iNEMI

International Electronics Manufacturing Initiative

iNEMI Nano-Attach Project

Grace O'Malley, iNEMI
Reporting for Project Development Team

Advancing manufacturing technology

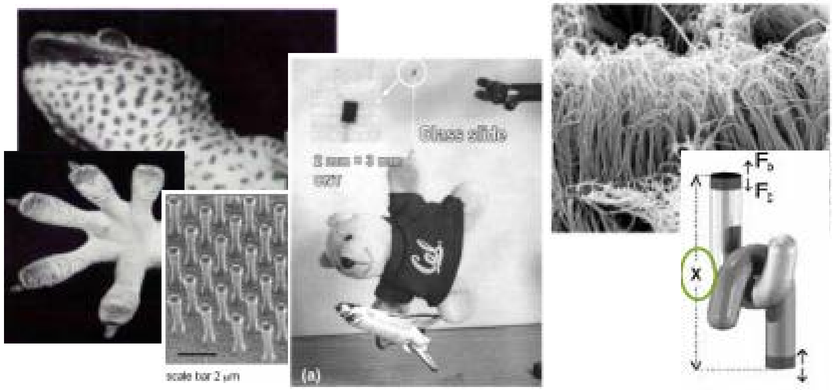
Miniaturization Thrust Area

iNEMI Nano-Attach Project

Goal: Develop low-temperature or room temperature assembly processes that have the potential to improve field reliability, streamline manufacturing, and reduce cost

Strategy:

- **Use nanotechnology based dry adhesive technologies, e.g., nano-velcro or biomimetic systems ("gecko foot") to replace high temperature solder attach systems**
- **Project Lead: Hope Chik (Motorola)**



Tactics

- **Phase 1: Discovery and Concept Development** - Define requirements necessary to adapt nano-structure attachment schemes in electronic assembly
- **Phase 2: Evaluation and Proof of Concept** - Identify and evaluate currently available nano-attach technologies and explore these approaches
- **Phase 3: Demonstration and Prototype** - Proof-of-concept material evaluation and fabrication of assembled prototypes

Milestones & Issues

- **Phase 1 – Discovery ……..................................Q407**
- **Phase 2 – Evaluation ...…………………………Q208**
- **Phase 3 – Demonstration ………………………Q408**
- **Issues:**
  - ✓ **Is the technology mature enough to have a high probability of success in Phase 2 and 3**

