

The Characterization of Bulk Plasmons and Bulk Phonons using Energy-filtered Diffracted Beam Holography and Energy-filtered Kossel-imaging Holography

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In M&M 2003 and M&M 2004, it was shown that it is possible to observe the interference of elastically and inelastically scattered electrons by Diffracted Beam Holography (DBH) [1, 2], which enabled the measurement of the spatial coherence of bulk plasmons. These measurements, and those made by others [3, 4, 5], of the partial spatial coherence of the inelastically scattered electrons created in the bulk material will contribute significantly to our understanding of the contrast in high-resolution lattice images and enhance our understanding of material properties at the nanoscale.

Energy-filtering the DBH holograms (EF-DBH) verified the hypothesis [1, 2] that the fringes formed outside the hologram boundary, which is determined by the condenser aperture, were due to the plasmon scattered electrons (Fig. 1) [6]. For normal imaging conditions, these fringes were not found outside of the hologram for energy-filtered zero loss electrons. The degree of coherence of the bulk plasmon scattered electrons in GaAs was measured from the intensity modulations of the fringes in the holograms to be ~ 0.3 , which was the same for the zero loss electrons. The transverse spatial coherence width (δ) can be measured by separating the two interfering beams to the point at which fringes do not form. These measurements of the bulk plasmon scattered electrons represent either the true spatial coherence of the bulk plasmon or the Coulomb interaction length between the bulk plasmon and the fast electron, with the former measurement likely since measurements by EF-DBH on Si, GaAs and Al vary between 2 – 10 Angstroms, whereas, Coulomb interaction lengths tends to be on the 10s of nanometer scale.

Since the energy loss of phonon-scattered electrons (~ 0.1 eV) is less than the energy spread of the FEG electron emitter, two filters are required to separate them from the zero loss electrons and plasmon loss electrons. The GIF separates the zero loss and phonon loss electrons from the plasmon loss electrons. The condenser aperture can then be used to separate the phonon loss electrons from the zero loss electrons since the zero loss electrons will not deviate from the hologram's boundary set by the condenser aperture. Over-exposed holograms revealed continued intensity of the beam and the presence of fringes away from the aperture (Fig. 2) suggesting that these phonon loss electrons have a sufficient degree of coherence to form fringes. Their transverse spatial coherence length has not yet been measured.

In DBH, the electron biprism is used to interfere two convergent beams onto the back focal plane without touching or interfering with the beams. If the convergence angle of the beams is reduced, then Kossel images are produced. The biprism can also form holograms from the Kossel-images (Fig. 3) but for this condition the electron biprism interferes with the beams. Two advantages of Kossel-imaging holography over DBH is that it requires less stability of the microscope and the biprism and it can produce holograms of larger nanoscale structures, both which are useful for the measurement of the properties of bulk plasmons and bulk phonons in nanodevices. Fig. 3 shows that zero loss electrons have larger δ than the plasmon loss electrons.

1. R. A. Herring, Microscopy & Microanalysis 2003 (San Antonio, Texas).
2. R. A. Herring, Microscopy & Microanalysis 2004 (Savannah, Georgia) 990.

3. H. Lichte and B. Freitag, *Ultramicroscopy* 81 (2000) 177.
4. K. Kimoto and Y Matsui, *Ultramicroscopy* 96 (2003) 335.
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6. R.A. Herring, *Ultramicroscopy*. Submitted.

