Molecular Beam Epitaxy of Coalesced AlGaN Nanowires: Ultraviolet Transparent Electrodes for Large-Area LEDs

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Nanowire based AlGaN optoelectronics have the advantage of providing high crystalline quality material on a variety of different substrates. However, the efficiency of nanowire-based LEDs is not on par with similar thin film devices. This is in part because each individual nanowire must be wired in parallel. Typical heterostructures have a p-type up design, requiring a conformal metal top contact which is highly opaque in the ultraviolet (UV) wavelengths. This work uses plasma assisted molecular beam epitaxy (PAMBE) to demonstrate coalesced n-AlGaN nanowires as a transparent semiconductor electrode top contact to improve the light extraction efficiency of UV nanowire LEDs on Si. Electron microscopy reveals coalescence of nanowire tops into a continuous top electrode. Conductive atomic force microscopy (cAFM) is used to measure the uniformity of the resistance of the coalesced nanowire LEDs. Direct imaging of operational devices is used to investigate the homogeneity of the current spreading in the coalesced nanowire LEDs at the sub-micron scale. Compared with conformal semi-transparent metallic contacts, the UV transparent n-AlGaN coalesced layer results in efficiency improvement of about 37×. Additionally, the coalesced contact avoids the direct wiring of electrical shorts resulting in a greatly increased yield of working large-area (>1 mm^2) nanowire UV LEDs.

