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Large Field of View Strain Characterization in a Scanning Transmission Electron Microscope Using a Designed Coherent Sampler

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With today's resolution and stability of the probe-corrected electron microscopes, it is possible to acquire a Scanning Transmission Electron Microscope (STEM) Moiré hologram by coherently interfering the 2D periodic scanning grid with a crystalline lattice [1]. The STEM Moiré hologram is a result of an undersampling artifact (aliasing) that modifies the spatial frequencies of the crystalline lattice into lower ones [2]. The structural properties of the crystalline sample embedded in the STEM Moiré hologram (such as the deformation field) can be retrieved using concepts from sampling theory. A simple shift in Fourier space transforms a Moiré wave vector from the STEM Moiré hologram into its corresponding crystalline wave vector. After applying the conversion, the Geometrical Phase Analysis method [3] is applied on the reconstructed crystalline wave vectors to map the 2D strain field on the entire STEM Moiré hologram [4]. The interest of STEM Moiré GPA (SMG) method is to break the limit of the classic application of GPA on oversampled High-Resolution STEM electron micrographs. The oversampling condition (minimum of two pixels per fringe) restricts the application of GPA to roughly 150nm in field of view (FOV). As a consequence, the SMG technique enables the mapping of the strain field in a crystalline material over a large field of view (up to a few micrometers in length) directly in STEM mode.

While the theory describes well the STEM Moiré hologram formation, the choice of sampling parameters (i.e. pixel spacing, scanning rotation) is not straightforward from the experimental point of view (Fig. 1 a), b) and c)). One main reason is that the evolution of the features present in the STEM Moiré hologram is dependent on both the structure of the crystalline sample and the 2D periodic sampler. In this study, we propose a generic procedure to determine a range of sampling parameters that optimizes the use of SMG for any single crystal material. First, the STEM Moiré hologram formation is simulated in Fourier space to map the distribution and the evolution of the Moiré reflections with different pixel spacing (Fig. 1 d)). Then, suitable sets of pixel spacings are determined by choosing the resolution of the strain maps (setting a minimum distance between reflections). If necessary, the scanning rotation is finally applied as a fine adjustment to extend the range of the suitable pixel spacing sets. The procedure is then tested on a simple InP/$InAs_xP_{1-x}$/InP sample grown by Molecular Beam Epitaxy. The SMG results (processed using STEM_Moire_GPA software [5]) are discussed and compared to other strain characterization methods such as Dark Field Electron Holography and HR STEM GPA (Fig. 2). In conclusion, SMG reveals to be a robust strain characterization technique easy to apply in any modern scanning transmission electron microscope [6].

References

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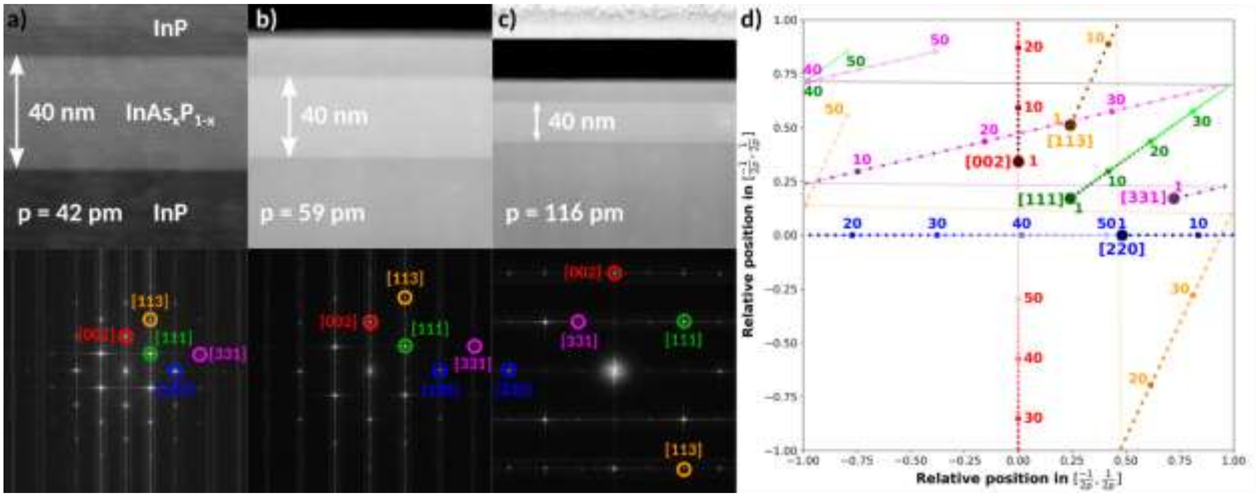

Figure 1: Evolution of several InP crystal reflections with different pixel spacing *p*. a), b) and c) STEM electron micrographs recorded with a pixel spacing *p* of respectively 42 pm, 59 pm and 116 pm with their corresponding Fourier transform. d) Simulation of several InP reflection positions with a pixel spacing *p* varying from 50 pm (point #1) to 250 pm (point #50) with equal steps.

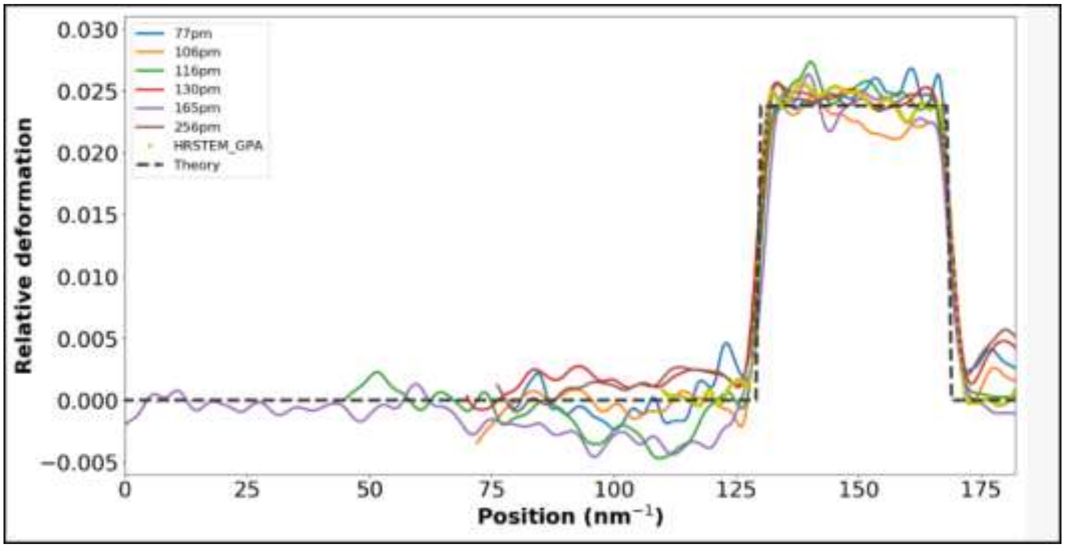

Figure 2: Relative deformation line profiles along the [001] direction in the InP/InAs$_x$P$_{1-x}$/InP sample extracted from SMG maps with different pixel spacing and from HRSTEM GPA maps.