iNEMI Nano-Attach Team Members

Boston Scientific
Delivering what's next.™

CELESTICA

DELPHI

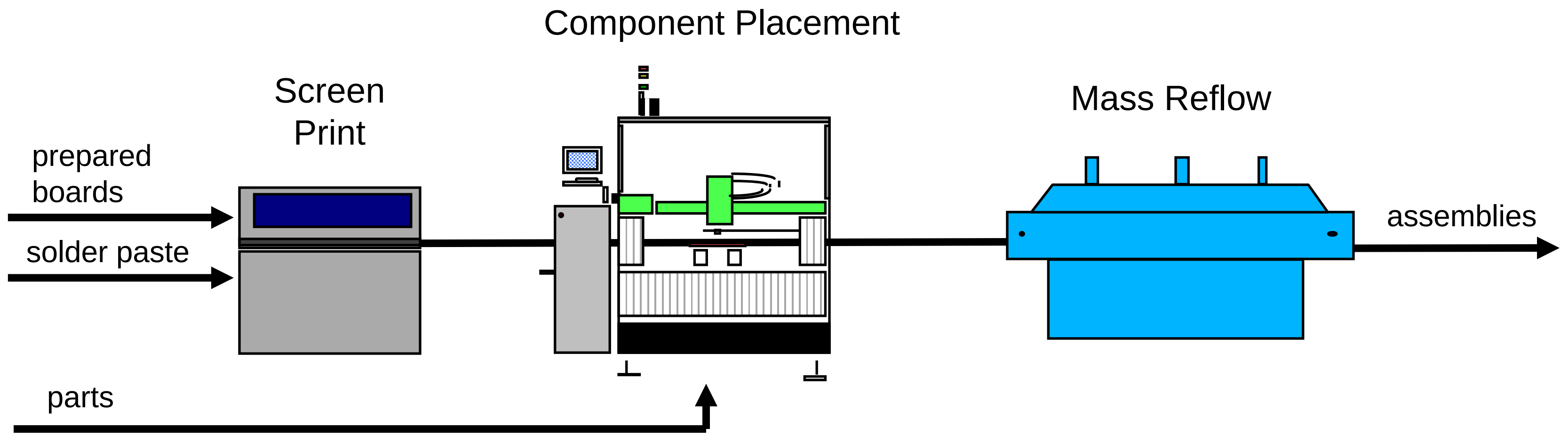
intel® Leap ahead™

MOTOROLA

PLEXUS®
The Product Realization Company

iNEMI

Motivation for Nano-Attach Technology

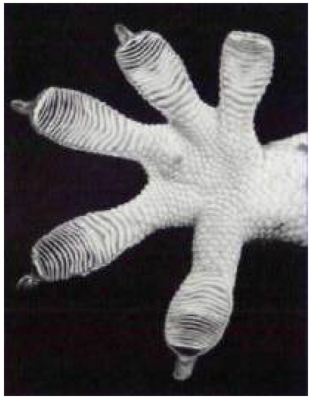


Current electronic assembly process:

- Use of elevated temperatures (mass reflow, selective soldering, conductive adhesive curing, etc.)
- Introduces thermal excursions increasing reliability risks to components and boards
- Exacerbated with even higher temperature Pb-free assembly processes
- Individualized solutions for temperature-sensitive components

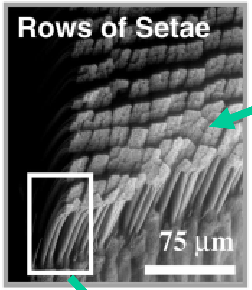
Nanotechnology – The Gecko

Hierarchical structure

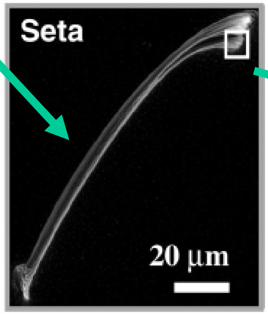


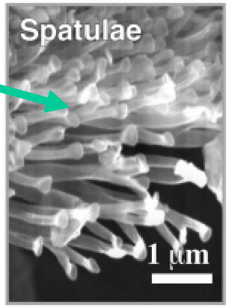
Foot:
- 14,400 setae/mm^2
- 10 N/cm^2
- Uses only 3% of setae

