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Sequential tilting 4D-STEM for reliable electric field mapping across junctions

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Background incl. aims

Momentum-resolved scanning transmission electron microscopy (MRSTEM) is an increasingly popular technique to map nanometer range electric fields [1]. Such measurements are of particular importance for device structures, for example pn-junctions [2], in order to understand functional properties of devices at the relevant length scales. To measure electric fields, MRSTEM determines the momentum transfer from an electric field to an electron beam via the deflection of the electron beam. However, relating the momentum transfer to the electric field is significantly complicated under dynamic diffraction conditions. Therefore, strategies are required to reliably determine electric fields from MRSTEM measurements under dynamic diffraction conditions. One such approach is tilting the incident beam relative to the sample in order to probe different diffraction conditions [3]. In this contribution, we explore how tilt patterns can be optimized and how MRSTEM based electric field mapping can be improved.

Methods

To get full control over the beam tilt, we use a custom developed beam tilt procedure. Here, we first calibrate the beam tilt and de-tilt coils of our microscope to allow us setting arbitrary beam tilts in STEM mode. In a second step, we calibrate the beam shift pivot points to obtain negligible beam shift at the sample for different beam tilts. These alignments enable us to repeatedly scan over the same sample region with different beam tilts, generating the data required for detailed MRSTEM analysis. We apply this acquisition technique to high quality lattice-matched AlAs/GaAs multi layers. These samples have the advantage that the mapped momentum transfer originates almost exclusively from a change of the mean inner potential across the materials interface, making assessment of the MRSTEM results easier.

Results

To analyze the effects of beam tilt on MRSTEM measurements, we scan across the AlAs/GaAs interface as shown in Fig. 1 a). We apply the scan patterns shown in Fig. 1 b), both consisting of 61 beam tilts, by sequentially scanning across the interface 61 times and collecting MRSTEM data for each tilt. Fig. 1

c) compares the measured electric fields for the annular and the full circle tilt patterns. The full circle pattern results in a sharp peak at the interface and an electric field close to zero away from the interface, as expected for AlAs/GaAs layers, while the electric field measured with the annular pattern shows stronger deviations from the expected behavior. In addition, we also have access to diffraction patterns of individual beam tilts. Fig. 1 d) shows the electric fields mapped with the beam tilts marked in Fig. 1 b). The strong differences for different beam tilts demonstrate that having access to this information is essential to improve MRSTEM measurements.

Conclusion

Our results show that full control over beam tilts and the capability to create arbitrary tilt patterns has a huge potential to improve the quality and reliability of MRSTEM measurements. Particularly, the sequential acquisition of the data, giving access to individual beam tilts, is very beneficial for post-acquisition data examination and thus being fully consistent with the spirit of 4D-STEM of using as much information encoded in the data as possible.

Fig. 1: a) shows an annular dark field STEM image of the investigated AlAs/GaAs junction. The green line indicates the region scanned for field mapping. b) shows schematics of annular and full circle beam tilt patterns in reciprocal space, both consisting of 61 individual beam tilts with a maximum tilt angle of 7 mrad and a beam semi-convergence angle of 1 mrad. c) shows the electric field profiles obtained for the tilt patterns in b) scanned along the line indicated in a). d) shows electric field profiles of the same scan but for individual beam tilts. The corresponding beam tilts are indicated by colored circles in b).

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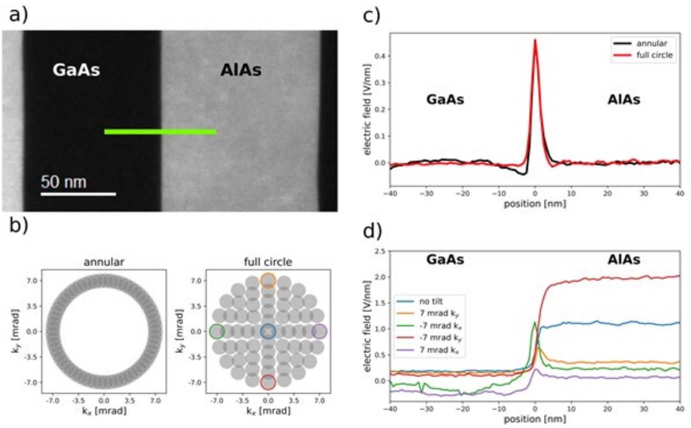
Graphic:



Keywords:

4D-STEM, momentum-resolved STEM, PED, heterojunctions

Reference:

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