Double crystal interference experiments

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In 1978, Rackham and co-workers observed remarkable and unusual diffraction patterns from an object that consisted of two perfectly aligned, simultaneously reflecting crystals that were separated by a gap [1]. They reported that they could obtain such double crystals routinely by ion bombardment. However, their specimen preparation method did not allow the the gap between the crystals to be controlled and the maximum gap that they achieved was on the order of 1-2 μm. A subsequent realization of a double crystal interferometer (DCI) was achieved using voids in spinel [2], again with a crystal spacing of below 1 μm. In 1995, Zhou and co-workers [3] presented new results by combining a Si double-crystal interferometer with convergent beam electron diffraction (CBED), taking advantage of a special structure formed at the broken edge of a Si [111] crystal. The gap was still on the order of 1 μm or below.

Here, we use focused ion beam (FIB) milling to build DCIs that have gaps of up to 8 μm and to provide better control over results that were previously obtained by chance. Figure 1 shows a top view scanning electron micrograph of such an interferometer. The gap separation is 800 nm. Both single crystal and double crystal areas have been patterned. Superimposed on the image is a sketch of the ray path of a convergent beam that illuminates the upper crystal, generating a transmitted beam and a diffracted beam. These beams, in turn, impinge on the second crystal, generating further transmitted and diffracted beams that overlap in the diffraction plane, resulting in the formation of interference fringes.

Figure 2 shows a comparison of diffraction patterns recorded from a single crystal (left) and two overlapped crystals (right). The spacing of the interference fringes depends on the electron wavelength, the excited Bragg reflection and the camera length. More impressive results are obtained when the orientation of the crystal is close to a zone axis. Figure 3 shows a comparison of a standard CBED pattern (left) with a complicated system of interference fringes arising from overlap of many diffracted beams (right). The interference phenomena in these patterns encode information about the crystal structure. The fringe spacing is inversely proportional to the gap width. Therefore, for an 8 μm gap, ten times more fringes are present in the overlapped discs and the interferogram can be considered as a hologram, as shown in Fig. 4.

As suggested by the first experimenters [1], accurate lattice parameter measurements can be made using a DCI when one crystal is the specimen of interest. If, instead, a specimen in inserted between the crystals or deposited onto the lower crystal, then it will be possible to obtain an off-axis Fresnel hologram with a reduced exposure time that is not affected by Fresnel diffraction from the edges of a biprism wire, as is the case when an electron biprism is used as an interferometric device. Moreover, the reduced exposure time due to amplitude division beam splitting could open the way to dynamic recording and processing of holograms.

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References:
Figure 1: Secondary electron image of two crystalline Si slabs, with schematic ray paths superimposed for a two beam condition. The scale bar is 1 μm.

Figure 2: Single crystal (left) and double crystal (right) CBED patterns recorded from Si, showing interference fringes in the double crystal pattern.

Figure 3: Single crystal (left) and double crystal (right) CBED patterns recorded from Si, showing interference fringes in the double crystal pattern due to overlapping diffracted discs in a near-zone-axis orientation.

Figure 4: CBED pattern recorded from a double crystal of Si with a gap of 8 μm. The inset shows the interference fringes at higher magnification.