Characterization, Standards, and Commercialization of Carbon Nanotubes

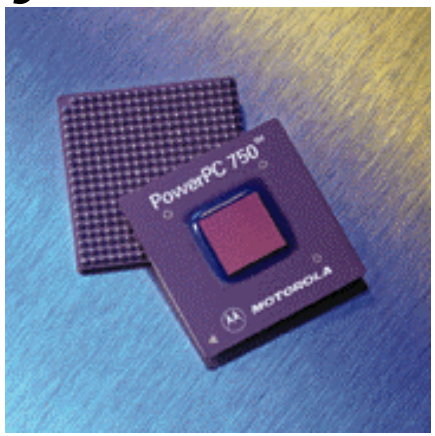
Daniel Gamota, Motorola

and

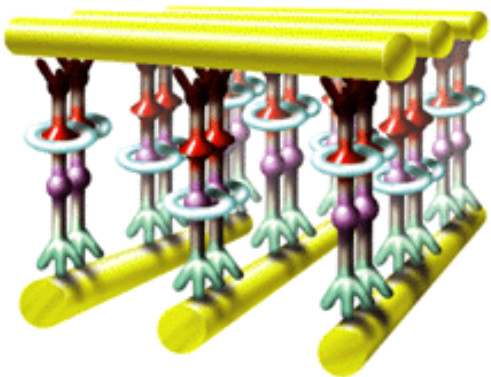
Edward Rashba, IEEE

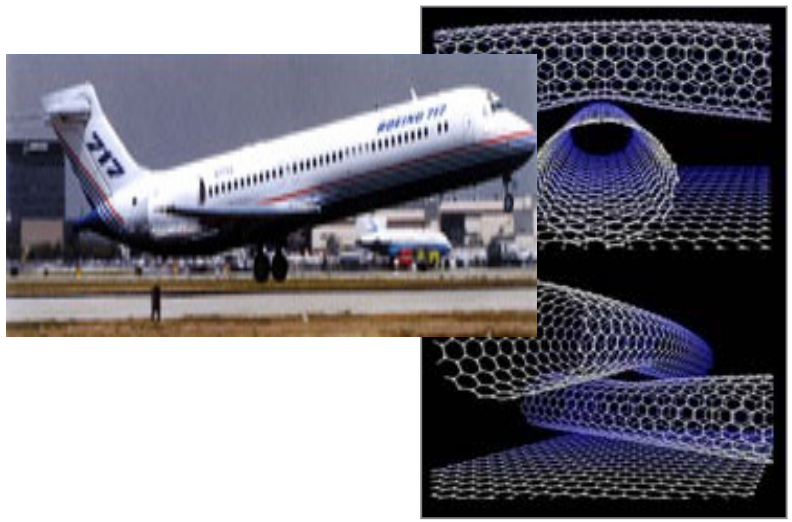
Nanotechnology

Evolutionary



and Revolutionary





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Revolutionary – ***CURRENT*** Products with Nano

Water Proof – Stain Proof

Nanowax: CERAX

Carbon nano-tubes

Nano-clay composite gas diffusion barrier

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Nano Makes Products Better ……Nano-Enabled Phone

Polymer Nano-composite: increased polymer stiffness with low CNT filler loading

- Color changing housing
- Ultra soft key-pad
- Housing Sensorial: using embedded strain gauges

Use of Nano particles alloys to reduce manufacturing related costs

- Bacteria -Virus detection
- Components: ceramic filters, oscillators….

Self-healing

Self Cleaning Surface:
Easy to wipe face, hand, finger oils, and cosmetic residue.

Scratch resistance

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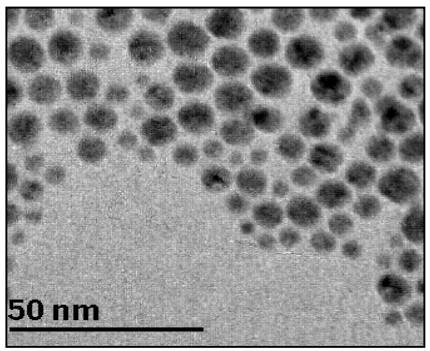
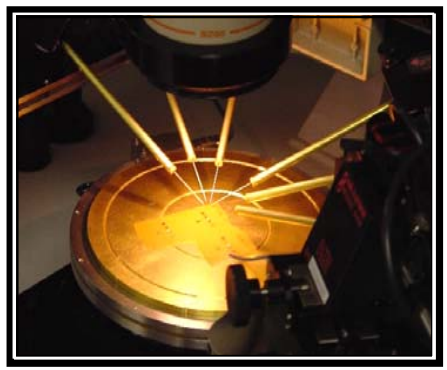
Integrating Nanotechnologies in High Volume Products Requires a Well Established Nanotechnology Value Chain

Nanotubes and Nanoscale Materials Offer Many Early Opportunities

Materials → **Processing/ Equipment Platforms** → **System Testing** → **Design & Applications**





Too Many to List!!!