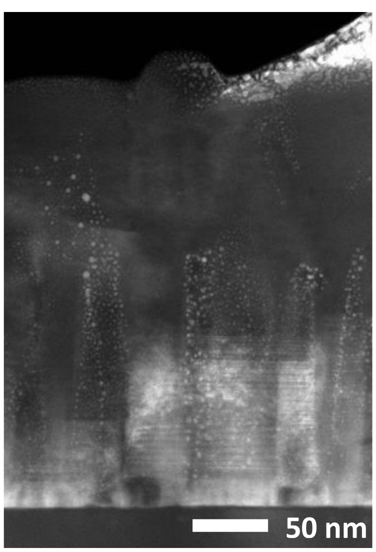


Figure 1: STEM image of coalesced nanowires

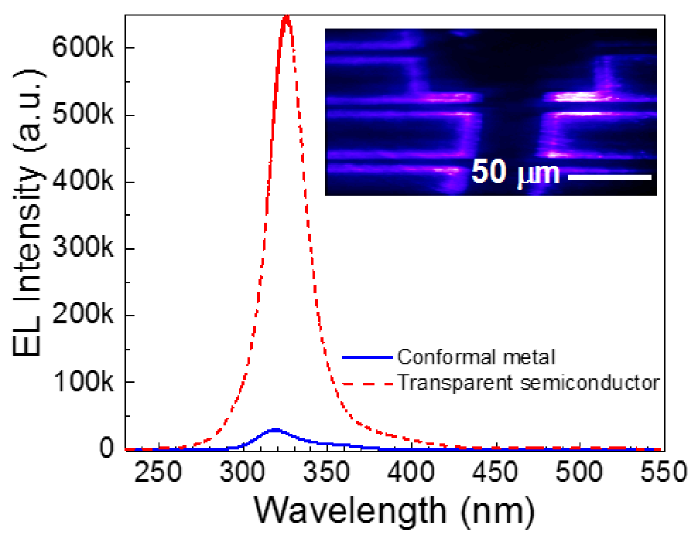
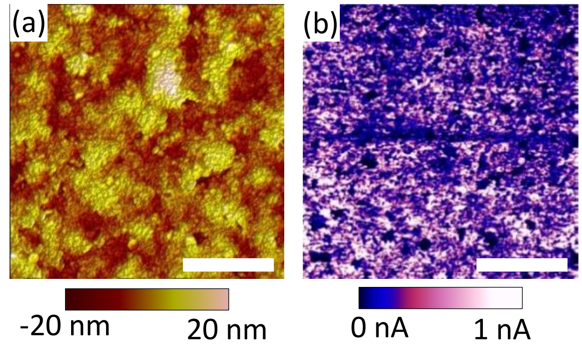
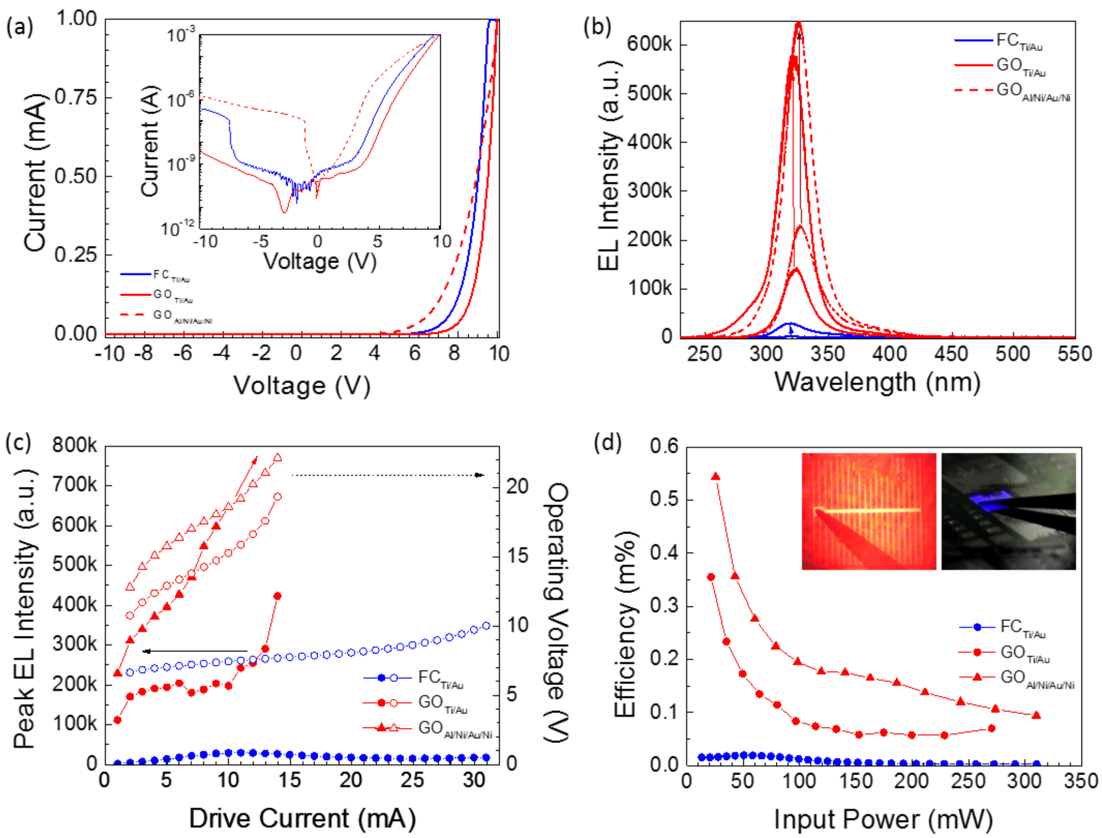


Figure 2: Electroluminescence spectra of LEDs with fully conformal metal (blue) and transparent contacts (red) at 10mA injection current. Inset shows light emission from operational 1×1 mm device.

