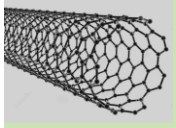
Nanotechnology in Electronics Packaging, Interconnect, & Assembly: Hype or Reality?



Charles E. Bauer, Ph.D.
Herbert J. Neuhaus, Ph.D.
TechLead Corporation

Presentation Outline

- Nanotechnology Fundamentals
- Application Opportunities
  - Packaging
  - Interconnect
  - Assembly
- Commercialization Strategies
  - Evolutionary
  - Revolutionary
- Reality or Hype?

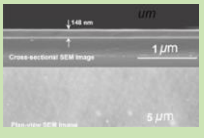
Nanotechnology Fundamentals

Section 1

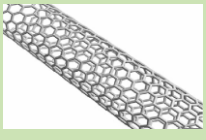
Nanotechnology?

- The study of matter on the scale of atoms & molecules
- 1 to 100 nm in at least one dimension

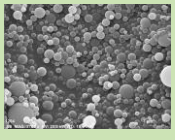
1D – Films



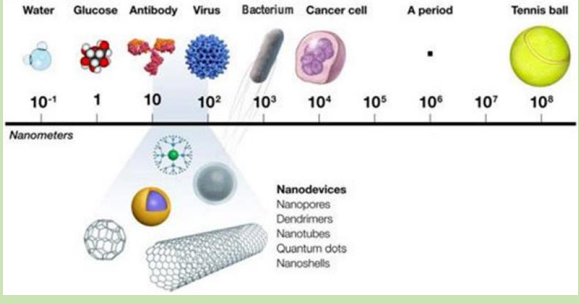
2D – Tubes



3D – Particles



How Small Nano?

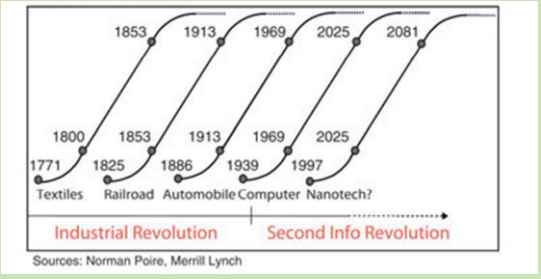


Nanotechnology Today

- Smaller
- Lighter
- Faster
- Stronger
- More Durable

Sound Familiar?

Next Great Innovation?



Sources: Norman Poire, Merrill Lynch

 Data to *Information*; Knowledge to *Understanding*

CNT as Cu Interconnect Replacement?

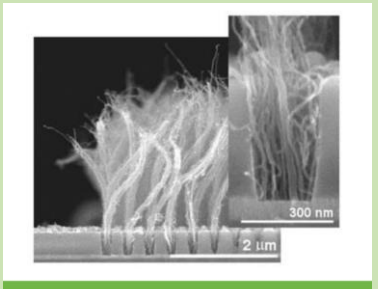


Figure 1. Dense Bundles of CNTs Grown in Contact Holes on Silicon Wafers

 Data to *Information*; Knowledge to *Understanding* Source: IMEC

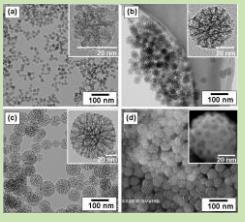
What Makes Nano Interesting?

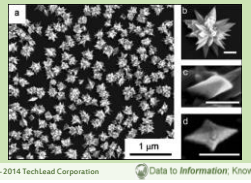
- Physical processes do not scale uniformly
  - Gravity
  - Friction
  - Combustion
  - Electrostatic
  - Van der Waals
  - Brownian
  - Quantum

 Data to *Information*; Knowledge to *Understanding*

What Makes Nano Interesting?

- Affects all materials
  - Metals
  - Ceramics
  - Polymers
  - Biomaterials

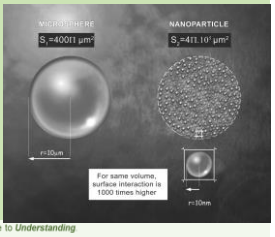




 Data to *Information*; Knowledge to *Understanding*

What Makes Nano Interesting?