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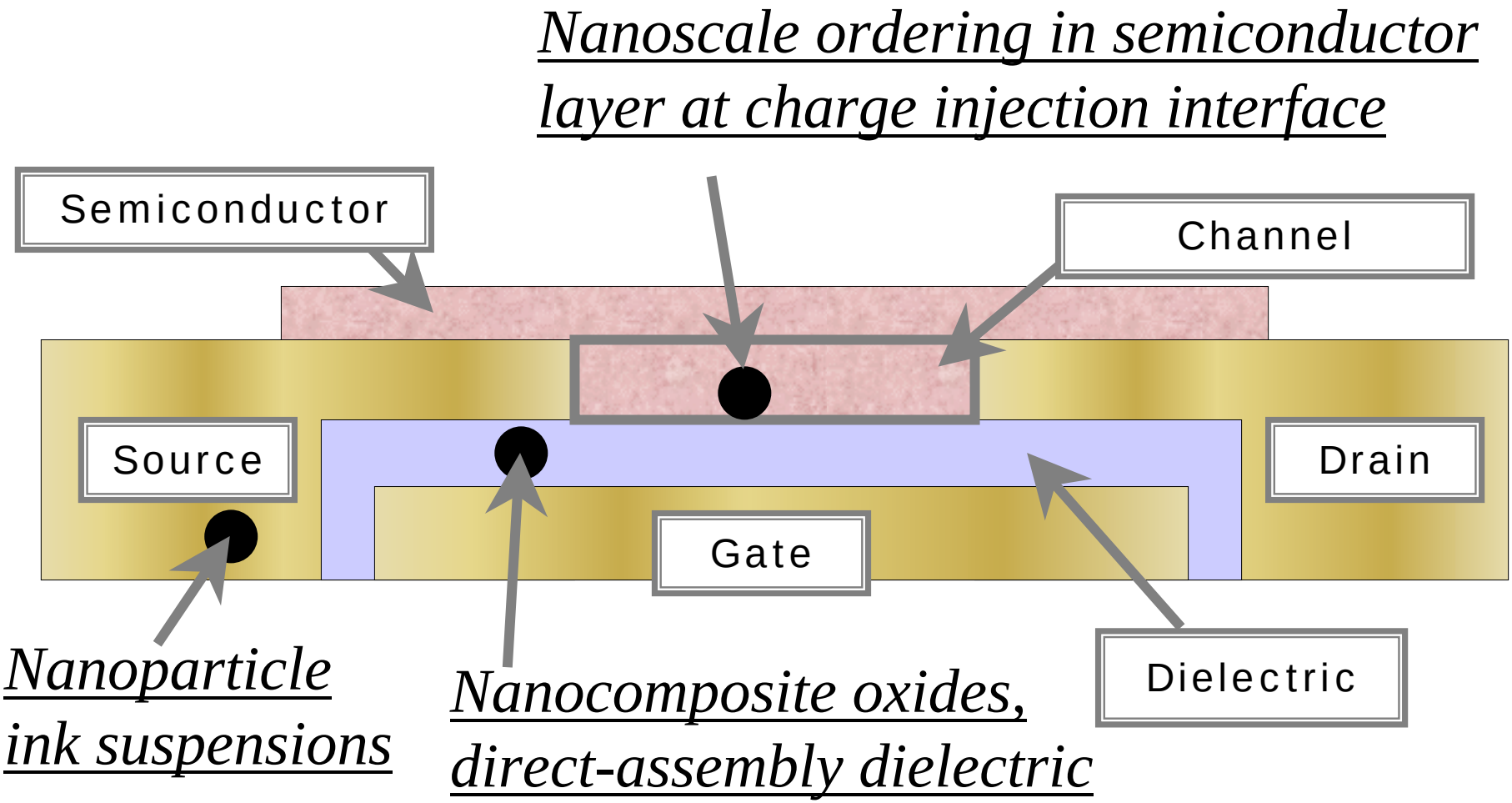
Nanoelements of a Printed Transistor



