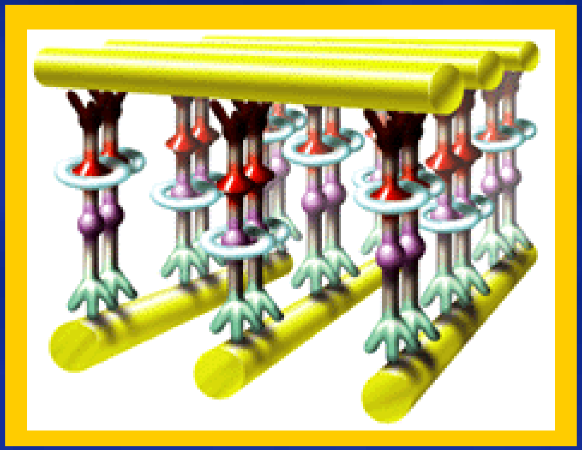
The Next Technology Revolution - NANOTECHNOLOGY

Dr. Iwona Turlik

Motorola Labs



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Outline

- Background
  - Opportunities in Nanotechnology
  - Industry Trends
  - Nano is here – Current product implementations
- Nano as an industry disruptor
- Nano Focus Areas
- Application Opportunities (Electronics)
- Examples of Current Motorola Activities

Nanotechnology Revolution

Nanotechnology has the potential to transform life as we know it.

The ability to do things (measure, see, predict and make) on the scale of atoms and molecules thereby making products either smaller, faster, stronger or with new properties.

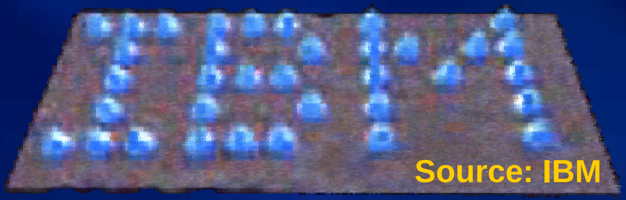
- Potential for the leap into devices utilizing quantum physics.
- Could enable new technologies, applications and industries never before imagined.

"Nanotechnology is the sixth truly revolutionary technology introduced in the modern world…" --D. Allan Bromley

Former Assistant to The President of the United States for Science and Technology (1989-1993)

1700s	1940s	1950s	1960s	1980s	1990s	2000s
1. Industrial Revolution	2. Nuclear Energy	3. Silicon	4. Green	5. Information		6. Nanotechnology and Bio-Tech

History



Timeline:

1959 Richard Feynman's speech - "There's plenty of room at the bottom"

1974 First Molecular Electronic Device patent.

1981 IBM Invents **scanning probe microscope**: measure and identify structures at nano-scale. Ability to move individual atoms and molecules on surface.

1981 Drexel published Molecular Engineering : molecular machinery

1985 Curl, Kroto, Smalley **discovered buckey balls.** Stable molecules that contain 50 to 500 carbon atoms in a ball, using laser vaporized carbon.

1989 IBM Almaden Research Center : **wrote IBM with 35 Xenon atoms**.

1991 Discovery of **carbon nanotubes** by Sumin Iijima at NEC Research Labs.

1993 First US research lab devoted entirely to nanoscience. Smalley at Rice University.

2000 US launch of National Nano-technology Initiative (NNI)

2003 President Bush signs Nanotechnology R&D act - $3.7 Billion over 4 years

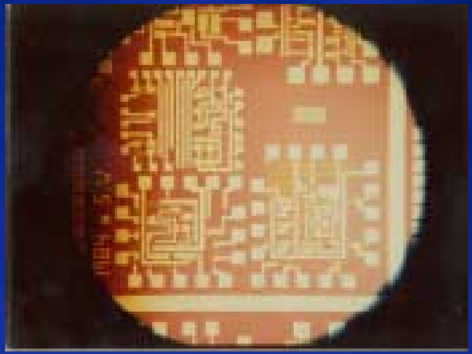
Societal Impact of Nanotechnology

from CREDIT SUISSE: Equity Research, May 2003

- Nano-technology is about manipulation at the atomic level and looks like a General Purpose Technology, e.g. steam engines, electricity, transistors.

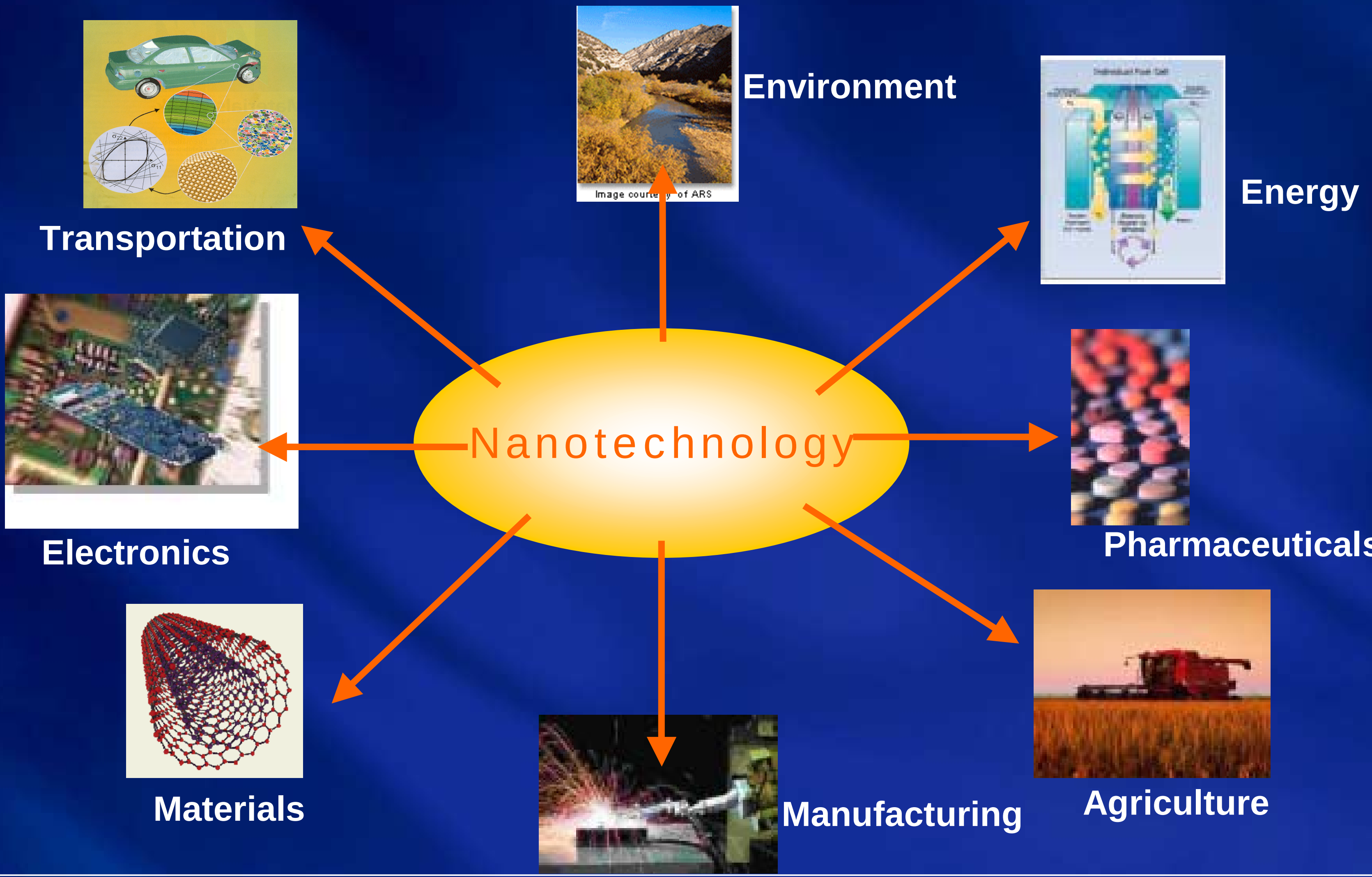
- Leads to creative destruction and major economic revolutions.

- Starts as fairly crude technologies with limited use, but spread rapidly into new applications and enable new markets and industries.