- Nanotech materials exhibit remarkable new properties based on
  - Small dimensions
  - Large surface area
  - Novel structures
  - Unique combinations



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Application Opportunities

Section 2

 Data to *Information*; Knowledge to *Understanding*

Nanotech Application Opportunities

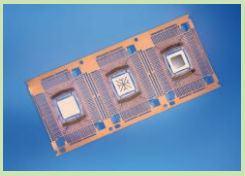
- Packaging
  - Die Attach
  - Flip Chip Bonding
- Interconnect
  - Additive Circuit Formation
  - Tin Whisker Control
- Assembly
  - Adhesives
  - Stencil Printing
  - 3D Printing

Die Attach Materials

Table 3-1. Die Attach Materials by Package Technology

Package Technology	Die Attach Material	Type
Pressed Alumina Ceramic (CERDIP)	Silver-Filled Glass	Inorganic Adhesive
Laminated Alumina Ceramic (PGA, CQFP, Side-Braze)	Gold-Silicon Eutectic Silver-Filled Cyanate Ester	Hard Solder Organic Adhesive
Molded Plastic	Silver-Filled Epoxy	Organic Adhesive

- Functions:
  - Mechanical
  - Electrical
  - Thermal



Source: Intel, Delo

Conventional Die Attach Limitations

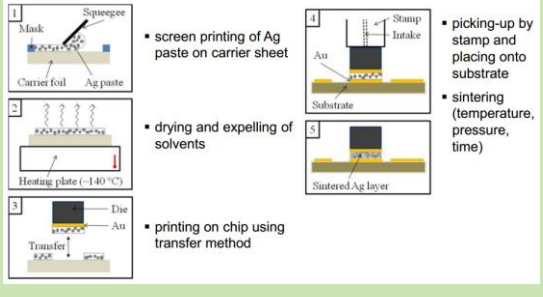
- High T Devices
  - Wide band gap power devices (SiC)
  - Hi-Bright LEDs
  - Higher melting point & thermo-mechanical properties
- Temperature Sensitive Devices
  - III-V photodetectors
  - Lower process temperatures

Nano-Based Alternatives

- Low Temp Sinter nano-Ag Paste
  - Sinters once surfactant volatilized
  - Highly reactive nano-Ag forms strong bonds
  - Several (pre)commercial sources

Source: NBE Tech

Nano-Based Alternatives

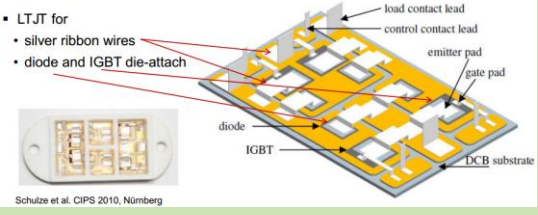


- screen printing of Ag paste on carrier sheet
- drying and expelling of solvents
- printing on chip using transfer method
- picking-up by stamp and placing onto substrate
- sintering (temperature, pressure, time)

Source: TU Braunschweig

Nano-Based Alternatives

- Modules for electrical power train of hydrid cars, fuel cell cars, …
  - increasing power density / device temperature range
  - at high mechanical stress
  - no lifetime loss
- LTJT for
  - silver ribbon wires
  - diode and IGBT die-attach



Schulze et al. CIPS 2010, Nürnberg

Source: TU Braunschweig

Nano-Based Alternatives

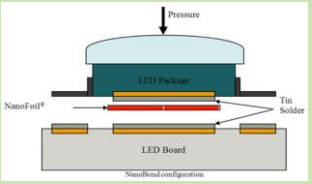
- Indium Corporation NanoFoil®
- Reactive multi-layer foil providing instantaneous heat
- Vapor deposited alternating nano-layers of Aluminum (Al) & Nickel (Ni)
- Activated by pulsed local energy (electrical, optical or thermal)
- Foil reacts exothermically precisely delivering localized heat up to temperatures of 1500°C in thousandths of a second

 Data to *Information*; Knowledge to *Understanding*

Nano-Based Alternatives

NanoFoil®

- Join components
- Melt adjoining solder layers
  - Without reflow temperatures
  - In air & at room temperature
  - No flux requirement
  - Fraction of a second
  - No reflow equipment



