Depth-Resolved Confocal Micro-Raman Spectroscopy of III-nitride Light Emitting Diode Structure

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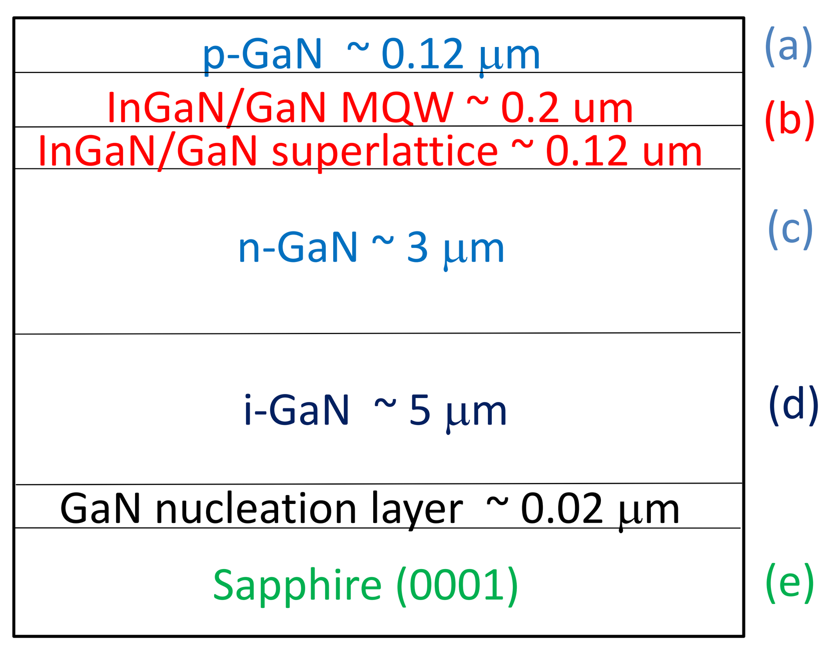
Abstract

III-nitride material with an active InGaN/GaN multi-quantum well (MQW) layer has become widely used for light emitting diodes (LED).[1] The active layer greatly increases the emission efficiency while allowing tunability of the emitting wavelength. One important aspect for improving the quality of these LEDs is in reducing the strain on the MQW to eliminate the electric polarization fields. Another challenge is to understand the mechanism in the active layer that cause the reduction of the LED efficiency when operating under high current densities (droop).[2] Special test structures and quasi-bulk InGaN layer has been grown in order to experimentally perform measurements associated with the active layer inside LED.[3,4] By combing micro-Raman spectroscopy with confocal microscopy, we demonstrate the ability to characterize the active layer *in situ*, thus allowing the study of this important layer in a standard LED device.

