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IT-5-O-2679 Challenges and Opportunities in Materials Science with Next Generation Monochromated EELS

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The development of monochromated scanning transmission electron microscopes (STEM) offering energy resolutions of better than 20 meV and electron probes of 0.1 nm in size provides a new tool for materials characterization. Unique opportunities opened by access to ultra-high energy resolution low loss EELS include determination of optical properties in the IR, bandgap mapping, detection of defect interband states and localized vibrational spectroscopy. At ASU we are currently applying ultra-high energy resolution low-loss EELS to a variety of materials that are important in fields such as energy, environmental science and information technology. Here we show representative initial results acquired on a newly installed Nion UltraSTEM equipped with a probe corrector and monochromator [1].

The optical properties of carbonaceous atmospheric aerosols are an important contributor to radiative forcing for climate change. By applying Kramers-Kronig techniques to energy-loss spectra acquired from the Nion, Figure 1 shows that the refractive index can be determined out to photon wavelengths of 2500 nm, thus covering most of the incoming solar spectrum [2].

Local measurement of bandgaps and states within the gap is of great importance for opto-electronic materials. Figure 2 shows the low-loss spectra from ceria (CeO_2) and a ceria co-doped with Gd and Pr ($Ce_{0.85}Gd_{0.11}Pr_{0.04}O_{2-\delta}$). From EELS, local bandgaps were about 3.5 eV and in some regions additional peaks were detected within the bandgap (Figure 2b). Interestingly, all the ceria based samples showed significant uniform intensity within the bandgap which will be discussed in terms of Cerenkov radiation, defects, and surface layers.

At lower energy transfers, localized phonon spectroscopy becomes possible. We have been able to identify vibrational peaks in a variety of compounds like SiO_2 which match the Raman spectrum [1]. Figure 3 shows two regions of the low-loss spectrum from TiH_2. The peak at 150 meV is prominent under aloof beam conditions.

Ultrahigh energy resolution EELS is an exciting new tool for characterization of materials. However, to realize its full potential, considerable experimental and theoretical work must be undertaken to develop a fundamental understanding of this form of EELS.

[1] O.L. Krivanek et al, these proceedings (2014)

[2] J. Zhu et al, these proceedings (2014)

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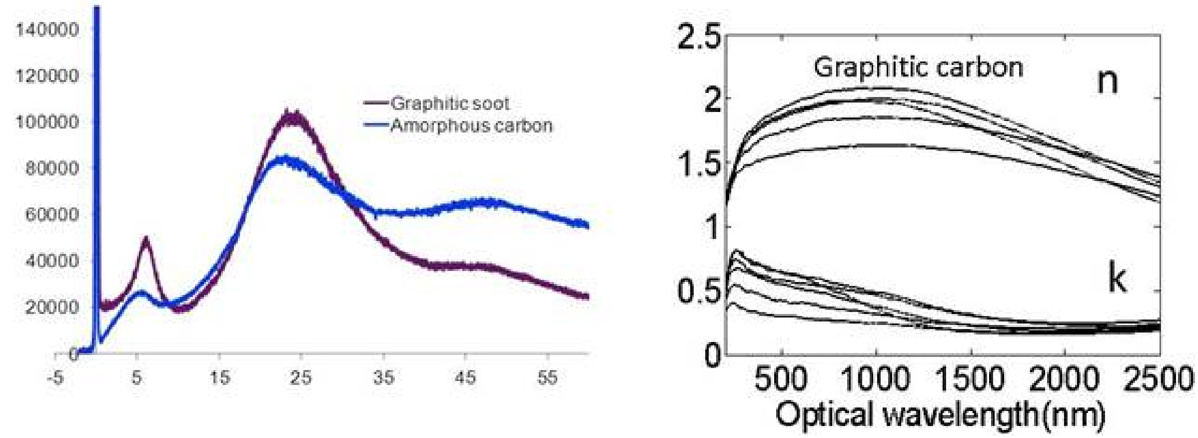

Fig. 1: (a) EELS from two forms of carbonaceous particles. (b) Complex refractive index derived from EELS covering photon wavelength range 200-2500 nm.

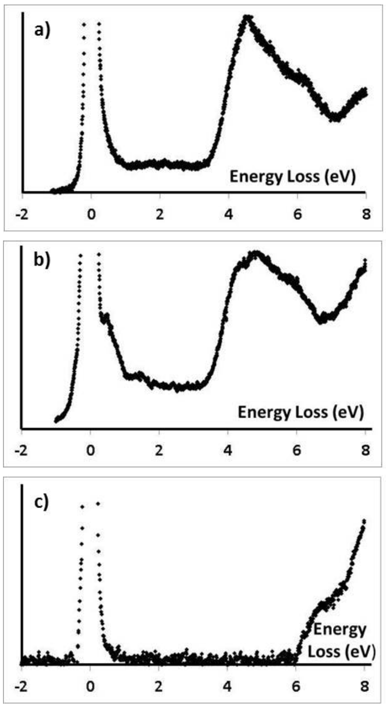

Fig. 2: Low-loss spectra from a) CeO_2, b) $Ce_{0.85}Gd_{0.11}Pr_{0.04}O_{2-\delta}$ and c) hexagonal BN.

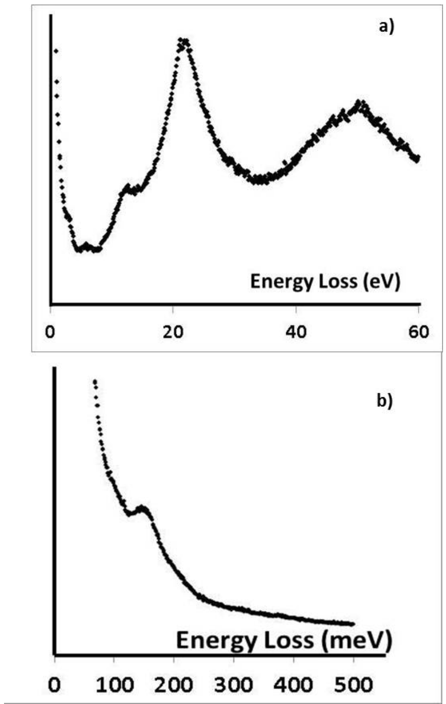

Fig. 3: EELS from TiH_2 showing a) wide energy range on sample and b) very low energy-loss region in aloof beam mode (~5 nm off sample).