Controlled growth and characterization of epitaxially-laterally-overgrown InGaN/GaN quantum heterostructures

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Crystal material quality is fundamentally important for optoelectronic devices including laser diodes and light emitting diodes. To this end epitaxial lateral overgrowth (ELO) has proven to be a powerful technique for reducing dislocation density in GaN and its alloys [1,2]. Implementation and design of ELO process is, however, critical for obtaining high-quality material with high-efficiency quantum structures for light emitters [3].

In this study, we present our systematic study on controlled lateral epitaxial overgrowth and characterization of InGaN/GaN quantum heterostructures using metal organic chemical vapor deposition (MOCVD). Here we correlate performance of these ELO-InGaN/GaN epi-structures using their room-temperature photoluminescence (RT-PL). Each of these epi-structures is grown on identical single-sided sapphire templates of 2 inch in diameter. The templates are comprised of 5 µm thick GaN on c-plane sapphire substrate, each having a different epitaxial lateral overgrowth stripe pattern. The ELO patterns consist of plasma enhanced chemical vapor deposition (PECVD) grown SiN mask stripes of 4, 7 and 10 µm in width [1-100] direction, separated by 4 µm windows. During the ELO process, a low-dislocation-density, 7 µm thick, n-type GaN (N_{Si}~$4x10^{18}$ cm^{-3}) layer is grown on top of SiN stripes, together with targeted complete coalescence planes in the centers of the stripes. After the ELO process, we continue with the vertical growth of 5 pairs of 2.5 nm thick InGaN quantum wells and 7.5 nm thick GaN barriers, and 150 nm thick p-GaN (N_{Mg}~$6x10^{17}$ cm^{-3}) layer. In addition to the patterned templates of ELO process, we use an additional identical template with no pattern on it as the reference (negative control group). Epitaxial growths of all the samples are performed simulataneously using four of the six 2 inch sample holders.

We perform the photoluminescence characterization of our epi-structures using a He-Cd laser with an excitation wavelength of 325 nm at room temperature under identical experimental conditions. Moreover, in each of our measurements, we adjust the pump beam spot size and position such that we measure PL signal only coming from low dislocation density regions of our structures. We present these PL spectra of our quantum strucutres in Figures 1(a)-(d). We also show the analysis involving the PL peak intensities, PL peak wavelengths and full width at half maximum (FWHM) values in Figures 2 (a)-(c).We obtain PL peak wavelengths in the range from 460 to 473 nm, which indicates that a close level of InN is incorporated into the quantum well structures of each sample. From the sample with 4 µm mask size, we obtain PL emission with the highest peak intensity and the narrowest spectrum, which shows that fluctuation of InN concentration throughout the quantum wells is the lowest and the material quality of multiple quantum well structures is the best.

Moreover, we observe the longest peak wavelength for the 10 µm mask sample. One of the possible reasons for that might be that this sample lacks complete coalescence, forming more of InN-rich regions compared to other samples. The reason for the fluctuations in the long wavelength tail of the reference sample might be similar, since during the lateral growth step of ELO the surface roughness of this sample increases, which in turn increases the number of InN-rich regions throughout the quantum well layer.

In conclusion, we presented our systematic study on controlled epitaxial growth and characterization of InGaN/GaN quantum structures with low defect densities, grown simultaneously using epitaxial lateral overgrowth technique with different mask and window widths. The epi-sample with 4 µm mask and growth window widths yielded the hightest PL peak intensity with the narrowest spectrum.

