Low Temperature Photoluminescence Spectral Mapping and Fluorescence Lifetime Imaging Microscopy of GaN-based LED Grown on Patterned Sapphire Substrate

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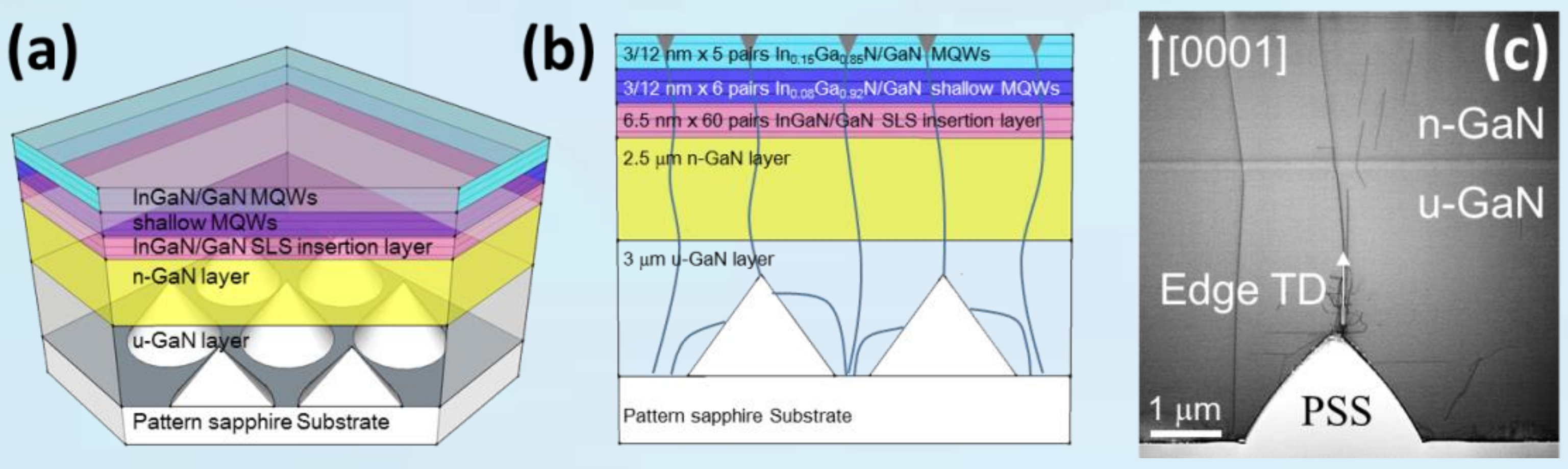
Abstract

