Small Stuff in Search of the Big Bucks: 
Nanotechnology Commercialization 
Activities by Sector

Kristin Abkemeier, Analyst 
Lux Research Inc. 
December 18, 2007
Agenda

- Introduction
- Where does nanotechnology commercialization stand?
- Focus on nanotech in electronics and IT
- Nanotech activities – a couple of examples
Lux Research profile

- Introduced nanotech to Wall Street in 2001
- Lux Research spun off from VC firm Lux Capital in 2004
- Active in current U.S. nanotech public policy
  - Testimony before Congress twice
  - Trained FDA on nano in 2006
  - ANSI Nanotechnology Standards Panel
- Retained clients are primarily global 1000 organizations, but also include startups, investors, universities, and government
- Strong international connections – regular travels to Asia (China, Japan, Korea, Taiwan, etc.) and Europe
- Extensively cited in the press, including the Wall Street Journal, Forbes, Business Week, the Economist, Technology Review, Discover, etc.
- Rigorous methodologies based on:
  - Primary research: Hundreds of conversations annually with start-up CEOs, corporate executives, researchers, policymakers and thought leaders
  - Secondary research: Patent analyses, business and trade press, scientific literature

George W. Bush, U.S. President
Josh Wolfe, Director, Lux Research
21st Century Nanotech R&D Act Signing

Lux Research CEO Peter Hebert on CNBC

Lux Research President Matthew Nordan testifying before U.S. Congress
Lux Research offers advisory programs in ten technology domains

- Nanomaterials
- Solar
- Alternative power and energy storage
- Printable electronics
- Water technologies
- Advanced composites
- Alternative fuels
- Displays
- Waste technologies
- Memory technologies

- To come: synthetic biology, drug-device convergence, robotics…?
The nanotechnology value chain

Nanomaterials
Nanoscale structures in unprocessed form
Nanoparticles, nanotubes, quantum dots, fullerenes, dendrimers, nanoporous materials…

Nanointermediates
Intermediate products with nanoscale features
Coatings, fabrics, memory and logic chips, contrast media, optical components, orthopedic materials, superconducting wire…

Nano-enabled products
Finished goods incorporating nanotechnology
Cars, clothing, airplanes, computers, consumer electronics devices, pharmaceuticals, processed food, plastic containers, appliances…

Nanotools
Capital equipment and software used to visualize, manipulate, and model matter at the nanoscale
Atomic force microscopes, nanoimprint lithography equipment, nanomanipulators…
Nanotechnology will impact $2.9 trillion worth of products across the value chain by 2014

Sales of products incorporating nanotechnology, 2005 to 2014

Forecast based on Lux Research’s value chain ontology, secondary research, and more than 100 interviews with executives, thought leaders, and academics. Projections were triangulated from bottom-up, top-down, analogical, and third-party market estimates, as well as advanced evolutionary models.

Source: Lux Research Report “Sizing Nanotechnology’s Value Chain”
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The definition of “what’s nanotech” in the electronics & semiconductor industries is semantic and unproductive.

- **Less stringent**
  - Minimum layer thickness
  - Gate oxide length
  - Minimum feature size

- **More stringent**
  - Novel litho process (LIL? EUV? NIL?)
  - Use of novel nanomaterials (e.g. CNTs, QDs)

Applied Materials (Mark Pinto)
NSF (Mihail Roco); Intel (various)
Conventional wisdom (various)
Lux Research (arbitrary, for market forecasting purposes)
Purists (e.g. Stan Williams, HP)
Discovery keeps growing...