Nanotechnology

A technology that impacts many industries



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CURRENT Consumer Products

- Nano enhanced products are here!!
- Migrating from niche to mainstream consumer and industry applications

Nanowax: CERAX

Nanotex Materials

Nano-care™ treated fiber surface with ~ 200 nm "whiskers"

Water Proof – Stain Proof

Carbon nano-tubes

Nano-clay composite gas diffusion barrier

Nano Tin Oxide: Sunscreen

Outline

- Background
- Nano as an industry disruptor
  - Example: Nano Velcro
  - Example: Lifetime tires
  - Research to products
- Nano Focus Areas
- Application Opportunities (Electronics)
- Examples of Current Motorola Activities

Nanotechnology
A Technology and Market Revolution

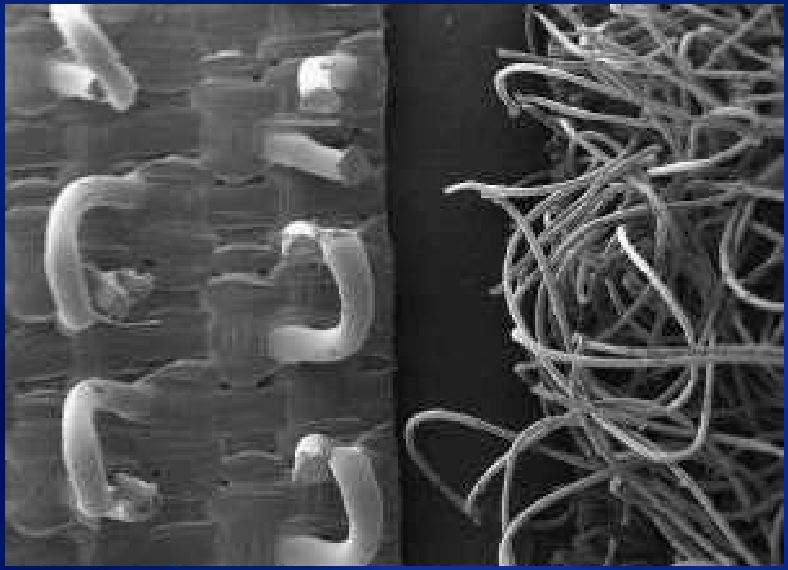
A truly new revolutionary technology completely disrupts Markets, Industries and Business Models

Example Scenario in electronics industry:

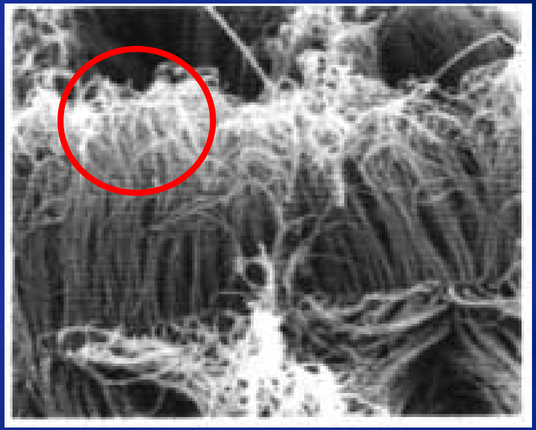
What if packaging interconnects can be be replaced by a conductive CNT-Velcro based assembly process?

Nano Velcro

- *Imagine* manufacturing assembly without solder or adhesive
- A joint stronger than many traditional assembly methods…. and materials
- Manufactured at room temperature

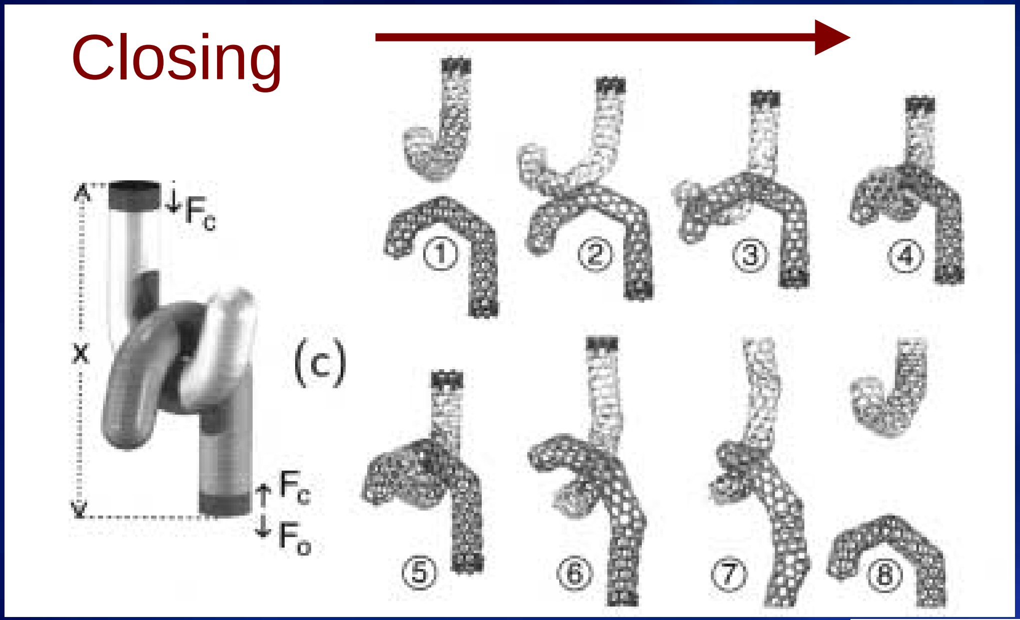


Nano-hooks



Berber, Kwon, and Tomanek,
Phys. Rev. Letters., Vol. 91, No 16
[13] Jean Gabriel

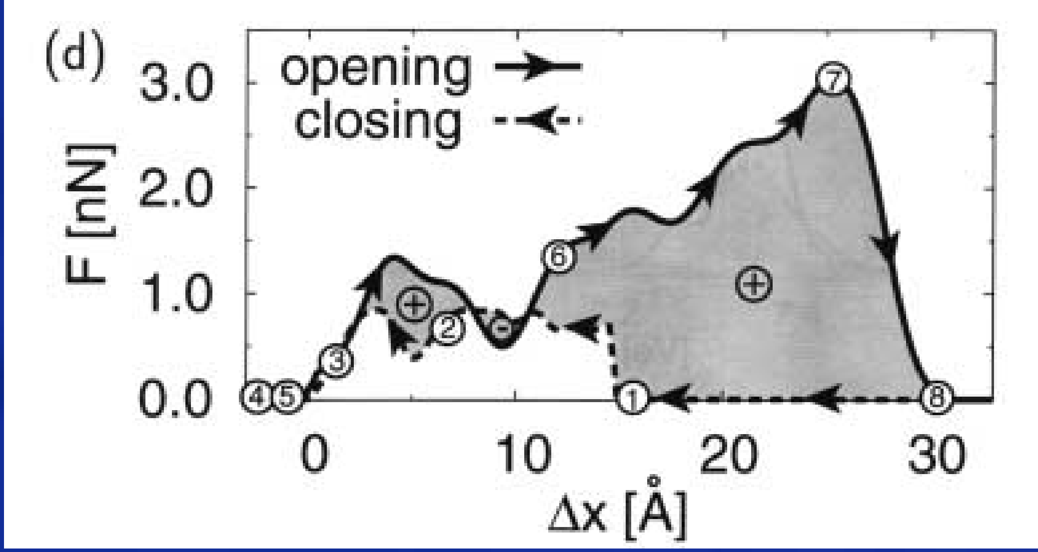
Molecular simulation of carbon nano-velcro



