molecular beam epitaxy on conventional substrates, such as $\text{Al}_2\text{O}_3$ or SiC, contain a high density of dislocations, on the order of $10^8$–$10^{10}$ cm$^{-2}$. The extended and point defects in GaN films may greatly impact the performance of many devices. For example, the microscopic inhomogeneity could limit the achievable gain of laser structures. Recently, there have been several reports on the studies of microscopic properties of the GaN materials at different spatial scales. In this letter, we report the high spatial resolution photoluminescence (PL) measurements of GaN films by near-field scanning optical microscopy (NSOM). We have performed spatially resolved studies of GaN films by near-field scanning optical microscopy (NSOM).}

We have performed spatially resolved photoluminescence from GaN films using a near-field scanning optical microscope (NSOM). GaN films grown by hydride vapor phase epitaxy (HVPE) and metal-organic vapor phase epitaxy (MOVPE) on sapphire substrates have been studied. We have performed spatial scans of topography, band edge, and yellow luminescence signals. Atomic force microscopy measurements were also made and compared with the NSOM topography. We have found spatial variations in photoluminescence characteristics at the submicron scale for both HVPE and MOVPE GaN. The observed enhancement of yellow luminescence at multiatomic step edges on the HVPE GaN surface suggests that the yellow luminescence is associated with chemical impurities incorporated during the growth of GaN films. © 1996 American Institute of Physics.

A near-field scanning optical microscopy study of the photoluminescence from GaN films

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We have achieved spatially resolved photoluminescence from GaN films using a near-field scanning optical microscope (NSOM). GaN films grown by hydride vapor phase epitaxy (HVPE) and metal-organic vapor phase epitaxy (MOVPE) on sapphire substrates have been studied. We have performed spatial scans of topography, band edge, and yellow luminescence signals. Atomic force microscopy measurements were also made and compared with the NSOM topography. We have found spatial variations in photoluminescence characteristics at the submicron scale for both HVPE and MOVPE GaN. The observed enhancement of yellow luminescence at multiatomic step edges on the HVPE GaN surface suggests that the yellow luminescence is associated with chemical impurities incorporated during the growth of GaN films. © 1996 American Institute of Physics.
source. A thin (15 nm) AlN buffer layer was initially grown on the sapphire substrate at 550 °C. The temperature was then increased to 1100 °C for growth of a nominally 3-μm-thick GaN layer. There were three Si doped samples and one nominally undoped sample. Electron concentration of the four samples were $<1 \times 10^{17}$ (not measurable), $2.6 \times 10^{17}$, $2.7 \times 10^{18}$, and $7.0 \times 10^{18}$ cm$^{-3}$, determined by Hall measurements.

The concentrations of chemical impurities in the HVPE GaN were determined by secondary ion mass spectroscopy (SIMS). The average concentrations within the analysis depth ($\sim 3 \mu$m) for Si and O were $1 \times 10^{18}$ and $4 \times 10^{19}$ cm$^{-3}$, respectively. C was found to be below the detection limit ($<6 \times 10^{18}$ cm$^{-3}$). The origins of these chemical impurities are presently unknown.

The topographic, BL and YL images collected over the same scan area on the HVPE sample are shown in Fig. 1. The AFM measurements were also performed and compared with the topography obtained by NSOM. Large terraces bounded by steps, several unit cells high, dominate the morphology. Both NSOM and AFM measurements yield an average step height of 3 nm. The average terrace width is 600 nm. The variation of BL at the submicron spatial scale is clearly observed with no correlation to the surface morphology. On the other hand, the YL and topographic signals are strongly correlated. The YL is clearly seen to be enhanced at the multiatomic step edges. The smallest feature observed in the YL image is $\sim 170$ nm.