K. Autumn, “How Gecko Toes Stick”, American Scientist, 94, 124 (2006)



setae:
- 110 mm long
- 5 mm diameter





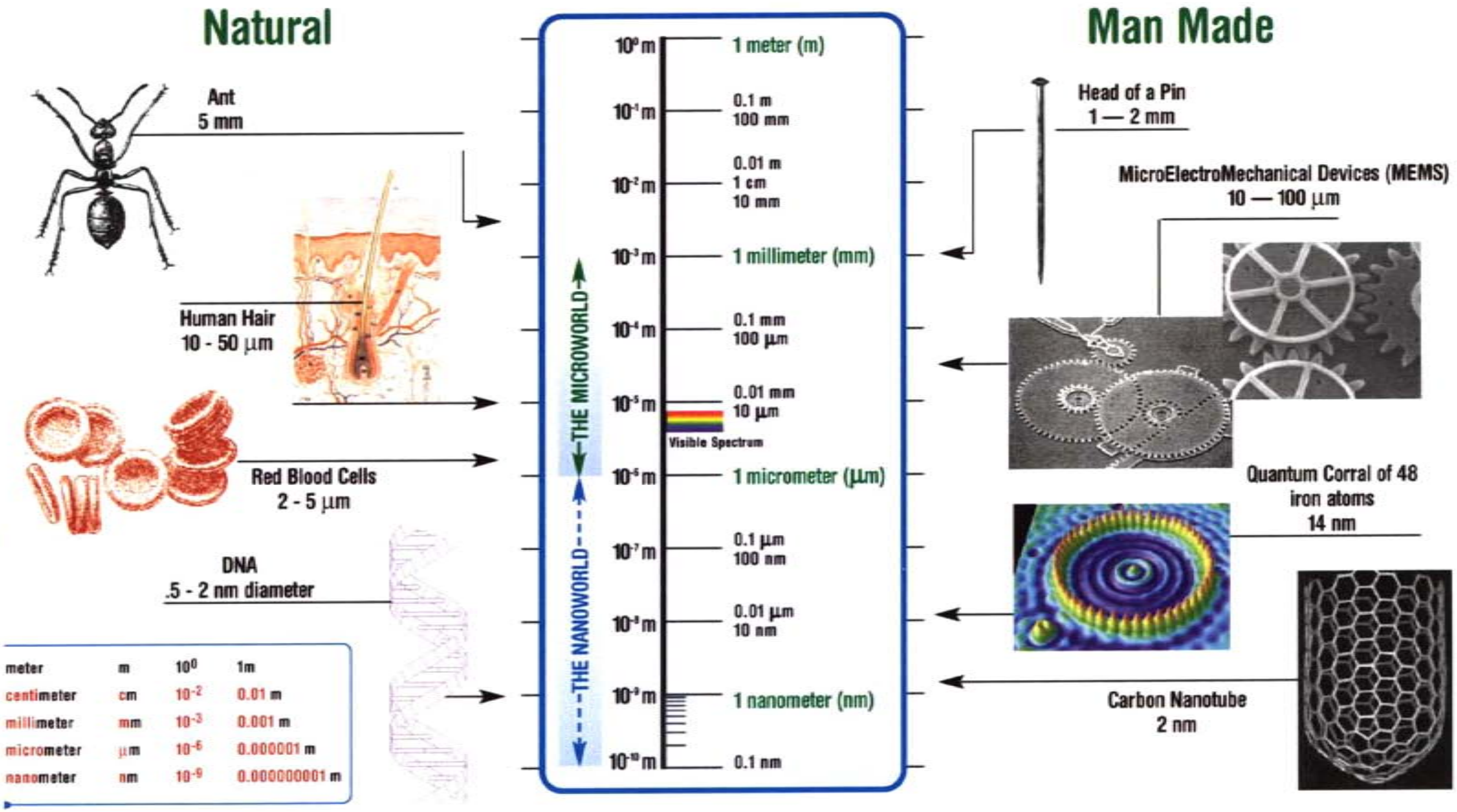
Hair:
- Branches to100 – 1,000 hairs
- 0.2 µm long and wide
- Spatula-shaped endings
- 100 nN/hair

- Unique ability to climb walls and hang from ceilings

Adhesion: van der Waals forces

K. Autumn, Y.A. Liang, S.T. Hsieh, W. Zesch, W.P. Chan, T.W. Kenny, R. Fearing, and R.J. Full, “Adhesive Force of a Single Gecko Foot-Hair”, *Nature*, 405, 681 (2000).

What is Nanotechnology?



meter	m	10^0	1m
centimeter	cm	10^{-2}	0.01 m
millimeter	mm	10^{-3}	0.001 m
micrometer	µm	10^{-6}	0.000001 m
nanometer	nm	10^{-9}	0.000000001 m

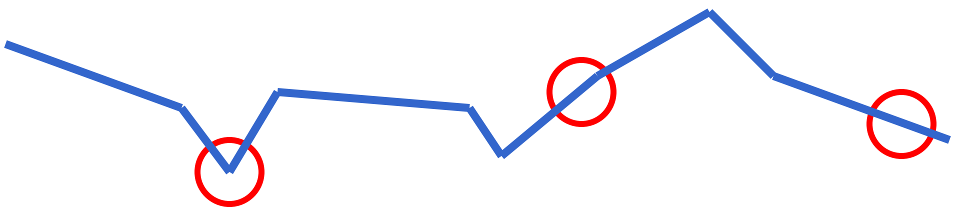
"What is Nano", Nano 101, Forbes/Wolfe 2002

How does nanotechnology help?

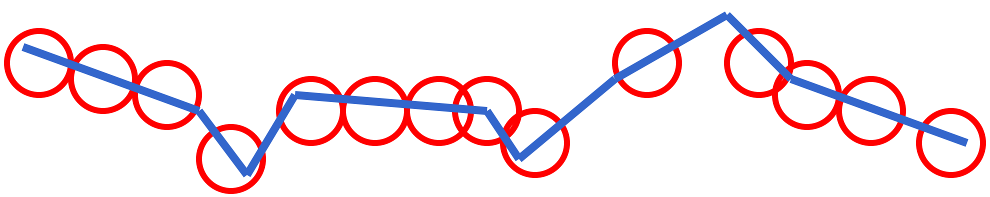
Why do two surfaces tend not to stick together?