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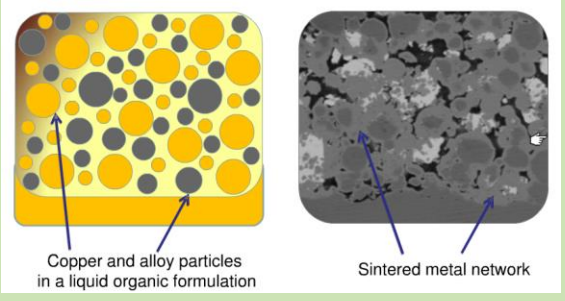
Nano-Based Alternatives

NanoFoil® Ignition

 Data to *Information*; Knowledge to *Understanding*

Nano-Based Alternatives

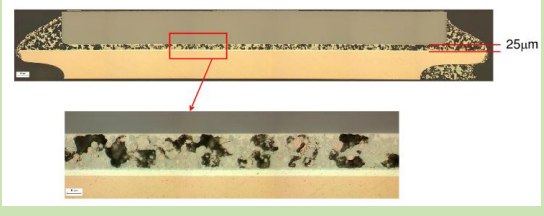
ORMET – Transient Liquid Phase Sintering



 Data to *Information*; Knowledge to *Understanding* Source: Ormet

Nano-Based Alternatives

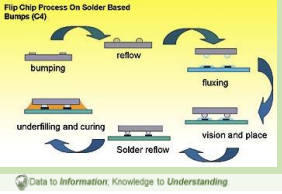
T reduction through nano-particle enhancement



 Data to *Information*; Knowledge to *Understanding* Source: Ormet

Flip Chip

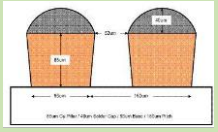
- Reduced footprint
- Reduced profile
- Reduced inductance
- Underfill compensates for CTE mismatch

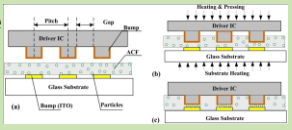


 Data to *Information*; Knowledge to *Understanding*

Conventional FC Limitations

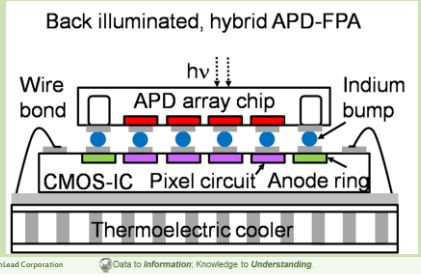
- Fine pitch FC results in low stand-off solder bumps
  - Cu Pillars increase stand-off
- Alternative: Eliminate reflow
  - Sinterable nano-materials
  - Anisotropic conductive adhesives





Nano-Based Alternatives

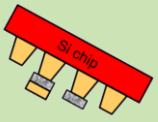
- Focal Plane Array Assembly
  - Replace Indium (In) bumps

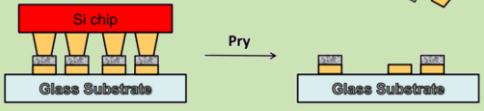


Nano-Based Alternatives

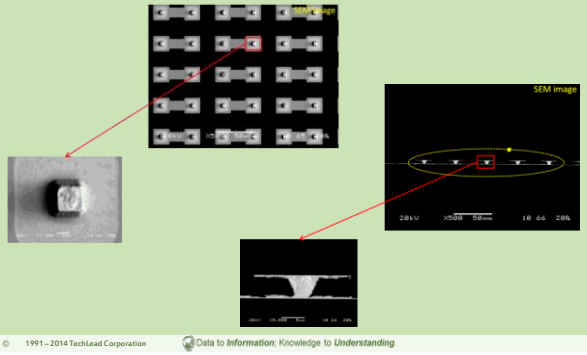
Focal Plane Array Assembly

- Nano-Ag low temp sinterable paste + Au pillars
- 32 μm pitch, 6 μm pads
- 15 μm pitch (next gen)

