Detecting and depth profiling defects in semiconductors using synchrotron radiation: Insight from x-ray excited optical luminescence

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When considering materials for use in devices, their overall electronic properties can be greatly perturbed by the presence of defects, making their identification and characterization a crucial issue. Performing x-ray excited optical luminescence (XEOL) measurements, in which an optical spectrometer measures the luminescence of materials under x-ray irradiation, using a bright, tunable synchrotron x-ray source provides two advantages when characterizing defects in semiconductors compared to conventional luminescence spectroscopy. First, the high photon flux allows optical transitions associated with defects to be observed which might be otherwise below the detection threshold using a standard laboratory optical/x-ray excitation source. Second, the x-ray attenuation length for most materials varies by at least an order of magnitude over the excitation energies accessible at a synchrotron beamline (such as the VLS-PGM beamline at the Canadian Light Source). This makes it possible to develop depth profiles of particular defects in a material. Although previous work has demonstrated the utility of XEOL [1,2], these particular advantages have been underutilized. We demonstrate these properties in three case studies.

First, we consider the Zn-IV-N_2 system. This semiconductor system is predicted to have widely tunable properties, such as the band gap, which has recently been grown using ammonothermal synthesis. Using XEOL, Shockley-Read-Hall recombination and the presence of additional defect levels in this system are identified. Second, we consider freestanding InN grown via ammonothermal synthesis [3]. Using XEOL, the formation of trapped gas was observed and additional information about the degradation of the sample was obtained.

Finally, we consider an Al_2O_3-$SrTiO_3$ bilayer system. In this system, a two-dimensional electron gas (2DEG) with very high carrier mobility forms at the interface. Since the electronic properties of this 2DEG are sensitively related to the distribution of oxygen vacancies in adjacent layers, characterizing this distribution, and potentially linking it to the underlying synthesis conditions is of great interest. We demonstrate that we can develop a depth profile of oxygen vacancies in this system.

[1] R. J. Green *et al*., Phys. Rev. Lett. (2015) 115, 167401.
[2] T. Tolhurst *et al*. Chem. Mater. (2017) 29, 7976-7983.
[3] M. Ruhul Amin *et al*. J. Phys. Chem. C (2019) 123, 8943-8950.