Mapping the three-dimensional electroluminescence and photoluminescence of GaN-based light emitting diode with laser scanning confocal spectromicroscopy

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Abstract

Recently patterned sapphire substrate (PSS) has become widely used for growing GaN-based light emitting diode (LED) nanostructures, such as InGaN/GaN superlattices (SLs) and multi-quantum wells (MQWs). The LED active layer greatly increases the emission efficiency while allowing the tunability of emission wavelength. However, it was suspected that epi-growth related defects (v-pits) in the MQWs could be associated with the droop of the LED emission efficiency. In our previous study, we used confocal Raman and PL spectromicroscopy to show that the distribution of the v-pits of a LED nanostructure can be correlated with the PSS. Furthermore, PL spectral mapping of this LED structure reveals the intensity and spectral shift in the MQW active layer are related to the stress distribution of GaN, which can be traced to the PSS. To furthermore explore this effect under normal operating conditions, we performed PL and electroluminescence (EL) mapping on a real GaN-based LED device with our home-built laser scanning confocal spectromicroscope. We find that EL confocal mappings of the LED active layer show v-pit features plus bright and dark areas similar to previous PL mapping, though with a much weaker contrast. However no significant EL spectral shifts were observed between the dark and bright areas in the active layer. Unlike PL mapping, EL mapping shows less spatial contrast and slight depth intensity variation, but allows clear delineation of the PSS structure. The discrepancy between PL and EL mapping can be understood in terms of their different illumination methods. While PL mapping exhibits the PL emission from the laser focal point, EL mapping reveals the total EL emission collected at the focal point of objective.

Sample Description

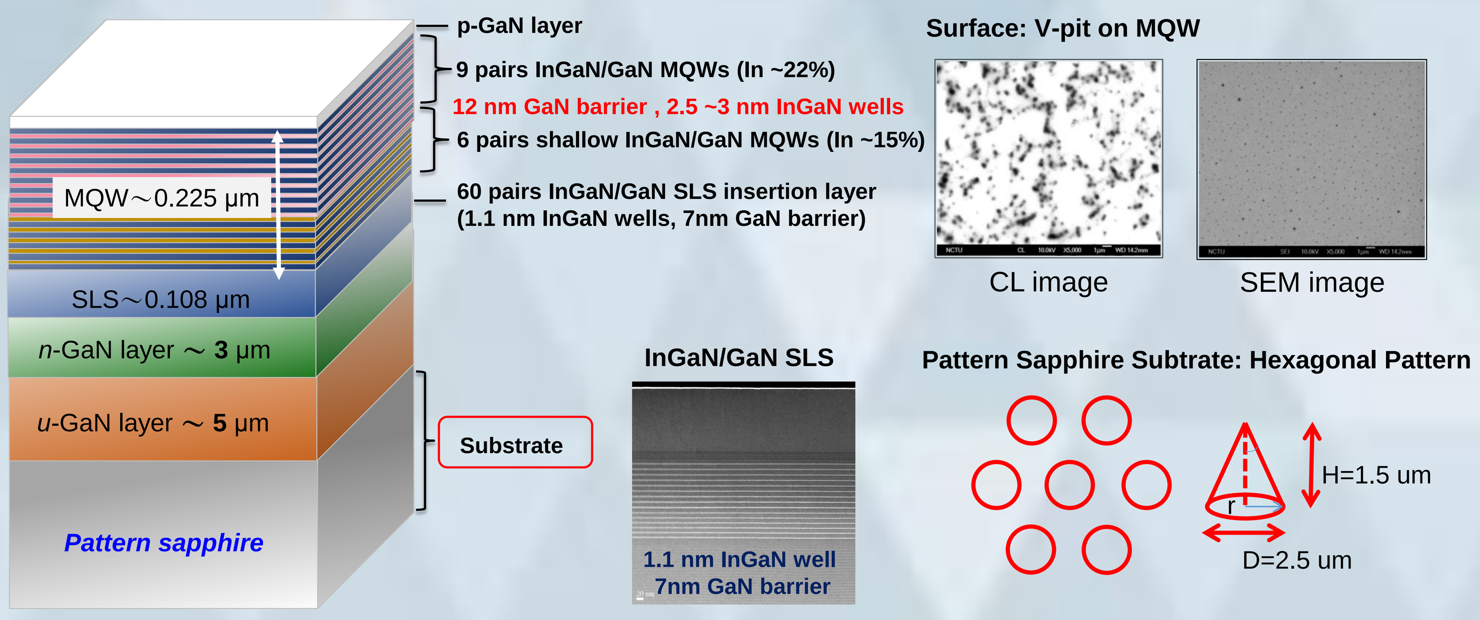

Fig. 1. The GaN LED sample was grown using metal organic chemical vapor deposition system (MOCVD) on a pattern sapphire substrate. The layer structure is shown above. The active region consists of 30 pairs of InGaN/GaN MQWs.

