The contribution of phonon scattering to HREM

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Introduction

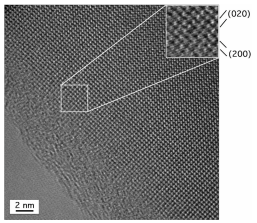
It has been suggested that phonon scattering may make a significant contribution to lattice images and thus may be the cause of the experimentally measured low contrast, often known as the Stobbs factor.

Here we use energy filtered electron holography to measure the proportion of phonon scattering and its effect on lattice fringe contrast in high resolution images of ZrB_{12}.

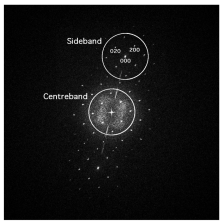
The lattice image reconstructed from the hologram fringes, the sideband, is formed by interference with a reference wave and thus contains only elastic scattering.

The normal lattice image, the centreband, (formed by filtering out the hologram fringes) contains both elastic and phonon scattering. The holograms are energy filtered to ensure that the centreband contains no inelastic scattering.

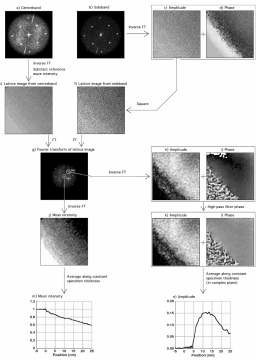
Measuring phonon scattering using holography



One member of a defocus series of energy filtered electron holograms of a ZrB12 crystal oriented close to an [001] zone axis. The inset enlargement shows the holographic interference fringes and the (200) and (020) lattice fringes of ZrB12.



Fourier transform of the hologram with the "centreband" and "sideband" marked. The two circles show the sizes of the apertures used when reconstructing the lattice images



Stages involved in the determination of mean intensity and lattice fringe amplitude profiles from holograms.

(a) and (b) Centreband and sideband of the hologram Fourier transform.

(c) and (d) Amplitude and phase of the hologram reconstructed from the sideband.

(e) Lattice image reconstructed from the centreband, after the intensity of the hologram reference wave has been subtracted.

(f) Lattice image calculated from the square of the amplitude image reconstructed from the sideband.

(g) Fourier transform of either the centreband or the sideband lattice image, and the masks applied to the Fourier transform for the subsequent steps in the procedure.

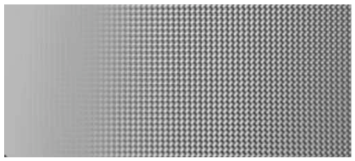
(j) Mean intensity of the lattice image, calculated by applying a mask to the 000 beam in (g).

(h) and (i) A similar mask applied to the 200 beam in (g) provides the amplitude (h) and phase (i) of the 200 lattice fringes.

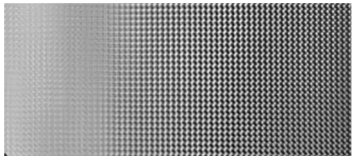
(k) and (l) Amplitude and phase after high-pass filtering the phase.

(m) and (n) The mean intensities and amplitudes of the lattice images (e) and (f), which are projected parallel to the edge of the sample in (j) and (k), are shown in the form of line profiles in (m) and (n).

Images



Defocus –50 nm
averaged over
7 by 21 unit cells

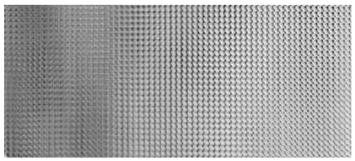


Elastic + phonon
(centreband)

black = 0
white = 1.5

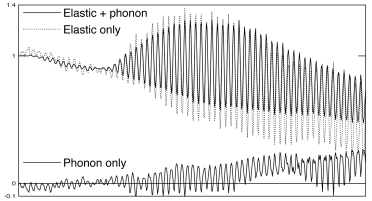
Elastic only
(sideband)

black = 0
white = 1.5



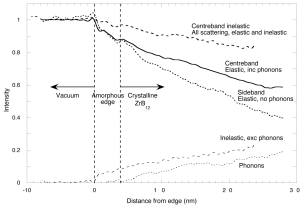
Phonon only
(centreband – sideband)

black = –0.3
white = 0.4



Line profile through
centre of image

Mean image intensity



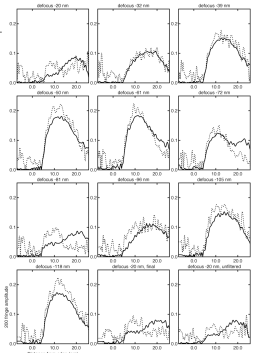
Mean intensities of the centreband images, sideband images and an unfiltered image plotted as a function of the distance from the specimen edge.

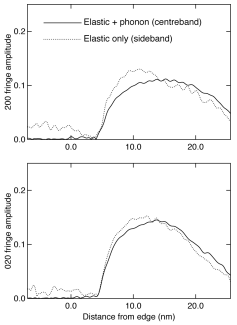
The mean image intensity shows that in the lattice image phonon scattering increases with increasing specimen thickness.

Lattice fringe amplitudes

200 lattice fringe amplitudes measured as a function of distance from the specimen edge for the centreband images (solid line) and sideband images (dotted line), for all ten defoci in the focal series and for the initial defocus repeated at the end of the series and an unfiltered image taken at the start of the series.

At low thickness sideband (elastic only) amplitudes are higher than centreband (elastic + phonon).





Average amplitudes of the 200 lattice fringes (top) and 020 lattice fringes (bottom), averaged over all of the defoci.

The lattice fringe *amplitude* is higher in purely elastic images than in images containing phonon scattering. For phonon scattering to reduce the lattice fringe amplitude the phonon scattering image must have opposite contrast to the elastic image.

Conclusion

For a sample whose thickness is typical of that used in HREM, phonon scattering contributes about 15% of the intensity in an energy filtered image.

Phonon scattering reduces the lattice fringe contrast to about 70%, corresponding to a Stobbs factor of 1.4

This is not sufficient to account for the observed lack of contrast in experimental lattice images, typically a factor of 2 to 3, especially in thin regions.

Phonon scattering combined with disorder from amorphous surface layers may be enough to account for the Stobbs factor.

Acknowledgements

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