The NSOM measurements revealed the existence of inhomogeneities in optical properties on a finer scale than previously reported. Spectral characteristic variations, i.e., different spatial distributions of BL and YL signals, were clearly observed with high spatial resolution. Changes in either surface recombination velocity or the local defect or impurity levels could be possible sources of the observed submicron scale spatial variations of BL and YL intensities. The lateral extent of the probed volume in the NSOM-based PL experiment is determined by the probe size, surface recombination velocity, and the diffusion of photogenerated carriers in the semiconductor material. This lateral resolution, estimated from the PL images, is better than $\sim 200$ nm.

Both the YL and BL will be affected by the local changes in the surface recombination through the density of local changes in the minority carrier concentration as well as by their relative radiative and nonradiative transition rates. The YL is derived from transitions involving spatially localized deep level defects. Depending on the relative concentration of the deep levels responsible for the YL and its capture and recombination rates, a wide range of coupling between the BL and YL could be expected. Even though BL and YL are composed of competing and coupled radiative recombination mechanisms, the spatial distributions of these two PL bands are not correlated in the present study. The coupling of the radiative and nonradiative transitions at the surface, as well as in the bulk, is not apparent. This may be attributed to a variation of combined influences, such as low YL-related defect concentration or a large disparity in the radiative lifetimes associated with BL and YL.

We have observed the enhancement of YL intensity at multiatomic step edges on HVPE GaN surface. BL intensity, on the other hand, is not correlated with the step structure. This fact strongly suggests that a higher density of deep luminescence centers near step edges within the NSOM sampling volume, instead of a local change in surface recombination velocity, is the source of YL variation in HVPE GaN. The deep defects responsible for YL in GaN material have been suggested to be chemical impurities or native defects. In many growth systems, step edges serve as active sites for impurity incorporation. The probability of foreign atoms being incorporated into the crystal is higher at the strongly stepped riser (step edge) portion of the terrace than on the smooth terrace tread. Impurities can be trapped and incorporated in the terrace riser traces in the layer as the terraces migrate from the substrate to the surface in certain growth modes. Si and O are found by SIMS measurements to be present in the HVPE GaN sample at concentrations of $10^{18}$ and $10^{20}$ cm$^{-3}$, respectively. The enhancement of YL at step edges in HVPE GaN could be related to the enhanced incorporation of these chemical impurities at or near multiatomic step edges often seen in a variety of growth systems.
sure of the smallest feature size on an image. We have performed NSOM measurements on all four MOVPE samples with submicron scale spatial variations in BL and YL intensities clearly observed. However, the correlation between YL spatial distribution with step morphology could not be investigated in detail due to the high step density and the NSOM resolution limits.

In conclusion, we have studied the photoluminescence from HVPE and MOVPE GaN films with very high spatial resolution. The variations of photoluminescence characteristics at submicron spatial scale are clearly observed. The examination of the detailed correlation between morphology, band edge, and YL suggests that YL in HVPE GaN could be associated with defects, most probably chemical impurities, incorporated at step edges of both atomic and multilatiform steps.

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We have also performed NSOM scans on the MOVPE GaN samples and found much different surface morphology than the HVPE sample. The topographic, YL and BL images collected over the same scan area on the Si-doped MOVPE sample ($7.0 \times 10^{18}$ cm$^{-3}$) are shown in Fig. 2. These images were analyzed to determine the lateral correlation length and root mean square (rms) roughness which characterize these surfaces. The lateral correlation length is a quantitative measure of the smallest feature size on an image. The calculated lateral correlation lengths, included in the figure caption, indicate submicron variations of the optical signals. On MOVPE GaN, the terraces are much narrower than the ones on HVPE GaN. We have performed NSOM measurements on all four MOVPE samples with submicron scale spatial variations in BL and YL intensities clearly observed. However, the correlation between YL spatial distribution with step morphology could not be investigated in detail due to the high step density and the NSOM resolution limits.

In conclusion, we have studied the photoluminescence from HVPE and MOVPE GaN films with very high spatial resolution. The variations of photoluminescence characteristics at submicron spatial scale are clearly observed. The examination of the detailed correlation between morphology, band edge, and YL suggests that YL in HVPE GaN could be associated with defects, most probably chemical impurities, incorporated at step edges of both atomic and multilatiform steps.

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