Mapping the three-dimensional stress distribution of GaN-based light emitting diode with confocal Raman and photoluminescence spectromicroscope

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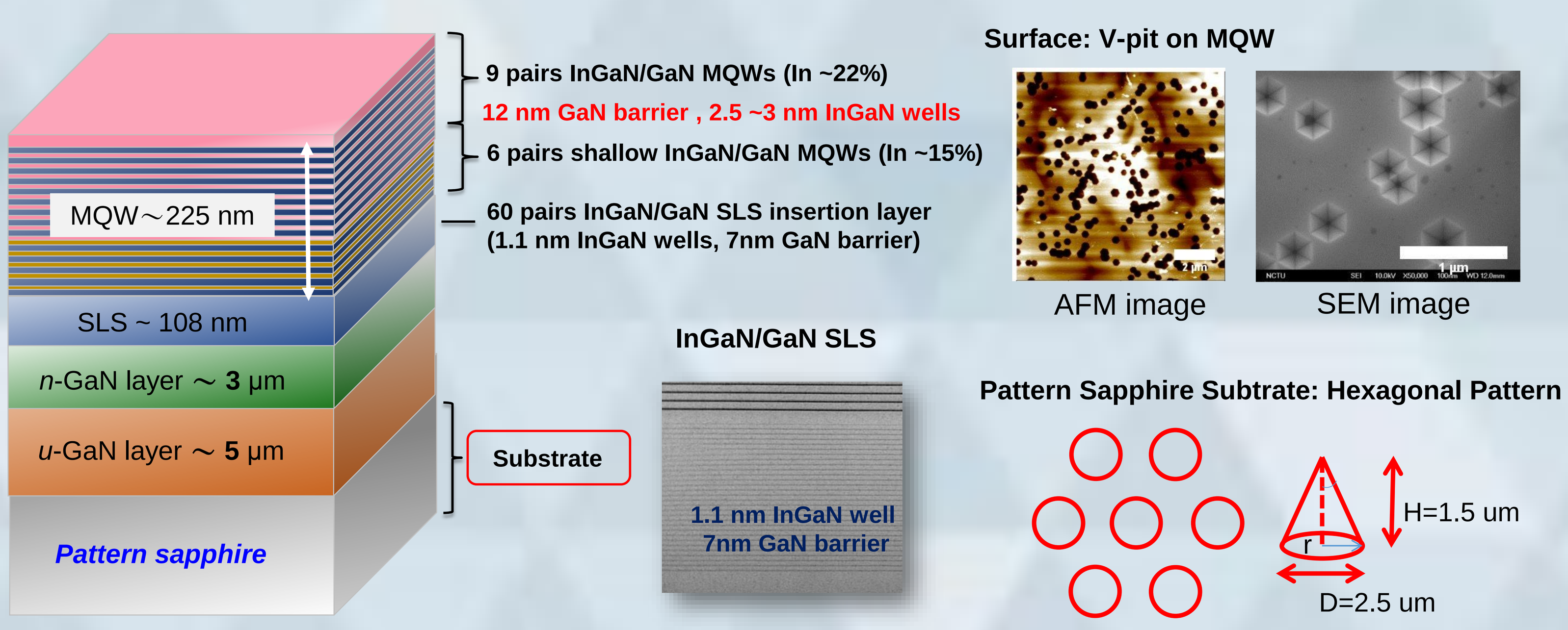
Abstract

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. To investigate this issue, we performed Raman and PL mapping on a typical GaN-based LED nanostructure grown on PSS with our home-built laser scanning confocal spectromicroscope. It was found that both the spatial inhomogeneity in the PL and Raman mapping of the MQWs layer can be directly correlated with the hexagonal structure of PSS and the position of v-pits. The variation in the PL peak and Raman line shift clearly reveals the stress distribution in the MQWs layer. Our results clarify the propagation and relaxation of stress originated from the PSS toward the LED surface.