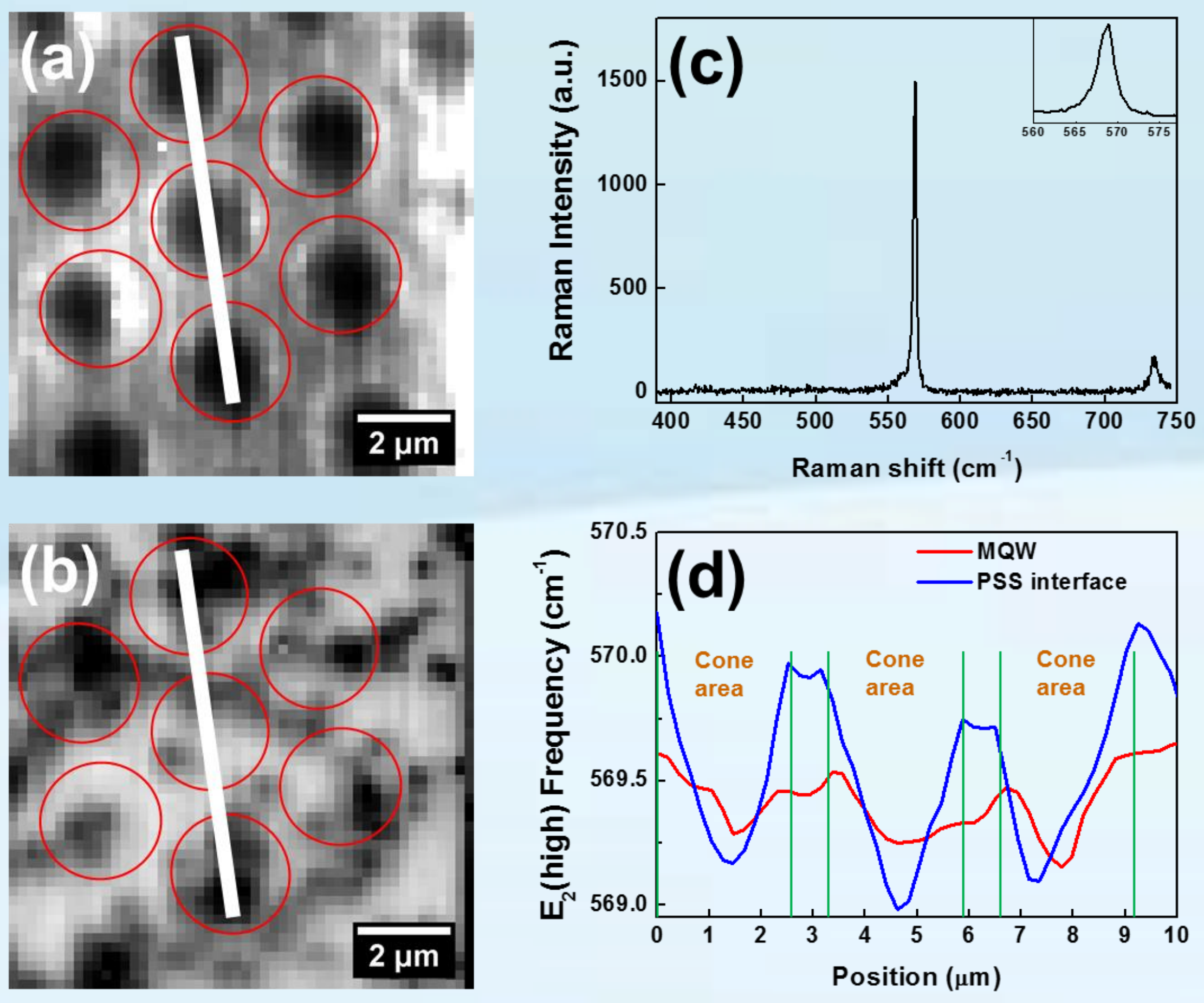
We performed low temperature photoluminescence (PL) spectral mapping and time-domain fluorescence lifetime Imaging (FLIM) of a GaN-based LED structure grown on a patterned sapphire substrate (PSS). The PL spectral mapping at 77K revealed several additional peak features, besides the two main peak features associated with the indium concentration in the two different multiple quantum wells of the LED structure. By performing multiple peak fitting analysis, we find that the peak wavelength and intensity distributions are closely associated with the PSS. Combined with the strain distribution from Raman spectral mapping, the variations in the PL spectra can be associated with the indium fluctuation distribution induced by strain propagation from the PSS. FLIM measurements provided further evidence for the reduced emission intensities observed in areas of high strain or low indium concentration.

