The Next Technology Revolution - NANOTECHNOLOGY

Dr. Iwona Turlik
Motorola Labs
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 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)
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.
2003  President Bush signs Nanotechnology R&D act - $3.7 Billion over 4 years
- 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.

Societal Impact of Nanotechnology
from CREDIT SUISSE: Equity Research, May 2003
Nanotechnology
A technology that impacts many industries

- Transportation
- Electronics
- Materials
- Pharmaceuticals
- Manufacturing
- Energy
- Environment
- Agriculture
CURRENT Consumer Products

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

**Nanotex Materials**

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

Water Proof – Stain Proof

**Carbon nano-tubes**

**Nano-clay composite gas diffusion barrier**

**Eddie Bauer**

**Nanowax: CERAX**

**Olay**

**Nano Tin Oxide: Sunscreen**

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• Nano as an industry disruptor
  ➢ Example: Nano Velcro
  ➢ Example: Lifetime tires
  ➢ Research to products

• Nano Focus Areas

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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 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

Berber, Kwon, and Tomanek,
[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

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

Michigan State University
Assembly Process Disruption

Current Electronics Assembly Process Flow

Electronic Components: Plastic packaging
Printed Wiring Boards:
- High Tg materials
- Glass-epoxy composites

Stencil solder paste
Place electronic components
Solder reflow

Electronics Assembly Process Flow with nano-Velcro

Electronic Components: Integrated circuit attach with nano-Velcro
Printed Wiring Boards:
- Room Tg materials
- Paper, thermoplastics

Stencil solder paste
Place electronic Components
Room temp. attach
Solder reflow
Nano Velcro Market Disruption

**Electronic Components:**
- Integrated circuit attach

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

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**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
Outline

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• 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

- 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

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

Source: CREDIT SUISSE: Equity Research, May 2003
# Nano Materials and Suppliers

## A Partial List

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

**Enablers for Devices and Applications**
# Electronic Device Companies

## A Partial List

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

### A Partial List

<table>
<thead>
<tr>
<th>Macro-Application</th>
<th>Company</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Composites</strong> (↑ stiffness, ↑ toughness)</td>
<td>PolyOne, Bayer, Nanocor, Honeywell</td>
<td>Higher reliability; lighter weight composites, thermal stability, etc.</td>
</tr>
<tr>
<td><strong>Self cleaning</strong></td>
<td>Degussa, BASF, STO, Fraunhofer</td>
<td>Cleaner surfaces, display appearance, etc.</td>
</tr>
<tr>
<td><strong>Scratch Resistance</strong></td>
<td>Du Pont, Nano film</td>
<td>Aesthetics (looks like new), longevity</td>
</tr>
<tr>
<td><strong>Color change</strong></td>
<td>Matsui, Qdot</td>
<td>New functionality, fashion</td>
</tr>
<tr>
<td><strong>Nano polymer films</strong></td>
<td>Honeywell, PolyOne, Bayer</td>
<td>Preserves freshness. Food wrapping, beverage containers</td>
</tr>
</tbody>
</table>
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• Nano as an industry disruptor

• Industry Focus Areas

• 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
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

Diamond  Buckyball

Graphite  “Rolled” graphite: carbon nanotube
Nano materials for tailored composites

Compared to current phone housing, nano materials will have:

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

![Graph showing modulus and break strength of different materials.](image)

Extremely flexible (reversible)


![Image showing deformation mode.](image)

Nano materials for tailored composites

Current Carrying Capacity
SWNT: $10^9 \text{ A/cm}^2$
Copper wire: $10^6 \text{ A/cm}^2$ (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

$E_{\text{max}} \propto \frac{V}{R}$
At 30 V concentrated electric field $\sim 10^7$ to $10^8 \text{ V/cm}$
Nano Silicate Polymer Composites

Nano-silicates: a natural nano-material

Cretaceous (85-125 M Years)

Molecular Simulation

Polymer is compatabalized with nano-silicate

Nano Silicate Polymer Composites

in-situ nano-silicate polymerization

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

<table>
<thead>
<tr>
<th></th>
<th>Nylon 6 Un-Reinforced</th>
<th>Nylon 6 Glass Filled 20 wt %</th>
<th>Nylon 6 Clay Nano Composites 4 wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>72</td>
<td>62 (0.9x)</td>
<td>115 (1.6x)</td>
</tr>
<tr>
<td>(MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>1.1</td>
<td>1.4 (1.3x)</td>
<td>2.1 (1.9x)</td>
</tr>
<tr>
<td>(GPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nylon Synthesis

Nylon 6 Nano-Composite

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

Source: Nanocor Inc.
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• Examples of Current Motorola Activities
  ➢ Organic Transistors
  ➢ Displays
  ➢ Self-healing
  ➢ Standards
Nanoelements of an OST

Nanoscale ordering in semiconductor material at charge injection interface

Semiconductor

Source

Nanoparticle suspensions

Channel

Gate

Dielectric

Nanocomposite oxides, direct-assembly dielectric
Nano Emissive Display

NED electrons from millions of carbon Nanotubes travel to a screen

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

CRT - electrons from three cathodes are scanned across screen
Self-Healing Materials, Inspired by Biology
Creating a Synthetic Autonomic System

Adaptive Fluids/Solids

Reactive Materials

Self-Regulating Function
Active Regulation

Self-Generating Function
Mesoporous Networks
Self-Healing Materials

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

Today

> 90% strength recovery

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

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

Fan et al., *Nature* 2000

White et al., *Nature* 2001

Self-heal at nano scale

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Motorola Chairing IEEE Nanotechnology Working Group


http://grouper.ieee.org/groups/1650
IEEE Nanotechnology Standards Roadmap Workshop - Standardization Along the Path from R&D to Commercialization

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

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

[http://grouper.ieee.org/groups/nano](http://grouper.ieee.org/groups/nano)
Nano-today is only the beginning......

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

1918-1988

**Molecular Level of Assembly:** 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.