Sample Description

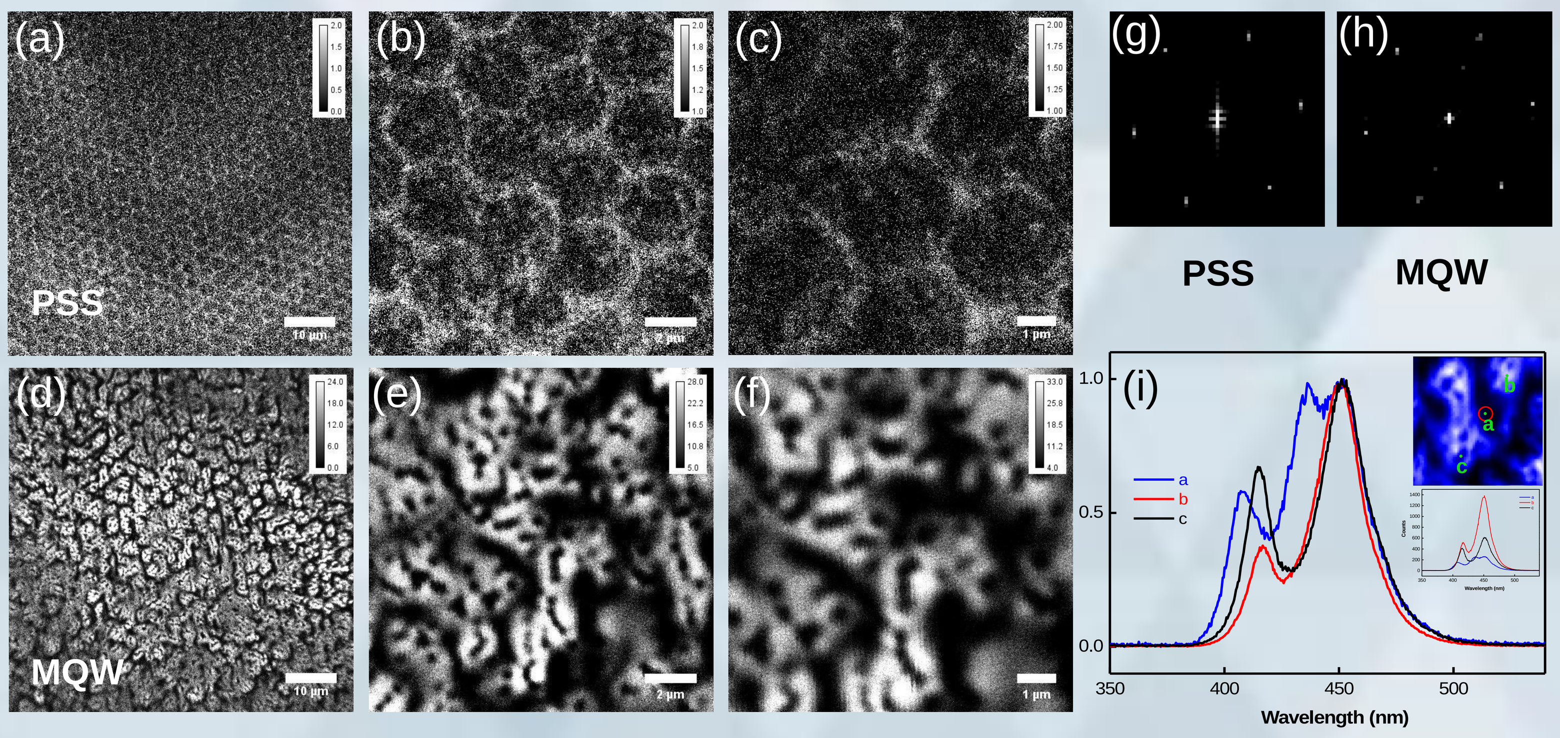


The GaN LED sample was grown using metal organic chemical vapor deposition system (MOCVD) on a pattern sapphire substrate. The layer structure is shown above. The active region consists of 15 pairs of InGaN/GaN MQWs. No p-GaN capping layer was grown in order to explore the effects of the v-pits.