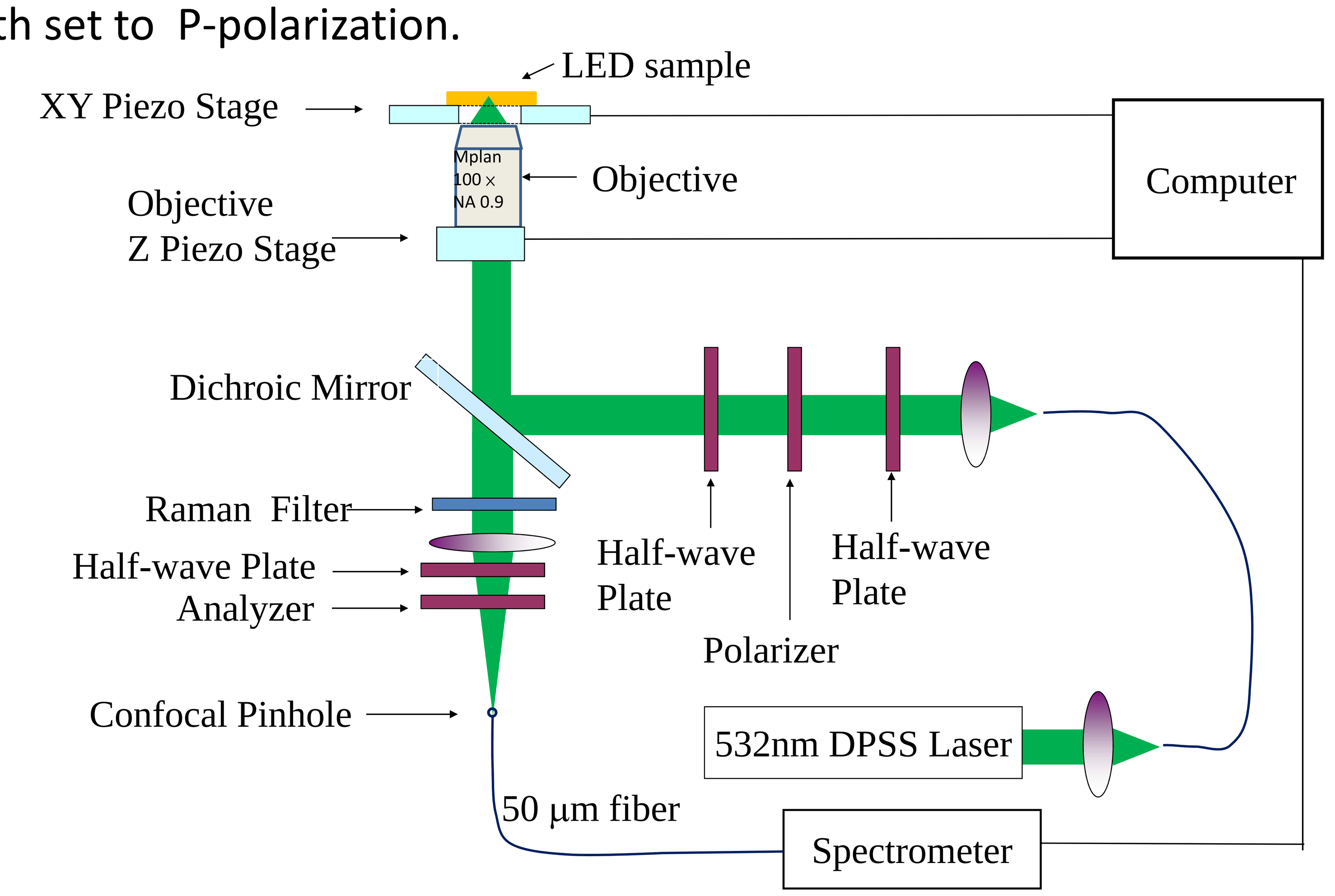
Sample Description

The GaN LED sample was grown using metal organic chemical vapor deposition system (MOCVD) on a c-plane sapphire substrate. A diagram of the structure is shown on the right. The active region consists of 20 pairs of InGaN/GaN MQWs.