Fabrication of GaN-based LED



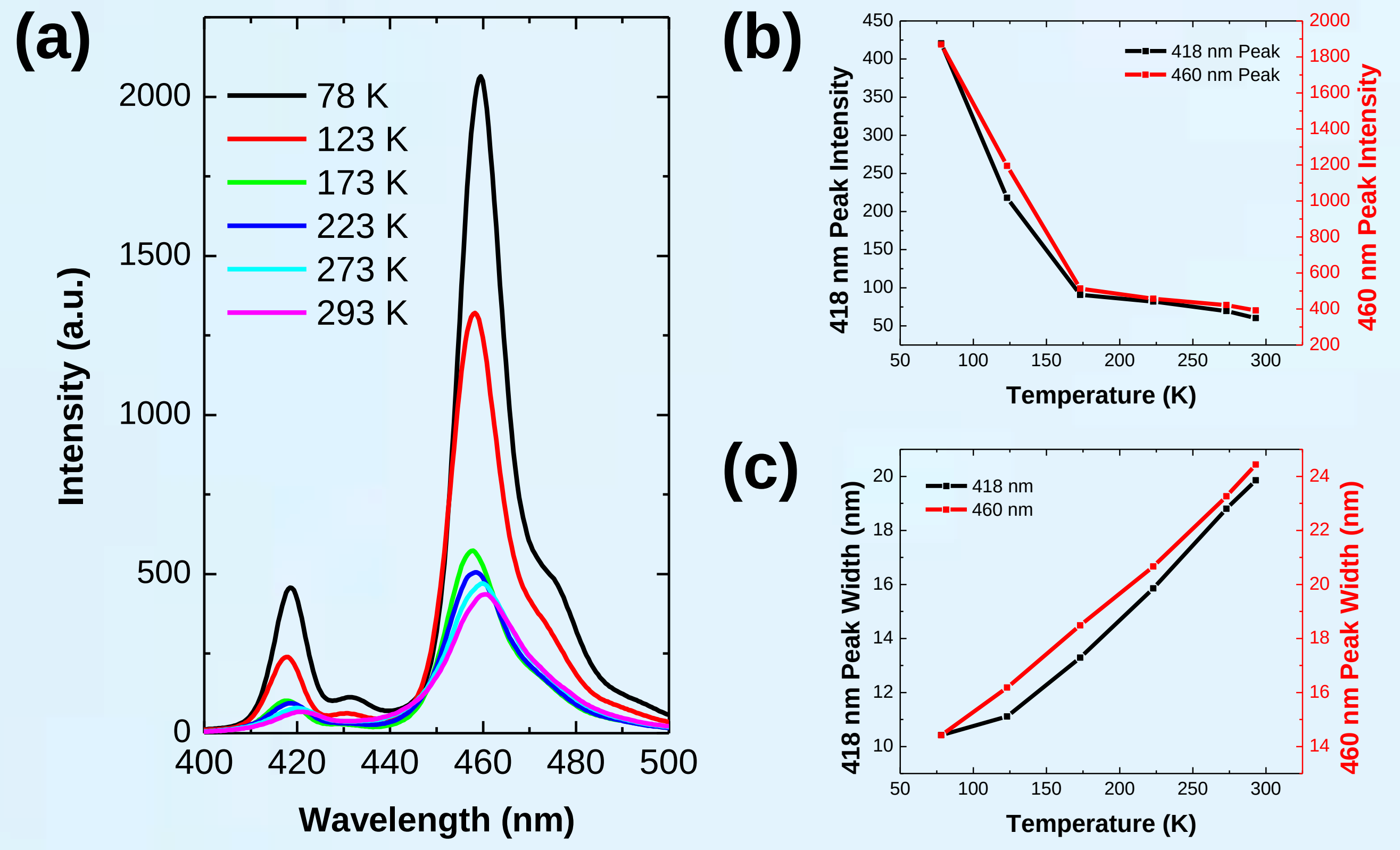
(a) Three-dimension schematic and (b) two-dimensional cross-section schematic of the epitaxial GaN layers grown on PSS, showing the thickness of each layer. The solid blue lines indicate the propagation of threading dislocations, which end up with V-shaped pits on the surface. (c) TEM cross-section image of epitaxial GaN layers around a PSS cone. The LED structure used in this work was grown on a c-plane PSS by metal organic chemical vapor deposition (MOCVD). The final layer consists of an InGaN/GaN multi-quantum wells (MQWs) active layer. There are two groups of quantum wells, each with a different indium composition.

