

Electronic Supplementary Material

Mechanical Properties of ZnO Nanowires Under Different Loading Modes

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Supporting information to DOI 10.1007/s12274-010-1030-4

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 neighbouring long cantilever as a reference. A similar setup was used for the tension tests.

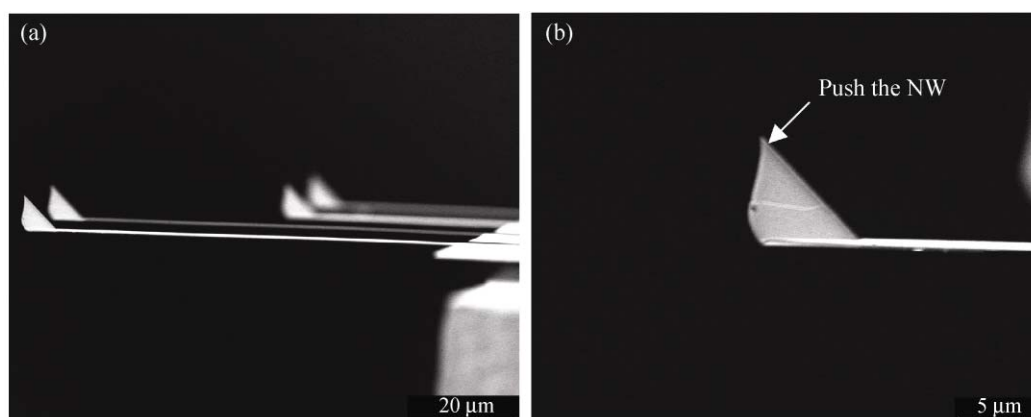


Figure S-1 (a) Low-magnification and (b) high-magnification SEM image of the cantilever for the buckling tests

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

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

$$I = \int_A y^2 dA = \frac{1}{4} \pi R^4$$

$$K = \int_{\partial A} y^2 dl = \pi R^3$$

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

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

or

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

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

- [1] Miller, R. E.; Shenoy, V. B. Size-dependent elastic properties of nanosized structural elements. *Nanotechnology* **2000**, *11*, 139–147.
- [2] Chen, C. Q.; Shi, Y.; Zhang, Y. S.; Zhu, J.; Yan, Y. J. Size dependence of Young's modulus in ZnO nanowires. *Phys. Rev. Lett.* **2006**, *96*, 075505.



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