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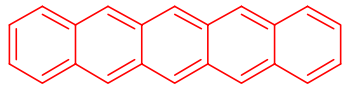
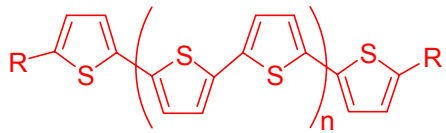
Functional NanoInks - Conductive, Semiconductive, and Dielectric Inks

Attributes

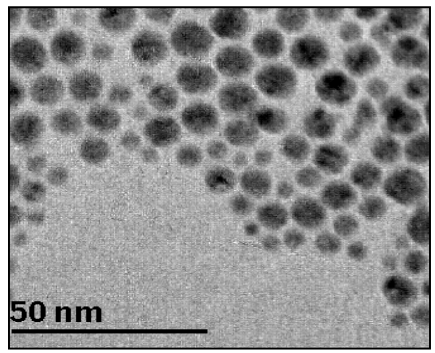
- Nanotubes and nanoscale particles
- Characteristics similar to traditional electronic materials
- Solution processable for low cost manufacturing
- Robust synthesis/formulating routes
- Materials and device stability in-air
- Large area processing routes demonstrated
- Devices fabricated on graphic arts manufacturing printing platforms

Semiconductor Inks





Silver Nanoparticle Conductive Inks



Advent of Electronic Nano Inks Provide A Large Opportunity To Capture NEW LARGE REVENUE STREAMS

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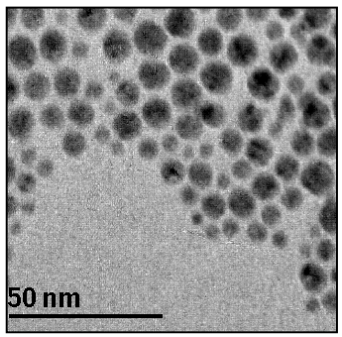
Tools & Methods to Characterize Functional NanoInks

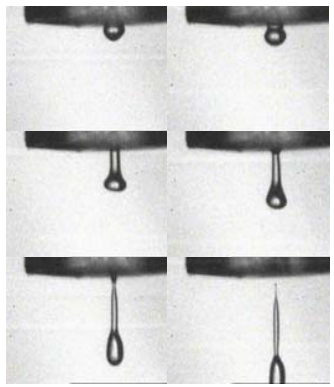
Electronic Materials Characterization

- Fluid properties
- Solution stability/shelf-life
- Curing/Sintering/Annealing temperature and schedules
- Nanoparticle interactions



