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SIS-HOLZ Strain Measurements Through the Thickness of a SI Crystal

Mana Norouzpour[1] and Rodney Herring[1]

[1.] University of Victoria, Canada

Accurate measurement of strain plays an important role in the development of the electronic, photonic and physical properties of materials being the subject of intense work for decades. Knowing the strain in 3D at the atomic scale is highly desired for microelectronic devices as it can enhance the performance by increasing the electron and hole mobility known as strain-bandgap engineering. DBI (Diffracted Beam Interferometry) has enabled recovering the phase information related to the crystal typically lost during recording images. This DBI method uses the Self-interference of Split Higher Order Laue Zone (SIS-HOLZ) lines to form high contrast fringes when self-interfered (Fig 1) [1 - 6]. The retrieved phase provides information of the strain distribution through the thickness of the crystals along the path of the electron beam providing a new, and still only, method to determine the three-dimensional (3D) strain profile. Split HOLZ lines are well known for measuring strain with a remarkable sensitivity of 10^{-4}. The method complements CBED used to map the direction and relative magnitude of the displacement field in the plane perpendicular to the beam direction [7].

The Hitachi HF-3300v STEHM having Cs + Coma correction of its TEM mode operating at 200 kV was used to conduct the SIS-HOLZ experiments. The specimen was fabricated by the lift out technique using a Hitachi FIB-2100 from a wafer of $\mathrm{Si/Si_{0.8}Ge_{0.2}}$ supperlattices on a Si substrate. In order to avoid any strain modification, in addition to the tungsten deposition, a very low voltage beam (8-10 kV) was employed for the final cut. The specimen was then $\mathrm{Ar^{+}}$ ion milled to remove the FIB damage layer at a glancing angle of ±15 degrees at 5µA and 3kV for 3-4 minutes. The remaining surface radicals were removed using a Hitachi Zone Cleaner for 10 minutes on each side. A region of interest at 80 nm distance from the highly strained interface of Si and $\mathrm{Si/Si_{0.8}Ge_{0.2}}$ produced the split HOLZ line (Fig 2a). A biprism is inserted into the center and parallel to the split HOLZ line defocused by 6 micron in order to align the biprism and the virtual sources, S_1 and S_2, onto the same plane. An interfering biprism voltage of 4.5 V was applied to self- interfere the two halves of the split HOLZ line. The resulting interferogram (Fig 2b) was recorded by a 2K × 2K Ultrascan GIF camera at a camera length of 30 m. Finally the reconstruction of the digital phase image (Fig 2c) included using a Fast Fourier Transform (FFT) of the interferogram, filtering a side band and applying an inverse FFT of the sideband performed using Holoworks (Gatan) resulting in the phase profile (Fig 2d) used to determine the strain through the thickness of the Si crystal in the direction of the electron beam enabling a 3D strain measurement.

