Cathodoluminescence Hyperspectral Imaging of Nitride Core-Shell Structures

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1. Cathodoluminescence hyperspectral imaging

The luminescence properties of semiconductor materials may be probed by various related spectroscopic techniques, which differ in the method by which excess carriers are introduced into the material. In electroluminescence and photoluminescence measurements (using direct current injection and optical excitation, respectively) far-field diffraction limits the spatial resolution. By contrast, the resolution of *cathodoluminescence* (CL) is limited only by the spatial distribution of excess carriers which are generated in the material under a beam of high energy electrons in a scanning electron microscope, allowing the nanometer-scale emission properties to be mapped.

While wavelength-filtered imaging and point-wise spectroscopy are established CL tools, extension into the *hyperspectral imaging* (HSI) mode offers several advantages. By recording a spectrum at each pixel in an image scan it becomes possible to *spatially map* different spectral parameters such as peak energies and widths. It also becomes possible—via the application of *multivariate statistical analysis* techniques to the resultant data cube—to simplify analysis by automatically identifying the most statistically significant spectral components of the dataset [1].

2. Application to nitride nanostructures

In this work, we demonstrate the use of hyperspectral CL in the evaluation of periodic arrays of GaN/$In_xGa_{1-x}N$ core-shell nanorods. These were fabricated using a top-down approach, in which columns are formed from a GaN template using nano-imprint lithography and ICP etching, followed by MOCVD regrowth [2]. The formation of quantum wells (QWs) on the *m*-plane sidewall facets offers a route to avoiding the detrimental electric fields associated with LEDs grown on the *c*-plane, while the use of periodic features has the potential to improve light extraction and directionality. Figure 1 shows such an array; a CL hyperspectral image was measured from this region and the area-averaged spectrum extracted from this dataset is plotted.

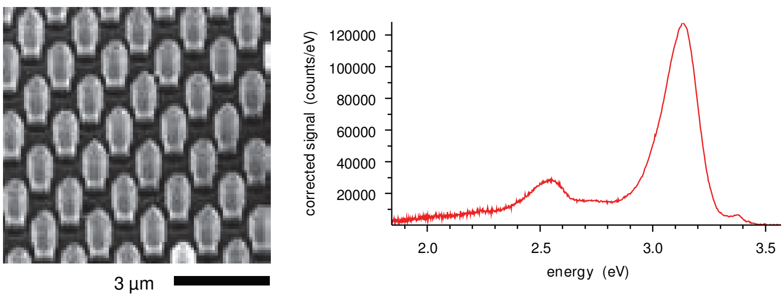

Figure 1: Secondary electron image of GaN/InGaN core-shell nanorod array, and room temperature CL spectrum extracted from the hyperspectral dataset and averaged over all spatial pixels.

In order to confirm the formation and uniformity of the sidewall QW, we extract a number of images from the single CL dataset, shown in figure 2. The emission is dominated by a peak in the 3.0–3.3 eV range associated with the QW exciton, and the intensity map is plotted by integrating the data over this range. Statistical measures of the variation in the QW peak energy and width are generated by evaluating the centroid and standard deviations of the signal over this same range, and show a high degree of uniformity, both within a facet and between different nanorods.

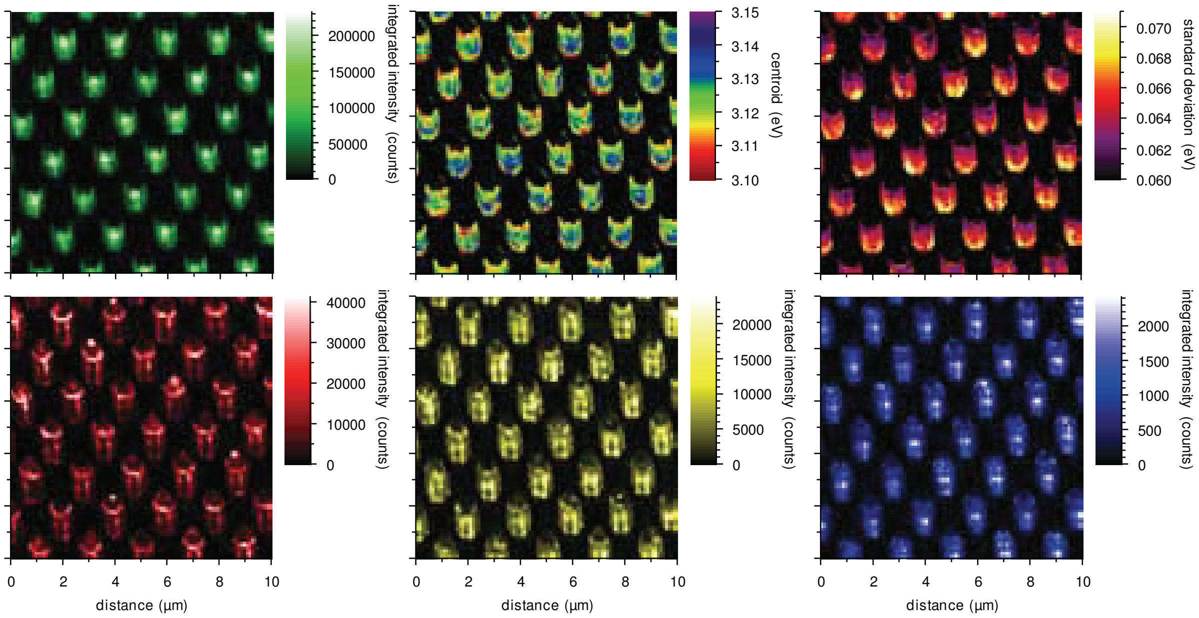

Figure 2: Maps extracted from a single 200×200×800 pixel CL hyperspectral image of the nanorod array, showing (top, left–right) integrated intensity, centroid energy and standard deviation of the 3.0–3.3 eV QW band, and (bottom, left–right) intensity of three additional peaks at 2.4–2.6 eV, 2.7–2.9 eV and 3.35–3.45 eV (GaN bandedge).

Further exploiting the richness of this multidimensional dataset, figure 2 also shows the intensity of three additional bands: an InGaN-related peak at 2.4–2.6 eV emanating from the feature edges; 2.7–2.9 eV luminescence associated with a resonant optical mode within the structure (confirmed by the presence of fringes within the associated spectra, not shown); and GaN near-bandedge emission—also showing evidence of a cavity mode—at 3.35–3.45 eV.

We will also describe the treatment of such datasets using other techniques. These include the deconvolution of overlapping emission bands using nonlinear least-squares fitting to multiple peak profiles, as well as spectral unmixing methods based on multivariate statistical approaches such as those based on principal component analysis.

3. References

[1] P. R. Edwards, L. K. Jagadamma, J. Bruckbauer, C. Liu, P. Shields, D. Allsopp, T. Wang and R. W. Martin "High-resolution cathodoluminescence hyperspectral imaging of nitride nanostructures", Microscopy and Microanalysis **18** 1212 (2012).

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