Electronic Supplementary Material

Mechanical Properties of ZnO Nanowires Under Different Loading Modes

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1. AFM cantilever as load sensor

Figure S-1 shows the shape of the AFM cantilever used in the buckling tests. As can be seen from Fig. S-1(a), there are two long and two short cantilevers aligned on one side. In our experiments, NWs were pushed against the long cantilever, as shown in Fig. S-1(b). The deflection can be measured with the neibouring long cantilever as a reference. A similar setup was used for the tension tests.

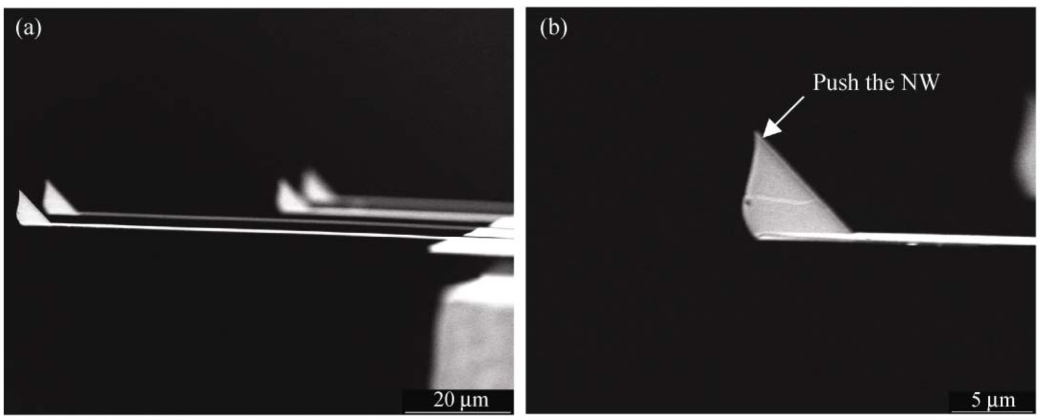

Figure S-1 (a) Low-maginification and (b) high-maginification SEM image of the cantilever for the buckling tests

2. Continuum models of elasticity size effects

1) Core–surface (or Miller–Shenoy) model

This model assumes that an NW consists of a core with elastic modulus E_c and a surface with so-called surface elastic modulus S. Under tension,

$$EA = E_c A + Sl$$

where A is the cross sectional area, and l is the perimeter length.

For a circular cross section, the measured (or effective) Young's modulus E under tension is given by

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$$E = E_c\left(1+\frac{S}{E_c}\frac{l}{A}\right) = E_c\left(1+2\frac{S}{E_c}\frac{1}{R}\right) = E_c + 4\frac{S}{D}$$

where R is the radius and D is the diameter of the circular cross section.

Under bending,

$$EI = E_c I + SK$$

where I is the moment of inertia and K is the so-called "perimeter moment of inertia" [1] of a circular cross section, which are, respectively, given by

$$I = \int_A y^2 \mathrm{d}A = \frac{1}{4}\pi R^4$$

$$K = \int_{\partial A} y^2 \mathrm{d}l = \pi R^3$$

Then the effective Young's modulus E under bending is given by

$$E = E_c\left(1+\frac{S}{E_c}\frac{K}{I}\right) = E_c\left(1+4\frac{S}{E_c}\frac{1}{R}\right) = E_c + 8\frac{S}{D}$$

2) Core–shell model

This model assumes that the NW consists of a core with elastic modulus E_c and a shell with elastic modulus E_s. Under tension,

$$EA = E_c A_c + E_s A_s$$

where A_c is the area of the core, and A_s is the area of the annulus as shown in the inset of Fig. 4(a).

For a circular cross section, it is written as

$$E\pi R^2 = E_c \pi (R-r_s)^2 + E_s \pi [R^2 - (R-r_s)^2]$$

The measured (or effective) Young's modulus E under tension is given by

$$E = E_c\left(1-\frac{r_s}{D}\right)^2 + E_s\left(2\frac{r_s}{R}-\frac{r_s^2}{R^2}\right)$$

or

$$E = E_c\left[1+4\left(\frac{E_s}{E_c}-1\right)\left(\frac{r_s}{D}-\frac{r_s^2}{D^2}\right)\right]$$

Under bending,

$$EI = E_c I_c + E_s I_s$$

For a circular cross section, it is written as

$$E\frac{\pi R^4}{4} = E_c\frac{\pi (R-r_s)^4}{4} + E_s\frac{\pi [R^4 - (R-r_s)^4]}{4}$$

Then the effective Young's modulus E under bending is given by [2]

$$E = E_{c}\left[1+\left(\frac{E_{s}}{E_{c}}-1\right)\left(4\frac{r_{s}}{R}-6\frac{r_{s}^{2}}{R^{2}}+4\frac{r_{s}^{3}}{R^{3}}-\frac{r_{s}^{4}}{R^{4}}\right)\right]$$

or

$$E = E_{c}\left[1+8\left(\frac{E_{s}}{E_{c}}-1\right)\left(\frac{r_{s}}{D}-3\frac{r_{s}^{2}}{D^{2}}+4\frac{r_{s}^{3}}{D^{3}}-2\frac{r_{s}^{4}}{D^{4}}\right)\right]$$

References

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