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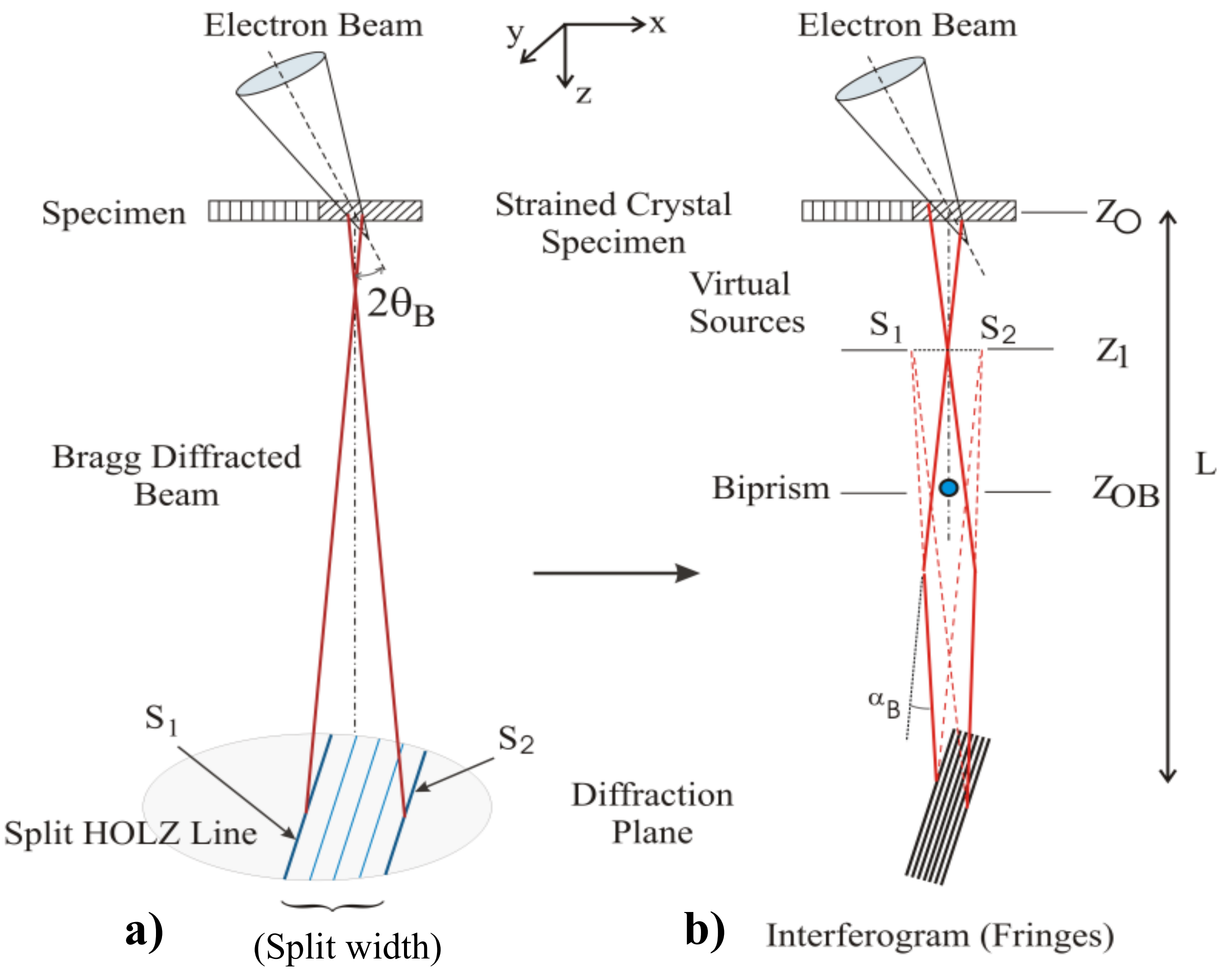

Figure 1. a) Schematic of DBI technique, b) Experimental split HOLZ line in the dark field mode, c) the formed interference fringes by DBI parallel to HOLZ line.

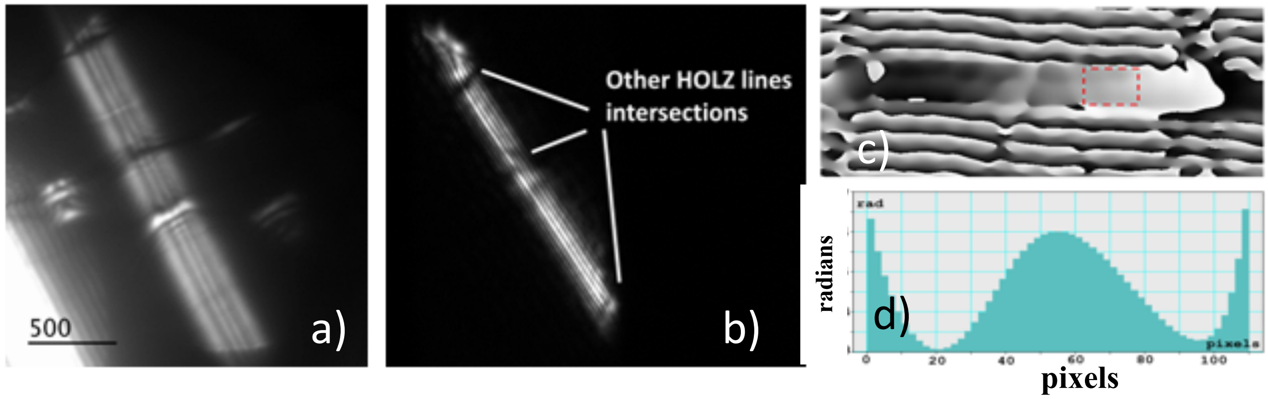

Figure 2. a) a 008 split HOLZ line, b) its self-interference using the electron biprism, c) the reconstructed phase (rotated) and d) its profile used to measure the through-thickness crystal strain within the Si close to the $\mathrm{Si}/Si_{0.7}Ge_{0.3}$ interface.