Estimated ideal pull strength = 3 GPa

Measured yield point of #1010 CR steel ~ 0.3 GPa

Opening



Hook formed by insertion of pentagon and heptagon rings in all hexagon nano-tube

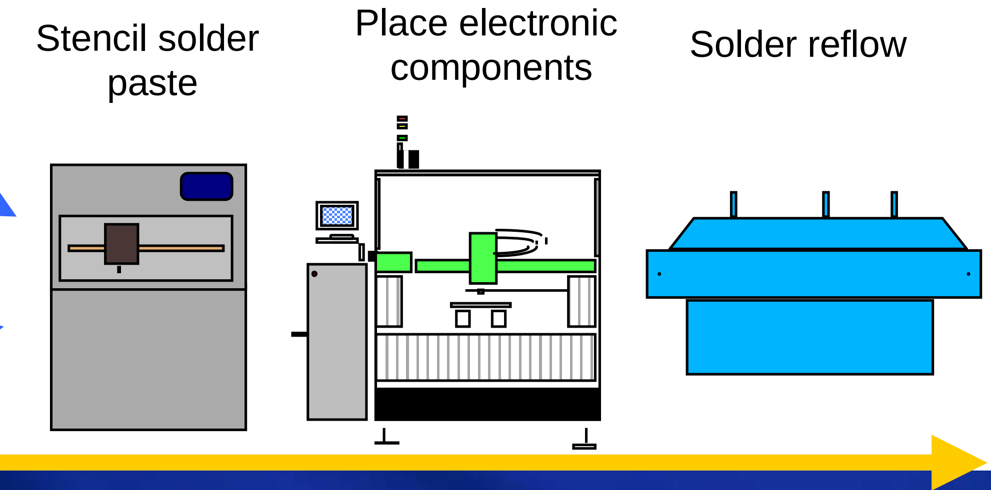
Berber, Kwon, and Tomanek,
Phys. Rev. Letters., Vol. 91, No 16
Michigan State University

Assembly Process Disruption

Current Electronics Assembly Process Flow

Electronic Components:
Plastic packaging

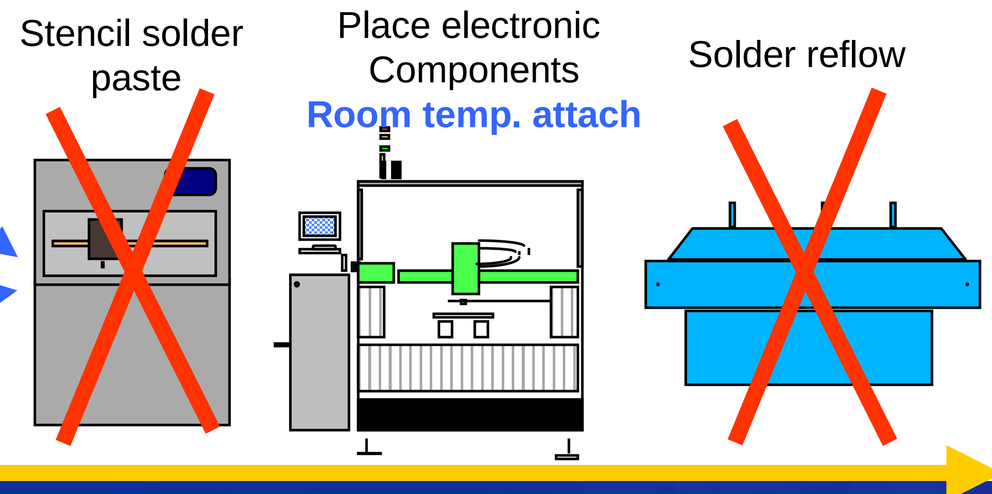
Printed Wiring Boards:
- **High Tg materials**
- **Glass-epoxy composites**



Electronics Assembly Process Flow with nano-Velcro

Electronic Components:
Integrated circuit attach with nano-Velcro

Printed Wiring Boards:
- **Room Tg materials**
- **Paper, thermoplastics**



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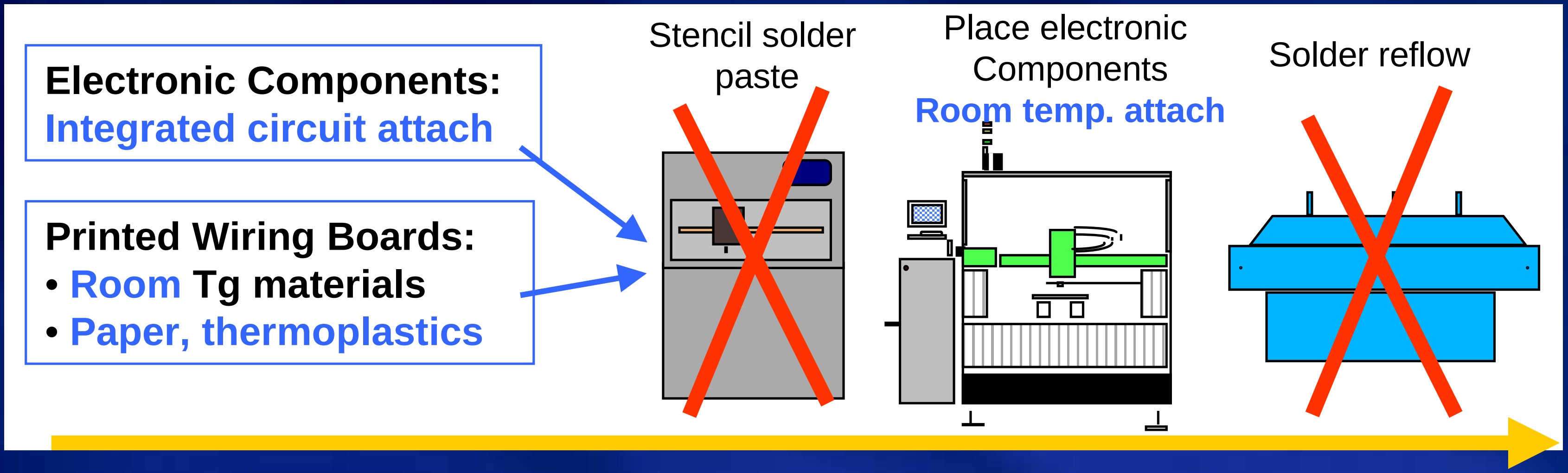
Nano Velcro Market Disruption

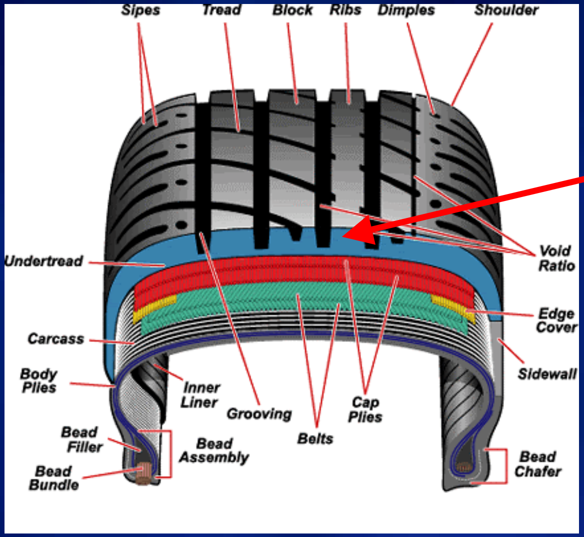


Market Disruption

- Create new industry: paper, textile, thermoplastic high density "PWB's"
- Create new industry: Velcro finish electronics components
- Create new industry: Reel-to-reel, paper and textile electronics assembly
- Create new industry: Ultra-thin flexible IC manufacturing to replace traditional IC plastic packaging

Example Scenario In Auto Industry

Lifetime Tires

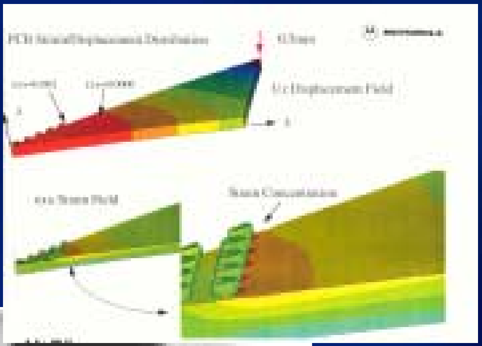


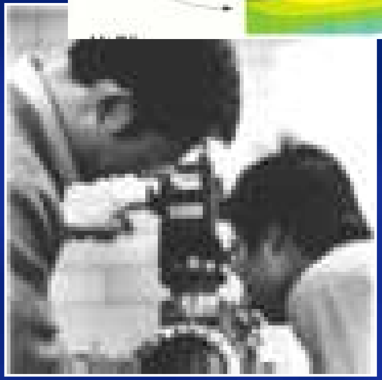
High wear resistance
Nano elements in tires could enable OEM tires to last the lifetime of the car

Of the 250 million passenger car tires shipped in 2002, 190 million were replacement tires (MTB, RMA)

A potential innovation that completely disrupts the tire industry business model i.e., low price OEM tires and high price replacement tires

Research to Products





Typical prerequisites:

- Scalable manufacturing processes
- Low cost tools for testing and evaluation
- Well developed supplier base
- Standards

Some disruptive nanotechnologies may be inherently scalable with very low go-to-market times

Nano will enable incremental innovation in some areas, while leading to disruptive innovation in others

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- Background
- Nano as an industry disruptor
- Industry Focus Areas
  - Basic Materials
  - Electronic Devices
  - Multifunctional composites
- Application Opportunities (Electronics)
- Examples of Current Motorola Activities

Nanotechnology

Major Research Areas for Electronics Industry

Basic Nano-Materials

Includes manufacturing processes, characterization, metrology and standards
E.g. Carbon nano tubes, quantum dots, nano powders, etc.

