Relationship between the structural properties of ZnO nanowires and their modulus of elasticity

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1. INTRODUCTION

Properties of nanowires (NWs), instead of material, are driven rather by effects collocated with dimensions and topology, especially surface-to-volume ratio [1]. In the measurement of NWs, diameter plays a crucial role, as does crystal orientation and the level of crystal defects [2]. Measurement of a single entity at different degrees of crystallinity may bring more understanding to the role played by separate factors.

We present a method for a single specimen measurement of the ZnO NWs at different degrees of crystallinity. Thermal treatment is carried out on the NW attached to the marked substrate in order to measure mechanical parameters on the same element. Measurements were conducted with atomic force microscopy (AFM). The measurements compared the Young's modulus of the ZnO NW with a hexagonal wurtzite structure as the crystallinity of the sample improved.

2. MATERIALS

Arrays of ZnO NWs with typical diameters in the range of 100-200 nm and lengths of several or a dozen µm were obtained by using one-step anodic oxidation of metallic Zn foil in a sodium bicarbonate electrolyte and thermal post-treatment [3].

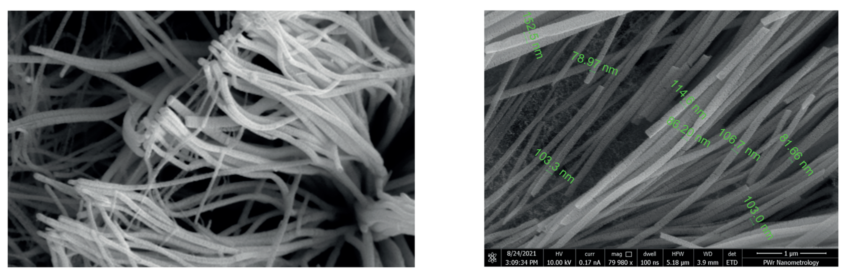
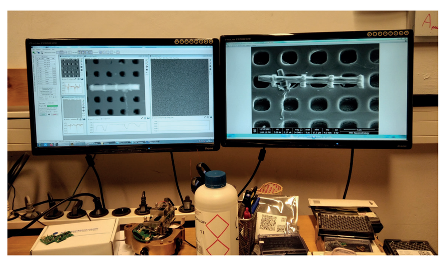


Figure 1. SEM images of ZnO nanowires

3. METHODS OF CHARACTERISATION

Figure 2. A dual-beam scanning electron microscope–focused ion beam (SEM-FIB) Helios Nanolab 600I from FEI equipped with the EasyLift nanomanipulator



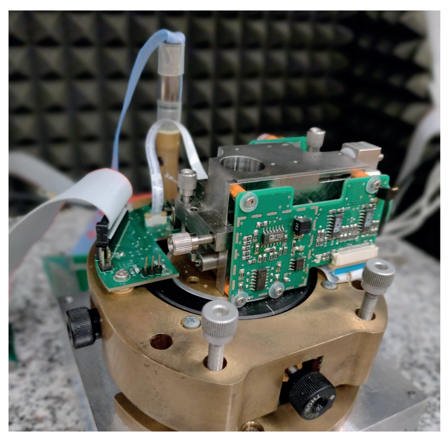


Figure 3. The self-built AFM system

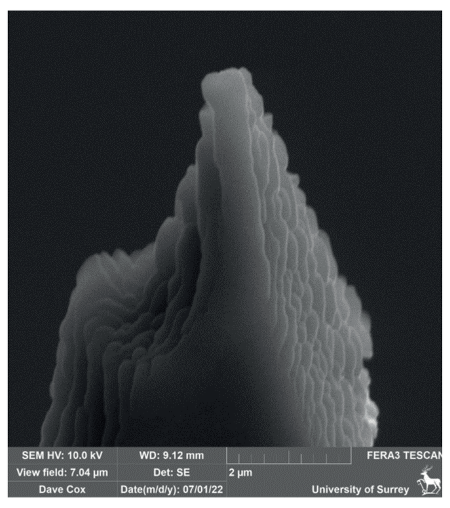


Figure 4. The monocrystaline conductive diamont tip for nanoindentation

X-ray diffraction on Panalytical Empyrean diffractometer in a 10–90° 2θ range with a step size of 0.013° at 21 °C. An X-ray source Cu-lamp (λ Kα = 1.5406 Å) was used.