Raman Mapping



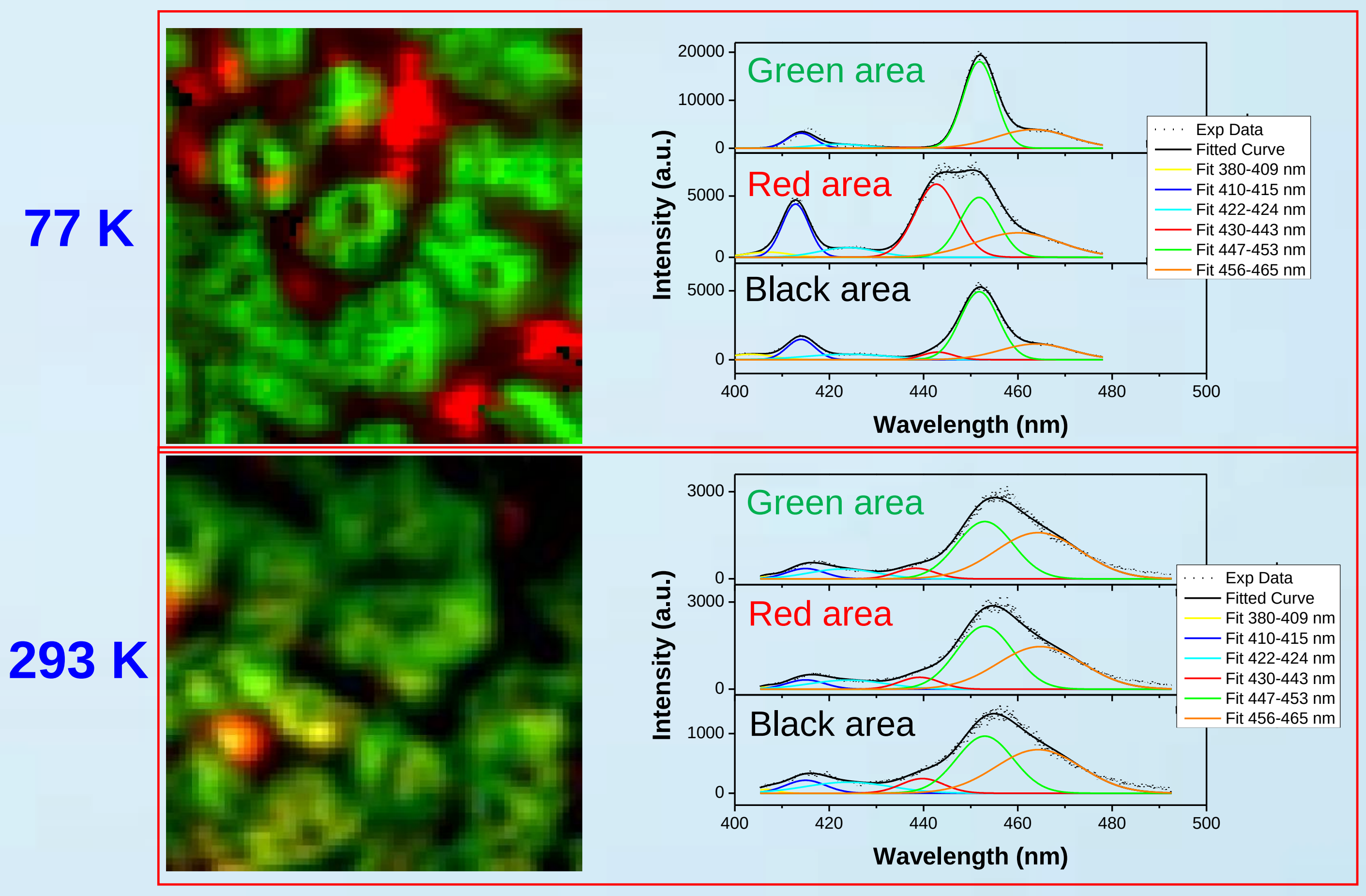
The mapping of GaN E_2(high) phonon peak intensity at (a) PSS-GaN interface and (b) InGaN/GaN MQWs layer. (c) A typical Raman spectrum collected for the mapping results of (a) and (b). Inset shows a zoom-in view of the E_2(high) peak. (d) Plot of E_2(high) phonon peak position variation along the white lines indicated in (a) and (b). Note that PSS cone areas are marked for reference. To investigate the strain distribution, we determine the GaN E_2(high) peak position to a precision of ~0.1 cm^{-1} by curve-fitting each point in the spectral mapping. E_2(high) peak position mapping shows stress variation which can be also correlated with PSS pattern.