Electronic Devices

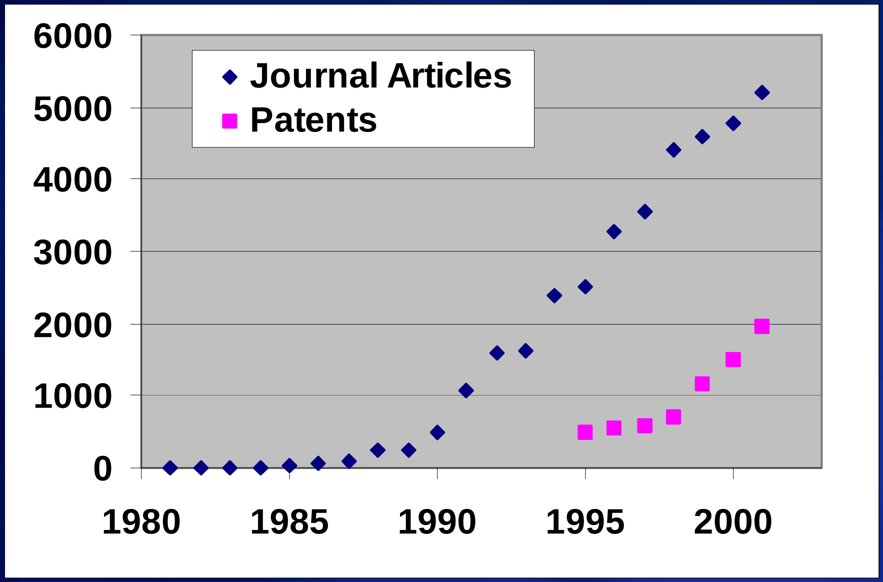
- Displays
- OFETS
- Nano pockets
- Memory
- Super Capacitors, etc.

Multifunctional Composites

- Self-cleaning
- Color changing plastics
- Self-healing
- Structural materials,
- ‘Aware’ materials, etc.

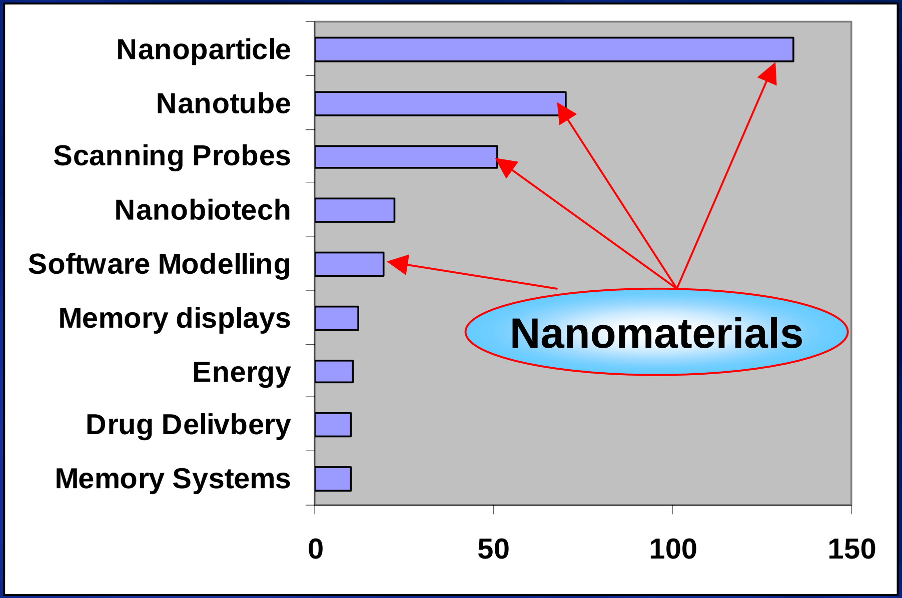
Nanotechnology
Current Technology Focus

Nano Publications And Patents



Source: "Nanotechnology – Size Matters", white paper, Institute of Nanotechnology

Nano Startups By Area



Source: CREDIT SUISSE: Equity Research, May 2003

- Majority of nano activity is currently focused on development, characterization, metrology and standards of basic nano-materials
- Significant applications in electronic-devices and multifunctional composites are beginning to emerge

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Nano Materials and Suppliers

A Partial List

Materials	Company	Applications
Carbon Nano Tubes	NEC, Sumitomo, Phillips, CNI, GE, Hyperion Catalysis, Carbolex, etc.	Displays Polymer Composites, computing, memory, sensors, fuel cells
Nano silicates	Nanocor, SW Clay Products, Bayer, Honeywell, etc.	Paint pigments Polymer composites
Metals	Argonide, Nanomat, NRC, etc.	Catalysts, soldering, welding
Metal Oxides	GE, Argonide, Nanophase, Nanomat, etc.	Thermal Substrates, heat dissipating polymers
Quantum dots	Qdot, GE, Phillips, Siemens, etc.	Medical electronics – diagnostics

Enablers for Devices and Applications

Electronic Device Companies

A Partial List

Devices	Company	Benefit
Nano Memory	Nantero, HP, IBM, etc.	Universal flash memory; higher density
Displays	Motorola, Samsung, NEC, Matsushita, etc.	Brighter, lower power, inexpensive displays
Transistor (Silicon and Organic)	IBM, Intel, AMD, TI, Motorola, etc.	Enabler for low power processing and memory
Data Storage	IBM (millipede), Seagate, HP, etc.	1TB/sq. in. density
Nano Computer	HP, IBM, Hitachi, Fujitsu, Intel, etc.	Size, performance and mobility; Pervasive computing

Multifunctional Composite Companies

A Partial List

Macro-Application	Company	Benefit
Structural Composites (↑ stiffness, ↑ toughness)	PolyOne, Bayer, Nanocor, Honeywell	Higher reliability; lighter weight composites, thermal stability, etc.
Self cleaning	Degussa, BASF, STO, Fraunhoffer	Cleaner surfaces, display appearance, etc.
Scratch Resistance	Du Pont, Nano film	Aesthetics (looks like new), longevity
Color change	Matsui, Qdot	New functionality, fashion
Nano polymer films	Honeywell, PolyOne, Bayer	Preserves freshness. Food wrapping, beverage containers

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- Nano as an industry disruptor
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- Application Opportunities (Electronics)
  - Mobile Phone
  - Nano composites
- Examples of Current Motorola Activities

Motorola

Motorola is engaged in several segments of the electronics and telecommunication industries