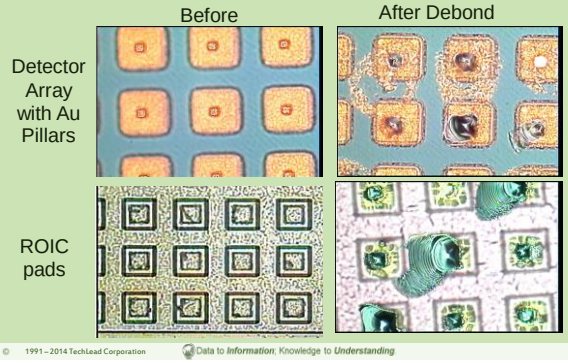




Nano-Based Alternatives

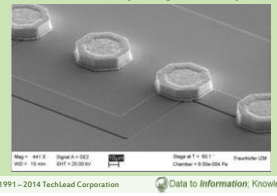


Nano-Based Alternatives



Nano-Based Alternatives

- Fraunhofer - Nano-Sponge
  - Highly compressible porous Au
  - Bonding at low T & low pressure
  - Electroplating silver-gold alloy + silver etching
  - Nano-Sponge bumps used for TC-Flip Chip bonding



Jürgen Wolf, Fraunhofer IZM

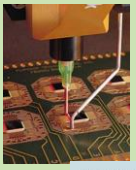
Nano-Based Alternatives

Fine pitch Flip Chip with Nano-ACF

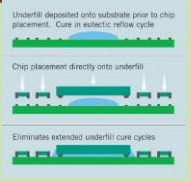
- 30um pitch silicon
- Copper pillar
- Nano-anisotropic conductive film
- Resistance comparable to solder for as assembled & HAST tested assemblies

Conventional FC Limitations

- Underfill bottleneck
  - Slow capillary flow
  - Post-reflow batch cure



- No-flow variants
  - Require lower filler loading
  - Results in higher CTE



Nano-Based Alternatives

- Nanocomposite no-flow underfill
  - Self-fluxing no-flow polymer
  - 120 nm silica particles at 50% mass loading
  - No solder-pad bonding interference

Additive Circuits

- Applications include
  - Solar cells & batteries
  - RFID tags
  - Flexible displays & lighting
  - Novelties: talking and scrolling packages

Printed Conductor Limitations

Conductive Inks (Particle fillers)

- Ink curing generally requires temperatures over 400ºC
- Exceeds capability of low cost substrates
  - PET degrades above 100ºC

Nano-Based Alternatives

- Novacentrix - nano copper oxide ink
  - Print copper oxide ink
  - Reduce to Cu with an optical flash process
  - Inks formulated for Inkjet & Screen print

Nano-Based Alternatives

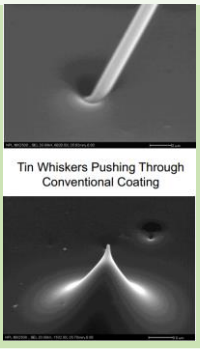
- IIMAK Graphene Ink
  - Electrically conductive carbon - graphene ink
  - Printed electronics applications
    - Membrane switches
    - Flexible circuits
    - Displays
    - Electroluminescent lighting
  - Screen print & dry to remove solvents, no cure

Tin Whiskers

- Conductive, crystalline "growths" from tin finishes
- System failure via short circuit
- No single accepted mechanism established

Conventional Mitigation Strategies

- Avoid pure Tin or Zinc
- Reduce stress in plated finishes
  - Hot solder dip
  - High temp anneal
  - Diffusion barrier (reduce intermetallics)
- Physical barriers (insulation)
  - Conformal coating
  - Increase spacing



Tin Whiskers Pushing Through Conventional Coating

Source: Chris Hunt, NPL

Nano-Based Alternatives

- Tin Oxide Nano Particle Coating
  - Surface oxides removed from tin-plated copper
  - Tin oxide nano particles water solution sprayed
  - Annealed to regrow oxide
  - Hillocks formed instead of whiskers
  - Theory: Tin Oxide nano-particles relaxed stress

  Albert Wu & Y. C. Ding, National Central University, Taiwan

Nano-Based Alternatives

- Rockwell-Collins - Nanocrystalline Coatings
  - Alkali silicate glass containing nano ceramic particles Al_20_3 ZnO 10-40nm
  - Reduced whisker formation
- Theory: Nano-particles fill cracks in Tin that produce whiskers

  Chris Dave Hillman, Rockwell-Collins

Nano-Based Alternatives

Lockheed-Martin - Lead Free Solder

- Printable Nano-Copper paste fuses at 200ºC
- Cu surface eliminates danger of whiskers
- Commercialization research at NTU (Singapore) in JV with LM