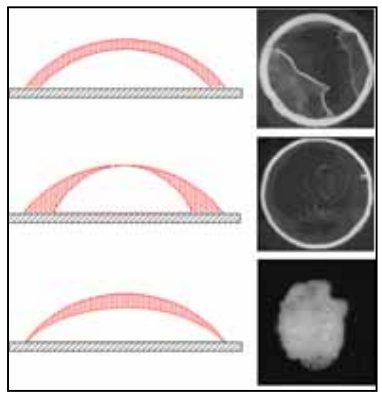
Fluid Dynamics

- Printing parameter optimization
- Meniscus oscillation
- Droplet pinch-off



Deposition Issues

- NanoInk/substrate wettability
- Droplet evaporation
- "Coffee Stain" phenomena



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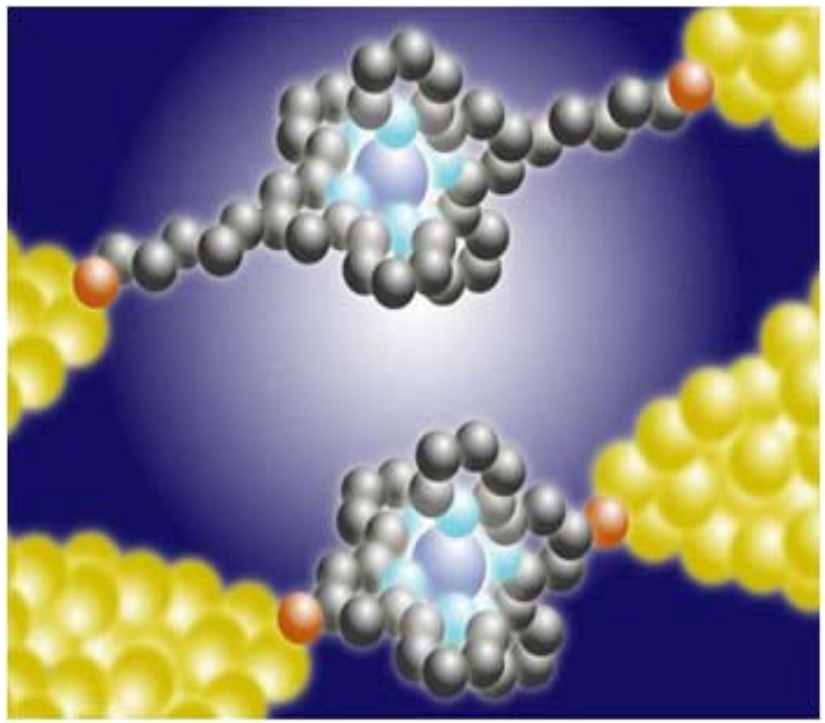
Nanotechnology Standards Roadmap – It's Under Construction As We Speak

Concept to Product



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Nano Related Standards Efforts

- IEEE P1650™ Working Group (http://grouper.ieee.org/groups/1650)
  - Draft Standard Test Methods for Measurement of Electrical Properties of Carbon Nanotubes
  - Drafting of standard in progress

- SEMI/IEEE
  - Joint Nanotechnology Initiative for Nanoparticles – types, characteristics, slurry requirements, metrology
  - Working Group Kick-off Meeting in July 2004

- Recently Initiated Activities
  - ANSI
  - ASTM
  - .....

- IEEE P1620™-2004 (http://grouper.ieee.org/groups/1620)
  - Standard for Test Methods for the Characterization of Organic Transistors and Materials
  - Standard available at http://shop.ieee.org/store

- IEEE P1620.1™ Working Group (http://grouper.ieee.org/groups/1620.1)
  - Draft Standard for Test Methods for the Characterization of Organic Transistor Based Ring Oscillators
  - Call for volunteers for Kick-off Working Group Meeting 3 August 2004

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IEEE P1650™ Working Group
(http://grouper.ieee.org/groups/1650)
Draft Standard Test Methods for Measurement of Electrical Properties of Carbon Nanotubes

IEEE P1650/D5
25 January 2005

Draft Standard Test Methods for Measurement of Electrical Properties of Carbon Nanotubes and Multi-Terminal Devices

Sponsored by the
Nanotechnology Council

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Need For Interoperability Standards: Silicon & Nano-electronics

Today we live in a silicon controlled world ……
but tomorrow we hope to introduce nano.

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Background

- 15 companies, 2 products each = 2450 permutations!
- Common product architectures? - unlikely
- All nano-device or hybrid solutions?
- Second supplier needed? – always, mitigates risk

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Need for Interoperability

- Device-level success ≠ Interoperability success
- Material property at macroscale, microscale, nanoscale
- Connect one device to another – It's a connected world!
- Seamless performance – a must (dropped cellular calls!)
- Customer satisfaction, acceptance, confidence
- Increase sales

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Interoperability Success Stories

- Storage networks industry
- Web services interoperability
- Public safety
- Havi (home audio visual)
- Open mobile alliance

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Nanotechnology & Interoperability

- Examples of products under development to address interoperability
  - **Zyric from Zyrex (Software Framework)**
  - **Synopsis (Electronic Design Automation)**
  - **Nano-Sim (Nanospace Simulator)**
  - **nanoTitan (Software Tools – Simulation, Visualization, Analysis)**

- It's here!

