Investigation of single-crystalline nano-whiskers by different TEM-methods

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Nano-wires and nano-tubes will form the building blocks of future nano-technology. So far only non-metals like carbon, ceramic and semiconductor nano-wire and nano-tubes have been synthesized with perfect, defect free atomic structure in freestanding, one-dimensional configuration. This work reports the synthesis of metallic, single crystalline, defect free and freestanding nano-whiskers. An initiator mediated filamentary crystal growth process based on the physical vapour deposition technique was developed. Metals with face centred (Cu, Ag, Au, Pd), body centred (Fe), and hexagonal (Co) crystal structure were synthesized successfully with the new technique. Typical diameters of the whiskers are 100 nm and lengths of up to 200 µm are observed, giving aspect ratios of up to 2000:1. Transmission electron microscopy studies revealed the absence of dislocations and grain boundaries in the volume of the whisker.

The shape of the filamentary crystals is governed by the surface energies of its confining crystal facets, being {111} and {100} crystal planes for the fcc metals. A growth model based on diffusion processes is proposed from results of preliminary growth studies. Apart studying the inherent properties of pure materials, whiskers can be used for fabrication of nano-composites from different materials. Tailored microstructures enable the formation of different configuration, such as axial or lengthwise multilayered whisker. A bridge between metallic macro-devices and structures down to those dominated by the quantum effect, and between metal and semiconductor devices may be formed by initiator mediated whisker growth.

Fig. 1a and 1b show scanning electron micrographs of two samples with nominal Cu whisker thicknesses of 45 nm and 200 nm, respectively, in freestanding, one-dimensional configuration. The investigation of the Cu whisker morphology is shown in Fig. 2a-e. A dark field TEM image taken in a two beam condition with diffraction vector $\mathbf{g_1} = (\bar{1}11)$ is presented in Fig. 2a. The growth direction of the whisker is $[01\bar{1}]$. No dislocations are visible, particularly no screw dislocations parallel to the whisker centerline are observed. In Fig. 2b and 2c relative thickness maps (using the log-ratio formula) are shown, where Fig. 2b has been taken before and Fig. 2c after rotation of the Cu whisker by 30° along the whisker axis. The corresponding projected thickness profile is drawn in the inset, and the dashed lines indicate projected thickness from Wulff calculations. In Fig. 2d the ideal whisker shape calculated by Cu free surface energies using the Wulff plot is shown in projection in the $[01\bar{1}]$ direction. The projection direction for Fig. 2b and 2c are labeled I and II, respectively. In Fig. 2e the Cu whisker shape model based on Wulff plot is presented, where the whisker side- and tip-facets are formed by {111} and {100} crystal planes.

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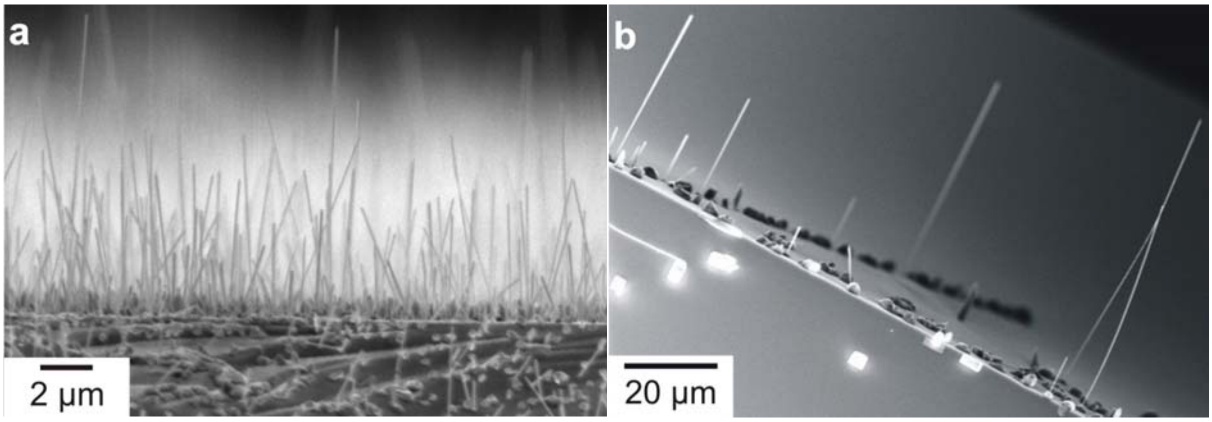

