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TEM observations on different length scales for characterization of AlN texture and columnar growth

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In the framework of the collaborative research center SFB 855 magnetoelectric (ME) materials are developed as strain-mediated piezoelectric-magnetostrictive nanocomposites for sensor applications. These sensors are considered as excellent candidates for biomagnetic interfaces enabling non-invasive medical imaging as magneto-encephalography or cardiography (MEG, MCG). For the piezoelectric component aluminum nitride (AlN) thin films exhibit outstanding performance [1]. The piezoelectric properties of AlN are directly associated with the crystal orientation and thus the morphology. For sensor applications highly c-textured films are desired with the film normal parallel to the polar crystal axis [0 0 0 1]. Modern TEM techniques, particularly automated crystal orientation mapping (ACOM) allow a detailed investigation of the morphology at different lengths scales ranging from nano- to the micron size [2,3]. The dominant color (figure 1b) and the diffraction patterns of the marked areas prove a columnar growth of AlN in [0 0 0 1] direction. However, several columns are misaligned from [0 0 0 1] orientation. These morphological defects can also be identified by PFM (piezo-response force microscopy) measurements from similar regions but on larger scale. Furthermore, a closer inspection of the orientation maps of figures 1c-d shows that the azimuthal rotation of the columns around the [0 0 0 1] direction is not subject to any restriction. Intrinsic features of the rotation at the grain boundaries and defect structures such as stacking mismatch boundaries (SMB, [4]) can be analyzed quantitatively by high resolution microscopy and (precession) electron diffraction. Moreover, a detailed study on defect structures was performed along the basal view ([0 0 0 1] zone axis. As depicted in the HRTEM micrograph in figure 2a, domain boundaries appear as strongly pronounced periodic contrast along the {2 -1 -1 0} planes (see also correlated FFT). The enlarged view of the domain boundary shows a convincing agreement between experimentally obtained and simulated high resolution contrast. In figure 2b and 2c, the polyhedral representation of the AlN structures are compared for the defect-free and the domain boundary case. In the bulk wurtzite type structure, the AlN tetrahedrons are linked by common corners. At the interface of the domain boundary the tetrahedrons share one common edge.

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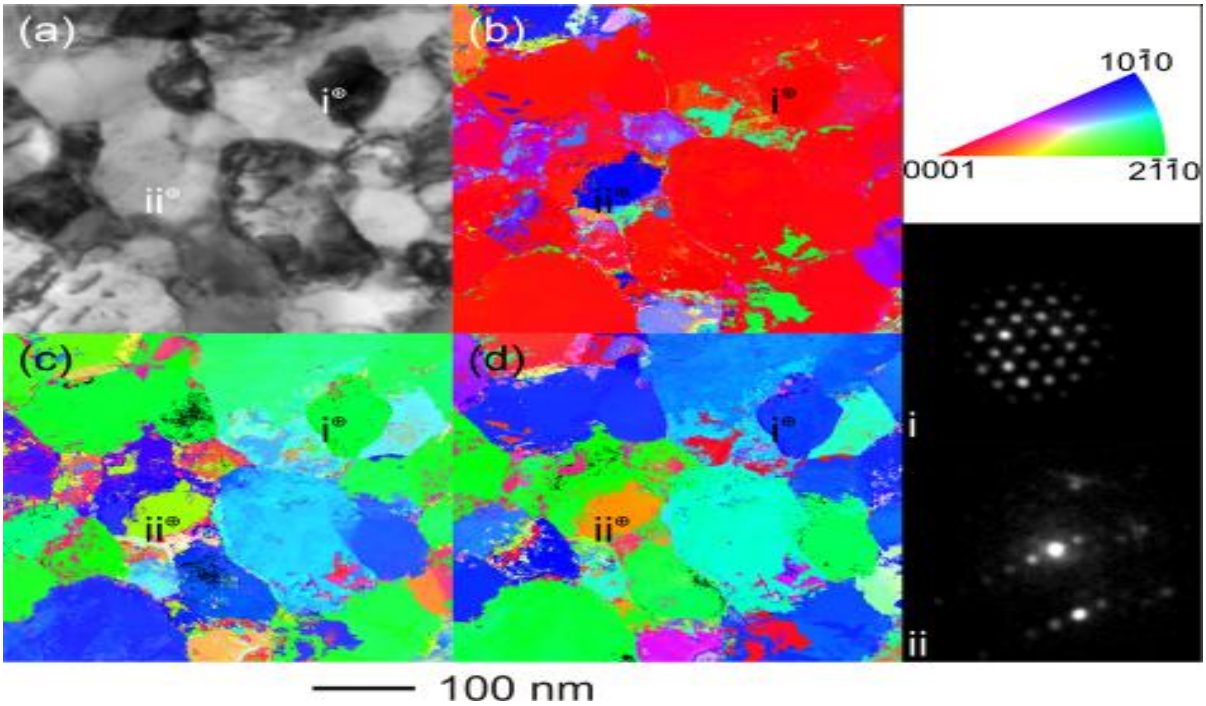

