Everything You Wanted to Know About Nanotechnology*
*But were afraid to ask
(Or what to say when your kid asks)

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Panel from ERINC brochure on NanoMaterials and Devices R&D
1. What is a nanometer?
   100,000X smaller than a human hair
   (which is 0.004” or 100 microns)

2. What are the scale sizes for nanotechnology?
   Approximately 1 to 100 nanometers

3. Is nanotechnology a technology?
   Only to a limited degree, it is mostly R&D

4. Is some nanotechnology commercially available?
   Each new computer ships with sub-100 nm device structures

5. Is nanotechnology research hard to do?
   Nanotechnology methods are often used because they are easier

6. What can nanotechnology already do?
   Move nanostructures around (Nanomanipulation)
   Grow materials with nanoscale features (Nanomaterials)
   Make structures smaller than ever before (Nanofabrication)
   Make nanoscale devices that work (Nanoelectronics/NEMS)
   Measure properties of small objects (Nanophysics/metrology)
   See objects smaller than the wavelength of light (Nanoimaging)
7. What are some interesting nanotechnology results to date?
   Images of single atoms
   Images of electron wave functions interfering
   Stretching single strands of DNA to breaking
   Biomolecular motors used to move microobjects
   Electrical circuits made of single organic molecules
   Molecular sieves/filters for separating molecules by size
   Replacing top-down lithography with bottom-up self-assembly

8. What instruments are used in nanotechnology R&D?
   Electron microscopes
   Electron beam pattern generators
   Scanning tunneling microscopes
   Atomic force microscopes (nanoprofilometer)
   Near-field optical microscopes (sub-wave imaging)
   Advanced deposition, growth & etch chambers
   Nanoimprinters (hot embossing with nanomolds)

9. What educational background is needed to work in the field?
   The ability to apply fundamentals of undergraduate education (e.g. chem, math, phys, engr, bio) to cross disciplinary problems
10. What are some current themes in the field?
Making devices ever smaller
Making devices with less effort and equipment
Measurement of fundamental quantum limits
Size dependent tuning of physical properties
Ethical/environmental/health impacts of nanotech

11. Is nanotechnology hype?
Yes: In the popular press coverage
Yes: By investment companies
No: In world government R&D investments
No: In updating educational curricula k-20
No: In the impact of potential breakthroughs

12. Is the word nanotechnology even needed?
No: The research was there long before the word was coined
No: It is a catch-all for a variety of existing research directions
Yes: In the way it excites students, parents, alumni about science

13-20. Still afraid to ask? If not, your questions here:
But first some pretty pictures and examples of nanotechnology
SIZE COMPARISON OF BIOMATERIALS, ELECTRONICS & THE THREE BEAMS

S. Asai and Y. Wada
Proc. IEEE, April 1997
E-beam written guitar strings are 50 nanometer diameter
QUANTUM CORRAL NANOSTRUCTURES

ELECTRON STANDING WAVE
ELECTRON MIRAGE

Don Eigler Group, IBM (see Nature 2/3/00)
MECHANICS OF BIOLOGICAL MATERIALS

THE KINESIN MOTOR PROTEIN

Vale & Milligan Science (4/7/00)

Chemistry, molecular biology and mechanics merge at the nanoscale
LASER TWEEZERS FOR SINGLE MOLECULE INTERACTIONS

Measures force applied by kinesin

Has been used to unwrap folded molecules

Motor proteins have been attached to silicon propellers

Steven Block, Stanford

optical trap

~ 70 nm

bead

kinesin

microtubule
ASSEMBLY OF MICROSTRUCTURES IN LIQUIDS WITH PROGRAMMABLE LASER PATTERNS

Programmed laser patterns

Laser first turned on \(= 1 \mu m\)

Laser on a while
After oxide etch the sidewall coating gives nanometer thick, microns in length pores.

M. Ferrari, Ohio State
THE MICROFABRICATED BIOCAPSULE

NANOPORE MEMBRANE

INSULIN

ENCAPSULATED CELLS

ANTIBODIES

NUTRIENTS

SILICON TO SILICON BONDING

M. Ferrari, Ohio State
GLASSBLOWING ANALOGY TO OUR POLYMER FIBER DRAWING METHOD

- Glass is custom drawn over a flame
- Polymer fibers are drawn from a pool of solvent-suspended polymer
- Each method makes custom structures
WHAT IS NANO-FAB/MANIPULATION?

Small tools making smaller structures
Enabling connections across scale sizes
We continue to find uses for nanomanipulation in our SEM
NEW INTERACTIVE AFM FOR NANO-FABRICATION AND MANIPULATION

USE FOR CUSTOM ASSEMBLY AND MANIPULATION OF NANOSTRUCTURES
GOAL: INTERACTIVE DRAWING AND SENSING OF FIBER FORMATION

HAPTIC

AFM

![Graph](image-url)

- Force (μN) vs. Distance (μm)
- Force events:
  - Capillary breakup event: 1.14 μN
  - Liquid contact
  - Hard contact
  - Extension
  - Retraction
- Distances and times:
  - 8 s, 58 s, 116 s, 192 s
  - In tension
  - In compression

![Image](image-url)
Directed Self-Assembly of Suspended Polymer Fibers for 3D Nanodevices

Fibers by capillary thinning

Used in nanofab

Tough flexible polymers fibers form in seconds at room temperature
Extensive functionality added by macromolecular syntheses
Nanodevices emphasizing fluidics, optics and mechanics are being fabricated and evaluated
LONG RANGE ORDER ACHIEVED WITH BRUSH ON METHOD

Poly Vinyl Acetate (50,000 MW)
MULTIFUNCTIONAL MEMS PLATFORM: SOFT FIBERS SUSPENDED ON RIGID SUPPORT

Output: light (electroluminescence)

Potential for standing wave resonance or lasing

Laser input and output

Evanescent mode coupler

Unclad polyfiber

Polyfiber templated capillary

Laser-trapped micro-bead resonator

Inputs: liquid, gas, voltage

Outputs: liquid, gas

Inputs: liquid, gas
HCl etch removes native oxide on Ga producing sphere needles as narrow as 25 nm have been made.
SHARPENING OF NANONEEDLES

The needle flattens from contacting the counter-electrode.

Is the mechanism deformation, wear or melting?

Plan to determine the mechanism.
AFM F vs. D EVALUATIONS OF Ag$_2$Ga NEEDLES

Dual Cantilever AFM tip is a ref. standard

Needle slides on silicon with 0.056 friction coeff.

Consistent results between various evaluation methods
Tough and flexible graphene with 2nm tip radius  
Need to develop selective attachment method

GaN handles to nanowires  
Easier to pick up with micromanipulator  
Possible optical coupler

GaN plates  
Slab optical guides  
Potential seeds for low defect substrates  
Substrates for pick and place 3D MEMS assembly

New morphologies being found on a regular basis
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20 QUESTIONS CONCLUDED (13-20)
Your questions & comments are appreciated
BRUSH-ON NANOFIBERS FROM LIQUID POLYMERS

Directed self-assembly of nanostructures with nano-effort!
BUCKLING OF NANONEEDLES

Consistent results between various methods incl. electric oscillation & AFM F-D

Mass loading projects to 200 zg ($10^{-21}$ g)

$D^* = 90 \text{ Å}$

$k_n = 4.75 \text{ mN/m}$

$k_n = 4.66 \text{ mN/m}$

$k_b = 18.73 \text{ mN/m}$

$k_0 = 4.66 \text{ mN/m}$

Theory: $k_b = 3.84k_0$

$17.89 \text{ mN/m}$