Experimental Setup

All the experiments were performed on a home-built confocal spectromicroscope using a 100x NA 0.9 objective, providing ~0.3 μm spatial resolution and ~1 μm axial resolution. PL and EL mapping were obtained using 375 nm laser excitation. PL and EL spectra were acquired with a home-built spectrometer.

Electrical Characteristics

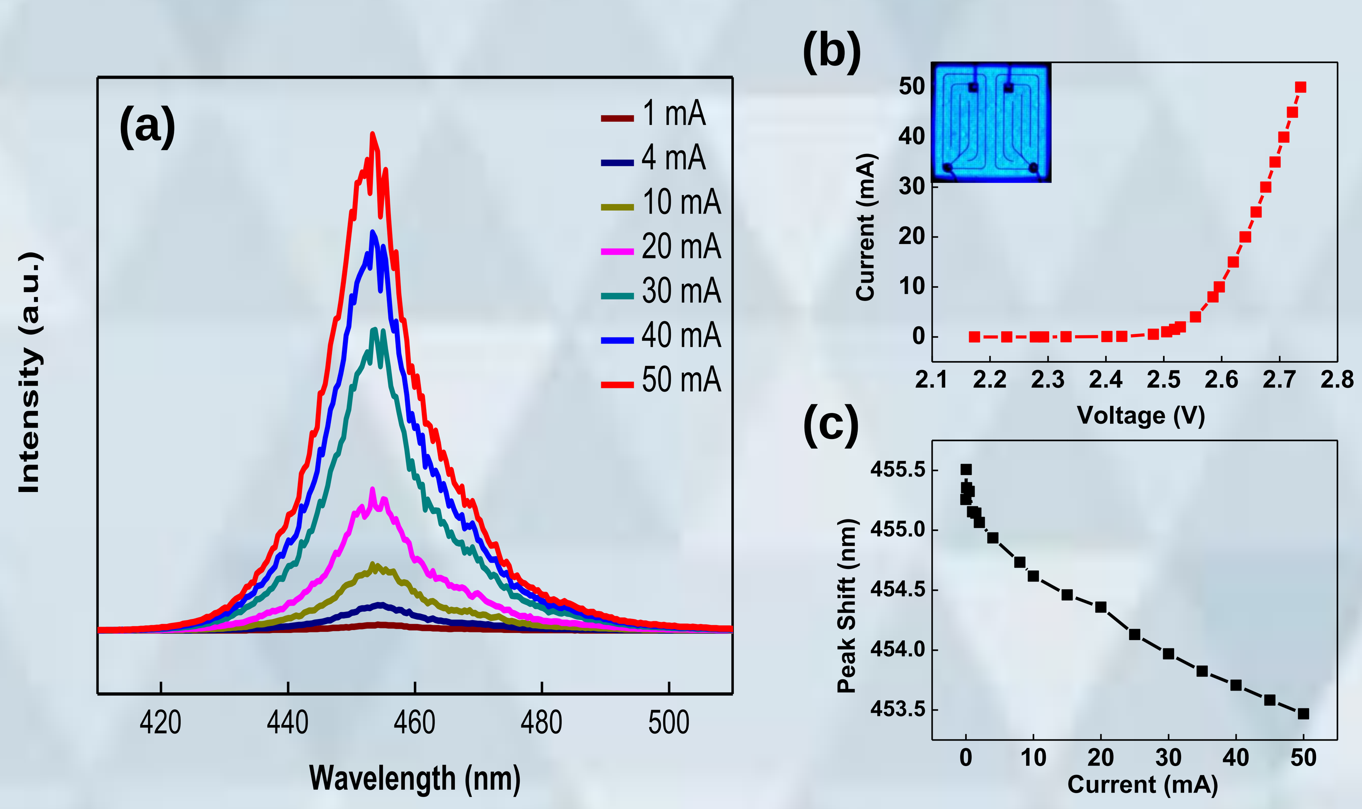

Fig. 2. (a) Electroluminescence spectra of GaN-based LED with varying DC current at RT. (b) The current-voltage characteristics of the fabricated GaN-based LED chip. The inset shows optical images of LED during light emission at an injection current of 0.5 mA. (c) Wavelength shift of the GaN-based LED chip in the 0.01–50 mA range.

