Simultaneous E-Field & Strain Mapping by Precession Electron Diffraction

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Measuring electric fields by means of scanning electron probes has recently gained a lot of momentum [1-3]. While techniques that rely on segmented detectors are based on oversimplified models [1-2], pixelated detector based methods that were proposed so far require extremely thin specimens [3].

In this abstract, we demonstrate a new method to reliably measure the electric field and the strain of a specimen simultaneously from the same data set (patent pending). By combining a nano-beam setting (convergence angle of around 2 mrad) with precession of the beam in a hollow cone, the E-field can be measured avoiding diffraction artifacts even for thick specimens with a probe size of less than 1 nm. The capabilities of this technique are investigated on piezoelectric specimens, where the simultaneous measurement of strain and E-field are especially interesting.

Using the prototype FEI Epsilon software for beam precession in a Titan Themis microscope together with a FEI Ceta CMOS camera, scanning nano-beam precession diffraction patterns are acquired with typically 2 mrad convergence angle, 0.3 precession angle, 100 pA beam current and 150 ms exposure time as 512 pixel images. The patterns are subsequently analyzed with a homemade DigitalMicrograph plugin which determines the strain from the distance of diffraction discs as extracted by means of auto-correlation. The E-field is measured from tracking of the central diffraction disc (which exhibits a homogeneous contrast due to precession) using template-matching. This has significant advantages in robustness over center-of-mass based techniques.

In Fig. 1 (a) an HAADF image of an a-plane grown GaN/AlN multi quantum-well structure in [0001] ZA is shown. In (b) one of the 50x50 diffraction patterns of the 4D-STEM series is depicted. A virtual HAADF image of the mapped region can be seen in (c). The shear, strain in growth direction and perpendicular to it can be seen in (d)-(f). Three dislocations running along the c-axis and therefore along the ZA can be seen, especially in (d) and (f). The piezoelectric fields in the GaN/AlN layers along the growth direction is depicted in (g). The horizontal component is shown in (h) and clearly reveals piezoelectric fields of the disclocations from their strain state. When obtaining the E-field from center-of-mass measurements instead of template-matching as shown in (i) and (j) the result is clearly worse and no dislocations can be observed.

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[3] K. Müller et al., Nature Comm. **5**, 5653 (2014).

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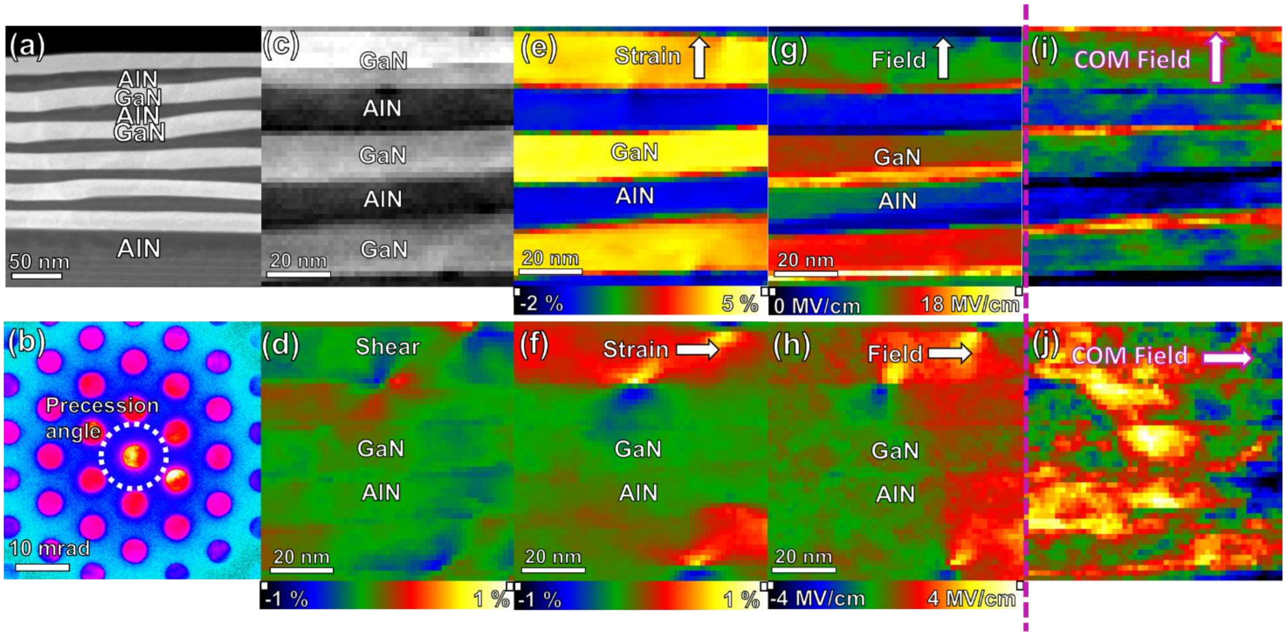

Figure 1: (a) HAADF image of the AlN/GaN sample and (b)typical diffraction pattern of the acquired 50x50 scan points 4D-STEM data set. (c) virtual HAADF image of the sampled region. (d)-(f) shear and strain in and perpendicular to the growth direction. (g)-(h) piezoelectric fields measured parallel and perpendicular to the growth direction. (i) - (j) E-fields obtained when using a center-of-mass approach.