4. NANOWIRES FEBID OPERATIONS

- Transfer to desired location
- Bonding with material deposited with focused electron beam
- Repeatable measurement of single and same nanowire

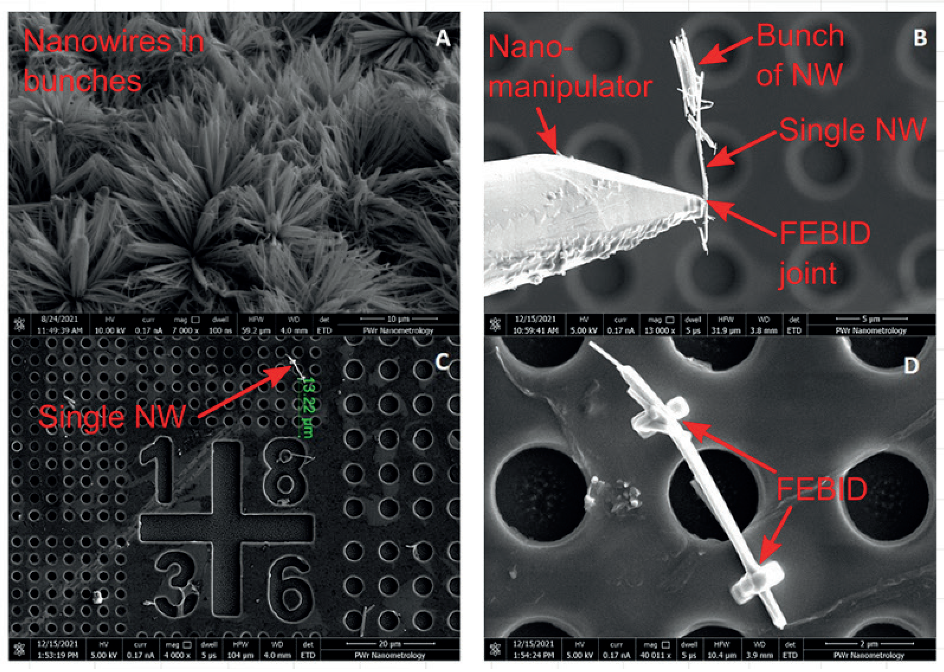


Figure 5. The process of transferring and mounting nanowires onto a substrate. Visible transport of the nanowire with manipulator and focused electron beam-induced deposition (FEBID) deposited mounting pads [4]

