Improved Power and Reliability of AlGaN-based Deep Ultraviolet LEDs

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Motivation—Solid-state deep ultraviolet (UV) light emitting diodes (LEDs) are needed for a range of applications, including fluorescence-based sensing of bioagents, non-line-of-sight communications, and portable water purification systems. Recently developed deep UV (270-280 nm) LEDs based on AlGaN semiconductor alloys show promise to meet the requirements of these applications, but to date have been limited in both output power and device lifetime. Our research has focused on advancing AlGaN epitaxial material quality to enable significant LED performance advances in these critical areas.

Accomplishment—A key challenge to advancing the performance of AlGaN LEDs is reducing the high density of threading dislocations which are predicted to act as non-radiative recombination centers and may contribute to device failure. These defects originate at the initial stage of epitaxial growth with the nucleation of AlN epilayers on lattice-mismatched sapphire substrates. Our materials optimization efforts have focused on modifying the metal-organic vapor-phase epitaxial growth process at this critical nucleation stage to reduce dislocation densities. Through this optimization process, we have succeeded in reducing the dominant edge-component dislocation density from ~3×10^{10} cm^{-2} to ~7×10^{9} cm^{-2}. We fabricated AlGaN LEDs on these lower dislocation density AlN epilayers by employing a p-i-n LED structure shown schematically in Figure 1. In Figure 2, we show the light output versus current (L-I) and current-voltage (I-V) characteristics of a 1 mm x 1 mm sized device with emission at 276.8 nm. For 600 mA DC current operation, this device yielded 2.4 mW of optical output power, exceeding the output of our previous devices by a factor of two.

While the exact mechanisms that limit AlGaN LED reliability are not completely understood, our device lifetime studies revealed distinct signatures associated with optical power degradation. LEDs operated under constant current conditions and demonstrating at least 50% output power degradation have consistently shown increased current leakage. Non-uniform light emission patterns were also observed in some cases. We hypothesized that threading dislocations may contribute to the current leakage, and non-uniform current injection due to epitaxial surface roughness may also factor into device degradation. We therefore implemented new p-AlGaN and p-GaN growth conditions for improved surface morphologies in concert with our efforts to lower dislocation densities. Device lifetime studies were performed on 300 μm x 300 μm sized LEDs employing these material improvements. The devices were operated at 30 mA DC and yielded output powers up to 0.18 mW. In Figure 3, we show lifetest data from one such LED that demonstrated less than 50% power degradation over 1500 hours. This performance shows dramatic improvement beyond the 10’s-100’s of hour lifetimes of previous devices.

Significance—The demonstration of compact, solid-state deep UV sources at milliwatt power levels and with improved reliability has accelerated their implementation into fluorescence-based bioagent detectors and non-line-of-sight communications systems. These devices offer new capabilities for applications of great interest to national security.

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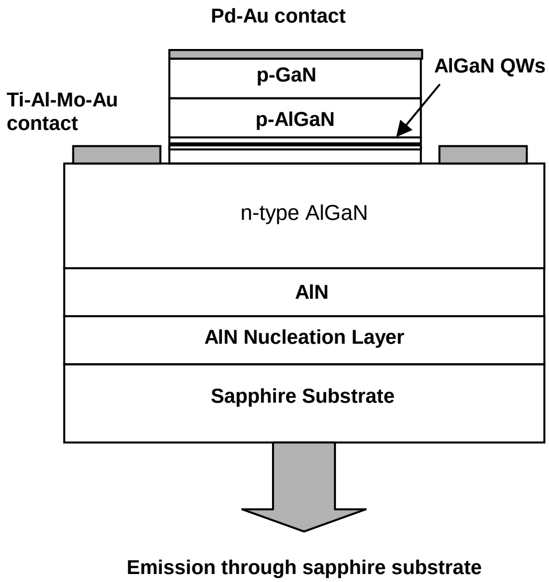

Figure 1. Schematic of a deep UV AlGaN LED. The devices reported herein consist of three 2 nm thick $Al_{0.47}Ga_{0.53}N$ quantum wells with 7 nm thick $Al_{0.58}Ga_{0.42}N$ barriers, a 25 nm thick $Al_{0.70}Ga_{0.30}N$ electron block layer on the p-side of the device and a 1.4 µm thick n-type $Al_{0.61}Ga_{0.69}N$ layer. Al compositions and layer thicknesses are estimated from growth calibration structures and XRD measurements.

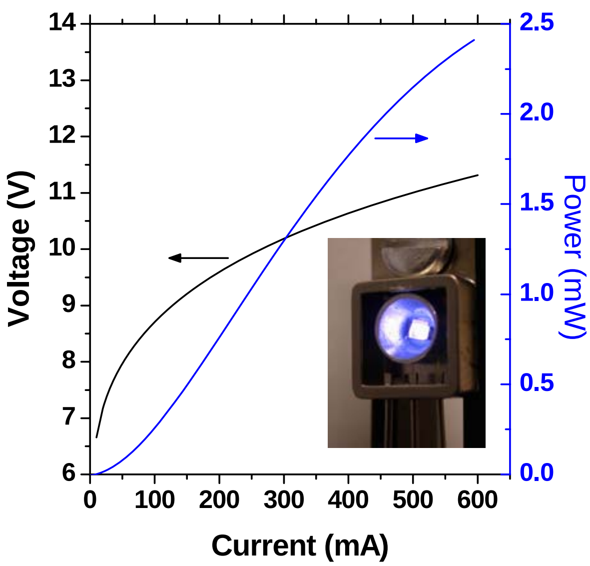

Figure 2. L-I-V data for a 1 mm x 1 mm LED with peak emission at 276.8 nm at 600mA. The inset shows a photograph of the flip-chip bonded LED packaged in a TO-257 header with an aluminum reflector.

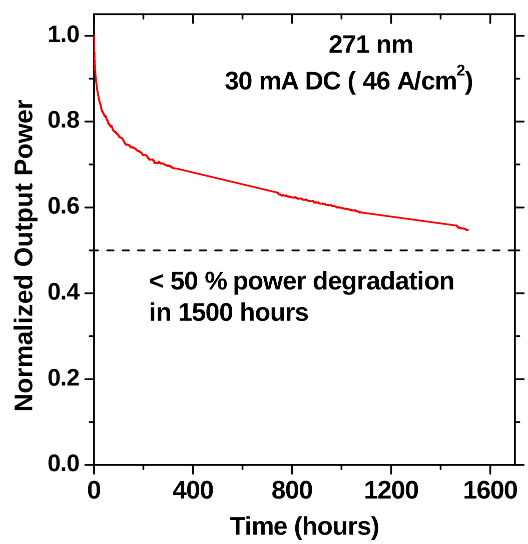

Figure 3. Lifetest data for a 300 µm x 300 µm sized device at 30 mA with peak emission at 271 nm. Output power is monitored by a silicon photodiode.