Temperature Dependent Photoluminescence



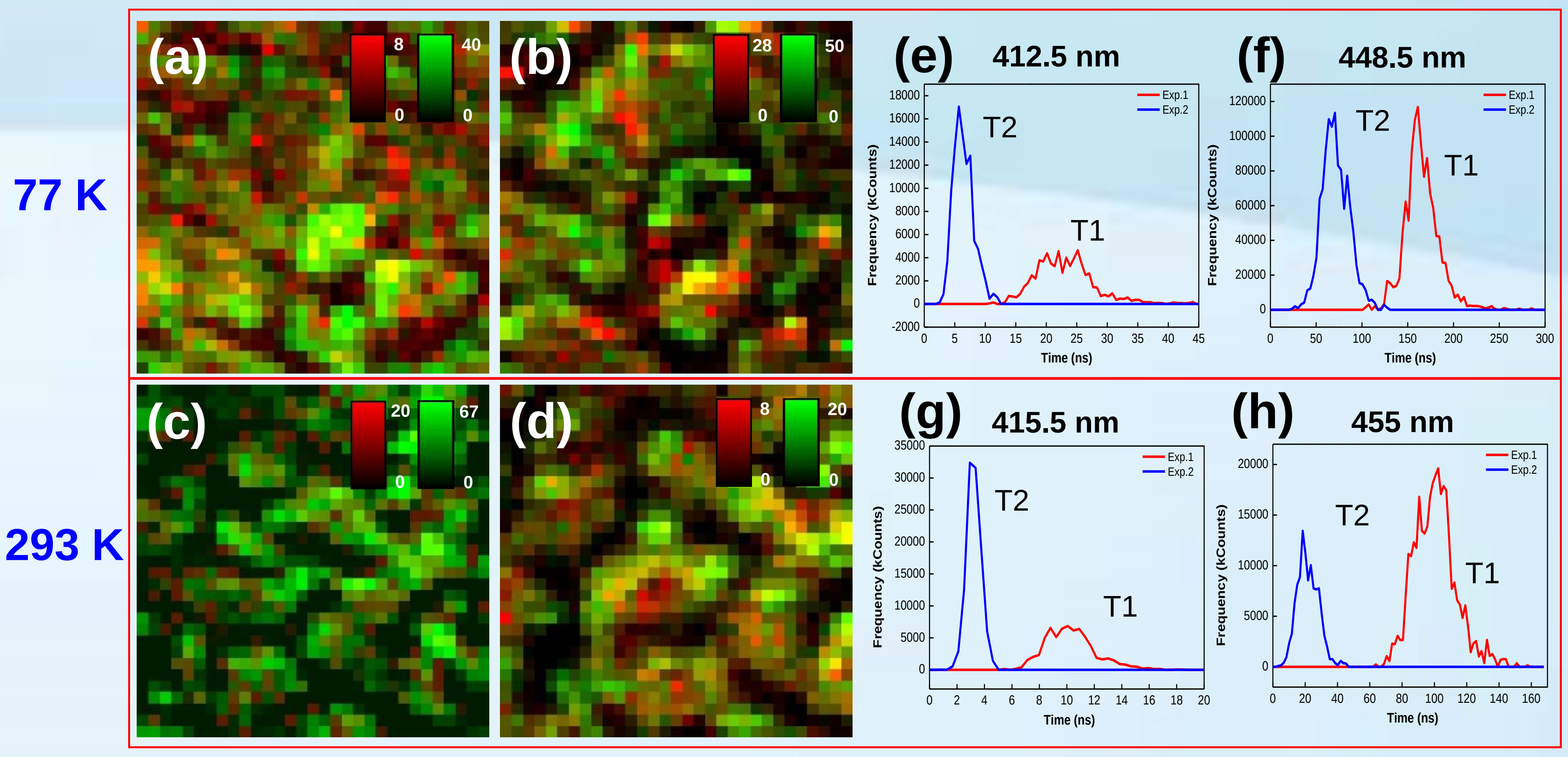
(a) The temperature dependent PL spectra of InGaN/GaN MQWs layer in LED. (b) The intensity and (c) the spectral width at 460 nm and 418 nm PL peaks vary as a function of sample temperature.

PL Spectral Mapping at 77 K and 293 K



The color mapping of the major and minor PL peaks derived from the curve fitting results of the PL spectral mapping at (a) 77 K and (b) 293 K. The green represents the intensity of the major peak with wavelength varying between 447 nm and 453 nm, and the red represents the intensity of the minor peak with wavelength varying between 430 nm and 443 nm. (c) and (d) show some selected PL spectra to represent the green, red, and black areas in (a) and (b).

Fluorescence Lifetime Imaging



The color mapping of the PL lifetimes at (a) 412.5 nm and (b) 448.5 nm PL peaks under 77 K and at (c) 415.5 nm and (d) 455 nm PL peak under 293 K. The lifetime distributions of GaN-based LED at (e) 412.5 nm and (f) 448.5 nm under 77 K, and (g) 415.5 nm and (h) 455 nm under 293 K. The red and blue curves represent the distributions of the long (T1) and short (T2) lifetimes.

Conclusion

1. The fluctuation pattern of compressive strain at the PSS interface exactly corresponds to the pattern of PSS, and the lower E_2(high) phonon frequency indicating a smaller compressive strain was measured at the cone area. Although the residual strain fluctuation in the MQWs is not as large as that in the substrate interface, the correlation between the strain fluctuation in the MQWs and PSS is still observed.
2. The residual strain in the InGaN/GaN MQWs active layer significantly influences the indium composition distribution and leads to the variations in the PL peak position and intensity.
3. For long wavelength peak, both long and short lifetime appeared at cone area; for short wavelength peak, short lifetime is everywhere but long lifetime appeared at cone area.

Acknowledgement

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