Figure 1ab. SEM images from Cu nano-whiskers

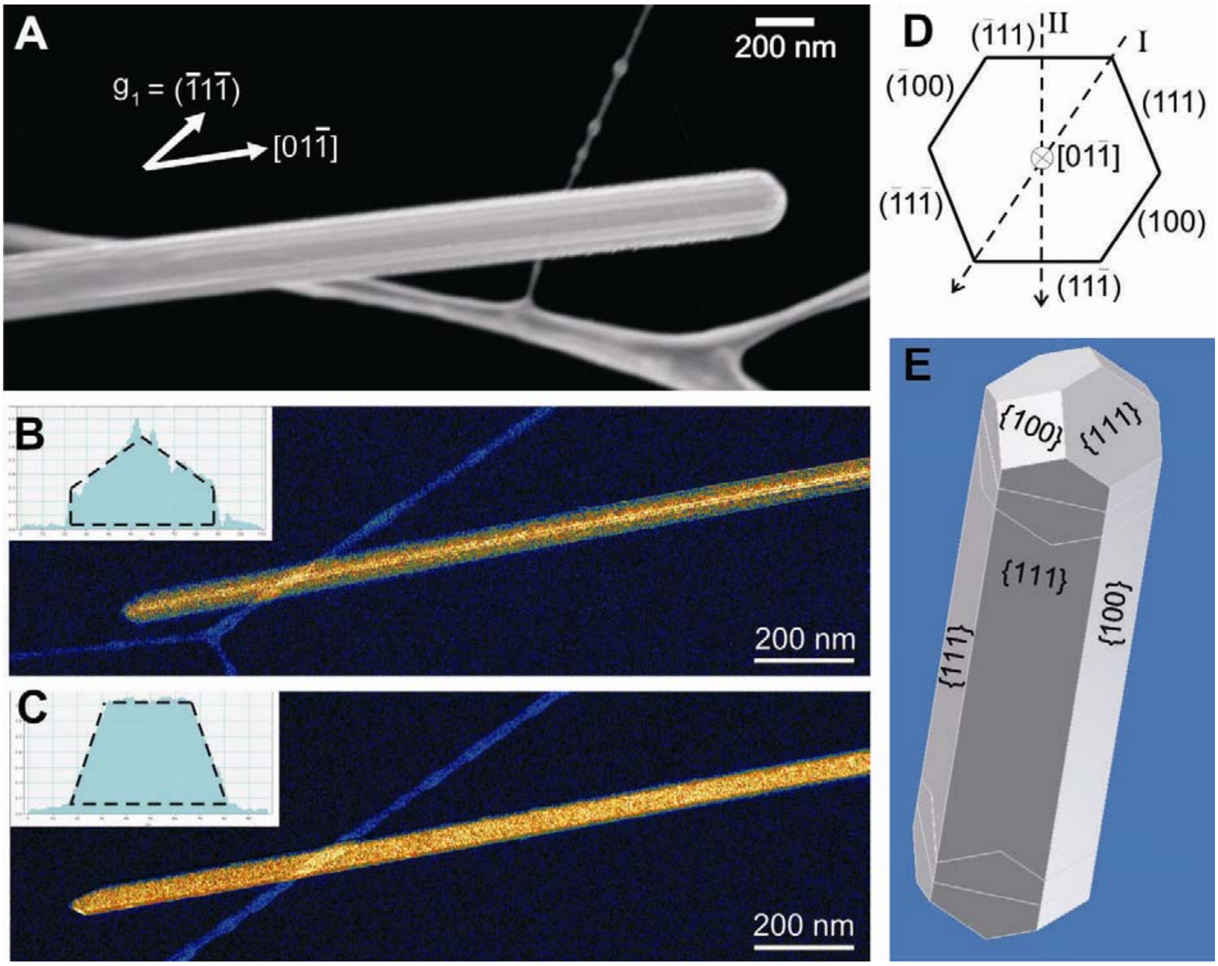

Figure 2a-e. Morphology of Cu nano-whisker

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