Origin of inhomogeneous emission spatial distribution in high-indium-content InGaN LED structures

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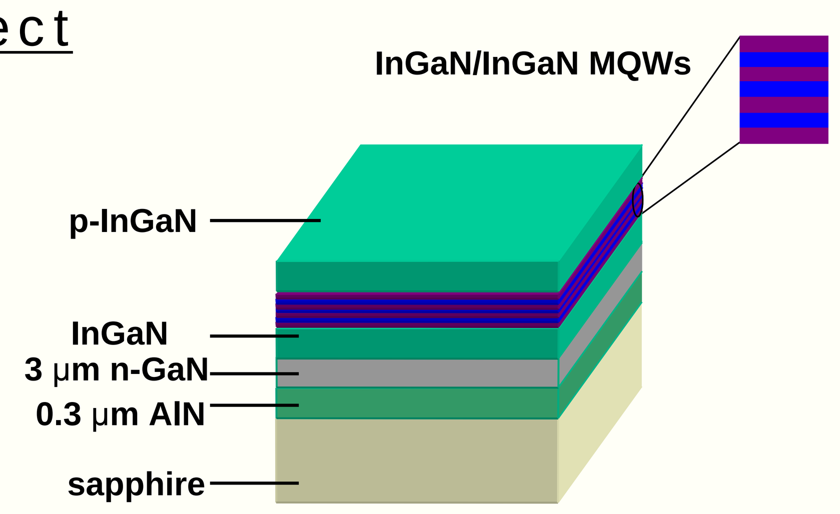
Introduction

InGaN-based violet-to-green LEDs have already been commercialized. However, the emission efficiency in InGaN with In content above approximately 20% sharply decreases. Thus, the further study of In-rich InGaN has both a scientific challenge and a practical importance.

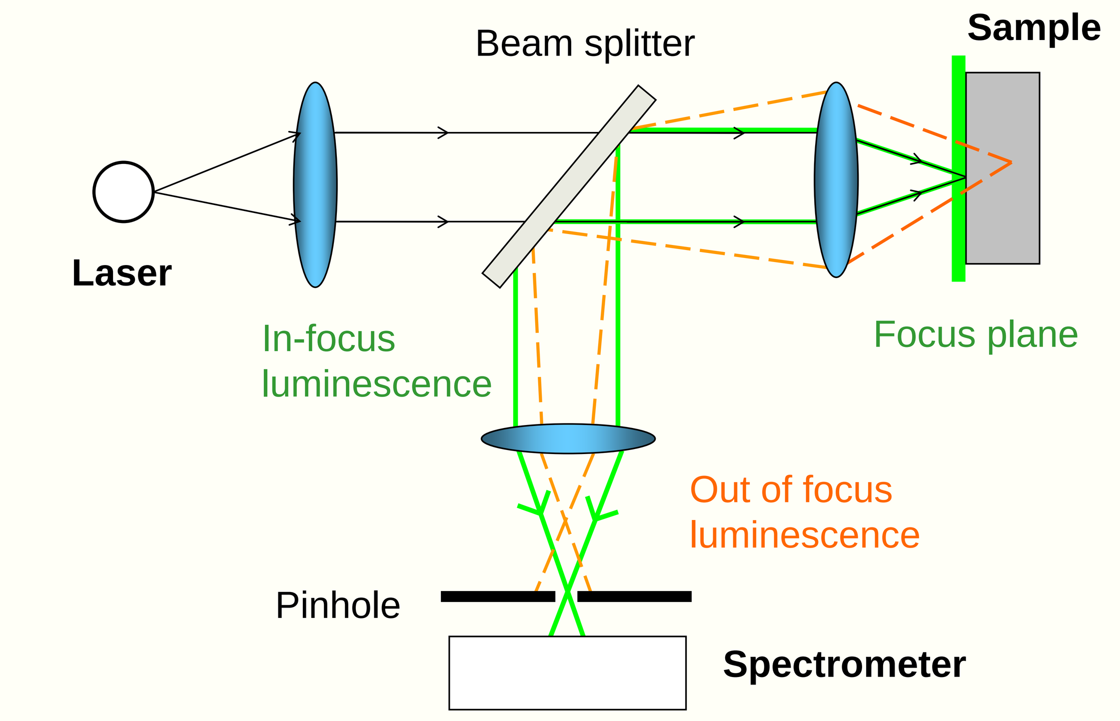
In this work, we present results of spatially-resolved PL study using confocal spectroscopy.

Object

Structure of a green LED with InGaN/InGaN multiple quantum wells (MQWs) were under study. The structure was grown by metal organic chemical vapor deposition (MOCVD) on c-plane sapphire.

