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**MS-1-O-1571 Influence of Strain State on the Formation of Short-Period InGaN/GaN Nanowire Superlattice by Electron Energy-Loss Spectroscopy**


1Department of Materials Science & Engineering, Brockhouse Institute for Materials Research, and Canadian Centre for Electron Microscopy, McMaster University, Hamilton, ON, Canada, 2Now at EMAT, University of Antwerp, Antwerpen, Belgium, 3Laboratoire de Physique des Solides, Université Paris-Sud XI, Orsay, France, 4Department of Electrical & Computer Engineering, McGill University, Montreal, QC, Canada

Email of the presenting author: woosy@mcmaster.ca

Ternary InGaN alloys have been sought-after for various optoelectronic device applications, including their prospect as highly efficient phosphor-free white light-emitting diodes (LEDs). The growth of high quality InGaN epilayers over the entire compositional range, however, faces a few obstacles impeding the realization of their full visible wavelength range tunability. The large InN/GaN lattice mismatch can induce a high density of threading dislocations, and the InGaN miscibility gap leads to inhomogeneity and difficult indium incorporation. Therefore the determination of composition, in particular quantitative elemental mapping at high spatial resolution, is imperative to further understanding the formation of III-N heterostructures. The growth of high quality III-N heteroepitaxy in a nanowire (NW) geometry is a promising alternative, as shown in the recently developed InGaN/GaN quantum dot (QD) superlattice towards controlled light emission across the entire visible spectrum [1]. In this work, multiple InGaN/GaN dot-in-a-wire nanostructures grown on Si(111) substrates by molecular beam epitaxy were characterized by aberration-corrected scanning transmission electron microscopy (STEM) to correlate their structural to optical and electrical properties. High-angle annular dark-field (HAADF) Z-contrast imaging showed that the 10 InGaN QDs are centrally confined within the active region, embedded between n- and p-doped GaN in the NW LED structure. Core-loss EELS spectrum imaging is used to evaluate the elemental distribution in the NW heterostructures. The In-content is quantified using a multiple linear least squares (MLLS) fitting routine, with combined internal and external reference spectra to fit the N K (399 eV) and In M (451 eV, in close proximity to the N K) edges in the spectrum image. A surface plot of the thickness-corrected In-map clearly illustrates the non-uniformity of InGa_N composition between the 10 dots (Fig. 1), which has occurred systematically despite the constant growth conditions of the QDs. Geometric phase analysis (GPA) of corresponding atomic-resolution STEM images was used to extract the local strain components at the nanoscale. Along the growth direction (Fig. 2(c)), a direct correlation between a GaN barrier’s strain state and the amount of In incorporated into the subsequent QD can be deduced. Examining the strain distribution of the QDs aids to elucidate their formation as governed by the incorporation of In. In addition, effects of the varying composition on emission wavelength in single NWs using nm-resolved STEM-cathodoluminescence will also be shown. [1] Nguyen et al., Nano Lett., 12(3), 1317-1323 (2012)

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Fig. 1: (a) HAADF-STEM image of a NW studied using STEM-EELS spectrum imaging, followed by subsequent MLLS fitting using combined internal and external reference spectra. (b) Surface plot of the thickness-corrected In-content map, generated from normalizing the MLLS-fitted In-map with the N-map, showing In$_{1-x}$Ga$_x$N composition ranging between \(x=0.12\)–0.38.

Fig. 2: (a) MLLS-fitted relative In-content map from EELS with internal references. (b) Corresponding HAADF-STEM image with its strain maps along the growth (c) and in-plane (d) directions, and dilatation matrix (e). The maps show that there is a direct correlation between the In-content as highlighted in (a) and the strain along the growth direction (c).