Journal articles on nanotechnology topics, 1996 to 2006

Source: Science Citation Index searches. Search string: TS=(quantum dot OR nanostruc* OR nanopartic* OR nanotub* OR fuller* OR nanomaterial* OR nanofib* OR nanotech* OR nanocryst* OR nanocomposit* OR nanohorn* OR nanowir* OR nanobel* OR nanopor* OR dendrimer* OR nanolith* OR nanoimp* OR nano-imp* OR dip-pen)
…but gets eclipsed by commercialization

Global nanotech funding, 2000 to 2006, fixed exchange rates (US$ millions)

Source: Lux Research data and projections.
Nanotech research efforts worldwide continue to drive publications and patents

Funding for nanotechnology R&D totaled $11.8 billion worldwide in 2006, up ~13% from 2005

Global nanotechnology investment by source, 2006 ($ billions)

- Government: $5.79 (9% growth)
- Corporate: $5.34 (19% growth)
- Venture capital: $0.70 (10% growth)

Funding for nanotechnology R&D totaled $11.8 billion worldwide in 2006, up ~13% from 2005

Global nanotechnology investment by region, 2006 ($ billions)

- North America: $3.89 (21% growth)
- Europe: $4.43 (34% growth)
- Asia: $3.16 (7% growth)
- Rest of world: $0.34 (12% growth)

Nanotech venture capital spending is maturing with a strong focus on electronics applications

Nanotechnology venture capital funding, 1999 to 2006 (US$ millions)

Source: Lux Research data and projections.
• EIT sector spending in nanotech represents 46% of total in 2006, and has received $22.3 billion out of a total of $47.5 billion.
Funding is spent differently across the three sectors

Nanotech spending by sector and organization, 2006

Materials and Manufacturing: $3.84 billion
- Academic and government labs: $1.76
- Start-ups: $0.30
- Corporations: $1.78

Electronics and IT: $5.46 billion
- Academic and government labs: $3.16
- Start-ups: $0.42
- Corporations: $1.88

Healthcare and Life sciences: $2.51 billion
- Academic and government labs: $0.41
- Start-ups: $0.33
- Corporations: $1.77

The Best Evidence of Nanotech Maturity: Multiple Applications In-Market

Materials & Manufacturing
- High-strength/low-weight composites
- Inks for printable electronics
- Additives/Catalysts

Healthcare & Life Sciences
- Polymer nanoparticles for targeted therapy
- Diagnostics
- Bio/chemical sensors
- Nano-encapsulation
- Anti-bacterial coatings
- Multi-functional coatings
- Cosmetics

Electronics & Energy
- Battery electrodes
- Batteries
- Sensors
- Memory

Product readiness vs. level of impact: Materials & Manufacturing

Level of impact

- High impact
  - Thermal management composites
  - Flexible/organic electronics materials
  - Inks for printable electronics
  - Hard composites
  - Insulation

- Medium impact
  - Barrier coatings
  - Multi-functional composites
  - Additives/Catalysts
  - Anti-wear/anti-abrasive coatings
  - Multi-functional coatings

- Low impact
  - Fuel cell catalysts
  - High-strength/low-weight composites
  - Multi-functional composites
  - Thermal management composites

Product readiness

- Early stage development
- Product development
- Commercially available

Product readiness vs. level of impact: Electronics & Energy

Product readiness vs. level of impact: Healthcare & Life Sciences

Level of impact

- High impact
  - Magnetic nanoparticle targeted drug delivery
  - Nanoparticle-based thermoablative cancer therapy
  - Diagnostics
  - Polymer nanoparticles for targeted therapy
- Medium impact
  - Single molecule diagnostics
  - Liposome drug delivery
  - Polymer nanoparticle drug delivery
  - Bio/chem sensors
  - Functional medical device coatings
  - Anti-bacterial coatings
  - Nano-encapsulation
  - Cosmetics
- Low impact
  - Early stage development
  - Product Development/Clinical trials
  - Commercially available

Nanotechnology Impact is Different in Each Sector

Breadth versus depth of impact for each sector

Depth of impact

High impact

Low impact

Number of industries affected

Breadth of impact

Healthcare and life sciences

Electronics and energy

Materials and manufacturing

Commercialization strategies need to be driven by sector-specific factors

- Correctly Balance Cost and Performance
  - Cost
  - Performance

- Replace technology push with market pull
  - Very difficult
  - Not difficult

- Actively manage the partnering process
  - Partner promiscuously
  - Focus on one or two partners

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Electronics and IT companies see nanotech as a big, but not a top three, priority

“How big a priority is nanotechnology at your company today?”

