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IT-5-P-2062 Nanoscale Luminescence Mapping of InGaN/GaN Multiple Quantum Dot Doped Nanowire LEDs with Scanning Transmission Electron Microscopy

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Ternary InGaN compounds show great promise for light-emitting diode (LED) applications because of bandgap energies (0.7–3.4 eV) that can be tailored to have emission wavelengths spanning the entire visible spectral range. Complex III-N device heterostructures have been incorporated into GaN nanowires (NWs) recently, but exhibit emission linewidths that are broader than expected for their corresponding planar counterparts, as measured with photoluminescence (PL) spectroscopy. It is thus critical to understand how the structural and optical properties interplay, using spectroscopic methods that can resolve localized signals at the nanoscale.

Multiple InGaN/GaN quantum dot (QD) embedded nanowire (NW) LED structures, grown on Si(111) substrates by molecular beam epitaxy, were characterized by STEM. Elemental mapping using EELS has shown a systematic non-uniformity of the In-content between the InGaN QDs that are centrally confined within the active region, embedded between *n*- and *p*-doped GaN in the NW LED structure (Fig. 2(c,d)). To correlate these observations to the inhomogeneous broadening observed in PL from an ensemble of NWs, nm-resolution STEM-cathodoluminescence (CL) spectral imaging on single NWs was performed using a custom-made system on a VG HB-501 STEM as described in [2]. Individual NWs examined showed diverse optical responses, but most NWs exhibit one main emission peak centered at 500–550 nm in the yellow-green. Spectral features consisting of multiple sharp peaks (25–50 nm at FWHM) spanning a wavelength range of ~100 nm arise from the active region (Fig. 1(b)), showing an apparent spatial dependence of the spectral shifts (Fig. 1(a)). This is consistent with the PL, indicating that the broad emission originates from within single NWs and is not an inhomogeneous broadening. However, typical wavelength-integrated CL mapping was too ambiguous in the spatial assignment of some peaks that have overlapping intensities. Improved spatial-spectral correlation was achieved by inspecting orthogonal spatial slices from the spectrum image singly along *x* and *y* (Fig. 2(a,b)) to define various combined position and wavelength maxima. Multiple optical signals of varying emission wavelengths arising from well-defined locations within the QD active region were identified, and can be attributed to the observed In-content variation between successive QDs. Lastly, the evidence of localized emission intensity in the QDs towards the *p*-GaN, likely due to the diffusion of charge carriers generated by the electron beam, could suggest the accumulation of carriers within the active region towards the *p*-GaN.

[1] H.P.T. Nguyen *et al*., Nano Lett., 12(3), 1317-1323 (2012)
[2] Zagonel *et al*., Nano Lett., 11(2), 568-573 (2011)

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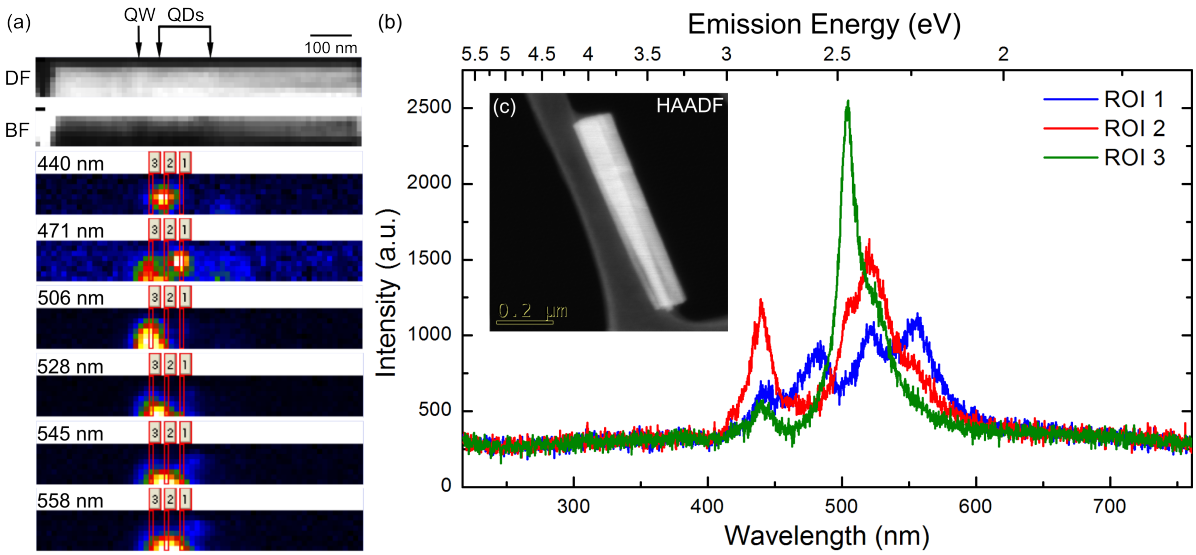

