Reduction of Deep Level Emission in AlGaN-based Deep Ultraviolet Emitters

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Motivation—Solid-state deep ultraviolet (UV) light emitting diodes (LEDs) are sought as excitation sources for fluorescence-based bio-sensing applications. Potential performance advantages over traditional lamp-based or laser-based systems include compactness, wavelength tailorability, cost effectiveness, and robustness. Recently developed deep UV (270-290 nm) LEDs based on AlGaN-alloys show promise to achieve these performance advantages but are limited by the presence of significant sub-bandgap, deep level emission bands in the electroluminescence spectrum. These emission bands overlap with relevant fluorescence bands and reduce the ability to achieve high detection sensitivity in bio-fluorescence measurements.

Accomplishment—Previous reports have shown that emission from deep level states of AlGaN multi-quantum well LEDs exists in at least two broad bands, one centered in the UV at approximately 330 nm and another band centered in the near-UV/blue (400-450 nm) region of the spectrum. The 330 nm band in particular can represent a significant portion of the total LED emission, with recent reports of a peak emission intensity that is only 10-100 times weaker than the quantum well emission band. We have demonstrated significant reduction in emission from 330 nm-band deep level transitions through optimization of the heterostructure design and growth conditions of AlGaN multi-quantum well LEDs grown by metal-organic vapor phase epitaxy. Our studies revealed that a potential limitation to both device efficiency and spectral purity was the lack of sufficient carrier confinement in the LED structure. In particular, electron leakage out of the quantum well region and subsequent recombination through deep level states in the p-type AlGaN layer of the structure was identified as a likely candidate for the sub-bandgap emission in the 330 nm region. To minimize this emission, we implemented a high bandgap $Al_xGa_{1-x}N$ (x~0.70) electron block layer on the p-side of the structure, as shown in Fig. 1. A key challenge of this approach is to minimize the detrimental barrier to hole injection while simultaneously reducing electron leakage. Optimization of the Al-composition profile, thickness and overall materials growth conditions of the electron block layer resulted in greater than 10X reduction in 330 nm band emission while maintaining or increasing the quantum well emission efficiency. A semi-log plot of electroluminescence spectra from a 300 µm x 300 µm AlGaN flip-chip LED structure is shown in Fig. 2a. The spectra are normalized to the quantum well emission band (274 nm) and shown as a function of injected current to reveal the saturation of deep level emission with increasing current. At 100 mA, the spectrum shows a 330 nm band that has a peak intensity approximately 700X lower than the main quantum well emission, representing a notable advance in the spectral purity of AlGaN-based LEDs. These LEDs were operated at 8.3V with an output power of 0.77 mW at 100 mA DC.

Significance—The demonstration of near-milliwatt level solid-state sources in the 270-290 nm region with reduced deep level emission has accelerated their implementation into prototype biosensing systems. The compactness and wavelength tailorability of these sources will enable next-generation biosensing systems with enhanced capabilities for addressing problems of great interest to national security.

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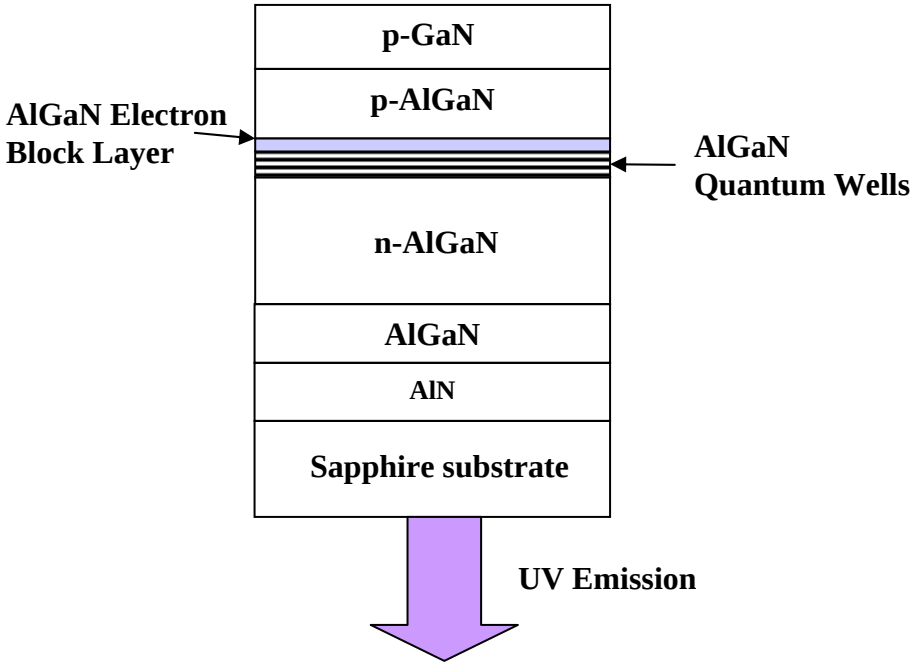