Application Example: Mobile Phone

optics

acoustics

displays

electronics

coatings

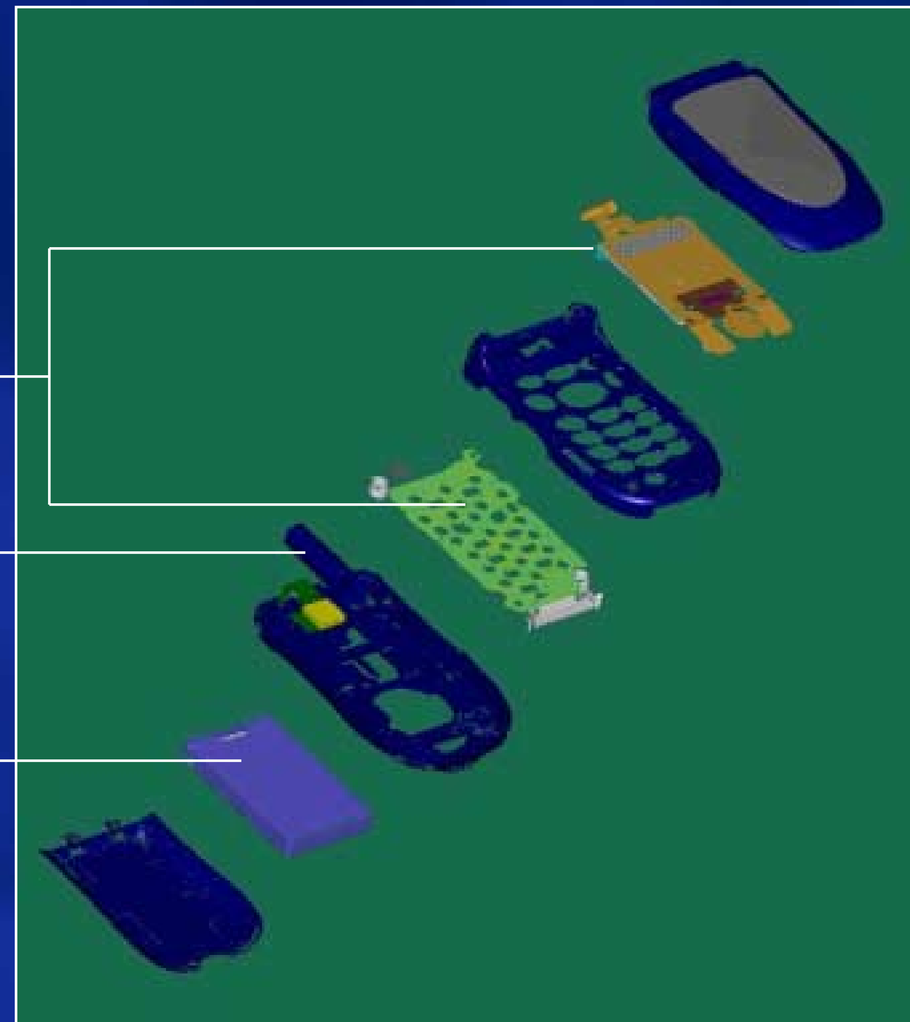
antennas

paints

batteries

composites

sensors/
actuators



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Some applications and benefits of Nanotechnology

Nano Composites: stronger, tougher, stiffer, lighter materials (adhesives, structural, electronic, optical functionality), nanobiotech for sensing, actuating, power functions

Nanodisplays: Large, lower cost and brighter displays based on embedded carbon nanotubes

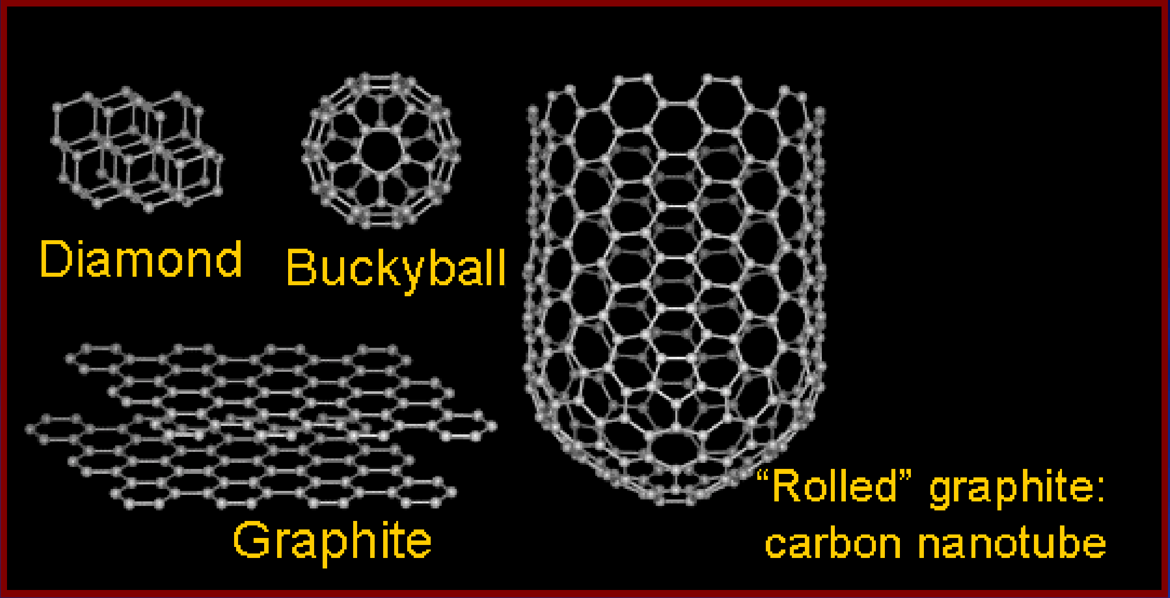
Nano antennas: Nano scale fractal antennas for multiple spectra and broadband

Nano power: High capacity power sources (storage, conversion, advanced fuel cells, photonic energy), parasitic energy harvesting, nanobiotech related functionality

Nano Composites

- A phone housing requires stiffness, toughness, moldability, paintability, surface finish, flame retardance, chemical resistance and thermal stability, recyclability, etc.
- Traditional engineering design is often a compromise of these competing requirements
- Nano materials enable application-specific, tailored material design

e.g:
CNTs and
Nano-silicates



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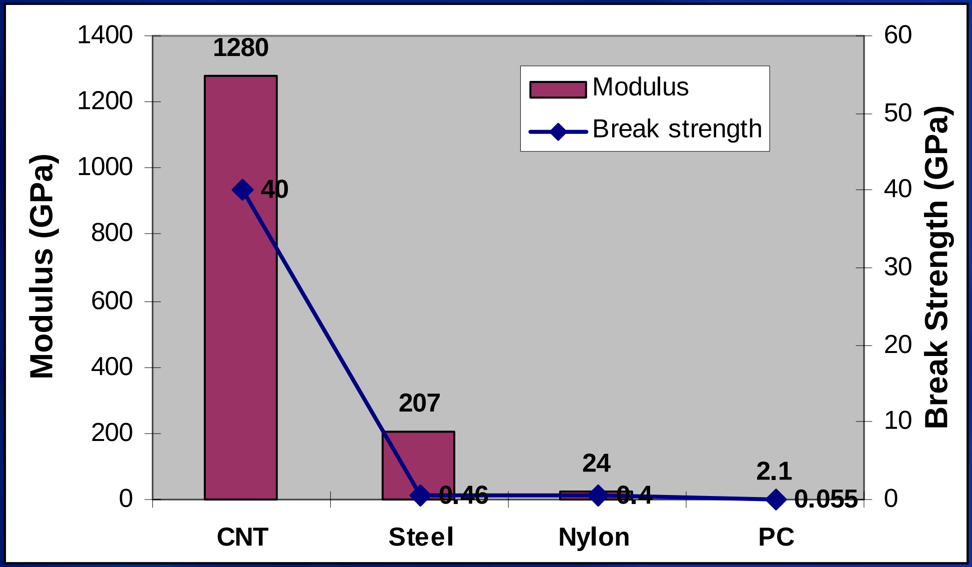
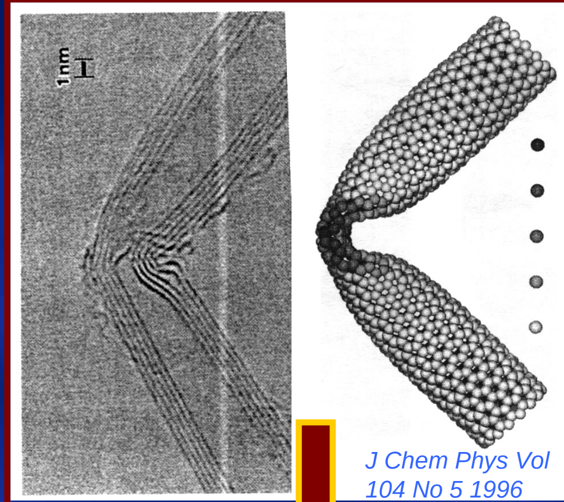
Nano materials for tailored composites

Compared to current phone housing, nano materials will have:

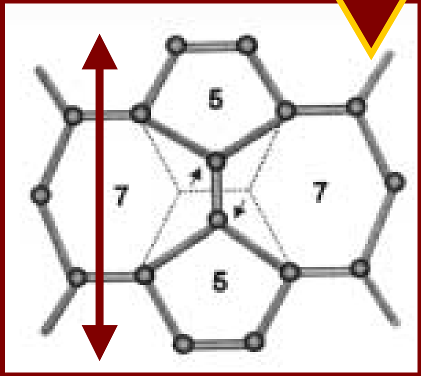
- High Strength
- High Stiffness
- High Toughness
- Multifunctionality, etc.