Spectral Mapping

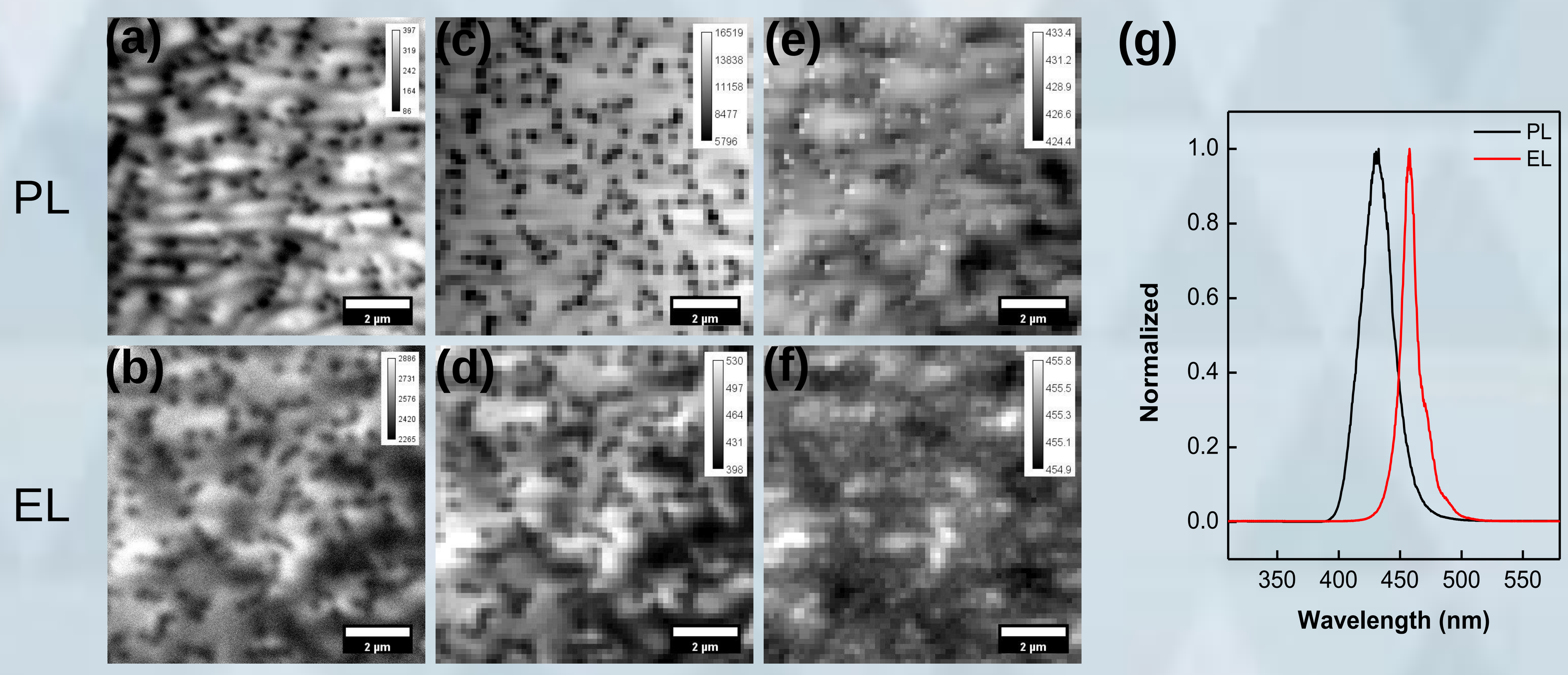

Fig. 3. (a), (b): The PMT images of PL and EL. (c), (d): The mapping of peak intensity of PL and EL. (e), (f): The mapping of peak position of PL and EL, where the peak position is determined by Gaussian peak fitting. (g) shows a representative PL/EL spectrum inside the sample.