- Surface roughness

Without nanotechnology:



With nanotechnology:



Contact Points:

1,000,000 /cm^2

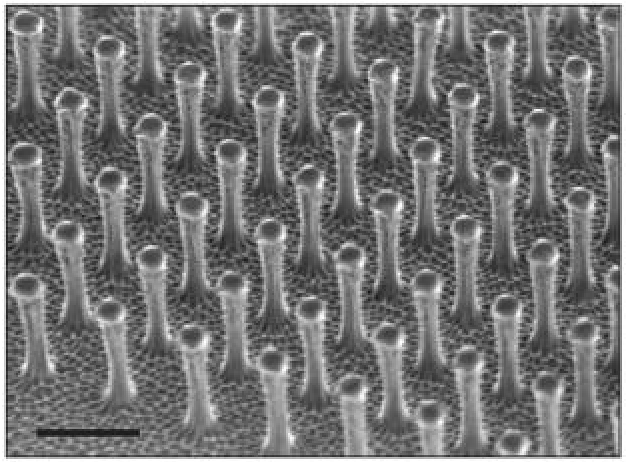
1,000,000,000 /cm^2

1,000,000,000,000 /cm^2 ??

Synthetic Gecko: Polymer

Polyimide Hairs on Si

- e-beam lithography
- 1 cm^2 sample



scale bar 2 μm

Proof-of-concept Experiments:

Control:
<0.001 N/cm^2

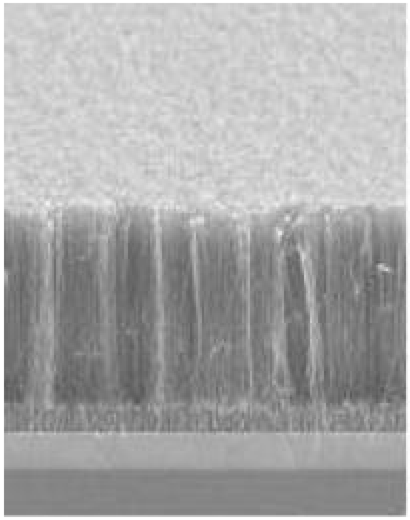
Nanostructures on Silicon:
0.01 N/cm^2

Nanostructures with flexible substrate:
3 N/cm^2

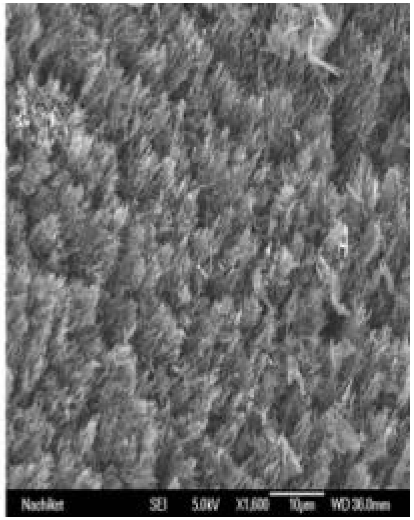
need for conformal contact

A.K. Geim, S.V. Dubonos, I.V. Grigorieva, K.S. Novoselov, A.A. Zhukov, and S.Yu. Shapoval, "Microfabricated Adhesive Mimicking Gecko Foot-Hair", *Nature Mat.*, 2, 461 (2003).

Synthetic Gecko: Carbon Nanotube



side view



top view

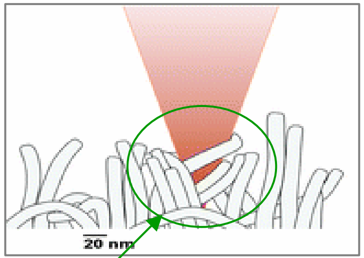
Does it scale to larger surfaces?

Vertical probe

- Density 7E11 /cm^2
- 1.6 x 10^{-2} nN/nm^2 [1,600 N/cm^2]

Control

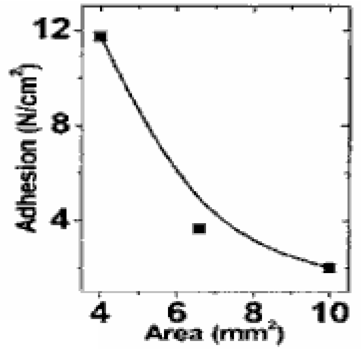
- Negligible adhesion without CNTs



small, highly efficient contact area

B. Yurdumakan, N.R. Raravikar, P.M. Ajayan, and A. Dhinojwala, "Synthetic Gecko Foot-Hairs from Multiwalled Carbon Nanotubes", *Chem. Commun.*, 3799 (2005).