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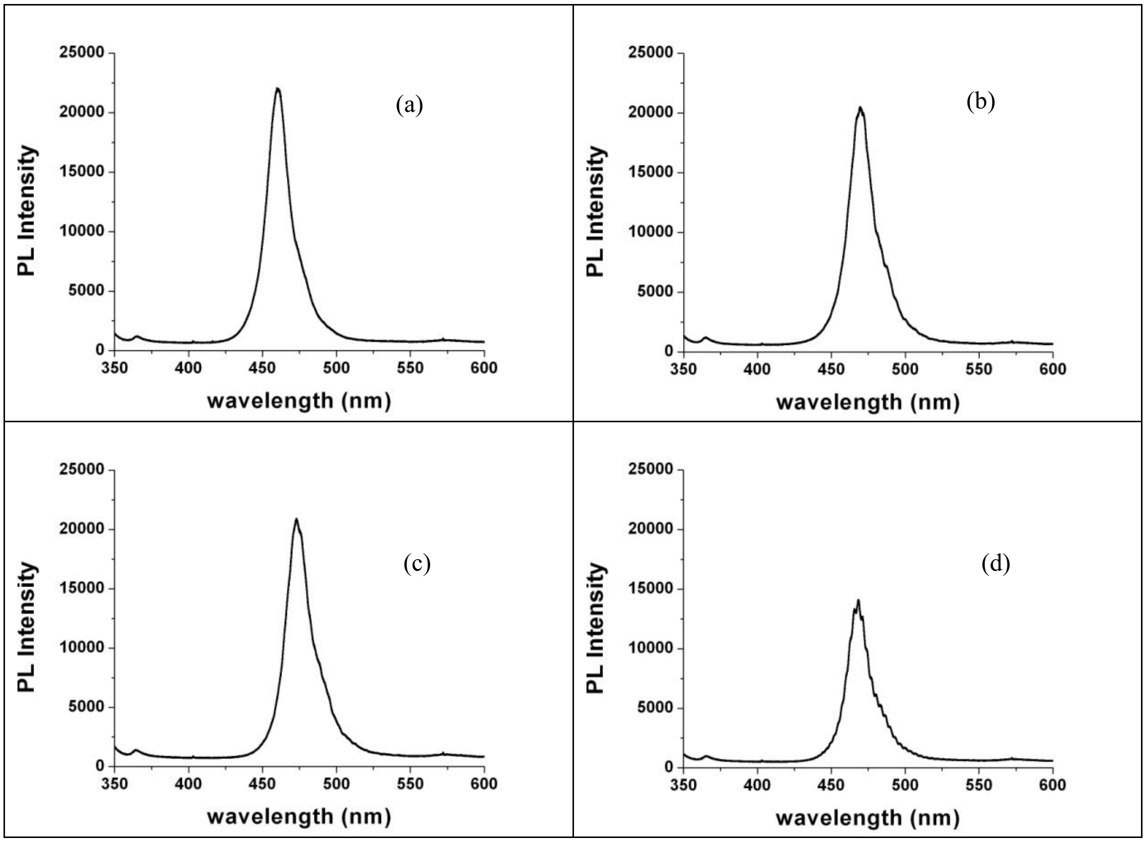

Figure 1. Photoluminescence spectra of our epitaxially-laterally-overgrown InGaN/GaN quantum heterostructures with mask widths of (a) 4 μm, (b) 7 μm and (c) 10 μm, and (d) reference (negative control group with no pattern).

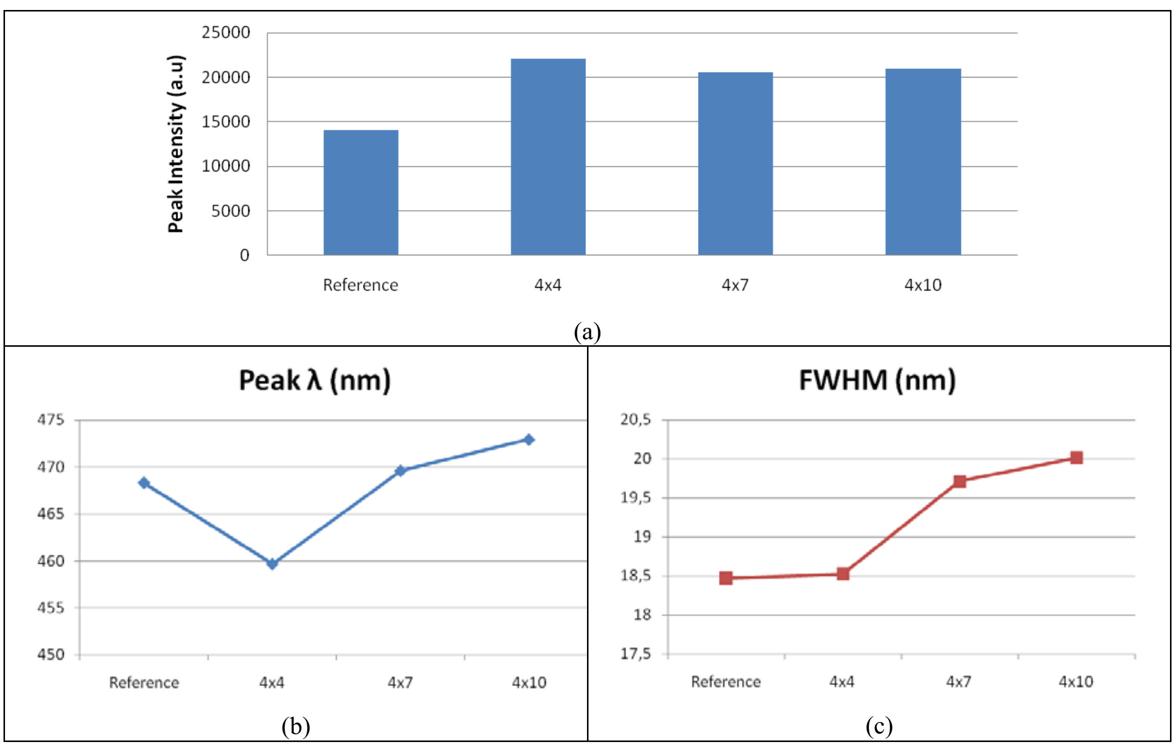

Figure 2. PL spectrum analysis of our ELO heterostructures, (a) peak intensity, (b) peak wavelength, and (c) FWHM.