FILAMENTARY GROWTH OF METALS: MICROSTRUCTURE AND PROPERTIES OF (NANO-)WHISKERS

Gunther Richter, Max Planck Institute for Intelligent Systems, Stuttgart, Germany
richter@is.mpg.de

Key Words: Nanowhisker, physical vapor deposition, transmission electron microscopy, microstructure, metals

One dimensional nanostructures have the prospect to change the properties of materials used in contemporary devices. Physical properties change with dimension and size. Ceramics, semiconductor and carbon materials are easily synthesized as one dimensional structures with typical diameters of several nanometers and length-diameter ratios of 1000:1. However, only the metals as one of the oldest are difficult to fabricate in similar geometries. In contrast, micrometer diameter, millimeter length macroscopic metallic nanowires were grown and reported decades ago via the reduction of metal halides, based on a process described already in 1574.
Recently we developed a process to grow perfect defect and flaw free nanostructures with diameters of several ten nanometers, attached on substrates. The initiator mediated filamentary crystal growth process is based on the physical vapour deposition technique. Metals with face centered (Cu, Ag, Au, Pd, Ni, Co) crystal structure were synthesized successfully with the new technique. Typical diameters of the nanowhiskers are 100 nm and lengths of up to 200 µm are observed, giving aspect ratios of up to 2000:1. Traditional theories attribute the growth of whiskers with the presence of a screw-dislocation. However, studies by transmission electron microscopy did disprove this growth mechanism. An alternative growth mechanism will be discussed.
The formation of the nanowhiskers is controlled by diffusion processes of adatoms on the substrate surface and in the emerging interface under the growing nanostructures. By changing substrate material or sequencing different materials during growth allow for the formation of alloy nanowhiskers. This will be described exemplarily by Metal-Si and binary metal alloys (Au-Ni and Ag-Ni).
Ex and in situ experiments were carried out to investigate the microstructure and basic physical properties. Microstructure characterization of the nanowires by electron microscopy and x-ray diffraction revealed a perfect, flaw and defect free bulk and surface crystal structure. No dislocations, stacking faults, or grain boundaries were detected. The growth direction is generally along the <110> crystallographic direction of the face centered cubic lattice.
Investigations of the physical properties of the nanowhiskers focused on the mechanical properties and the onset of the plastic deformation. Following up from the perfect crystal structure the whiskers exhibit tensile strengths close to the predicted theoretical strength. The deformation is carried by partial dislocation nucleation and propagation and consequently by twin formation.
Correlating also with the low defect density in the nanowhiskers is the low conductivity. No size effect is observed but a constant conductivity, again, close to the theoretical limits. The magnetic domain structure was studied by electron holography. Only one single domain is present in ferromagnetic metallic nanowhiskers.

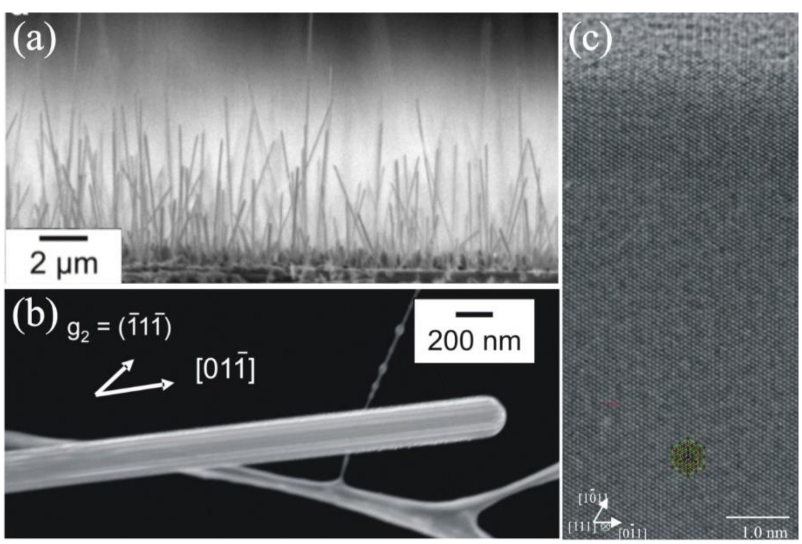

Figure 1 – SEM and TEM micrographs of Cu nanowhiskers