Synthetic Gecko: Carbon Nanotube



Adhesion to Glass Slide

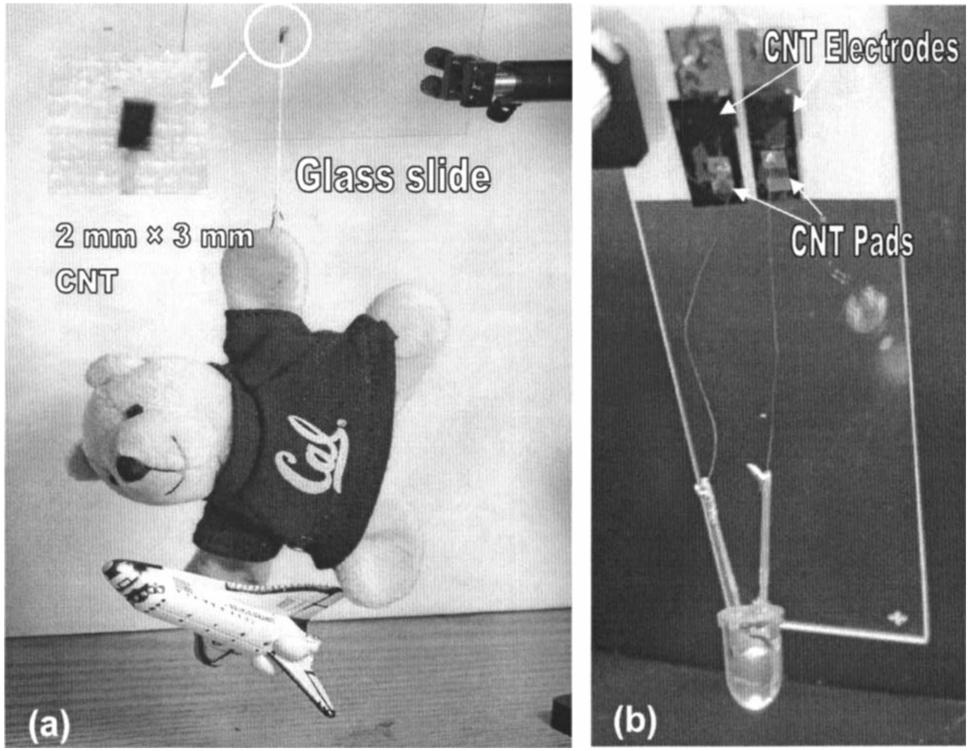
- **11.7 N/cm²** with 4 mm² contact area
- Decreases with larger sample size
- Negligible adhesion at 20 mm² contact area
- Surface roughness?

Y. Zhao, T. Tong, L. Delzeit, A. Kashani, M. Meyyappan, and A. Majumdar, "Interfacial Energy and Strength of Multiwalled-Carbon-Nanotube-Based Dry Adhesive", *J. Vac. Sci. Technol. B*, 24, 1071 (2006).

Carbon Nanotube Properties

	Current Performance	Current Material Systems	Carbon Nanotubes
Tensile Strength	~2 GPa	High-strength steel alloys	~45 GPa
Current Carrying Capacity	~1E6 A/cm^2	Copper wires	1E9 A/cm^2 (estimated)
Thermal	3,320 W/m*K	Diamond	6,000 W/m*K (predicted)

Synthetic Gecko Demonstrations



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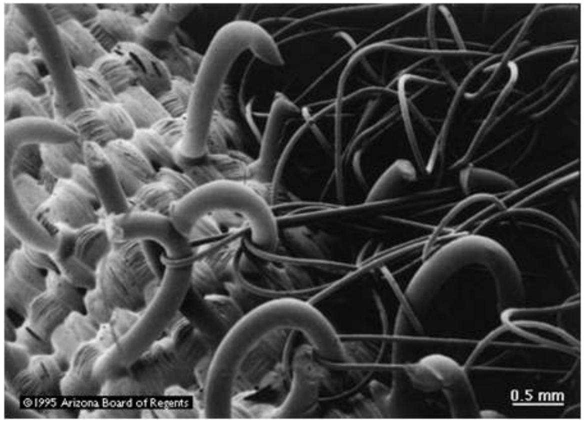
Nanotechnology - Nano-Velcro