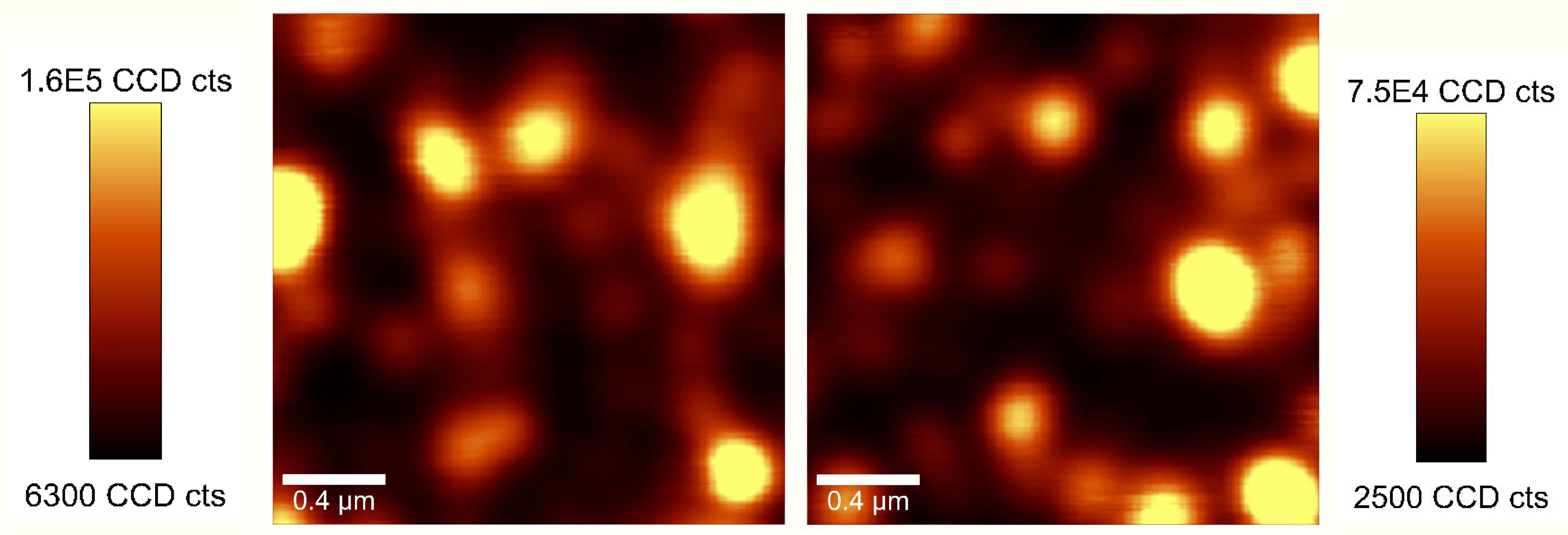


Confocal Spectroscopy

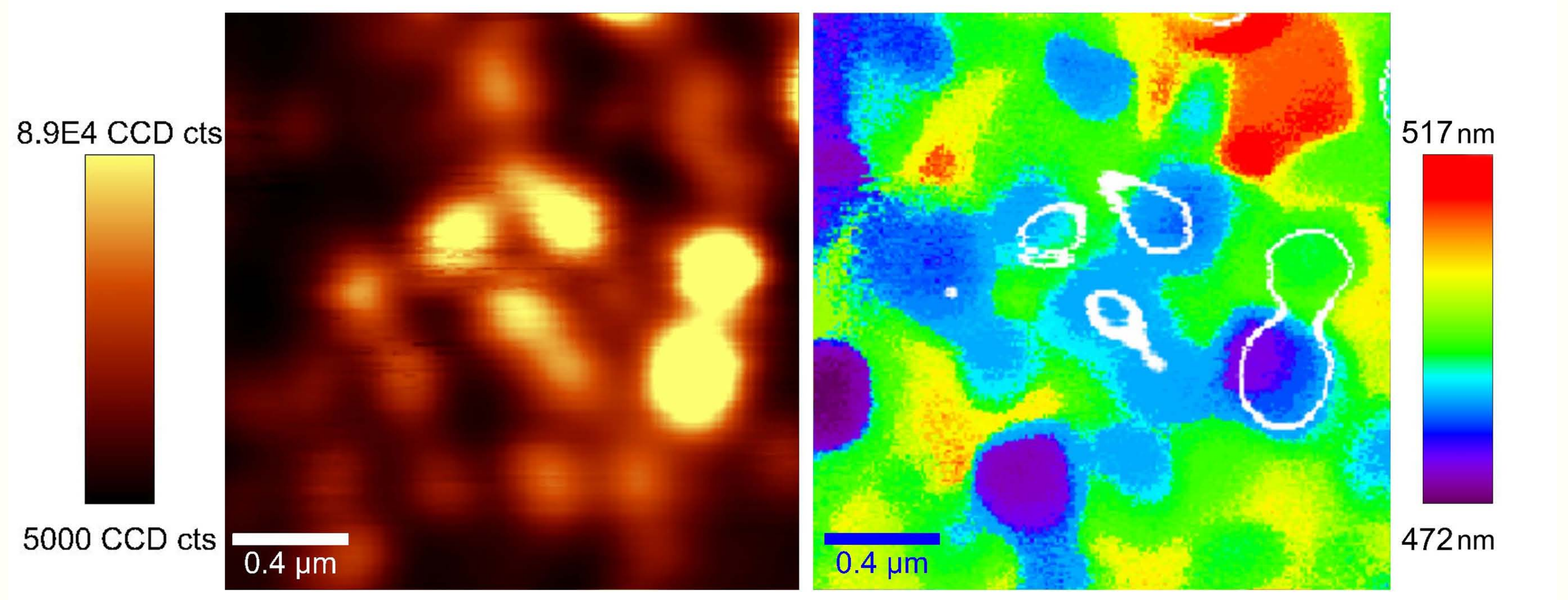


Confocal microscope system *Alpha 300* manufactured by *WITec* was used. He-Cd laser emission at 441.6 nm is focused onto the sample through high numerical aperture objective. After passing the confocal microscope, the PL signal was dispersed using a spectrometer and detected using a CCD. The spatial resolution of this system is approximately 200 nm.