Extremely flexible (reversible)



J Chem Phys Vol 104 No 5 1996



Deformation Mode: Stone-Wales Transf: Heptagon.

J Chem Phys Vol 104 No 5 1996

Nano materials for tailored composites

Current Carrying Capacity

SWNT: 10^9 A/cm^2

Copper wire : 10^6 A/cm^2 (burns)

Field Emission: Excellent field emitter; high aspect ratio and small tip radius of curvature are ideal for field emission.

- **SWNT Radius 0.6 to 1.8 nanometers**

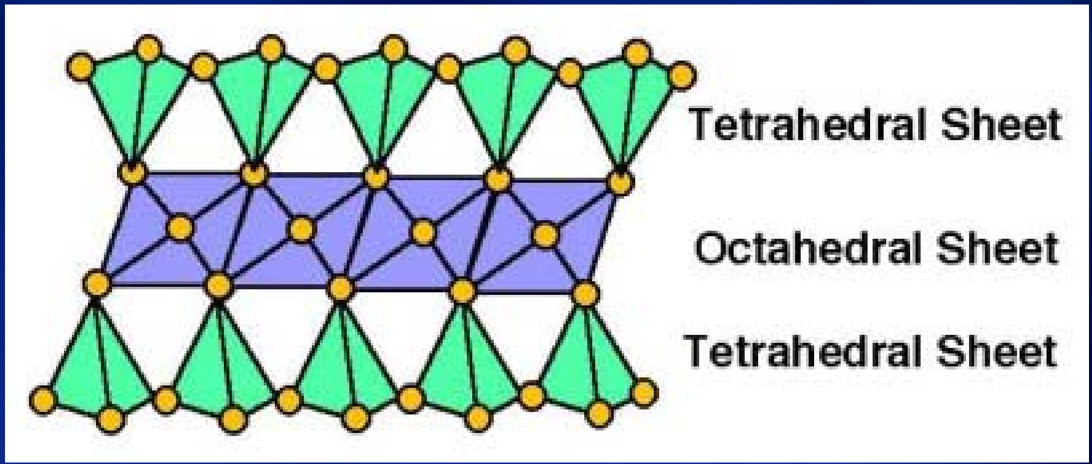
CNT can be metallic or semiconducting, depending on chirality

$$E_{max} \propto V / R$$

At 30 V concentrated electric field ~ 10^7 to 10^8 V/cm

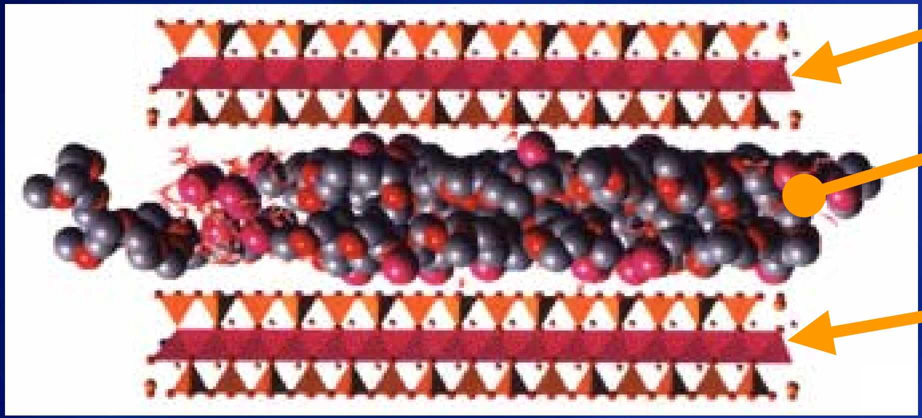
Nano Silicate Polymer Composites

Nano-silicates: a natural nano-material



Cretaceous (85-125 M Years)

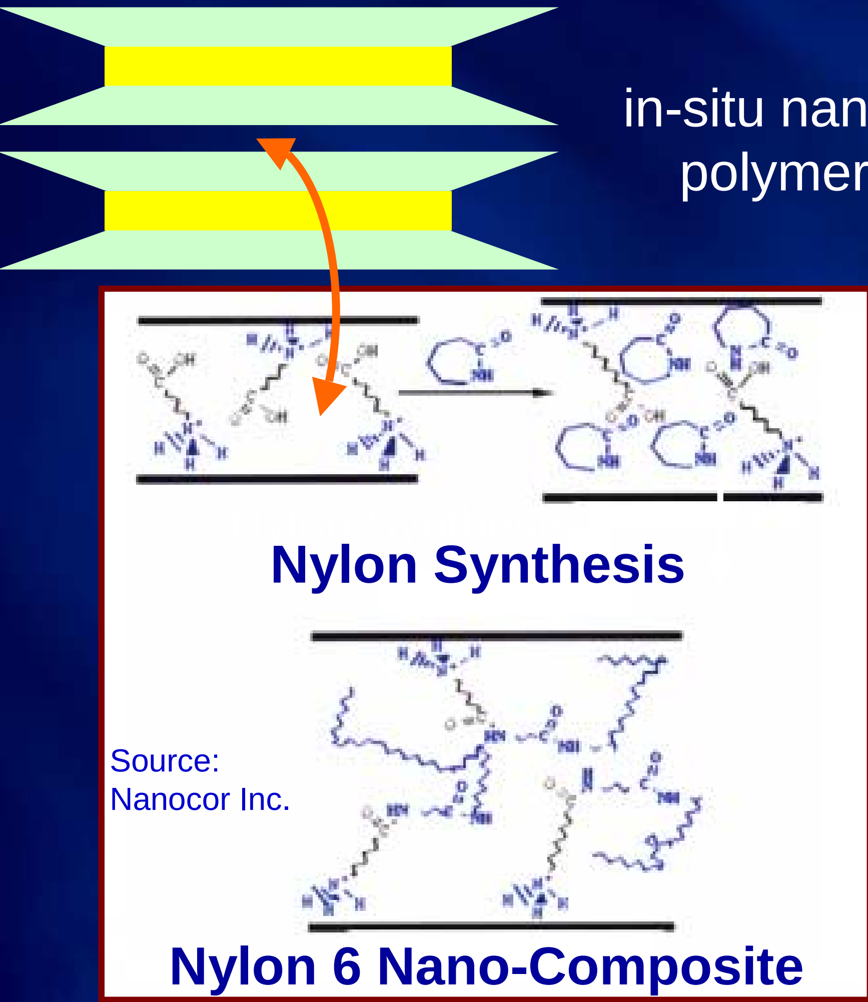
Molecular Simulation



Polymer is compatabalized with nano-silcate

Simulation from: Hacket, Mania and Giannelis, *Chem. Mater*. 2000, 12,2161-2167

Nano Silicate Polymer Composites



in-situ nano-silicate polymerization

Significant macro-property improvements.
A little goes a long way !