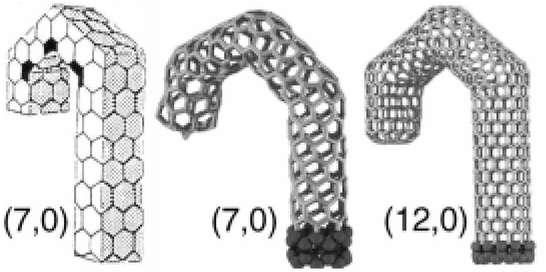


Velcro:

- Two-sided attachment scheme as need for nanostructures on both surfaces
- Hook & loop
- 2 hooks

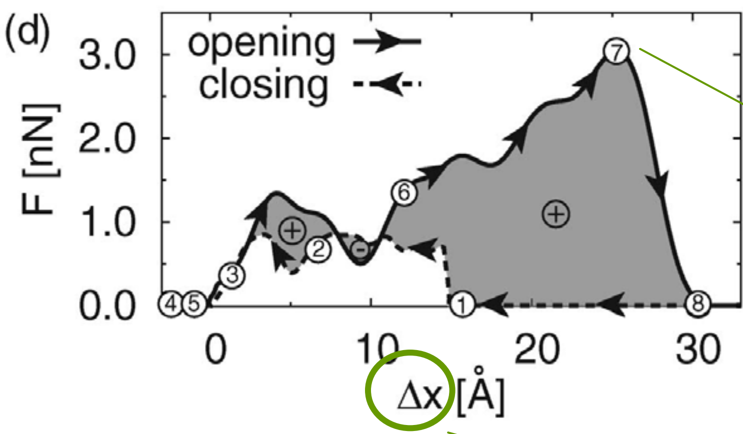
Carbon Nanotube Hooks

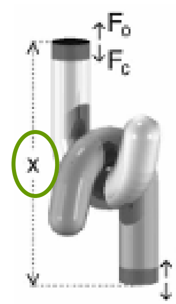
- Substitution of hexagon structure with heptagon-pentagon structures
- Energetically unfavorable
- System is flexible enough to redistribute strain

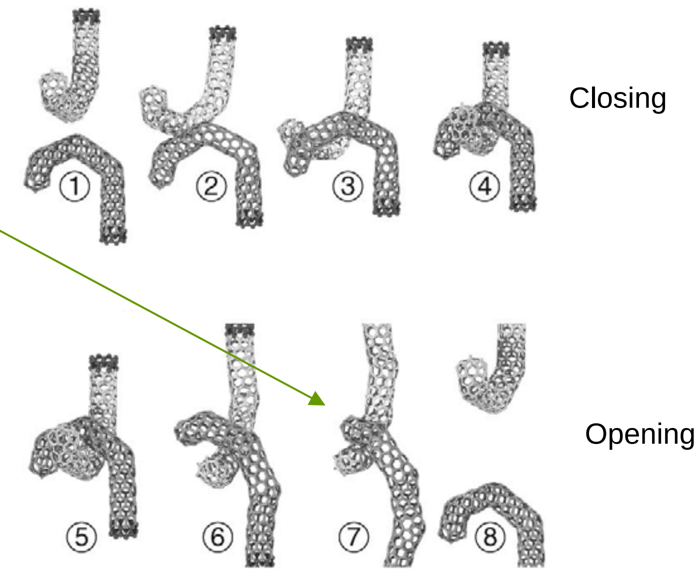


S. Berber, Y-K. Kwon, and D. Tomanek, “Bonding and Energy Dissipation in a Nanohook Assembly”, *Phys. Rev. Lett.*, 91, 165503 (2003).

Nano-Velcro (Nano-Hooks)