Source: December 2004 Lux Research Report “The CEO’s Nanotechnology Playbook”
Most electronics and IT companies have a dedicated nanotechnology effort

“How are your company’s efforts in nanotechnology organized?”

- Materials and manufacturing: 47% Centralized, 35% Decentralized, 18% Federated
- Electronics and IT: 60% Centralized, 30% Decentralized, 10% Federated
- Healthcare and life sciences: 0% Centralized, 100% Decentralized, 0% Federated

Source: December 2004 Lux Research Report “The CEO’s Nanotechnology Playbook”
Half of electronics companies claim to have an explicit nanotechnology strategy

“Does your company have an explicit strategy for exploiting nanotechnology innovations?”

<table>
<thead>
<tr>
<th>Industry</th>
<th>Yes</th>
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<tbody>
<tr>
<td>Materials and manufacturing</td>
<td>71%</td>
<td>29%</td>
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<tr>
<td>Electronics and IT</td>
<td>50%</td>
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<tr>
<td>Healthcare and life sciences</td>
<td>17%</td>
<td>83%</td>
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</table>

Source: December 2004 Lux Research Report “The CEO’s Nanotechnology Playbook”
Nanotechnology IP Landscape: Rising pendency is creating a significant backlog

- Backlogged pub. patent applications tops 20,000 dating back to 2004

Source: Lux Research patent analysis as of July 2007
Nanotechnology IP Landscape

Lux Research found 4,986 nanotechnology patents covering 102,651 claims, and did claim-by-claim analysis of eight nanomaterials covering 2,646 patents and 49,807 claims.

• It’s messy – detailed analysis required for each particle and application
• However, judicious firms can find freedom to operate

Source: June 2006 Lux Research Report “Nanotech IP Battles Worth Fighting”
Nanowires – Commercialization (1)

Application activity: Leading developers

- Based on an analysis of 654 issued patents and published patent applications from the USPTO
- Activity is mapped by year of earliest filing to remove USPTO processing lag, although data is complete only through 2005
- Leading applications developers
  - Hewlett Packard accounting for 19% of the total activity
  - Nanosys accounting for 9% of the total activity, but also holds licenses to significant university work

Number of patents/patent applications

Source: Lux Research patent analysis as of July 2007
Nanowires – Commercialization (2)

Application activity: Leading applications

- Based on an analysis of 654 issued patents and published patent applications from the USPTO
- Activity is mapped by year of earliest filing to remove USPTO processing lag, although data is complete only through 2005
- Leading applications are in two areas:
  - Active solid-state devices (e.g., transistors and diodes) accounting for 24% of the current activity
  - Semiconductor device manufacturing accounting for 22% of the current activity

Source: Lux Research patent analysis as of July 2007
## Nanowires – Commercialization (3)

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<td>Electronic digital logic circuitry;</td>
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Source: Lux Research patent analysis as of July 2007
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Nanotechnology IP Landscape: Activity of IBM, Intel, & HP

Source: Lux Research patent analysis as of July 2007
Overview

- Nanotech activities from IBM, Intel and HP contribute significantly to the scientific research in nanoelectronics.
  - Despite leading efforts in fundamental research on materials and applications, IBM’s nanotech efforts fall mostly into the realm of interesting science. Innovations that hold commercial potential will likely be licensed off rather than produced
    - **IBM follows an internal research and development protocol**
  - Intel must incorporate many of its innovations into products to maintain its leadership position in the semiconductor industry. Many advances in nanotech will be critical to continuing Moore’s Law
    - **Intel utilizes internal R&D, but more importantly its VC group**
  - HP holds out considerable commercialization potential, but a lack of a focused/targeted effort for its research makes it an unlikely champion
    - **HP focuses on universities and start-ups to complement internal R&D**
IBM’s Nanotech Activities

- **Background:** IBM’s core business is increasingly focused on services, but the company’s research labs conduct investigation into nanoelectronics with applications in semiconductors, memory devices, and photonic ICs.

- **Nanotech funding:** Since 2004 0.5% to 1% of its R&D budget to nanotech, $35 million in 2006.