  Alfred Zinn, LM Advanced Technology Center

Nano-Based Alternatives

- Johns Hopkins – Nano-Texturization
  - Grain refining additives during electroplating
  - Tin over Polycrystalline Cu – whiskers
  - Tin over Nano-Cu – no whiskers
- Theory: Additives regulated tin stresses

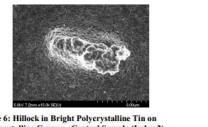


Figure 6: Hillock in Bright Polycrystalline Tin on Nanocrystalline Copper - Control Sample (Index 2)

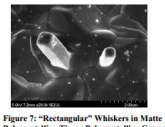
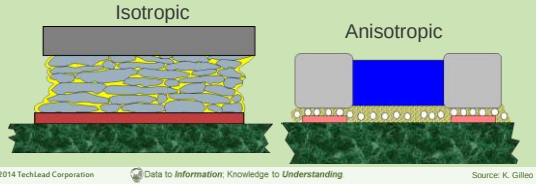


Figure 7: "Rectangular" Whiskers in Matte Polycrystalline Tin on Polycrystalline Copper Control Sample (Index 15)

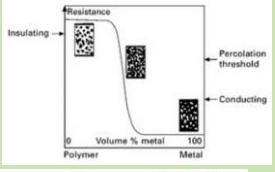
Conductive Adhesives

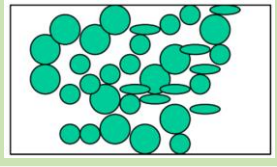
- Solder replacement
- Metal-filled composite
- Usually thermoset
- Used commercially for SMT & Flip Chip



Conventional Adhesive Limitations

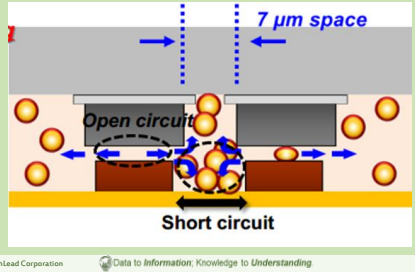
- Cost
  - Precious metal loading
- Conductivity
  - Filler packing





Conventional Adhesive Limitations

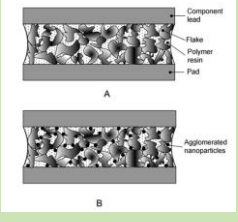
- Open circuits
- Short circuits



Nano-Based Alternatives

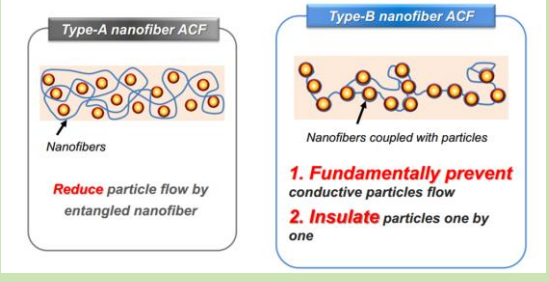
Nanoparticle impact

- Addition of nanoparticles forms additional bridges between conventional filler flakes
- Increases density of the conductive net
- Bimodal filler maintains good conductivity even at lower total filler loading
- Nano-particle reaction increases current capacity as well as conductivity



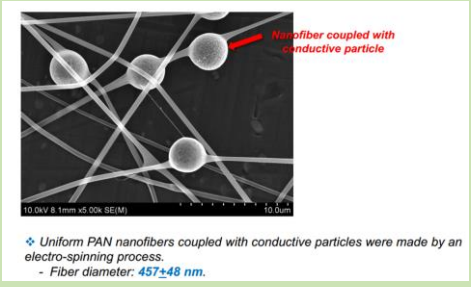
Nano-Based Alternatives

- KAIST – Nanofiber anisotropic ACF



Nano-Based Alternatives

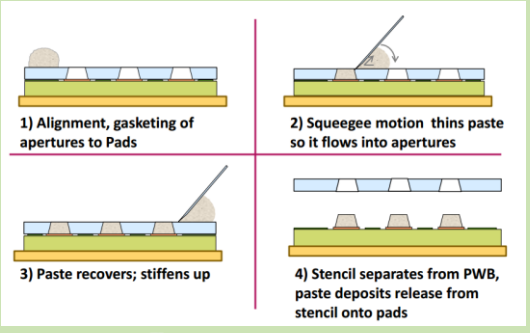
- KAIST – Nanofiber anisotropic ACF



❖ Uniform PAN nanofibers coupled with conductive particles were made by an electro-spinning process.
- Fiber diameter: 457±48 nm.