Photoluminescence Intensity Mapping



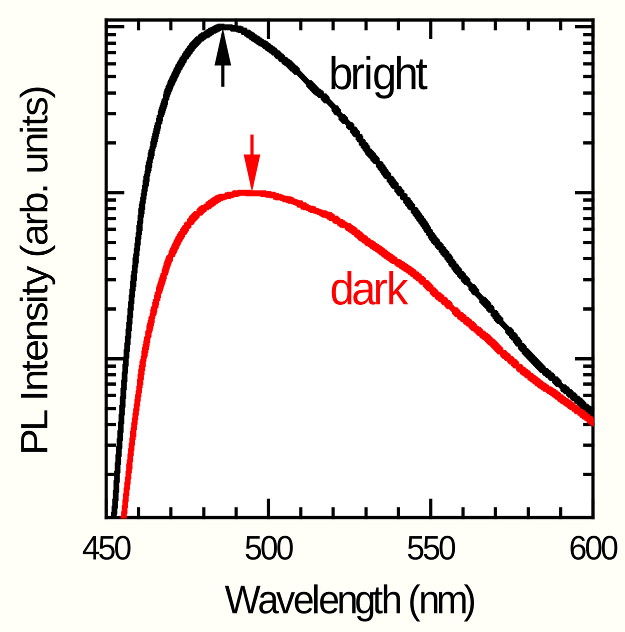
Typical spectrally-integrated PL intensity mapping immages of InGaN LED structure. The areas of bright PL have a typical size of 200 nm. They are surrounded by areas where the PL intensity is lower by a factor of ~10.



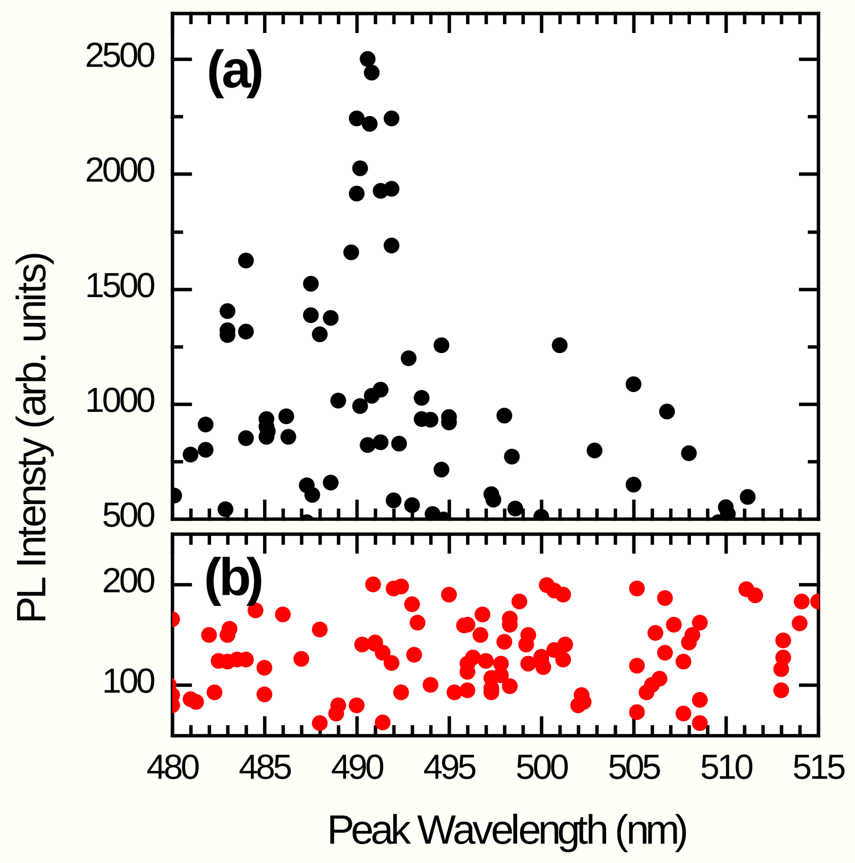
PL intensity mapping PL peak wavelength mapping