Experimental Setup

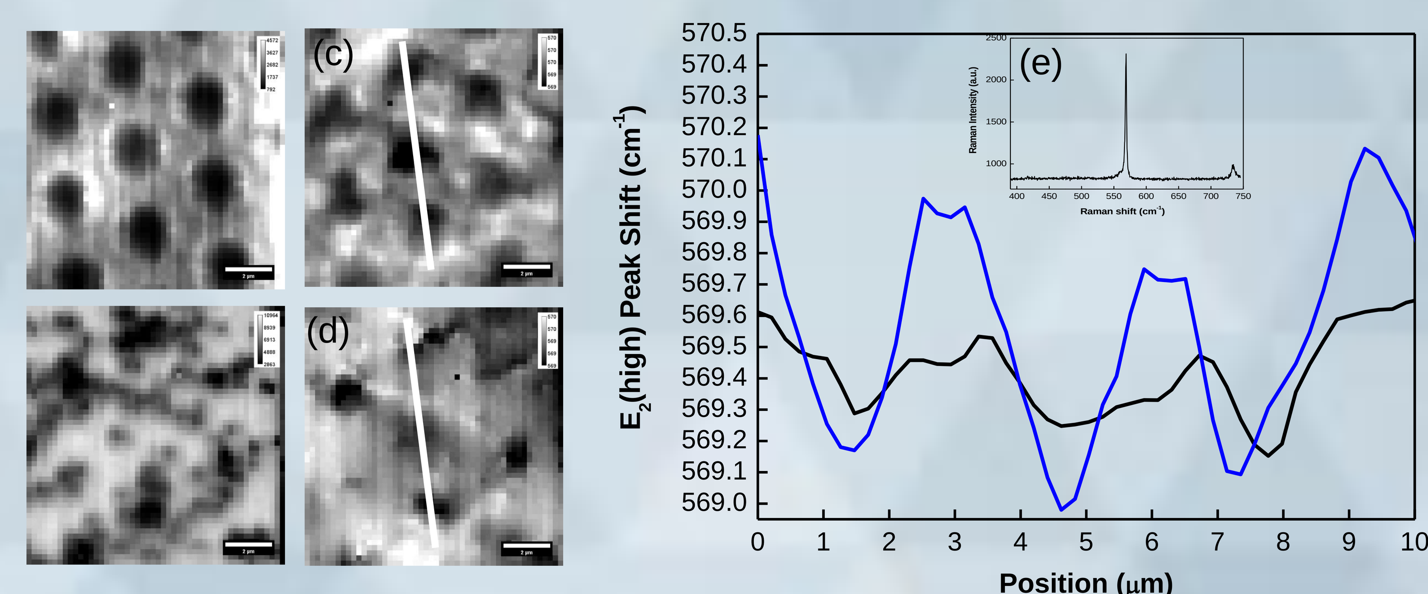
All the experiments were performed on a home-built confocal spectromicroscope using a 100x NA 0.9 objective, providing ~0.3 μm spatial resolution and ~1 μm axial resolution. PL and Raman mapping were obtained using 375 nm and 532 nm laser excitation respectively. Raman spectra were acquired with JY-FHR640 spectrometer with liquid nitrogen cooled CCD, and PL spectra were acquired with a home-built spectrometer. For E_2(high) Raman mapping, the signal was detected with a PMT in combination with a monochrometer.

PL and Reflectivity Mapping



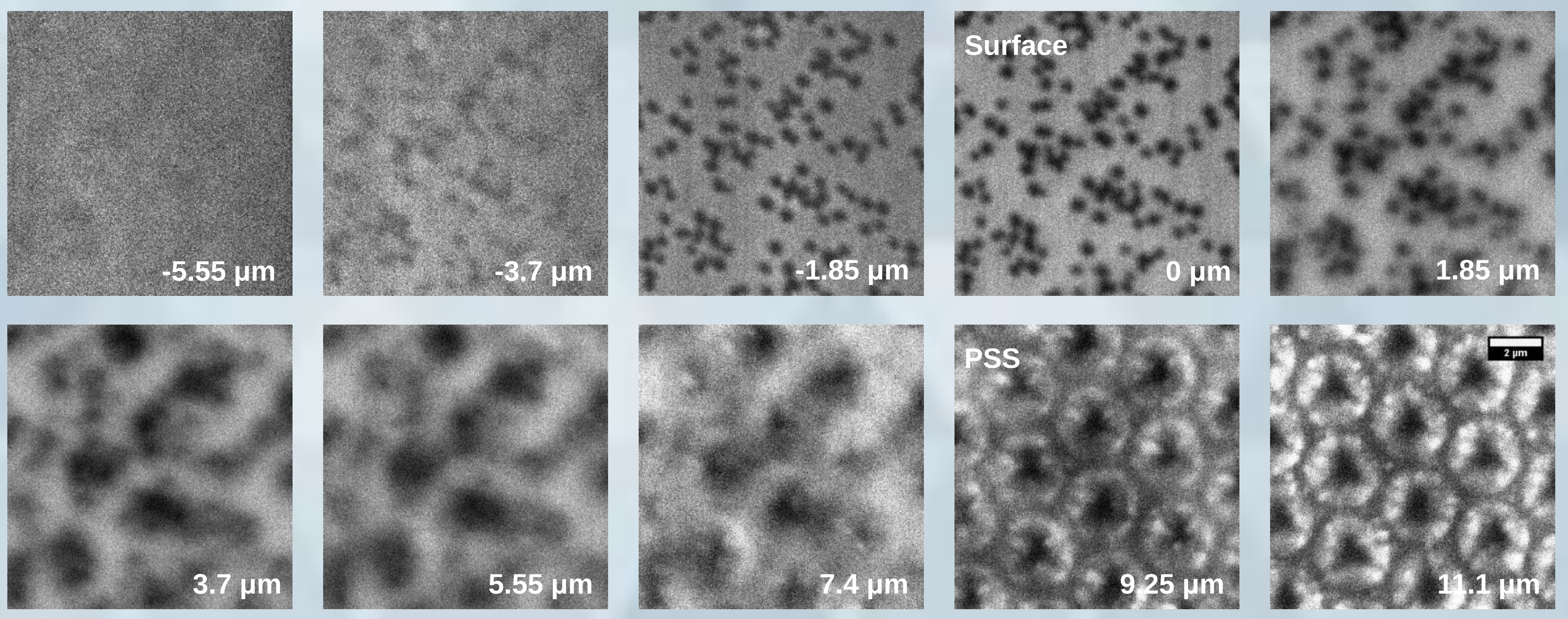
(a)-(c): Reflectivity mapping of PSS, and (d)-(f): PL mapping of MQW in different scales. (g),(h): Fast Fourier transform (FFT) of images (a) and (d) reveal that PL patterns in MQW is directly correlated with the structural pattern in PSS. The PL mapping of MQW layer can be divided into three areas: v-pit, bright area, and dark area. Normalized spectra correspond to these three areas as shown in (i).