Axial PL / EL Images

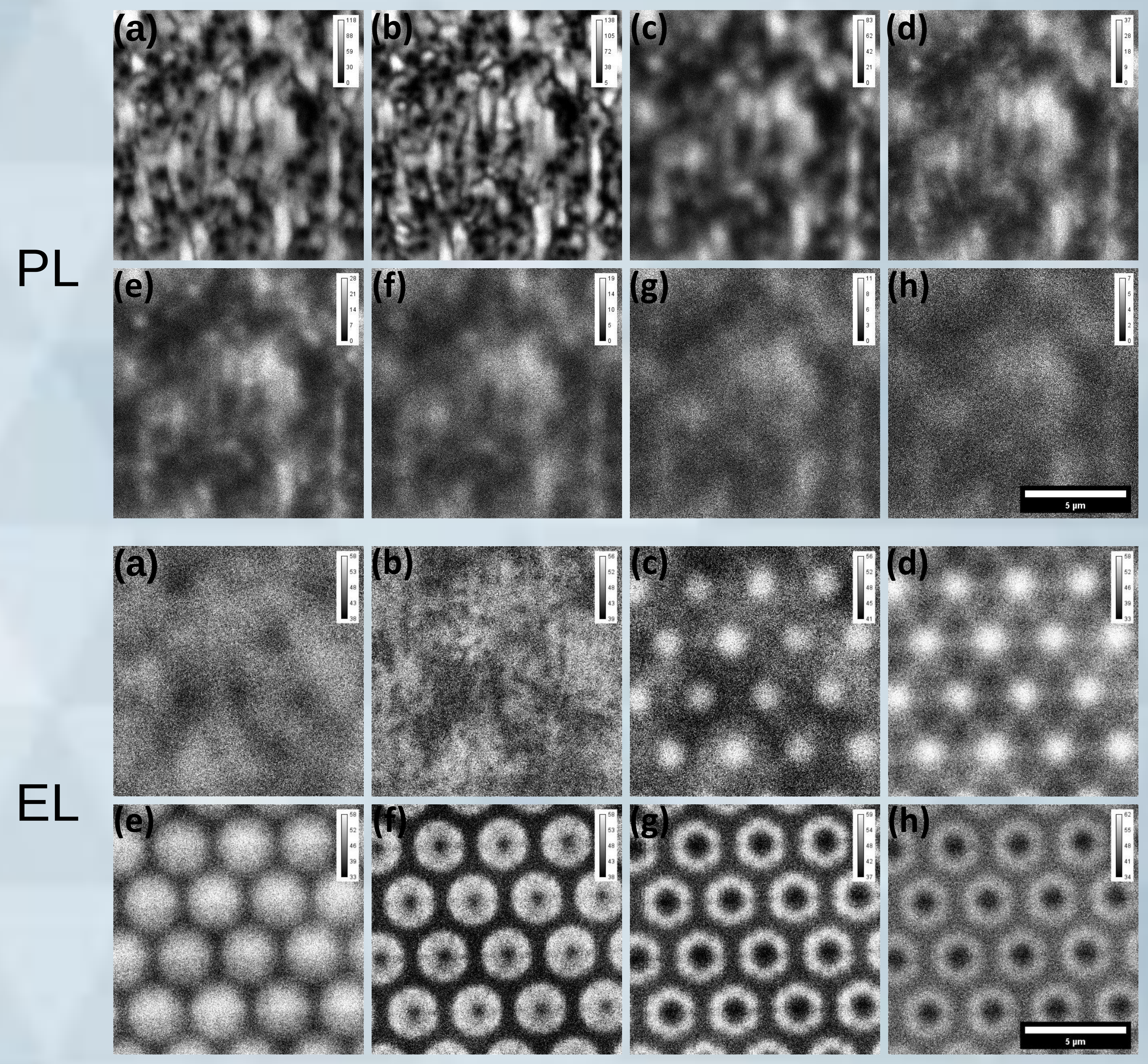

Fig. 4. (a) -1.175 μm, (b) 0 μm, (c) 1.175 μm, (d) 2.35 μm, (e) 3.525 μm, (f) 4.7 μm, (g) 5.875 μm, (h) 7.05 μm. These figures show photoluminescence/electroluminescence at various sample depths, where 0 μm corresponds to the sample surface and increases towards the substrate.

