Optimization of Two-Dimensional Scanning Moiré Patterns for Strain Mapping by Adaptive Sampling

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Scanning Moiré fringes arise when the scan grid of a sharp electron probe creates an interference pattern with the atomic potential of a crystal, which has been described by Su and Zhu [1]. As the frequency of the fringe pattern equals the difference frequency of scan grid and crystal lattice it 'amplifies' deformations. This was used by Kim et al. to measure strain in one direction in SiGe/Si layers [2]. More recently, Pofelski et al. have elaborated on the theory of these Moirés and used geometric phase analysis and their framework to determine 2D strain components [3].

In the following we use adaptive sampling to obtain optimized 2D scanning Moiré patterns for strain analysis. By changing the scan grid of the electron probe from a typical square pattern to a different geometry it is possible to fine tune the Moiré pattern as to have beneficial symmetry and frequencies [4]. This is demonstrated in Fig. 1 where (a) shows a typical HR-HAADF image of Si in [110] ZA and (c) after changing the scan grid to a rectangular shape with sizes that 'counteract the symmetry of the crystal ZA. The corresponding power spectra in (b) and (d) show how the image symmetry changes. This can then be used to tune 2D scanning Moiré patterns of any kind of crystal and ZA.

Fig. 2 (a) depicts a 2D Moiré pattern of a SiGe transistor in [110] ZA that was obtained using this method. The pattern can be tuned to compromise between spatial and strain resolution by slightly changing the sampling and thus the Moiré frequency. Using geometric phase analysis the Moiré spacings and angles in two crystallographic directions can be extracted. These can be used to go back to the 2D deformation of the sample and finally the strain. The result is depicted in (b)-(e) where the strain components of the device are shown (from an image with smaller Moiré spacings than (a)). The strain precision is around 6·10-4 with a resolution (sampling) of 2.09 nm horizontally and 1.46 nm vertically (rectangular due to the deformation of the scan). The fast acquisition and possible large fields of view render this method a candidate for strain mapping for the semiconductor industry.

[1] D. Su and Y. Zhu, Ultramicroscopy 110, 229 (2010).

[2] S. Kim et al., Appl. Phys. Lett. 103, 033523 (2013).

[3] A. Pofelski et al., Ultramicroscopy 187, 1 (2018).

[4] B. Haas, PhD thesis, Grenoble (2017).

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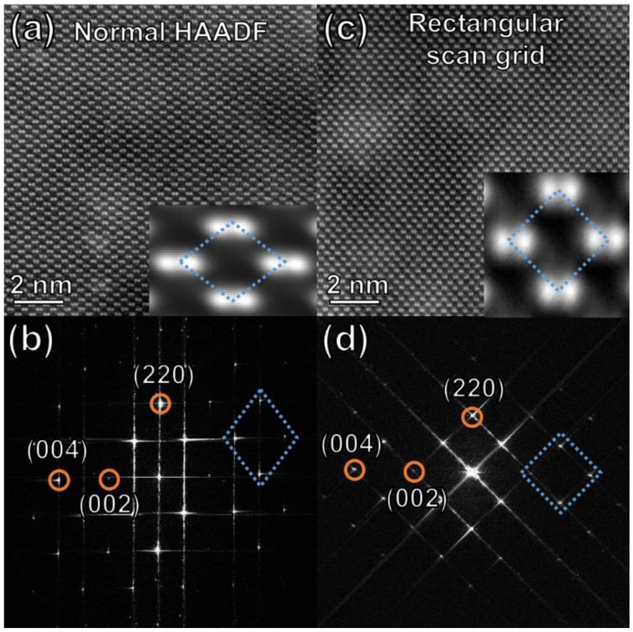

Figure 1: (a) HR-HAADF image of [110] Si with an enlarged view as inset and the corresponding power spectrum in (b). (c) Changing the scanning to make the scan grid rectangular results in a different image and the diffractogram (d) clearly shows the obtained square lattice from (220) and (002) planes.

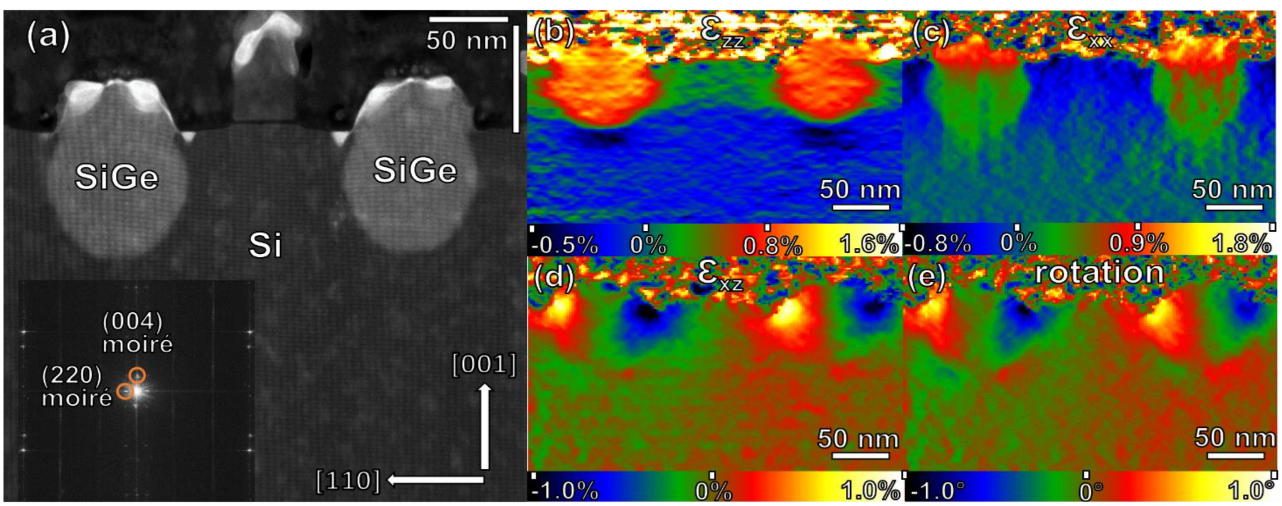

Figure 2: (a) 2D scanning Moiré pattern of a SiGe transistor in [110] ZA obtained by adapting the scan grid. (b)-(d) 2D strain components of the device retrieved from Moiré spacings using geometric phase analysis. The strain precision is around $6{\cdot}10^{-4}$.