***IN SITU* ULTRAFINE FORCE MEASUREMENT WITH NANOWIRE BASED CANTILEVERS IN SEM**

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In nanomechanics the measurement of ultrafine forces becomes increasingly important for unravelling subtle details of elastic and plastic deformation processes. In particular, achieving high force resolution in combination with *in situ* imaging is a major challenge which is becoming exceedingly difficult with conventional methods. In this work, we introduce a novel systematic method to measure ultrafine forces using well-defined nanowires as cantilever beams *in situ* in the Scanning Electron Microscope (SEM). Forces can be measured variably in the range from micro-newtons (mN) down to femto-newtons (fN), depending on the chosen reference nanowire. The reference wires are picked with a manipulator tip without the use of FIB (see Figure 1 a).

We demonstrate the feasibility of the method by directly comparing the mechanical bending behavior (see Figure 1 d and e) of five-fold twinned and single crystalline silver nanowires which enable us to reveal fine differences in their intrinsic elastic properties. More precisely, the ultrasensitive force measurement is used for a highly precise determination of the effective Young`s moduli and experimentally confirm the effect of extended defects on the elastic properties of the nanowire.
In addition, the versatility of the method is demonstrated by studying fundamental physical phenomena at the nanoscale including attractive dispersive forces between metal nano-objects (see Figure 1 f) and, for the first time, restorative forces counteracting slip of individual dislocations.

To calibrate and characterize the force-sensing nanowires, *in situ* resonance measurements in the SEM are carried out (see Figure 1 c). In the evaluation of the vibrational behaviour a complete analysis of geometrical, damping and Fano resonance phenomena directly linked to the properties of the nanowire is performed. In order to obtain the geometric dimensions non-destructively, a 3D tomographic reconstruction of the nanowire is obtained (Figure 1 b). To complete the overall characterization, FIB lamellae are prepared after testing to analyze the precise dimensions, internal defects and surface structure of the nanowires using high resolution scanning transmission electron microscopy (HR-STEM).

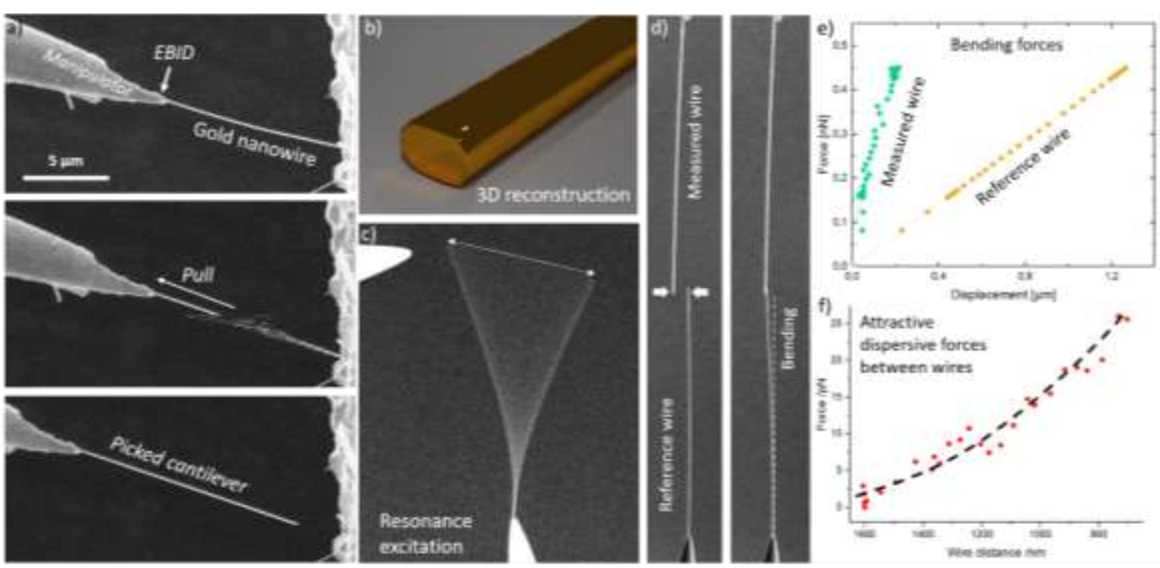

Figure 1: Nanowire force measurement approach. a) Picking process of gold single crystalline nanowires. b) 3D reconstruction of a picked wire. c) Calibration of the cantilevers is done by in situ resonance measurements. d) Using the nanowire cantilevers on other nanowires, bending forces (e) and attractive forces (f) can be measured.