Metrology and Standards for Electronic and Optoelectronic Materials

The electronics and optoelectronics industries require accurate materials properties data to improve their device fabrication, modeling, and evaluation processes. Our recent activities have emphasized optical and structural metrologies applicable to wide bandgap semiconductor nanowires, and UV Raman spectroscopy for the evaluation of strain in strained silicon-on-insulator structures.

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Nanowires, defined as semiconductor or metal structures having a quasi-cylindrical geometry with diameter in the range 1 to 100 nm, are expected to have a major impact on future electronic and optoelectronic technologies. A NIST program was recently started to develop growth and manipulation techniques, metrologies, and test structures for semiconductor nanowires, based on GaN growth by molecular beam epitaxy (MBE), and ZnO growth by the catalyst-assisted vapor-liquid-solid (VLS) method. We are contributing to this program by developing metrologies for structural and optical characterization of the nanowire samples and test structures.

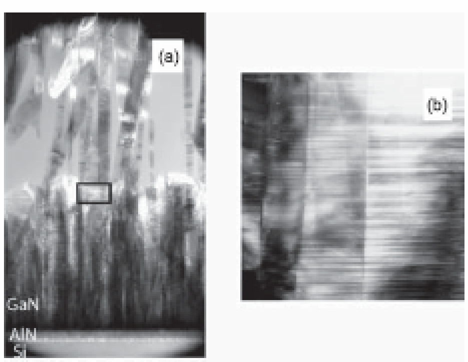

Figure 1: Dark-field TEM images of GaN nanowire and matrix structure grown on AlN/Si. (a) Lower magnification image shows nanowires and unwanted matrix layer both growing from AlN buffer. (b) Higher magnification image shows basal-plane defects in matrix layer.

TEM structure of one of our first GaN nanowire samples, grown by MBE on an AlN buffer layer on Si(111), is shown in Figure 1. The sample contains both nanowires and a rough, faceted "matrix" layer (lower half of Figure 1(a)). Growth of most nanowires appears to initiate at the AlN buffer, rather than within the matrix layer. The matrix layer contains a high density of basal-plane defects, which produce striations in the dark-field image (Figure 1(b)), and also give rise to streaking in electron diffraction (not shown here). In contrast, the nanowires appear free of extended defects in TEM.

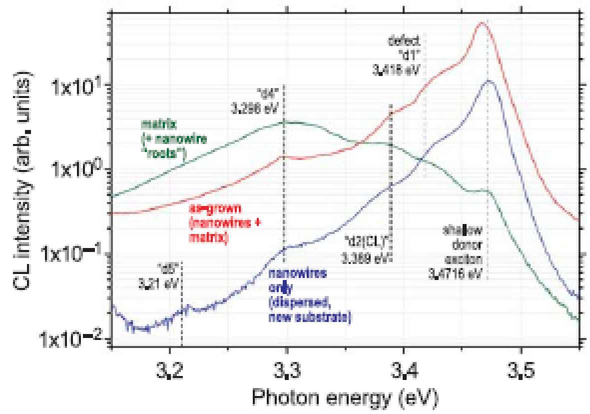

Figure 2: Low-temperature CL of GaN nanowire sample. Red curve: as-grown. Blue curve: nanowires only, removed from matrix layer. Green curve: matrix layer + nanowire "roots," with tops of nanowires polished off.

The nanowire structure from Figure 1 was characterized by low-temperature cathodoluminescence (CL), as shown in Figure 2. The CL of the nanowires is dominated by excitons bound to shallow donor impurities (3.4716 eV peak) while the matrix layer CL is dominated by excitons bound to structural defects (peaks "d1" through "d5") that may be related to the defects seen by TEM.

Similarly to the GaN samples, the ZnO samples were found to contain a highly defective "matrix" layer together with relatively defect-free vertical nanowires, but the matrix layer in the ZnO was found to consist of horizontally growing nanowires. The choice of metal catalyst (Ag, Au, or Cu-containing alloy) for VLS growth of the ZnO samples was found to have a strong affect on the CL spectra, ascribed to catalyst doping of the ZnO and concomitant formation of catalyst-related impurity levels. Our characterization results on GaN and ZnO nanowires were reported at the 2005 Electronic Materials Conference (Santa Barbara, CA, June 22–24).

Contributors and Collaborators

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