Figure 1. Automated crystal orientation mapping of AlN along the basal view. (a) Virtual bright field image. Orientation map along the out-of-plane z-direction (b), and two in-plane directions (c) x-direction, (d) y-direction. (Right) Color code of the stereographic triangle (hexagonal point group: 6*mm*) for all three maps. Diffraction patterns of area i) and ii).

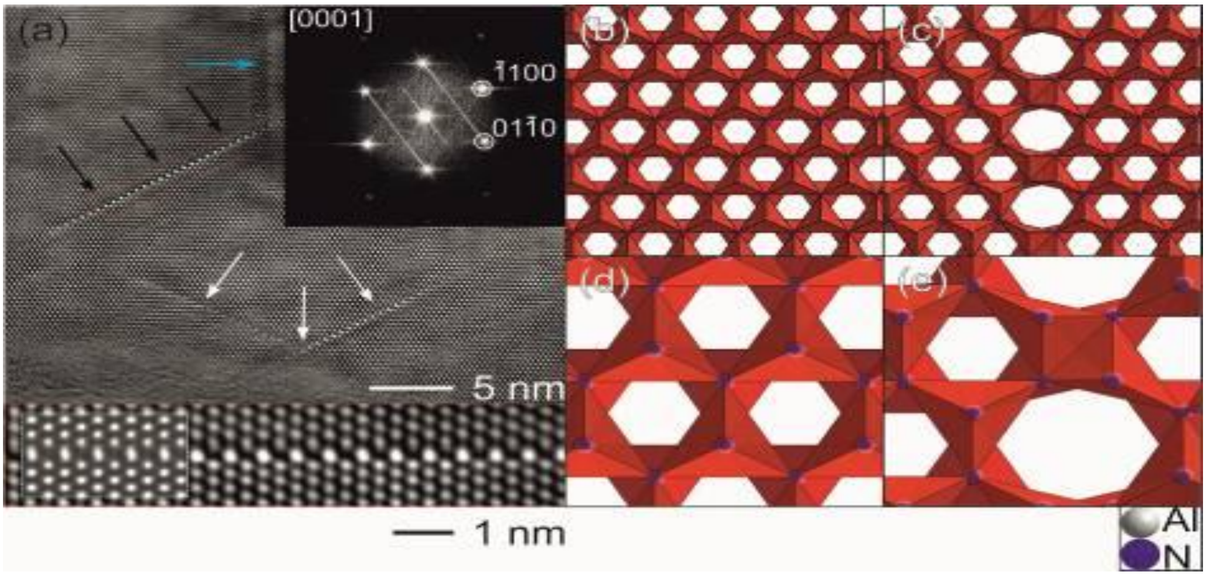

Figure 2. (a) HRTEM micrograph along the [0 0 0 1] zone axis with inserted FFT. Arrows mark the stacking mismatch boundaries. The enlarged panel at the bottom shows a stacking mismatch boundary with a simulation as inset (objective lens defocus | specimen thickness) of (-45 nm | ~5.5 nm). Schematic for the defect-free bulk structure (b) and the structure at the SMB (c) along the [0 0 0 1] zone axis. (d) and (e) corresponding enlarged views.