GATAN

AMETEK

Experiment Brief

Monarc Pro

Title

Spectroscopic analysis of ultra-wide bandgap semiconductors

Gatan Instrument Used

The Monarc® Pro system offers the most complete analysis of cathodoluminescence (CL) emissions and empowers all users to capture the highest quality data, whether novice or expert.

Background

Ultra-wide bandgap (UWBG) materials such as Al(Ga)N, Ga_2O_3, BN, and diamond offer significant benefits for high-power and high-frequency electronic and optoelectronic devices that operate at deep ultraviolet (UV) wavelengths. Furthermore, many UWBG materials improve operation in extreme environments where radiation damage or high temperatures obviate other materials from consideration.

Commercially viable devices require the development of high-quality, low defect materials. However, the UWBG (>3.4 eV) precludes the use of conventional photoluminescence setups commonly employed in process development as these materials are transparent at the laser-wavelengths commonly employed. Consequently, an alternative spectroscopic technique is required.

Materials and Methods

We used the technique of spectroscopic cathodoluminescence to analyze hexagonal boron nitride (h-BN) with a bandgap ~5.5 – 6.0 eV. The focused electron beam of a scanning electron microscope (SEM) is used to excite electron-hole pairs in h-BN. Then a Monarc Pro system fitted with a UV-optimized diffraction grating (600 l/mm blazed at 300 nm) captured and analyzed the radiative decay of excess carriers results in the emission of photons. Hyperspectral data containing both spatial and spectral information was collected by a technique termed spectrum imaging—the SEM's focused electron beam is scanned across the specimen surface in a pre-defined pattern, and a wavelength-resolved spectrum is recorded at each location. At room temperature, we analyze the near-bandgap luminescence (200 – 400 nm, 3.10 – 6.19 eV) associated with Frenkel excitons and defect or impurity color centers [M Silly et al., Phys. Rev. B 75(8) 085205 DOI: 10.1103/PhysRevB.75.085205], see Figure 1. A strong spatial variation between emission lines was observed as revealed by maps extracted by non-linear least-squares fitting, Figure 2.

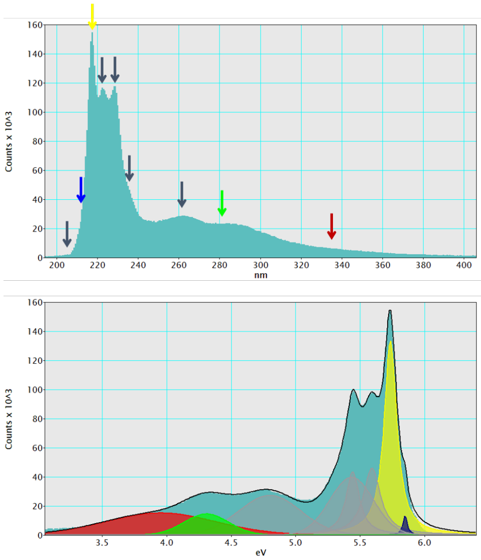

Figure 1. CL spectrum of the UV luminescence of an h-BN flake, recorded at room temperature. Deconvolution of the spectrum using non-linear least squares (NLLS) fitting revealed nine peaks corresponding to near-bandgap exciton emission and mid-gap color centers. The four models used to extract the maps displayed in Figure 2 are colorized consistently between Figures and the black line is the sum of all models demonstrating an excellent fit to the raw data.

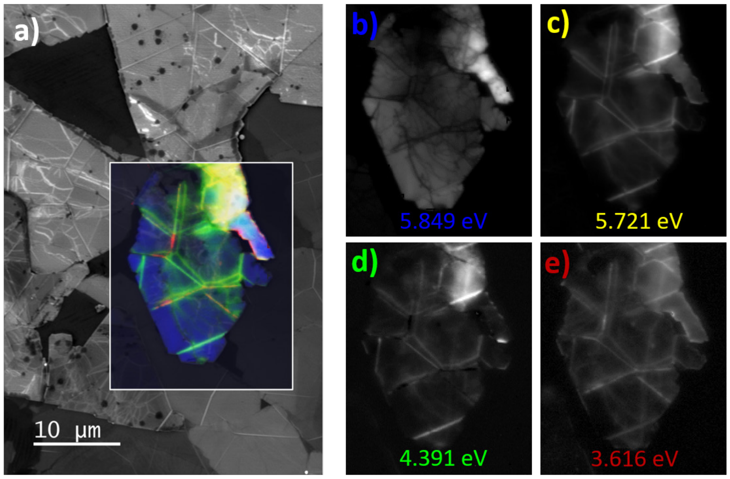

Figure 2. a) Secondary electron image of h-BN flakes overlaid with a colorized representation of a CL spectrum image; b) – e) maps extracted by NLLS fitting as shown in Figure 1. The colorized image in a) is a composite image formed from maps b) – e) and colorized consistently. Acquisition conditions (Figures 1 and 2): accelerating voltage = 10 kV, probe current = 1 nA, exposure time = 100 ms, spectrometer resolution = 0.67 nm.

Summary

We demonstrated hyperspectral data collection at room temperature of the UWBG semiconductor, hexagonal boron nitride. The unrivaled sensitivity and exceptional optical design of the Monarc Pro system provide the sharpest spectra and images, allowing the variations in exciton behavior and distribution of defects to be mapped at the highest spatial resolution.

EB-Monarc-UWBG-FL1-CA-MAR21