No direct correlation between intensity and PL spectrum in the bright and dark regions, respectively, but a clear shift in PL spectrum between these regions.

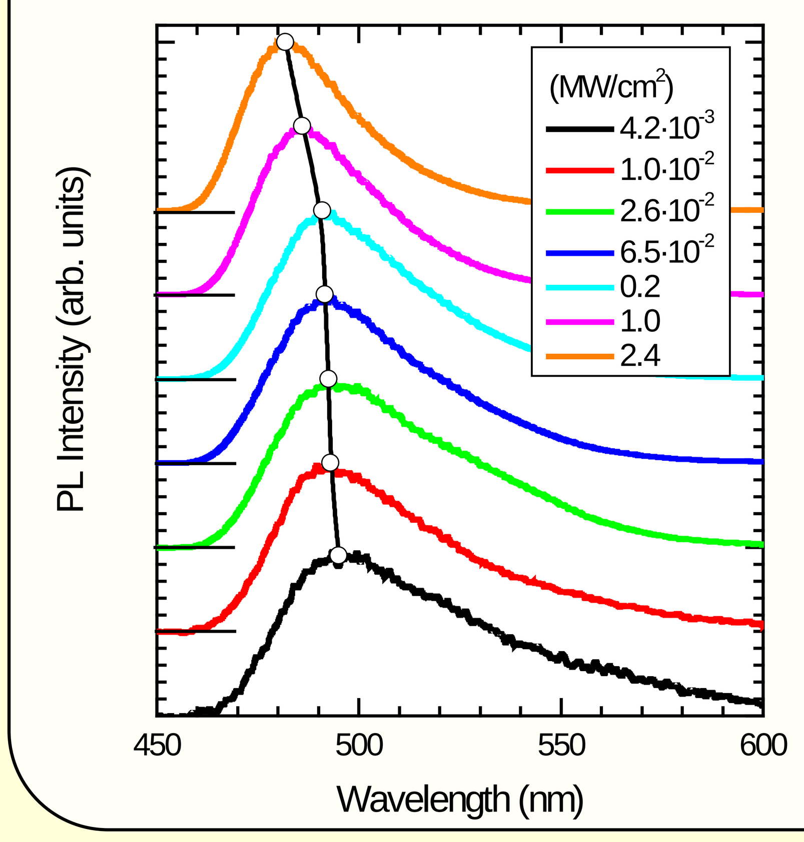
Photoluminescence Spectra



Spatially-averaged PL spectra from bright and dark areas.



PL intensity versus peak wavelength dependence at 100 randomly selected spots in bright (a) and dark (b).



PL spectra at different excitation power density (indicated).

Discussion

The inhomogeneous PL intensity distribution in the structure under study can be conclusively explained by inhomogeneous in-plane distribution of nonradiative recombination centers. The tail density of states is responsible for the low energy side of the PL band. An increase in the density of tail states with a low localization energy leads to an increase in the probability of site-to-site hopping and results in a higher probability for the hopping excitons to reach nonradiative recombination centers and recombine nonradiatively. This affects the emission intensity decrease on the high-energy side of the PL band. Since the PL intensity at the far-low energy side is the same in the dark and bright areas, we conclude that the tail states density is also the same.

The decrease of the PL intensity in the dark areas in the vicinity of 500 nm can be explained by a higher density of nonradiative recombination centers. The total PL intensity in the dark areas decreases and the band peak corresponds to lower localized states (longer wavelengths) than in the bright areas.

Conclusions

- PL intensity is distributed inhomogeneous, as observed before. The areas of bright PL have a typical size of 200 nm.
- PL intensity has no correlation with the band peak position.
- No saturation of the PL band shift with increasing excitation power density is observed.
- The inhomogeneous PL intensity distribution is caused by inhomogeneous distribution of nonradiative recombination centers.