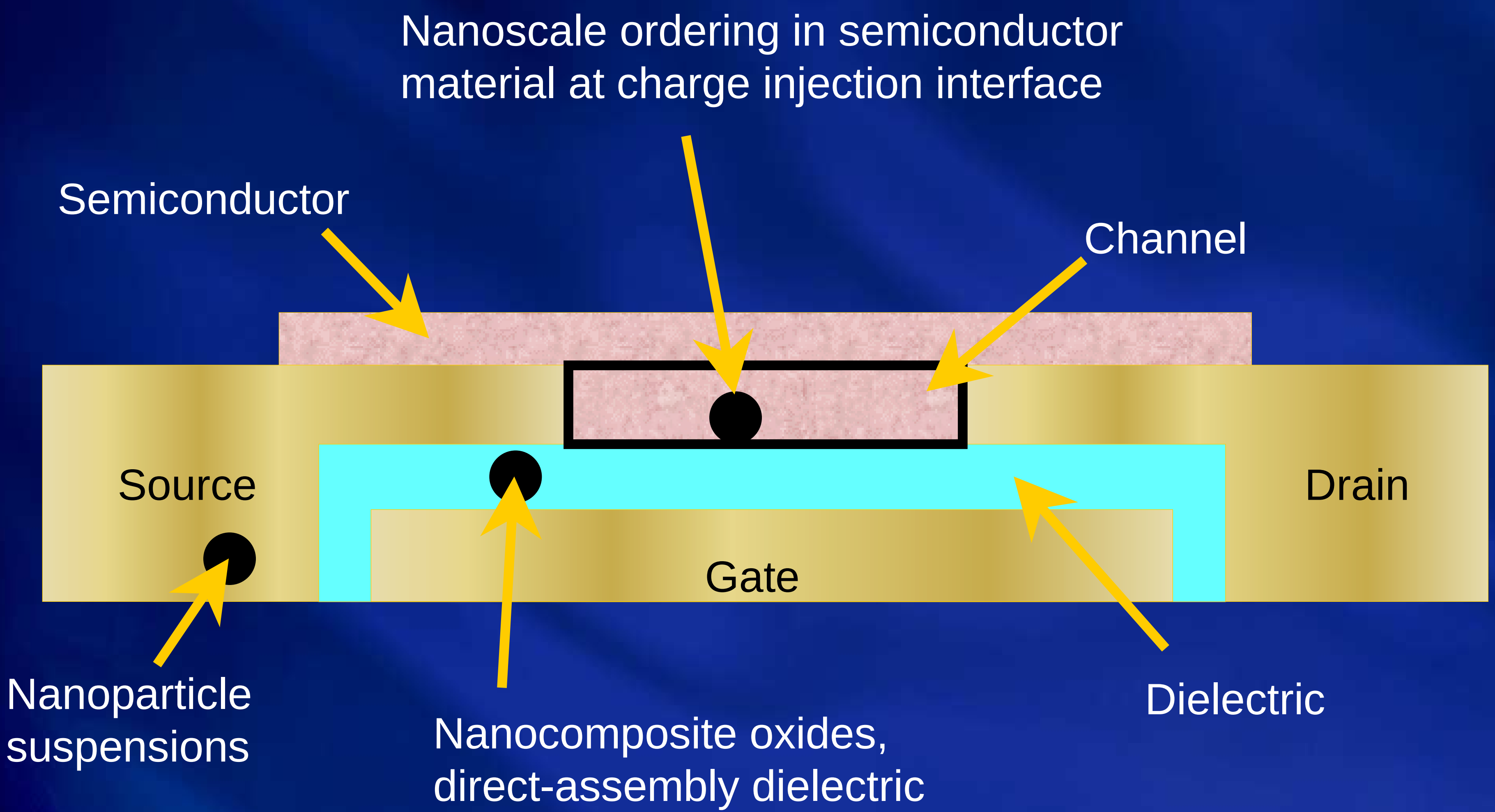
	Nylon 6 Un-Reinforced	Nylon 6 Glass Filled 20 wt %	Nylon 6 Clay Nano Composite 4 wt %
Tensile Strength (MPa)	72	62 (0.9x)	115 (1.6x)
Elastic Modulus (GPa)	1.1	1.4 (1.3x)	2.1 (1.9x)

- Nano materials enables unprecedented opportunities to tailor macro-properties.
- Key driver is interfacial effects versus weighted average of traditional fillers.

Outline

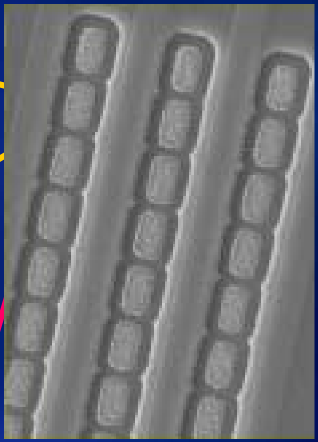
- Background
- Nano as an industry disruptor
- Industry Focus Areas
- Application Opportunities (Electronics)
- Examples of Current Motorola Activities
  - Organic Transistors
  - Displays
  - Self-healing
  - Standards

Nanoelements of an OST

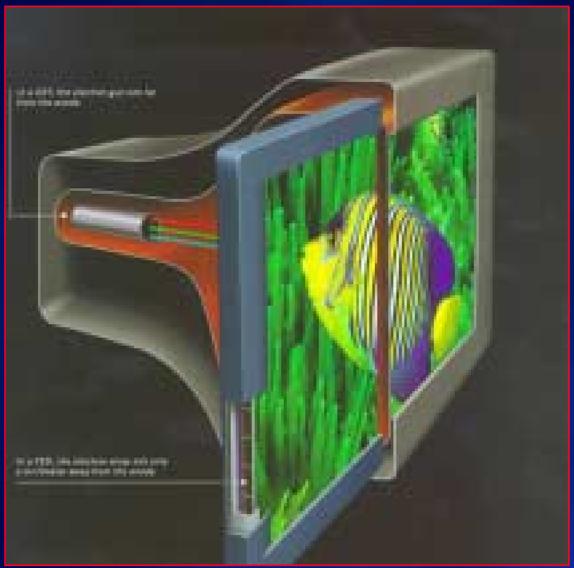


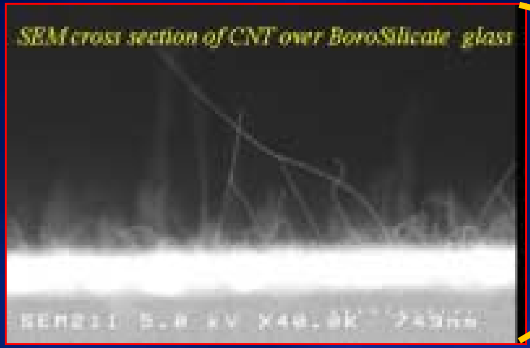
Nano Emissive Display

Selective growth only on pads



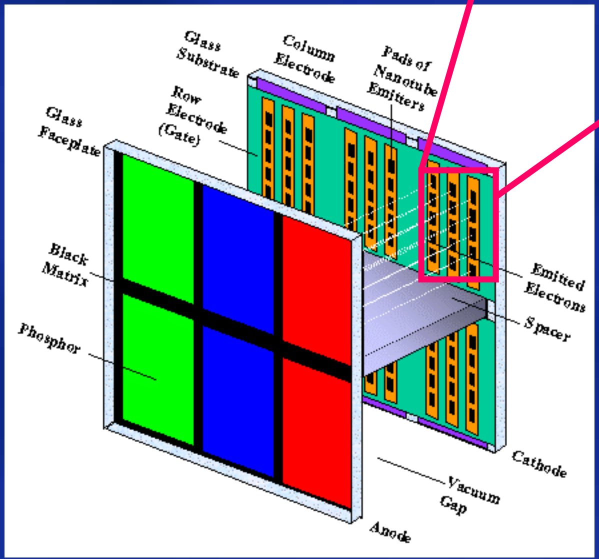
CRT - electrons from three cathodes are scanned across screen





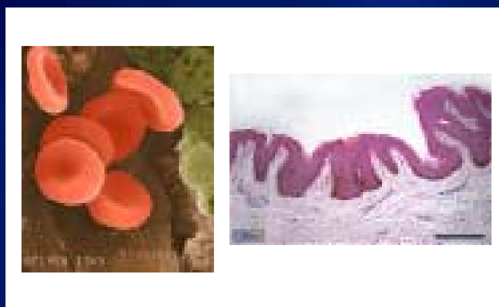
NED electrons from millions of carbon Nanotubes travel to a screen