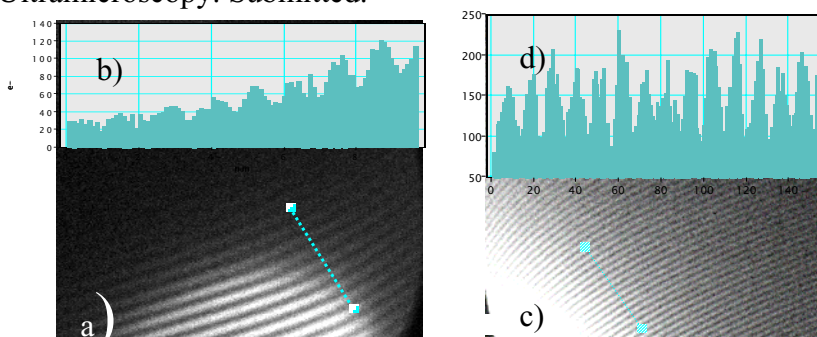


Fig. 1. Energy-filtered holograms using first plasmon loss electrons and the main beam (000) interfering with the 111 beam showing continued interference away from the aperture (see text) for GaAs in a) and its associated intensity profile in b) and for Si in c) and its associated intensity profile in d), both having a 5 eV window.

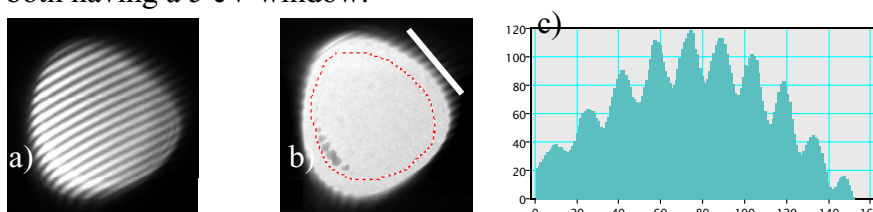


Fig. 2. Energy-filtered holograms using zero loss electrons, the main beam (000) interfering with the 111 beam of Si showing a normal exposure in a) and an over-exposure in b). An intensity spectrum in c) represents the white line in b) where the fringes are extending outside the aperture, which is approximately given by the dashed circle inside the over-exposed hologram.

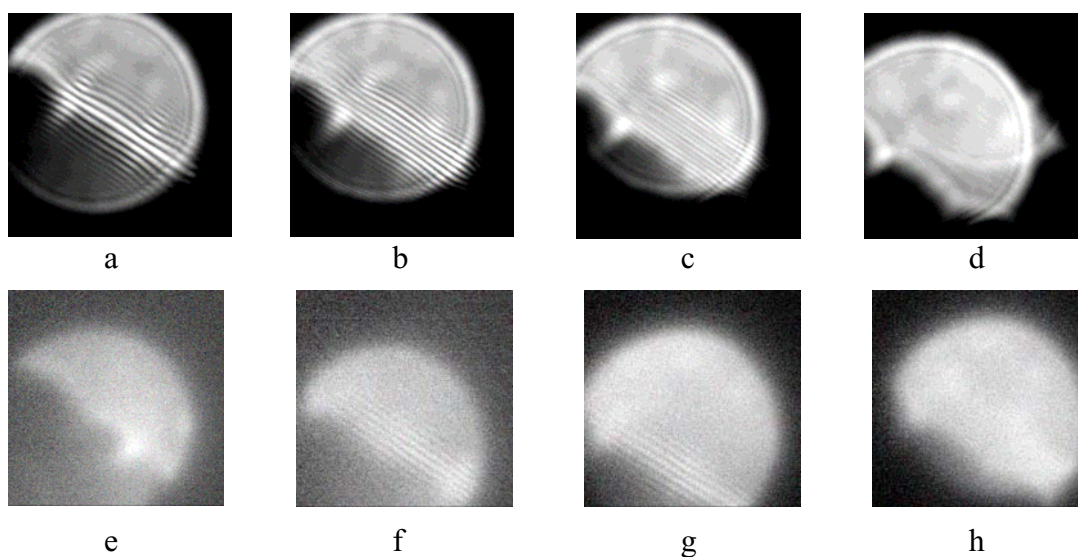


Fig. 3. a-d are zero loss Kossel-image holograms having an increase in biprism voltage of 25 eV, 30 eV, 35 eV and 45 eV, respectively, and e-f are plasmon loss Kossel-image holograms having an increase in biprism potential of 25 eV, 29 eV, 30 eV and 32 eV, respectively. The zero loss electrons have a much greater coherence width, δ , than the plasmon loss electrons.