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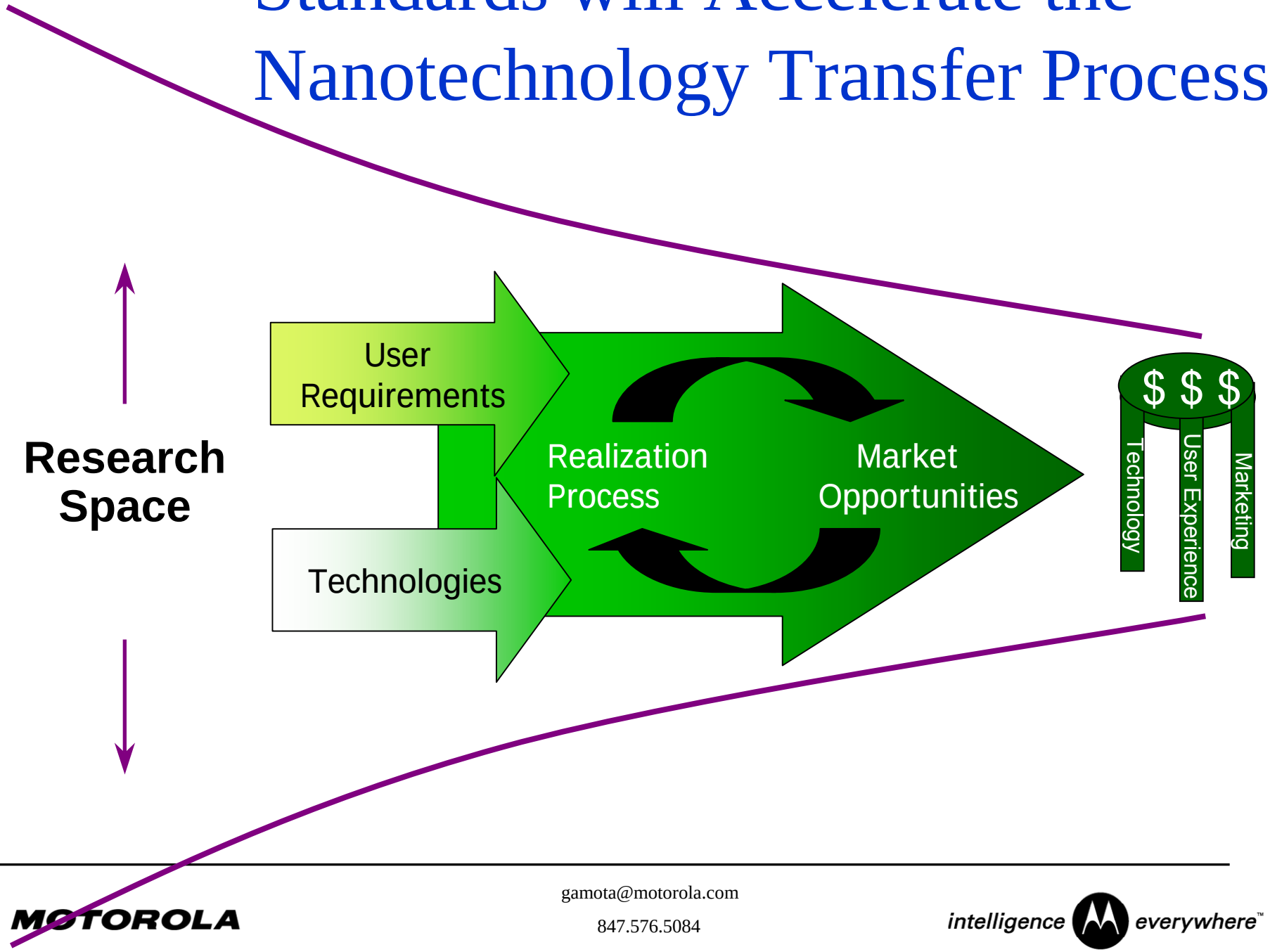
Standards will Accelerate the Nanotechnology Transfer Process



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Gated Project Plan Process

Market Intelligence and Analysis

Business Case Development Phase	Portfolio Planning Phase	Project Definition Phase	Implementation Phase	Launch and Closeout Phase
Gate 15 Idea Accepted	**Gate 12** Portfolio Accepted	**Gate 10** Project Initiation	**Gate 6** Design Readiness	**Gate 2** Volume Deployment
Gate 14 Concept Accepted	**Gate 11** Solution Lockdown	**Gate 9** System Requirements Baselined	**Gate 5** System Test Readiness	**Gate 1** Retirement Plan Approved
Gate 13 Solution Selected		**Gate 8** System Requirements Allocated	**Gate 4** Ready for Field Test	**Gate 0** End of Life
		Gate 7 Contract Book Baselined and Approved	**Gate 3** Ready for Controlled Introduction	

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Gated Project Plan Process

Accept Ideas and solutions

Initiate Project

Develop Design

Conduct Field Test

Controlled Introduction

Volume Deployment

End of Life

- Market share trends
- Benchmark
  - Competing products
  - Potential competitors
- Cost /revenue estimates

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Gated Project Plan Process

Accept Ideas and solutions

Initiate Project

Develop Design

Conduct Field Test

Controlled Introduction

Volume Deployment

End of Life

- Detailed requirements
- Specific means for measuring and achieving target values

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Gated Project Plan Process

Accept Ideas and solutions

Initiate Project

Develop Design

Conduct Field Test

Controlled Introduction

Volume Deployment

End of Life

- Conduct failure mode analysis
- Feed results back
- Identify inputs to future development efforts.