3D Construction of PL/EL Images

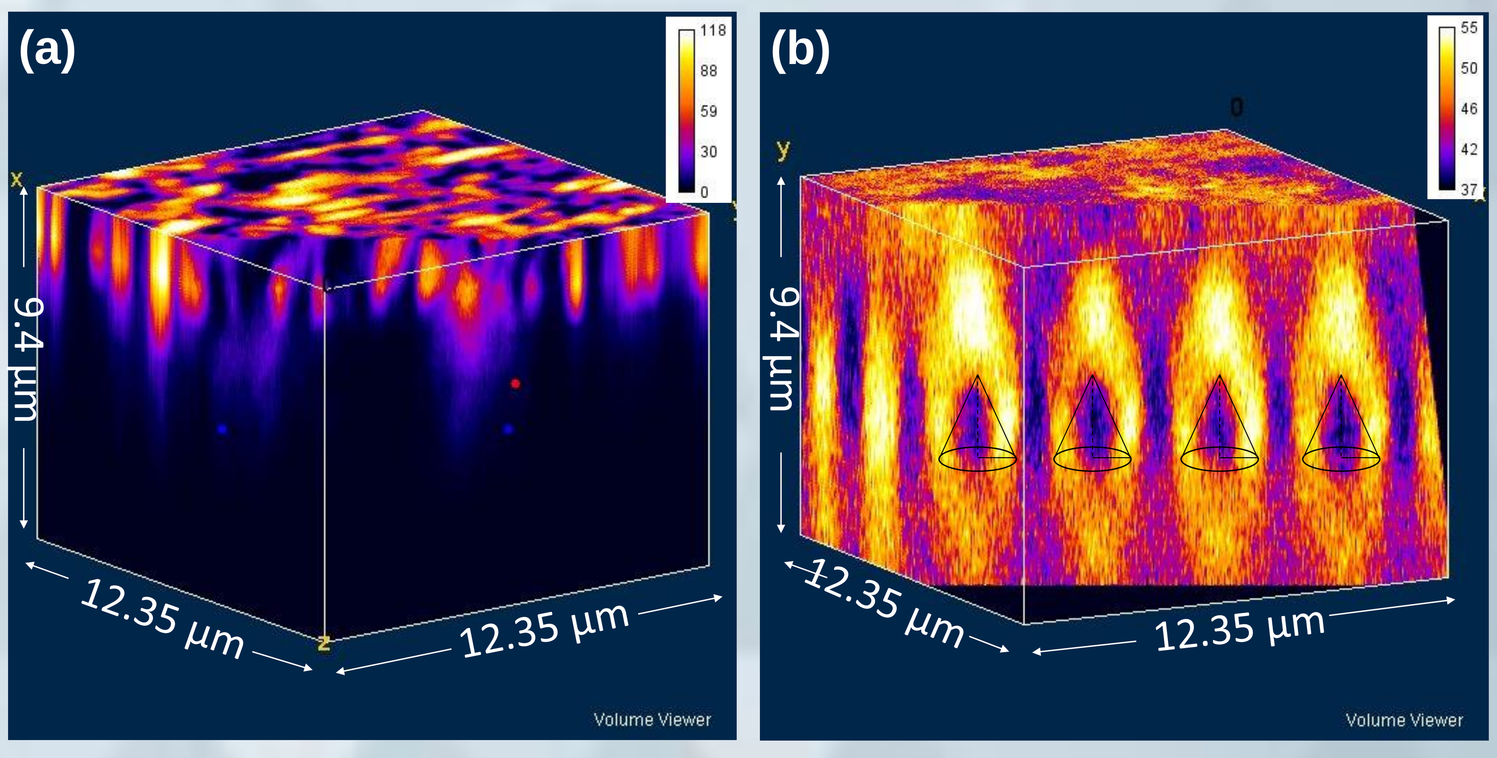

Fig. 5. The 3D reconstruction of (a)PL(b)EL Images.

Conclusion

The discrepancy between PL and EL mapping can be understood in terms of their different illumination methods. While PL mapping exhibits the PL emission from the laser focal point, EL mapping reveals the total EL emission collected at the focal point of objective. As a result, the EL spectra correspond to three feature areas (i.e. bright, dark and v-pit areas) show the same feature, but the PL peak position varies for these three feature areas.

References

[1] Chiao-Yun Chang et al., Proc. of SPIE Vol. 9363 93631Q-3

[2] W.-L. Chen et al., Rev Sci Instrum **84**, 113108 (2013)

Acknowledgement

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