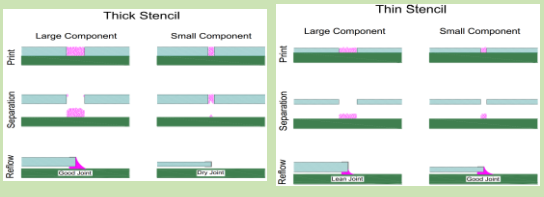
 Data to *Information*; Knowledge to *Understanding* Source: Kaist

Stencil Printing



 Data to *Information*; Knowledge to *Understanding*

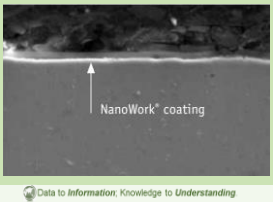
Conventional Stencil Limitations



 Data to *Information*; Knowledge to *Understanding*

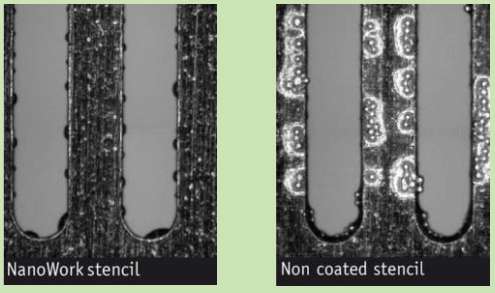
Nano-Based Alternatives

Nano-coated Stencils
- Nano-coatings on stencil bottom & aperture walls
- Nano-coating treatment follows laser-cutting
- Enhanced paste release from stencil apertures



 Data to *Information*; Knowledge to *Understanding* Source: LaserJob

Nano-Based Alternatives

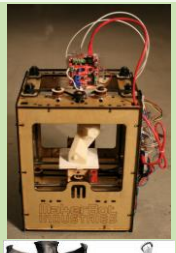


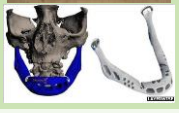
Stencil bottom side, after 5 prints without cleaning (QFP 500µm)

 Data to *Information*; Knowledge to *Understanding* Source: LaserJob

3D Printing

- No longer exclusive to hobbyists & hackers
- Commercial applications include
  - Rapid prototyping
  - Rapid manufacturing
  - Mass customization
- R&D applications include
  - Chemistry – creating novel compounds
  - Medicine – artificial organs & prosthetics





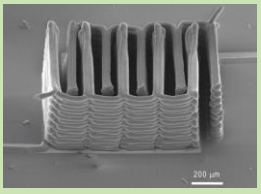
 Data to *Information*; Knowledge to *Understanding*

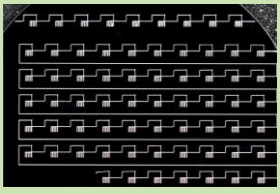
3D Printing Limitations

- Original 3D printers used thermoplastics
  - Applied in successive 2D layers
  - Fully additive process
- Plastic lacks rigidity & strength
- Plastic unsatisfactory “scaffold” for biologics
- Plastic nonconductive

Nano-Based Alternatives

- Electro-chemically active inks
  - 3D print micro batteries
  - lithium metal oxide compound nanoparticles
  - Inks for anode & cathode



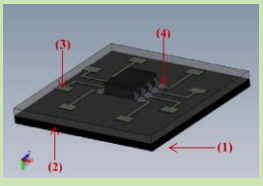


Nano-Based Alternatives

Nano-Based Alternatives

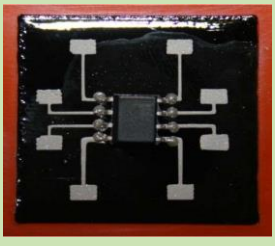
Direct printed additive packaging

- Direct print
  - CNT composite substrate (1)
  - Interconnect (3)
- Pick & Place conventional components
- Direct print
  - Conductive adhesive (4)
  - Encapsulant (2)



