Single Crystalline Germanium as Calibration Standard in NPM-Machines: Microscopic Investigations

Th. Kups, U. Schadewald, E. Remdt, L. Spieß

Ilmenau University of Technology, Institute of Materials Engineering and Institute of Micro- and Nanotechnologies, Department Materials for Electronics, PO Box 100565, Ilmenau, Germany.

thomas.kups@tu-ilmenau.de
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Investigations on Nanopositioning and nanomeasuring machines (NPMM) like the one developed within the SFB 622 at the Ilmenau University of Technology [1] are aimed at measurement and manipulation of materials on a nanometer-scale. This requires an exact positioning of the used tools or Atomic Force Microscopy (AFM) tips and the possibility to retrieve a small area of interest (nm) on a large sample (µm – mm). These demands are fulfilled by using markers with a special geometry and/or exactly known dimensions. Actual markers consist of µm-scale structures cut by focused ion beam technique [2]. To gain smaller markers and references the intrinsic crystallographic properties of certain materials seem useful. In particular high grade single crystalline Germanium (Ge) with its diamond structure and a theoretical lattice plane distance of $d_{(220)}$ = 0.200000 nm [3] for the (220) lattice planes (standard conditions) shows great potential for creating nano-scaled reference markers by using the lattice mismatch to create steps on the sample surface [4].

In this work first investigations of single crystalline Ge by means of High Resolution Transmission Electron Microscopy (HRTEM), Atomic Force Microscopy (AFM), Convergent Beam Electron Diffraction (CBED) and High Resolution X-Ray Diffraction (HRXRD) are presented. TEM investigations were used to verify the purity and perfection of the used material as well as to determine the real lattice plane distance in comparison to the theoretical values gained by crystallographic tables [3]. All TEM investigations were performed with an uncorrected TEM FEI Tecnai 20S - TWIN (LaB_6, 200 kV, point resolution: 0.24 nm) calibrated with SiGe standards. Figure 1a shows a TEM image of Ge with (220) lattice planes and a Fast Fourier Transformation (FFT) of the marked area. The filtered inverse FFT was used to show the stack of lattice planes more detailed and to measure the lattice plane distance via an intensity profile plot, Figure 1c. The mean value measured over a length of 50 lattice plane distances was $d_{(220)} = 0.2007$ nm $\pm 4.10^{-4}$ nm. Comparative measurements performed with HRXRD showed a lattice distance of $d_{(220)}$ = 0.2000050 nm $\pm 8 \cdot 10^{-7}$ nm. Electron Diffraction was used to align the sample to the zone axis <100> as well as to determine the indices of the lattice planes, Figure 1b.

Further investigations will also include the preparation of steps on the Ge surface with defined vertical and lateral dimensions. By knowing the lattice mismatch between the (220) lattice planes and the surface it is possible to calculate the exact dimensions of this steps. These values will be used to calibrate AFM/NPMM by assigning the calculated values to a real measured AFM profile of the steps. Counting 5 steps within an AFM measurement would allow calibrating the AFM on exact 1 nm. Another possible application is the calibration of TEM magnifications by using the (220) lattice plane distance gained from HRXRD measurements.

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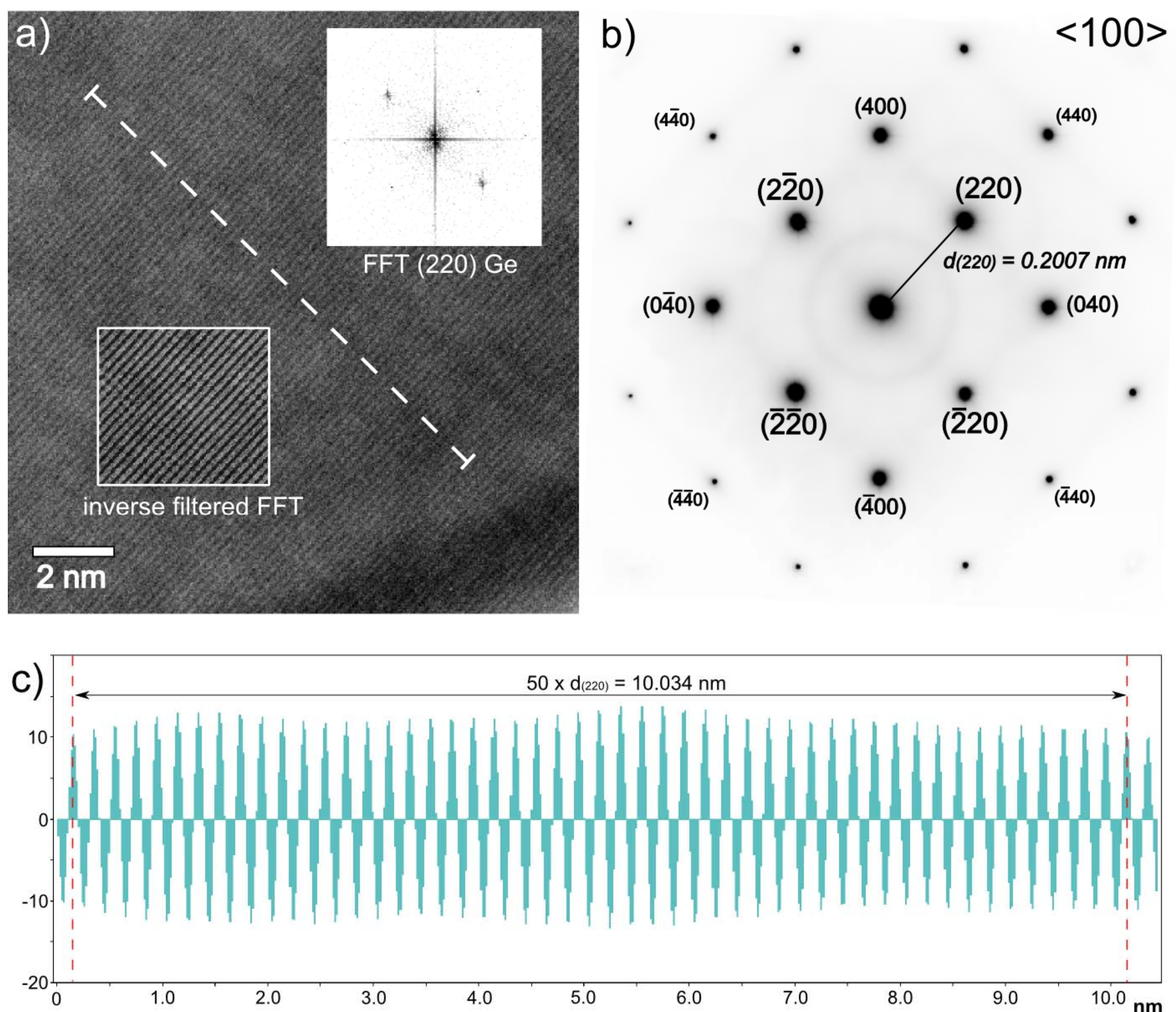

Figure 1. HRTEM image of Ge: **a)** box shows FFT of marked area; **b)** electron diffraction of a pattern of reciprocal lattice planes; **c)** intensity profile plot with a measured lattice plane distance of $d_{(220)} = 0.2007$ nm ± 0.0004 nm

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