Figure 1. Schematic of AlGaN-based deep UV LED structure, showing the primary n-type and p-type AlGaN layers, the quantum well active region and the AlGaN electron block layer.

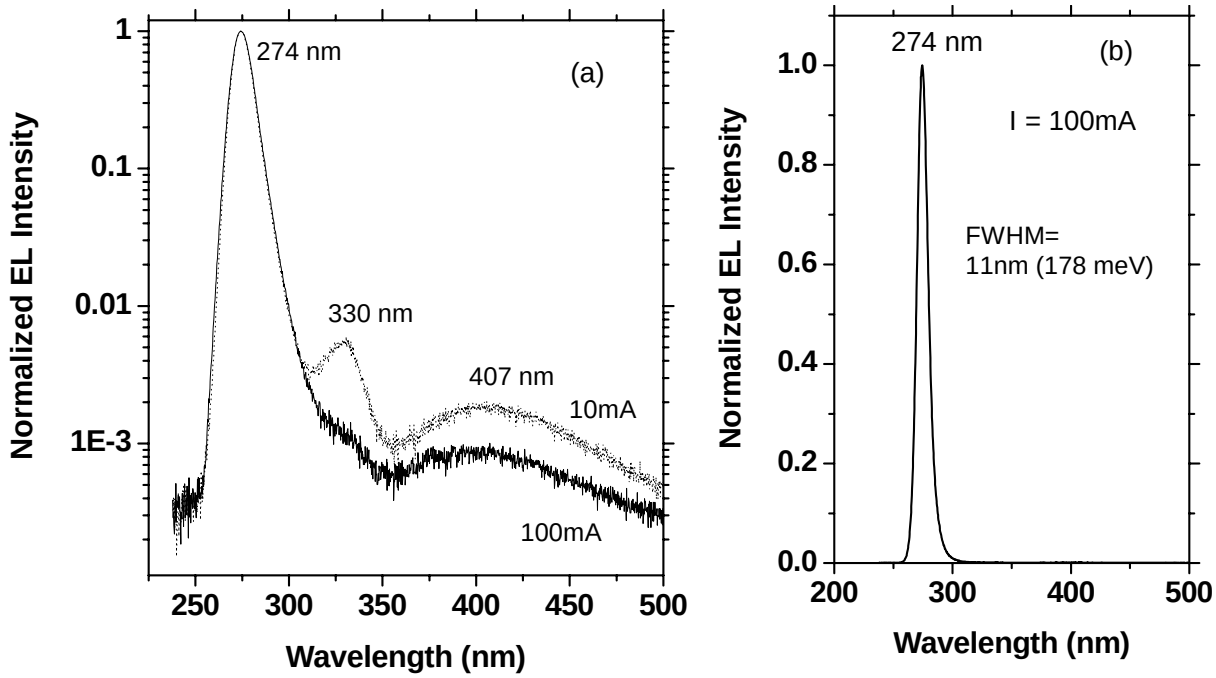

Figure 2. (a) Semi-log plot of normalized electroluminescence spectra from an AlGaN multi-quantum well LED at 10 mA and 100mA DC injection current. The primary quantum well emission is at 274 nm, and the deep level bands are at 330 nm and 407 nm. (b) Linear plot of electroluminescence at 100mA.