Fig. 1: STEM-CL spectrum image (SI) of the NW structures. (a) HAADF and BF image acquired simultaneously with the CL, and spatial maps of spectral features centered about the wavelengths labeled. The three marked regions of interest (ROI) that exhibit unique emission spectra are shown in (b). (c) HAADF image to better resolve the same NW studied using CL.

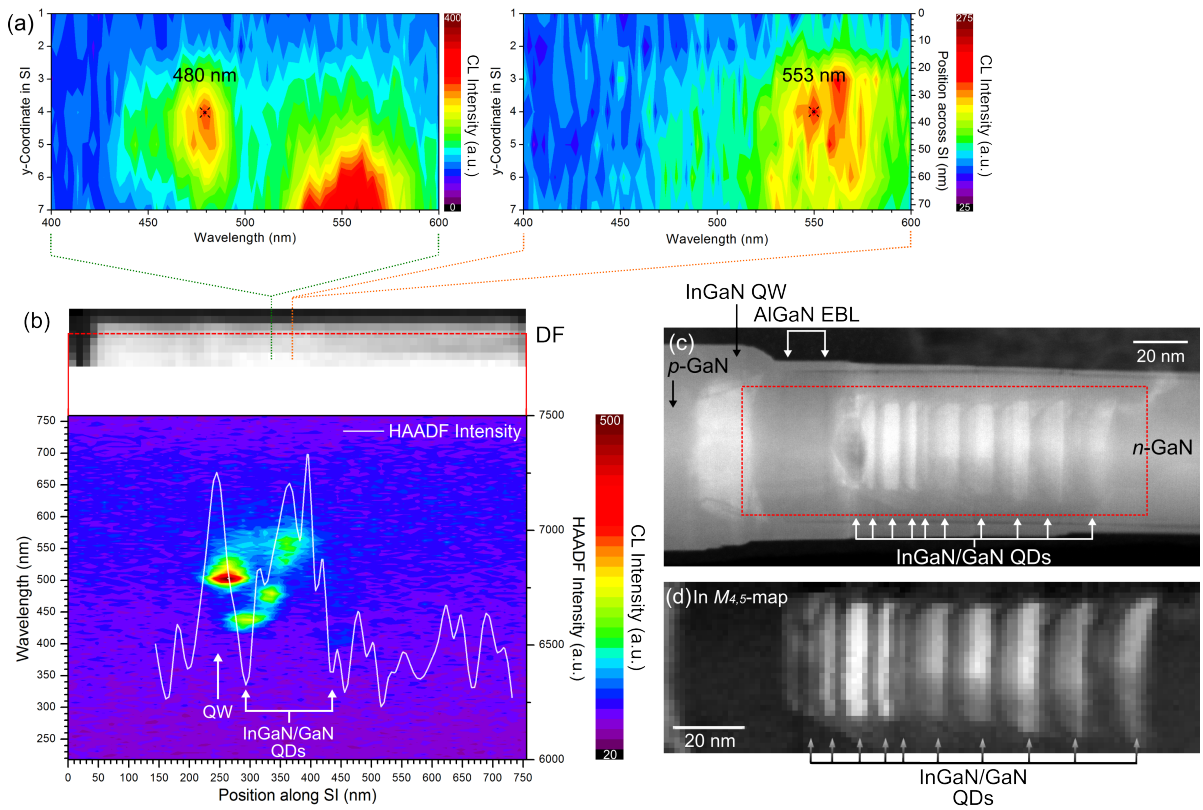

Fig. 2: Spatial-spectral plots of the SI from Fig. 1, (a) across the SI in the y-axis, (b) along the SI in the x-axis with concurrent HAADF signal overlaid to show the structure; CL intensity is color-coded. (c, d) HAADF image and corresponding STEM-EELS In-map of the boxed area in another NW, showing the varying In-content in the 10 InGaN QDs.