Raman Mapping



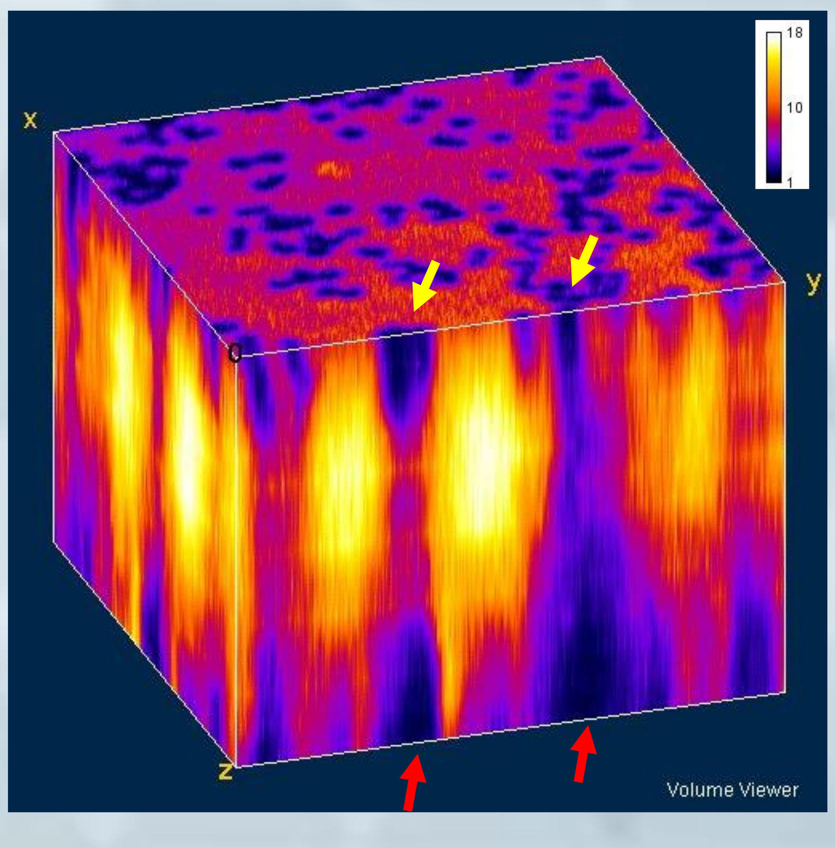
(a), (b): The mapping of E2(high) phonon peak intensity of MQW and PSS. (c), (d): The mapping of E_2(high) phonon peak position of MQW and PSS, where the peak position is determined by Gaussian peak fitting. (e) shows a representative Raman spectrum inside the sample. (f) Plot of peak position variation along the white lines shown in (c) and (d).

Axial Mapping of E_2(high) Mode



These figures show E_2(high) intensity mapping at various sample depths, where 0 μm corresponds to the sample surface and increases towards the substrate. The measured E_2(high) bandwidth was set to 20 cm^{-1}.

3D Construction of Raman Mapping



The 3D reconstruction of axial E_2(high) Raman mapping. The two lower dark areas (red arrows) correspond to the tip of two protruded patterns in PSS. From this three-dimensional image plot, the origin of the two v-pits (yellow arrows) in MQW can be traced to the two tips in PSS.

Conclusion

1. PL mapping of MQW layer shows that the MQW can be divided into v-pits, bright, and dark areas. The dark and bright areas form pattern that can be directly correlated to PSS structure.
2. E_2(high) peak position mapping shows stress variation which can be also correlated with PSS pattern.
3. 3D construction of the axial E_2(high) mapping reveals that the v-pits in MQW can be traced to the protruded tips of PSS.

References

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Acknowledgement

This work was supported by the National Science Council under the grant No. NSC102-2119-M-002-015-MY3.