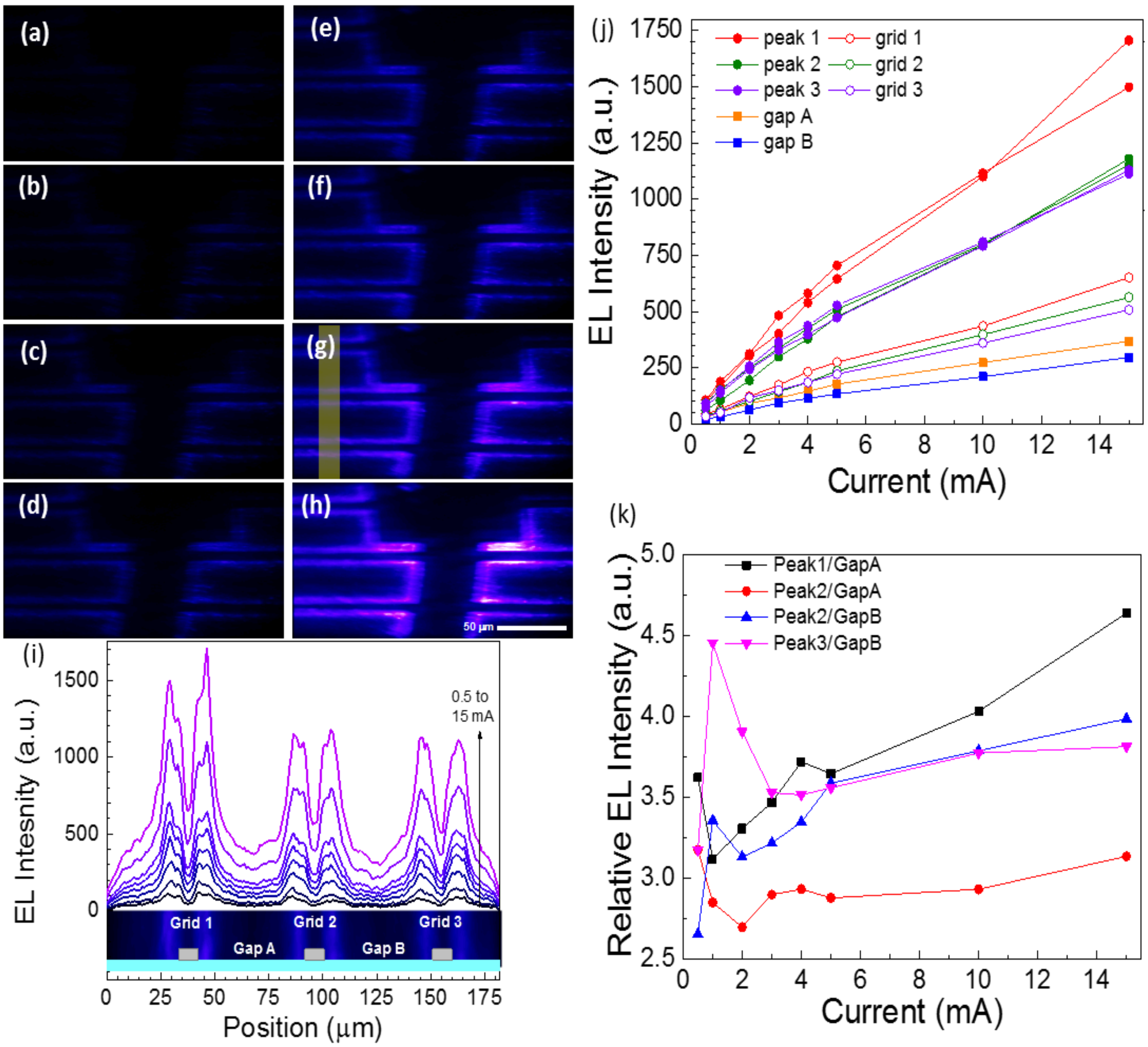
Supplementary Pages

Supplementary Figure 1: (a) Atomic force microscopy (AFM) image of coalesced nanowire surface and (b) conductive AFM image showing the current under 8 V bias after a ten minute etch in HCl. Scale bars are 1 μm





Supplementary Figure 2: (a) I-V curves (inset shows log scale) (b) elecrtroluminescence spectra (c) peak intensity (solid symbols) and operating voltage (open symbols) as a function of drive current and (d) efficiency as a function of input power for the fully conformal (blue) and transparent semiconductor contacts with a metal grid only (GO) design (red) (inset shows 1×1 mm device in operation)



Supplementary Figure 3: Images taken with a CCD showing light emission from a 1×1 mm device at injection currents of (a) 500µA, (b) 1 mA, (c) 2 mA, (d) 3 mA, (e) 4 mA, (f) 5 mA, (g) 10 mA, and (h) 15 mA (scale bar is 50 µm). (i) Intensity line scans across the left portion of the device (marked by yellow line in (g)) at the various injection currents. (j) The intensity values at various key locations from the line scan. (k) The relative intensity of areas near (peaks) and far (gaps) from the grid fingers as a function of injection current