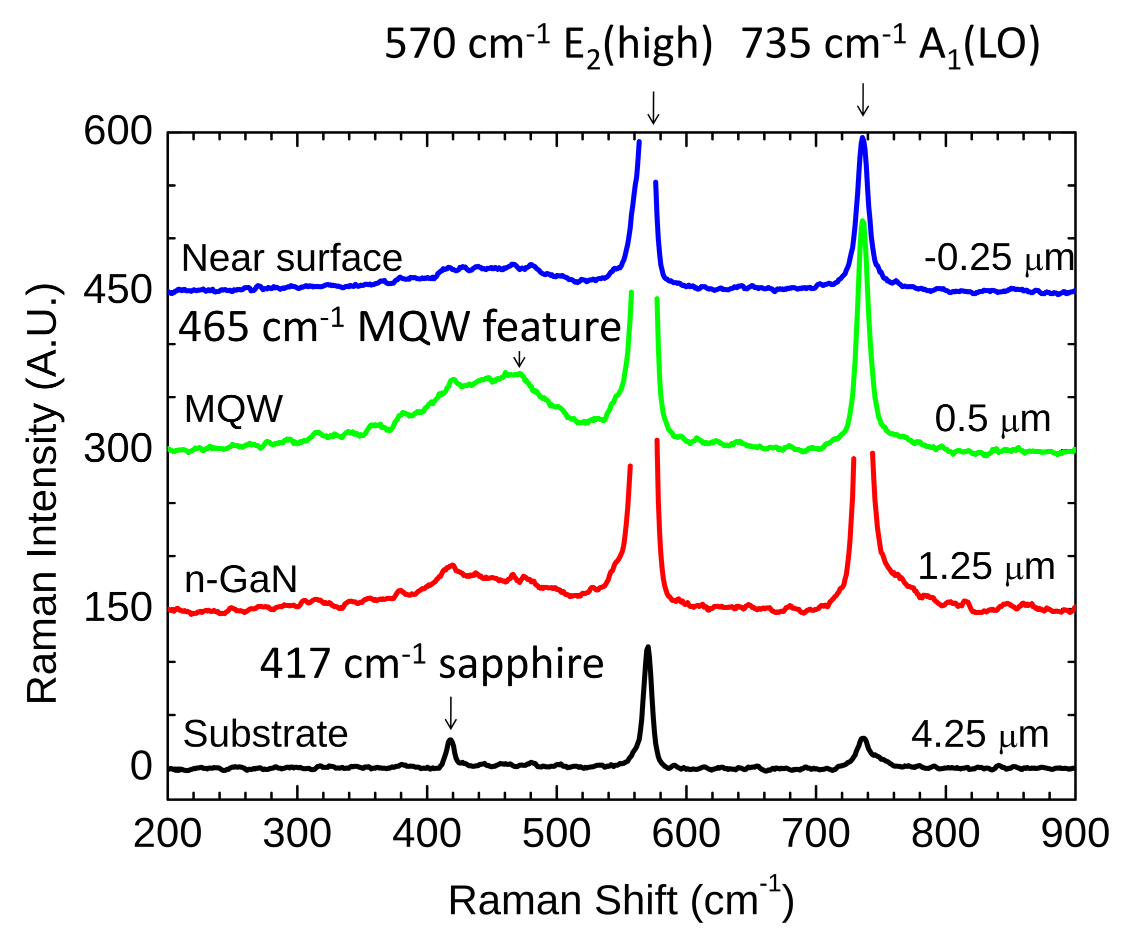
Experimental Setup

The confocal Raman spectrometer has a spectral and axial resolutions of ~1cm^{-1} and ~1μm, respectively. Both laser excitation and Raman signal detection were both set to P-polarization.



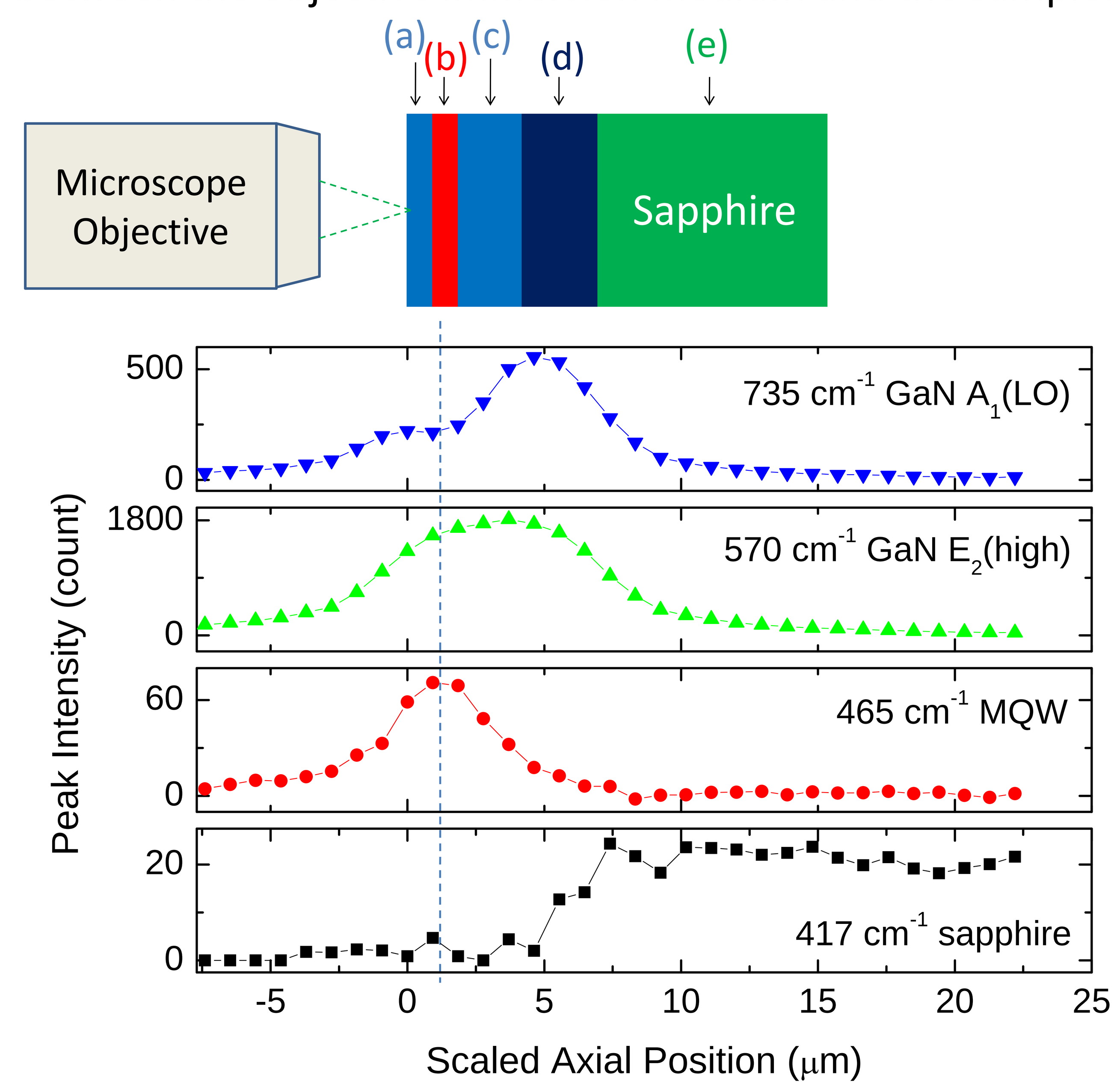
Depth Resolved Raman Spectra

The right-hand figure shows the Raman spectra of the GaN LED sample at various depths, where the origin is set at sample surface and increases away from the sample. A constant value of 150 is added to each sequential spectrum to facilitate their display.