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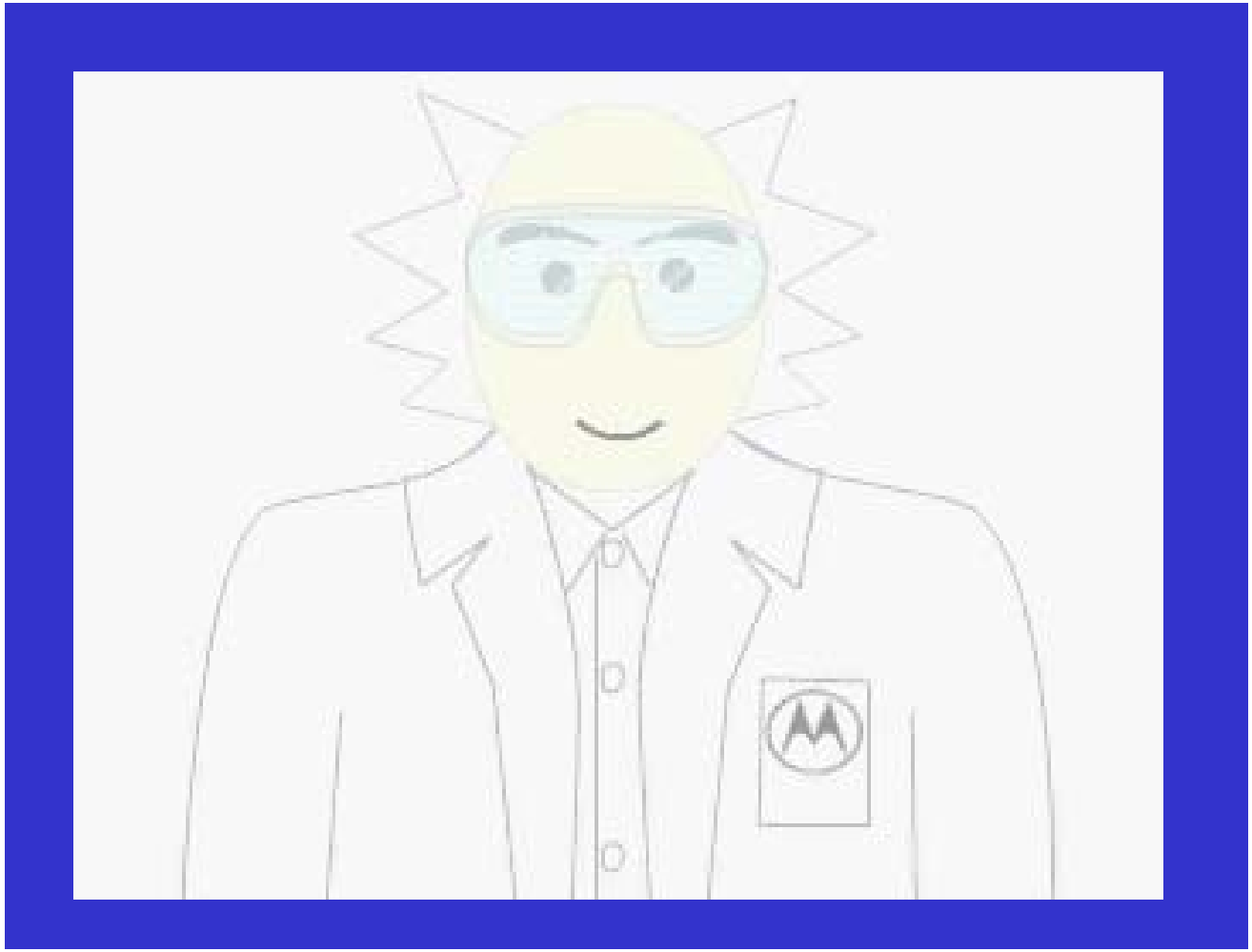
Molecular Self Assembly



Professor Mole: Self Assembly 101

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