5.STRUCTURAL STUDIES

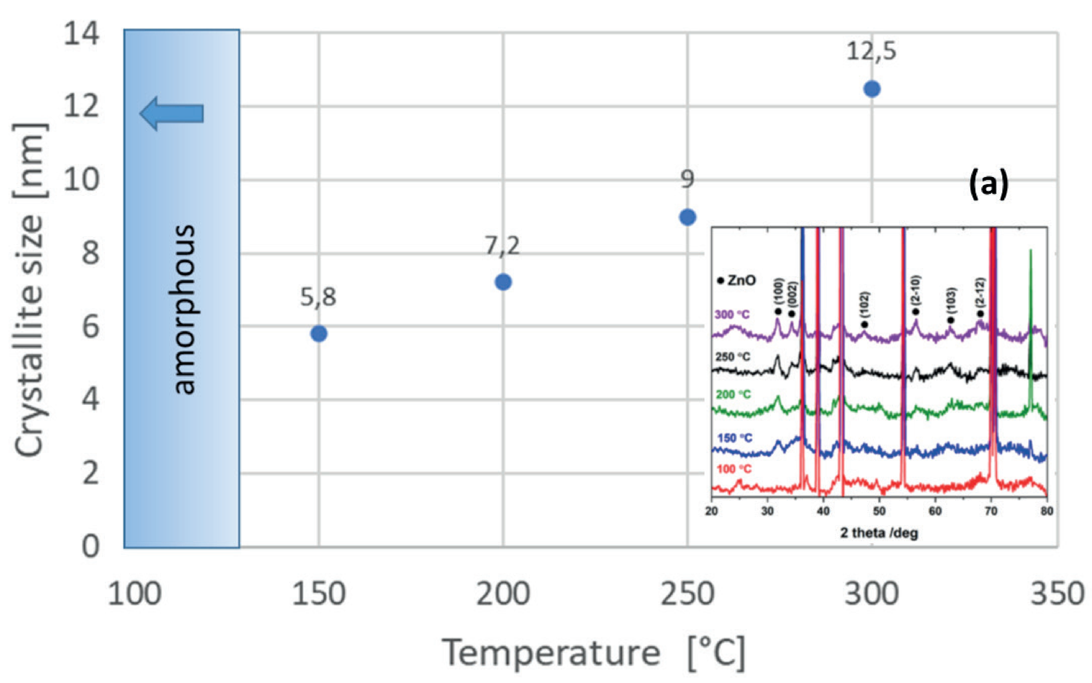
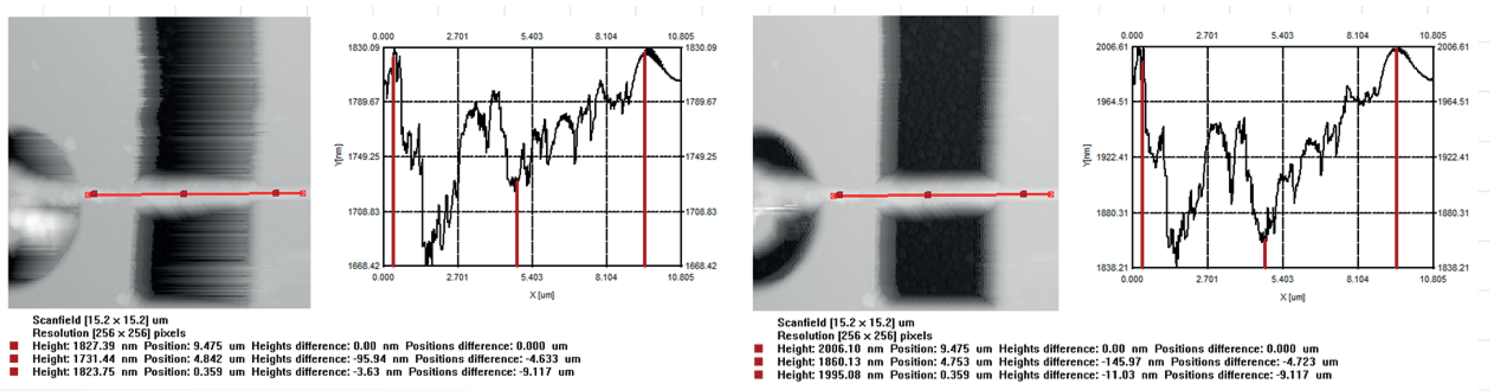
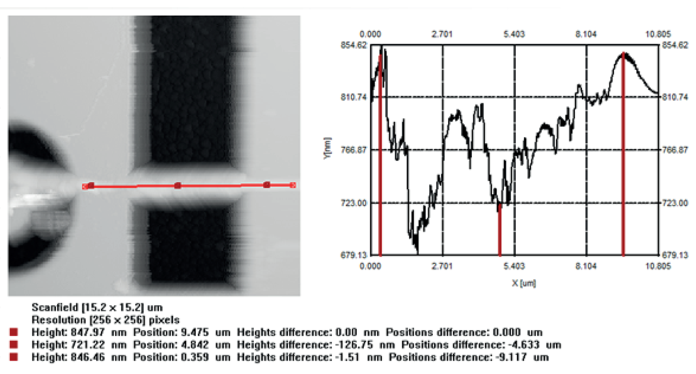


Figure 6. Estimated crystallite size determined for samples annealed at temperatures from 100 °C to 300 °C. (a) XRD patterns of anodic films after 2 h of annealing at temperatures from 100 °C to 300 °C [4]

6. MEASUREMENT OF MECHANICAL PROPERTIES ON SUBSTRATE





$$\Delta z = \frac{Fl^3}{6EI}$$

$$F = 900\ nN$$

$$l = 1{,}5\ \mu m$$

$$= \frac{\pi\phi^4}{64} = \pi \cdot \frac{300^4 nm^4}{64}$$

$$\Delta z = 24\ \text{nm}$$

$$E_{meas} \approx 53\ GPa$$

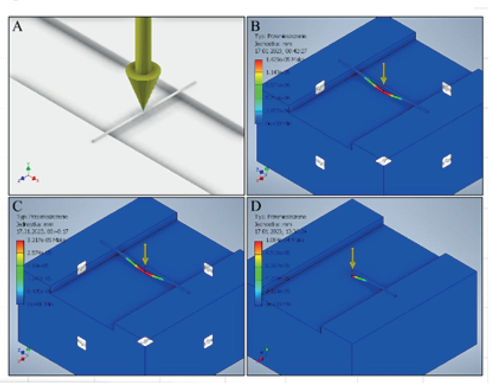


Figure 7. SEM Studies & Topography maps of nanowires acquired with given indentation forces. Height profiles along lines are shown accordingly. Cursors show heights in selected, repeated points [4]

7. SUMMARY

- The Young's modulus of single zinc oxide NWs with a hexagonal wurtzite structure annealed at different temperatures was measured using specialized substrates and atomic force microscopy.
- These studies are of great importance in establishing the synthesis-structure-property relationships that ultimately lead to the optimization of devices used in fields such as renewable energy (in harvesting devices), medicine (biomedical systems), and many others.

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https://www.ptb.de/empir2020/nanowires/home/

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