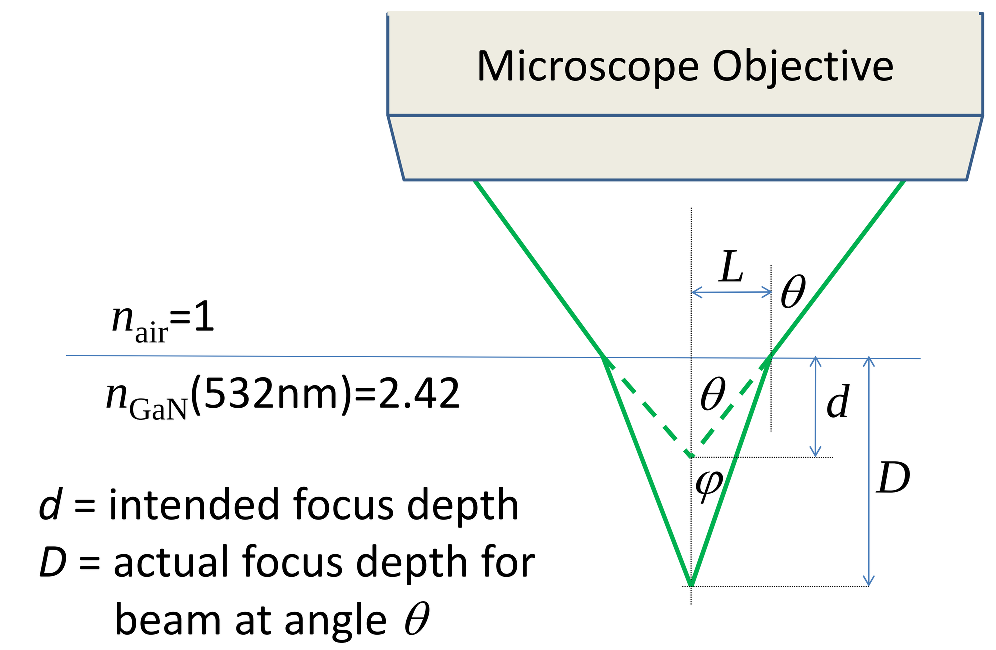
Axial Profile of Raman Peaks

Figure below shows the peak intensity axial profile for the Raman features from GaN, InGaN/GaN MQWs, and the sapphire substrate. A diagram of the LED sample showing the relative position of the layer structure is shown above the plot for reference. The axial position has been scaled to account for the focal shift due to refraction index mismatch between the objective immersion medium and the sample.



Focal Shift Due to Refraction Index Mismatch

As shown in the diagram below, the path of light ray entering the sample at angle θ intended for depth d is refracted at the sample surface and become focused at a greater depth D. The amount of focal shift D-d depends not only on the intended focus depth d, but also on the angle of incidence θ. Theoretical calculation based on geometric optics gives a depth compression factor of γ=3.7.



$$n_{air}\sin(\theta) = n_{GaN}\sin(\varphi)$$

$$\tan(\theta) = \frac{L}{d}$$

$$\tan(\varphi) = \frac{L}{D}$$

$$D = d\left(\frac{\tan(\theta)}{\tan(\varphi)}\right)$$

$$D = d\sqrt{\frac{n_{GaN}^2 - \sin^2(\theta)}{1-\sin^2(\theta)}} = d\gamma$$

Conclusion

We demonstrate that confocal Raman spectroscopy can resolve the layer structure of a GaN based LED, after proper focal shift correction to account for the refraction index mismatch between the objective immersion medium and the LED sample. By examining the axial profile of the Raman peaks , we can associate the unique 465 cm^{-1} Raman peak feature with the active layer, which is only ~0.3 μm thick and in fact below the axial resolution of our optical system. To the best of our knowledge, this Raman feature has not been previously reported in literature. Its presence is possibly due to the strain induced by the adjacent layer structures of the MQWs. The ability to *in situ* characterize this LED active layer makes this a potential powerful tool to investigate the current challenge in optimizing the emission wavelength and efficiency of the commercial nitride-based LEDs.

References

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Acknowledgement

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