- **Nanotech headcount:** 150+ employees are dedicated to research in nanotech, estimates from Tom Theis but may not represent fulltime activities in nanotech (note: at $200,000/year salary for a full time equivalent (FTE), 150 employees draws $30 million/year); the likely FTE at IBM is 75 to 100 people with other funds earmarked for equipment purchases.

- **Summary:** IBM’s work in nanoelectronics is diverse and ultimately targeted for commercial integration, however, the current status of many of the projects that IBM has undertaken is considerably earlier stage – in many cases either concept stage or lab stage. IBM is likely to choose only the most promising areas and license out other innovations along its services business model.

- **Projects:** Millipede, silicon nanophotonics, CNT electronics (oscillator).
Intel’s Nanotech Activities

- **Background:** As a leader in semiconductor process technology, Intel’s activities in nanotechnology look at harnessing nanoscale innovation to further Moore’s Law in scaling devices.
- **Nanotech funding:** estimated at 10% of total R&D
- **Nanotech headcount:** estimated at 100s of people spanning various R&D facilities
- **Key areas of focus:**
  - **Quantum dot memory:** Targeting a floating gate flash memory replacement, Intel is in a 3-way collaboration with technology partner, Micron, and nanotech startup Nanosys to develop a novel charge trap memory device that uses metal quantum dots of SiGe(5nm in diameter) as the charge storage medium. The quantum dots are synthesized offline and functionalized such that the nanomaterials can be coated onto the silicon wafer substrate in an ordered array. Likely incorporation at the 22nm technology node.
  - **Carbon nanotube interconnects:** While few nanomaterials are listed on Intel’s technology roadmap, the company continues efforts to research the potential use of carbon nanotubes as an interconnect material in ICs. Currently lagging in the conceptual stage, Intel anticipates potential commercial incorporation by 2012, and likely use of this technology will take the form of printable interconnects with CNT-based inks in chip package.
  - **Thermal interface media:** Using metal nanoparticles and carbon nanotubes, Since 2002, Intel has been investigating the potential use of novel materials to improve thermal interface between chip and heat spreaders.
- **Summary:** With the most to gain from implementing novel technologies to maintain its technology leadership position, **Intel is likely to lead commercialization of nanoscale innovations** that move beyond simple scaling of existing materials and architectures used in its IC products. With significant issues arising from processor heat generation, material innovations could appear here first, but it is unlikely that Intel will be vocal in publicizing these breakthroughs.
HP’s Nanotech Activities

- **Background:** Driven by a need to find new applications for its ink jet core competency, HP’s activities in nanotechnology tend towards innovations that will enable printed electronics capability.
- **Nanotech funding:** ~0.5% of R&D spending is allocated to nanotech research, $30 million in 2006
- **Nanotech headcount:** 65 employees are dedicated to nanotech research
- **Key areas of focus:**
  - **Nanoimprint lithography (NIL):** Using equipment developed in-house, as well as from NIL equipment suppliers like Molecular Imprints, HP puts considerable manpower to developing NIL expertise looking at all aspects including equipment, stamp, surface prep materials, patterning materials, and lift-off techniques.
  - **Nanowire arrays:** Stemming from research in nanoimprint lithography, HP has been able to develop ordered arrays of silicon nanowires
  - **Carbon nanotube-enable printed electronics:** A recent development at HP has been the undertaking of developing a carbon nanotube-based ink with noted CNT-based memory developer, Nantero. HP and Nantero are targeting the development of an ink-jet printable memory device based on carbon nanotubes explicitly for RFID. Other developments that will like stem from this collaboration are CNT-based conductive inks for other RFID tag components like the antenna.
- **Summary:** HP’s nanotech efforts are diverse and uncoordinated. The company has great potential to bring innovations to market given its broad product portfolio in electronics ranging from computers and printers to digital cameras. Despite this potential, the random assortment of innovations that the company has pursued in earnest to date are far from commercialization. With a focused partnership with Nantero, HP could advance its printed electronics activities.
Thank you

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