Nano-Based Alternatives

Completed test circuit built with direct print additive packaging



Commercialization Strategies

Section 3

Evolutionary

Section 3a

Evolutionary = Minimum Risk

- Incremental improvements to an established technology

Evolutionary = Minimum Risk

- "Drop in" solutions
  - e.g. nano coated stencils
- Understood by current customers
- Compatible with infrastructure
  - Supply chain
  - Equipment & processes
  - Specs & standards
- Favored by established vendors

Evolutionary ≠ Zero Risk

- Value capture difficult
  - Customers challenge price increases
  - Efficiency good for user but not vendor
- Improvement may not be "good enough"
  - Incumbents advance as well
- Startups & new entrants at substantial disadvantage

Revolutionary

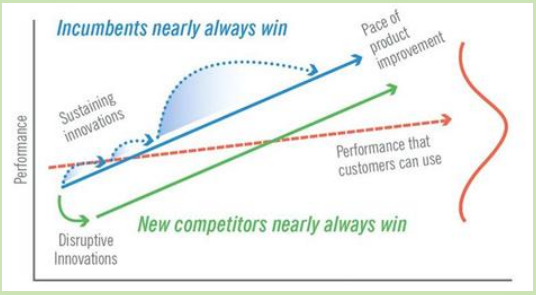
Section 3b

Revolutionary = Disruptive

New technology that unexpectedly displaces an established technology

- Lacks refinement
- Often introduces performance problems
- Appeals to a limited audience
- May not yet apply to a proven practical application

Incumbents Often Dismiss Disruptive Innovation



 Data to *Information*; Knowledge to *Understanding*

Winning Disruptive Innovations

- Telephone vs telegraph
- Steam locomotive vs diesel electric
- Solid state electronics vs vacuum tubes
- Mini-mills vs integrated steel producers
- Digital cameras vs film
- Amazon vs brick and mortar bookstores
- iTunes vs compact disks vs records

 Data to *Information*; Knowledge to *Understanding*

Value Recognition Critical

- Unrecognized value
  - Threat
  - Lack of a response is a response
- Recognized value
  - Opportunity
  - Rapidly reconfigure value chain
  - Integrate innovation into manufacturing

 Data to *Information*; Knowledge to *Understanding*

Disruptive Innovation Challenges

- Extensive qualification necessary
- Standards & specs don't exist
  - Standards bodies require critical mass
- Inertia: Resistance to change
  - Fault finding vs credit taking

 Data to *Information*; Knowledge to *Understanding*

Disruptive Innovation Opportunities

- Redefine value chain
  - Capture more value
- Advantage - Startups & New Entrants
- Customer pull vs market push

 Data to *Information*; Knowledge to *Understanding*

Nanotechnology: Reality or Hype?

Section 4

 Data to *Information*; Knowledge to *Understanding*

Reality or Hype?

Exaggerated & Over-promised
- Widespread misinformation
- Scientists exaggerate anticipated benefits to justify funding
- Alarmists peddle doom-&-gloom prophecies advancing their own agendas

► ***Hype***

Reality or Hype?

Provides vital performance enhancements
- Electronics packaging, interconnect, & assembly
- Evolutionary & revolutionary advances
- Commercially available today
- Exciting & promising R&D in progress

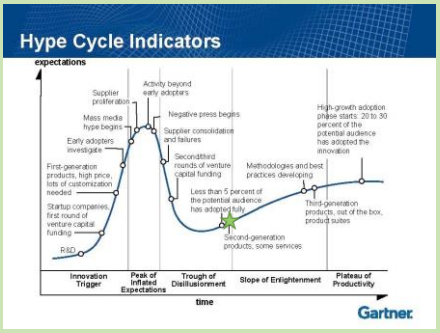
► ***Reality***

Reality or Hype?

► ***Both***

- Challenges
  - Separate the light from the heat
    - Identify
    - Communicate
  - Capitalize on low-risk evolution developments
    - Low hanging fruit
  - Exploit disruptive innovation carefully
    - Recognize opportunity & value

Reality or Hype?



Thank You!!

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