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Computer Vision Techniques Applied to the Reconstruction of the 3-D Structure Dislocations.

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Computer-vision, nowadays well integrated into electron microscopy sciences, is becoming an essential implement for the advancement of this field, in particular to take the most advantage of the cutting-edge electron microscopes. Computer vision techniques can be applied for automated detection and segmentation of structures in 2- and 3-D micrographs and 3-D reconstruction, as well as for deriving quantitative data from electron microscopy data [1-3].

3-D reconstruction of one-dimensional crystal defects called dislocations reveals key information about their network geometry and dominant interaction mechanisms [4]. Conventional tomography techniques in transmission electron microscopy (TEM) usually use a tilt-series of projections to retrieve the 3-D structure of many objects, including dislocation lines, through different reconstruction schemes [5]. The linear shape of dislocations can be incorporated as an important prior knowledge to lower the number of images that are needed for a reliable reconstruction.

In this contribution, we integrate several computational technologies including machine learning, segmentation methodologies, epipolar geometry, and triangulation to develop an efficient method for multi-view 3-D reconstruction of dislocation lines. We use state-of-the-art convolutional neural networks, specifically a U-Net, to first delineate dislocations and subsequently finding corresponding points as optical flow [6]. 3-D reconstruction is performed using an affine camera model estimated from point correspondences.

The strength of this method is experimentally demonstrated on the reconstruction of dislocations using bright-field, weak-beam and high-angle annular dark-field S/TEM images. As demonstrated in figure 1, dislocation lines were accurately traced in the 2-D BF-STEM images of a heteroepitaxial gallium nitride (GaN) membrane. Our 3-D reconstruction algorithm employed well-established computer vision techniques to match contours across images and to infer their 3-D shape. Finally, the 3-D configuration of these dislocations was reconstructed using these two images whose viewing directions are separated by only 3.2° [7]. The algorithm also takes the specificity of the setup into account by introducing customized smoothing techniques based on Gaussian filters of different sizes to overcome the non-homogeneous nature of the noise along different axes. The experiments that have been performed on real and synthetic data assert the approach is able to reach a significant precision in the 3-D reconstruction of dislocations lines even using a single pair of stereo images with a stereo tilt angle that spans from a few to some tens of degrees [7-9].

References:

[1] A. Lucchi *et al*, IEEE Transactions on Medical Imaging **34** (2015), p. 1096.
[2] C. Ophus, C, J. Ciston, C. T. Nelson, Ultramicroscopy **162** (2016), p. 1.
[3] L. Jones *et al*, Advanced Structural and Chemical Imaging **1** (2015), p. 1.
[4] M. Tanaka *et al*, Scripta Materialia **59** (2008), p. 901.
[5] P. A. Midgley, R. E. Dunin-Borkowski, Nature Materials **8** (2009), p. 271.
[6] O. Ronneberger *et al*, Medical Image Computing and Computer-Assisted Intervention (2015) p. 234.
[7] E. Oveisi *et al*, Submitted to Scientific Reports.
[8] E. Oveisi *et al*, Submitted to Ultramicroscopy.

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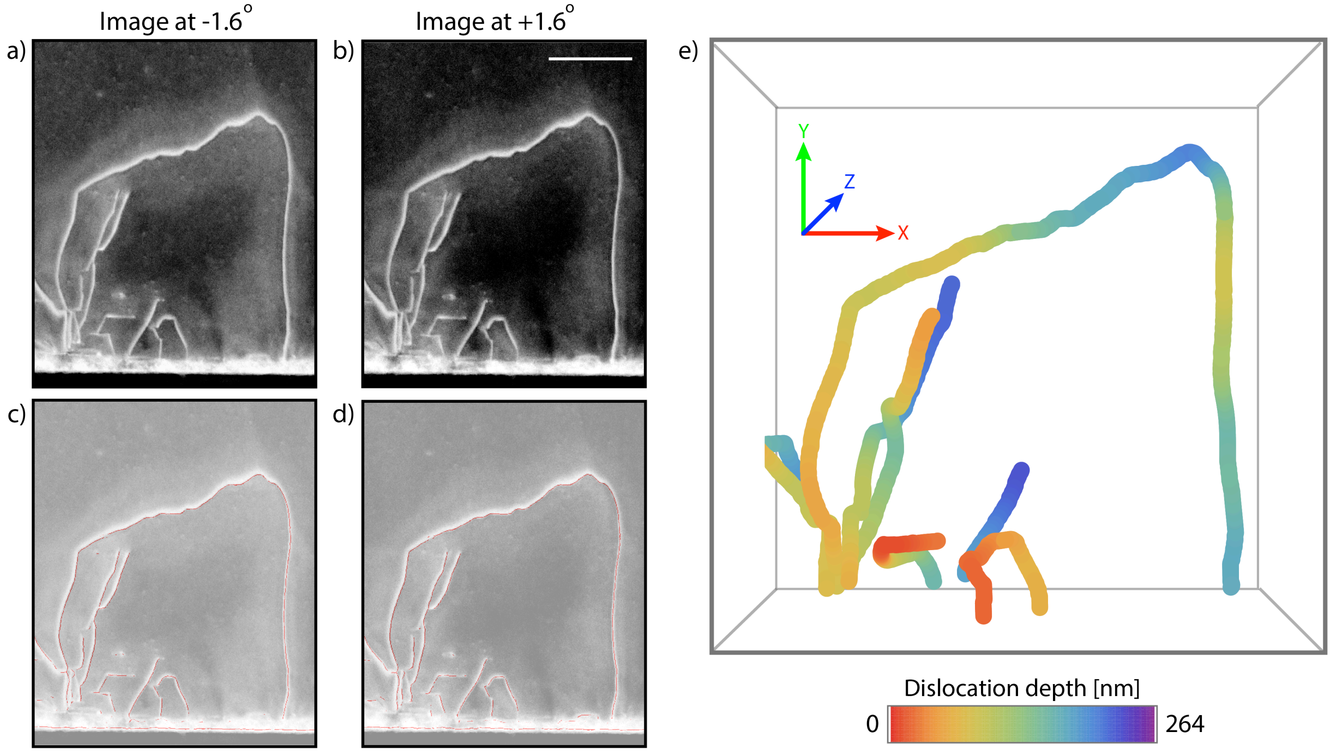

Figure 1. 3-D reconstruction of dislocations in the GaN layer of an InAlN/GaN-based heteroeptaxial membrane using stereo images with 3.2° tilt between them. **a,b)** Bright-field STEM images (inverted contrast) at -1.6° and +1.6° tilt. Scale bar, 200 nm. **c,d)** Traced dislocation lines are superimposed on the images **(a)** and **(b)**. **e)** Reconstructed dislocations lines. The colour code indicates the depth of each dislocation segment.