Mechanical Properties of Nanoparticles

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Materials 265
December 2008
Overview

- Measuring single nanoparticles
  - Why isn’t it done more often?
  - Compression of single nanoparticles
  - Some applied theories
Why Not Test a Nanoparticle?

- Nanostructured Materials
  - Hall-Petch (GB dominate dislocation behavior)

- Nanoparticle Composites
  - Often clay or CNT in polymer
  - Matrix softer, interface limited

- Nanoparticles in Solution
  - Jamming, lubrication, aggregation dominate

Y. Min, M. Akbulut, R.K. Prud’homme, Y. Golan, and J. Israelachvili
Fracturing a Nanoparticle

- **STM in TEM**
  - 300 nm radius tip
  - Berkovich Geometry
- **Si Nanoparticle**
  - HPPD

Plastic Deformation

- Si particle deforms plastically leaving residual stress
  - Shows on repeated compression


Hertzian Approximation

- Model of a deformable sphere between hard surfaces
- Hertzian curve underestimates modulus

Dislocations in Nanoparticles

- Crystal structure dependent
  - fcc hardens by dislocation starvation
  - bcc hardens by “traditional” work hardening

J. Greer MRL lecture 11/7/2008
Attached to a Surface

<table>
<thead>
<tr>
<th>$F_{\text{max}}$ (µN)</th>
<th>$H_{\text{Particle}}$ (GPa)</th>
<th>$h_{\text{max}}$ (µm)</th>
<th>$h_c$ (µm)</th>
<th>$R_C$ (µm)</th>
<th>$E_c$ (GPa)</th>
<th>$H$ (GPa)</th>
<th>$H_{\text{Particle}}$ (GPa)</th>
<th>$H$ by Linear Increase in Contact Area with Indentation Depth (GPa)</th>
<th>$H$ by Geometric Contact Area (GPa)</th>
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</table>

Average: $54.8 \pm 10.0$, $5.0 \pm 0.5$, $3.1 \pm 0.4$, $33.6 \pm 2.4$, $46.7 \pm 8.8$, $2.8 \pm 0.4$, $68.9 \pm 9.6$, $2.8 \pm 0.7$, $16.3 \pm 1.6$

$H_{\text{Particle}}$ is the nanoparticle height before indentation, $h_{\text{max}}$ is the maximum indentation displacement, $h_c$ is the contact depth, and $R_C$ is the contact radius.

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Silica on silicon

Nanoindenter, image from SPM

Other Considerations

- Fraction of surface atoms
- Curvature
- Defect density
- Allowed mechanical modes
  - Compression
  - Tension, torsion,