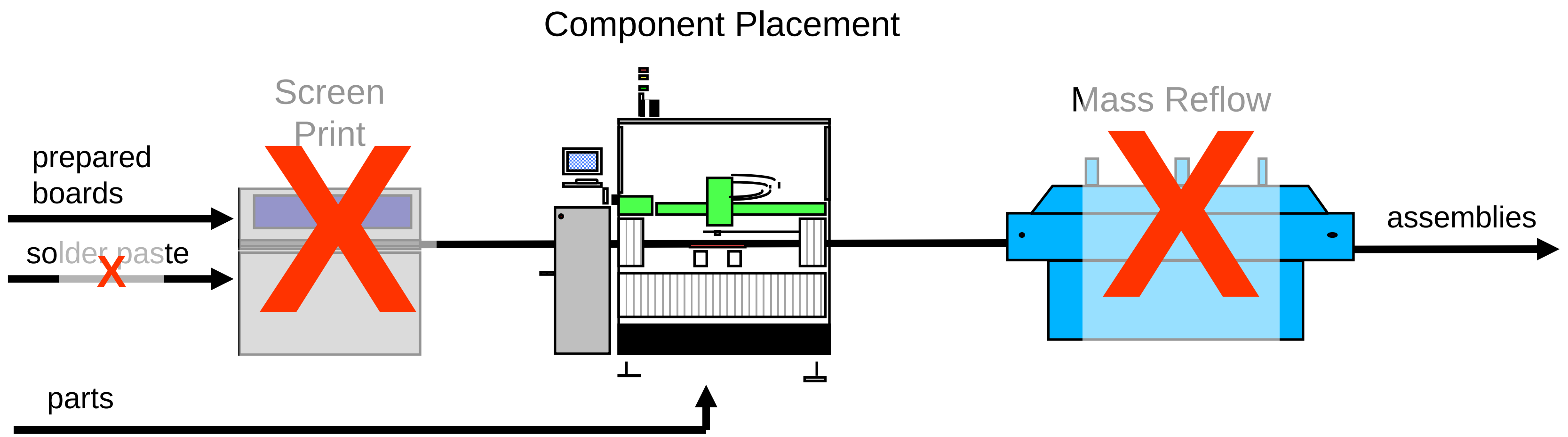
Modeling:

- Peak closing force 0.9 nN
- Peak opening force 3.0 nN
- 1 hook/nm^2 [density $10^{14}/cm^2$]
- 300,000 N/cm^2

Adhesion Reference:
Tape ~1s N/cm^2, Solder ~1,000s N/cm^2

S. Berber, Y-K. Kwon, and D. Tomanek, “Bonding and Energy Dissipation in a Nanohook Assembly”, *Phys. Rev. Lett.*, 91, 165503 (2003).

Example of Nano-Attach Assembly Process



Potential benefits with nanotechnology approach:

- Room temperature process
- Streamline manufacturing
- Improve field reliability
- Simplified rework
- Reduce cost

Nano-Attach Project Goals

Phase 1: Discovery and Concept Development

- Define ***application*** requirements
- Benchmarking nano-attach ***technology***
- Cost effective implementation

Go / No Go

Phase 2: Evaluation and Proof-of-Concept

- Material study
- Design guidelines
- Assembly development

Go / No Go

Phase 3: Demonstration and Prototype

- Build working prototype
- Develop supply chain

Phase 1: Discovery and Concept Development

Deliverables:

- Publish design targets for industrial development
- Publish design targets derived from Phase 1 findings
  - Generate interest in the electronics industry
  - Attract new players
  - Accelerate development
- Refine project plan, deliverables, and timeline for Phase 2
- Publish white paper summary for iNEMI members
- Recommend go/no-go for Phase 2

Issue: Is the material technology mature enough to have a high probability of success in Phase 2?

Gate 1: Go / No Go

Phase 2: Evaluation and Proof-of-Concept

Deliverables:

- Define and develop evaluation vehicle(s)
- Define materials characterization methods
- Performance assessment using evaluation vehicle(s)
  - Assembly
  - Reliability
- Develop material design guidelines
- Publish summary of test results
- Refine project plan and timeline for Phase 3
- Publish white paper summary for iNEMI members
- Recommend go/no-go for Phase 3

Issue: Is the technology mature enough to have a high probability of success in Phase 3?

Gate 2: Go / No Go

Phase 3: Demonstration and Prototype

Deliverables:

- Demonstrate prototype device
- Present prototype vehicle test results
- Supply chain identified
- Publish white paper summary for iNEMI members
- Recommend next steps

Nano-Attach Project: Current Status

- Compiled list of applications that would benefit from nano-attachment technology and their (mechanical, electrical, thermal) requirements
  - Identified electronic and non-electronic assembly applications

- Identify technology gaps
  - Preparations for Phase 2 work

- Discussions with technology leaders
  - Potential collaboration / partnership

Summary

Potential Low-Temperature Assembly

Technology at Research / Proof-of-Concept Stage

Lots of Questions (i.e. performance, reliability)

Exciting Opportunities

→ **Paradigm Shift in Assembly**

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