Millions of cathodes enable a thin, high clarity flat screen TV

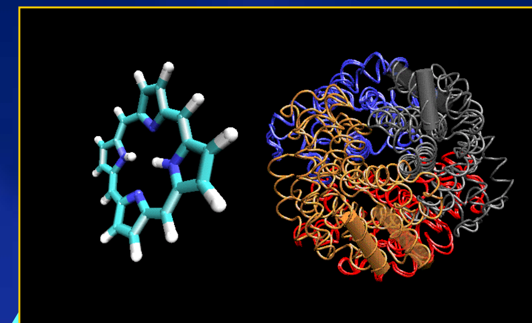


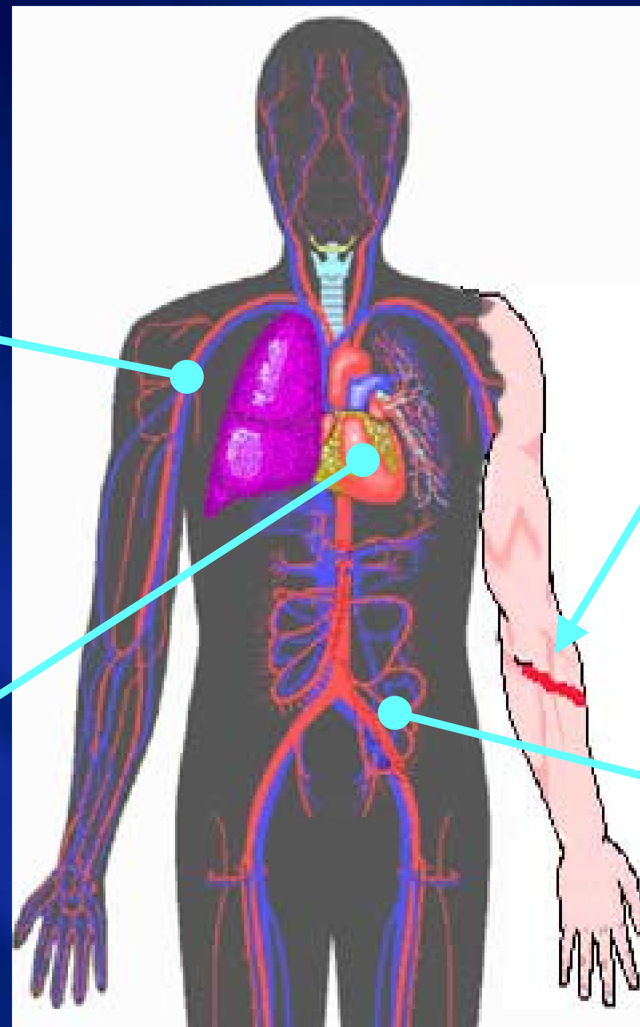
Self-Healing Materials, Inspired by Biology
Creating a Synthetic Autonomic System

Adaptive Fluids/Solids



Reactive Materials

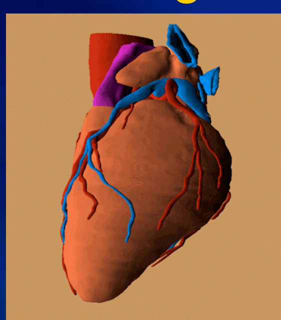




Self-Regulating Function

Self-Generating Function

Active Regulation



Mesoporous Networks

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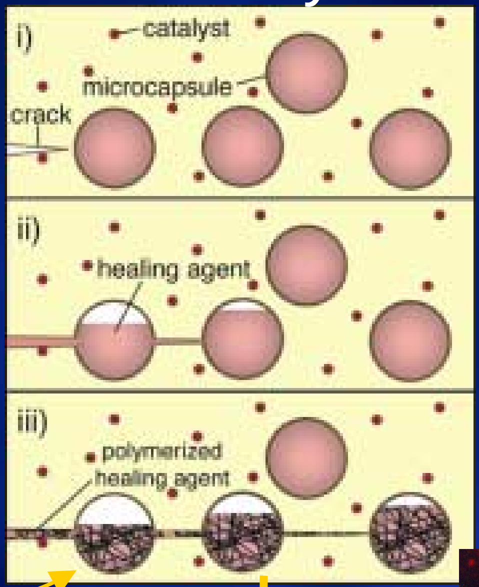
Self-Healing Materials

Self-healing Functionality: The ability to repair damage automatically without manual intervention.

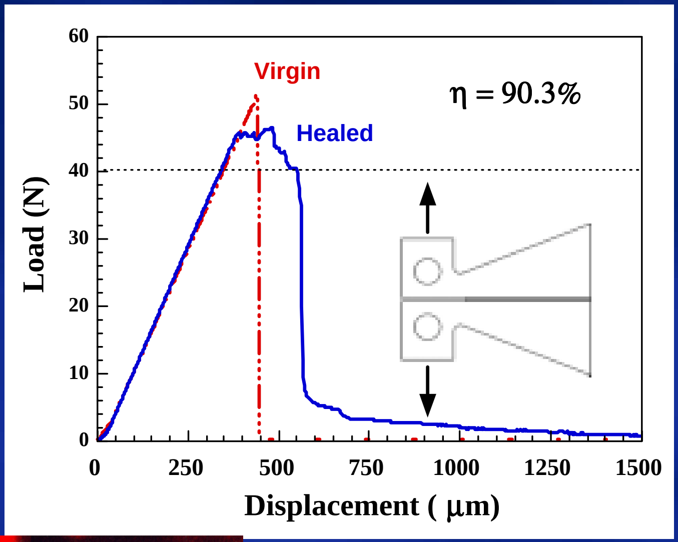
Today

White et al., *Nature* 2001



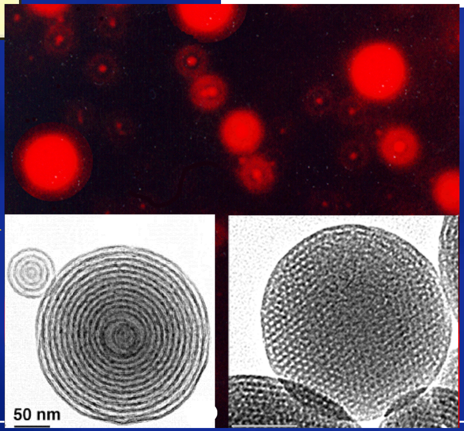
Micron scale

> 90% strength recovery



Brown et al., *Exp. Mech.*, 2002

Nano can enable self-assembled nano-containers: Self-heal at nano scale



Collaboration with Prof. Nancy Sottos TAM Dept. & Beckman Institute for Advanced Science and Technology

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Fan et al., *Nature* 2000
Lu, et al., *Nature* 2001

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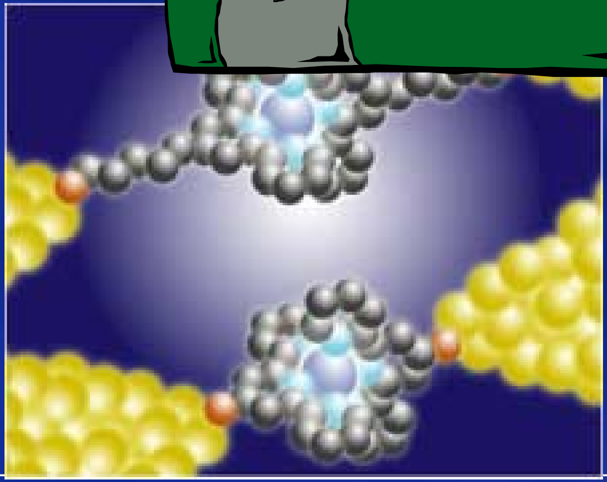
Motorola Chairing IEEE Nanotechnology Working Group

Draft Standard Test Methods for Measurement of Electrical Properties of Carbon Nanotubes (P1650^{TM})

http://grouper.ieee.org/groups/1650

IEEE Nanotechnology Standards Roadmap Workshop - Standardization Along the Path from R&D to Commercialization



<u>Workshop Held on 11/5/03 –</u>
<u>90 Registrants from Industry, Academia and International Labs</u>

IEEE Workshop to Create a Standards Roadmap for Nanoelectronics - materials, devices, and systems

http://grouper.ieee.org/groups/nano

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Nano-today is only the beginning……

1918-1988

Richard Feynman, 1965 Nobel laureate in physics: "There is Plenty of Room at the Bottom" envisioned:

<u>Molecular Level of Assembly</u>: Today we carve what we need from a large piece of material. Nano is the reverse, builds from the molecular level up. Building atom by atom enables increased product complexity and exact composition, even molecular machinery.