iNEMI

International Electronics Manufacturing Initiative

Nano-Attach Project

Hope Chik, Motorola

Celestica-iNEMI Technology Forum

May 15, 2007

Advancing manufacturing technology

Outline

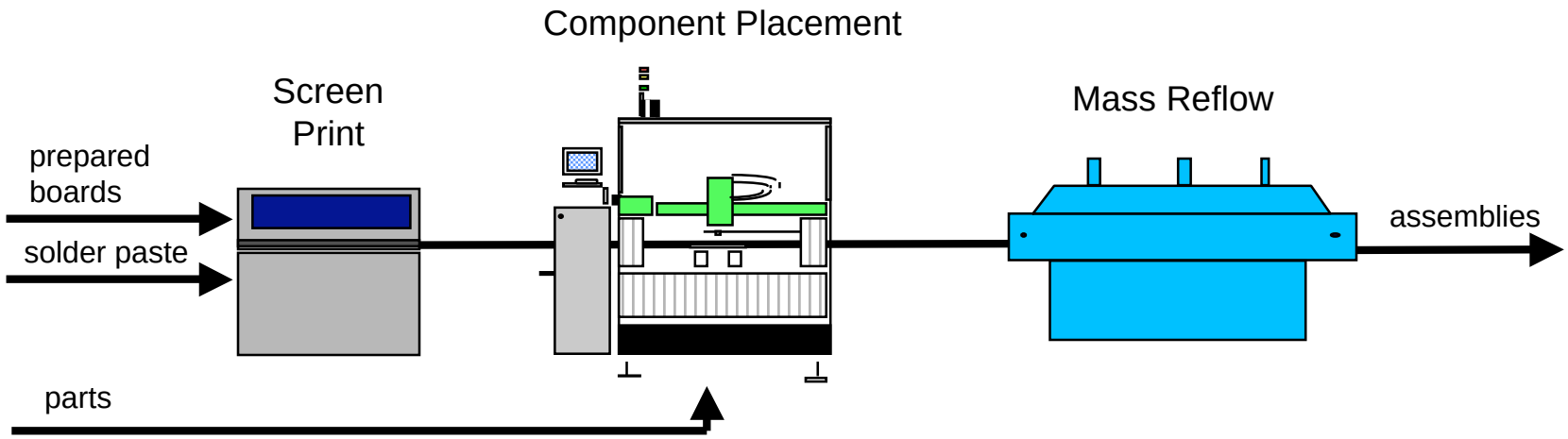
Motivation

Nanotechnology

- **Advantages**
- **Approaches**
  - **Biomimetic**
  - **Nano-Velcro**

iNEMI Nano-Attach Project

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

Gecko

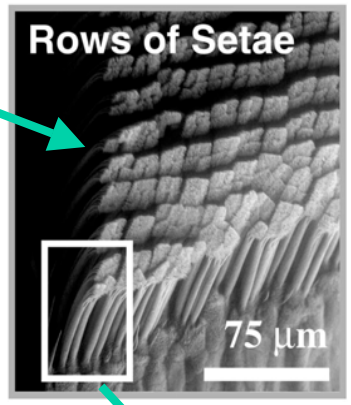
Unique ability to climb walls and hang from ceilings

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).

Gecko Foot



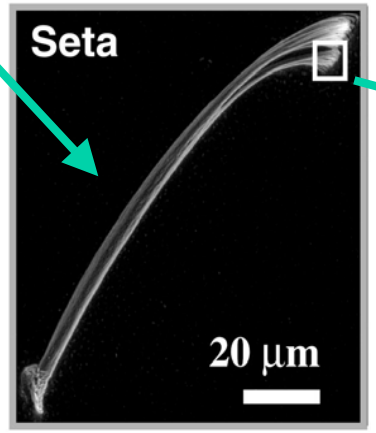
hair:

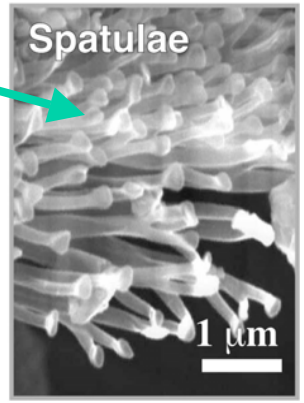
- branches to100 – 1,000 hairs
- 0.2 μm long and wide
- spatula-shaped endings
- 100 nN/hair

Hierarchical structure

setae:

- 110 μm long
- 5 μm diameter





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).

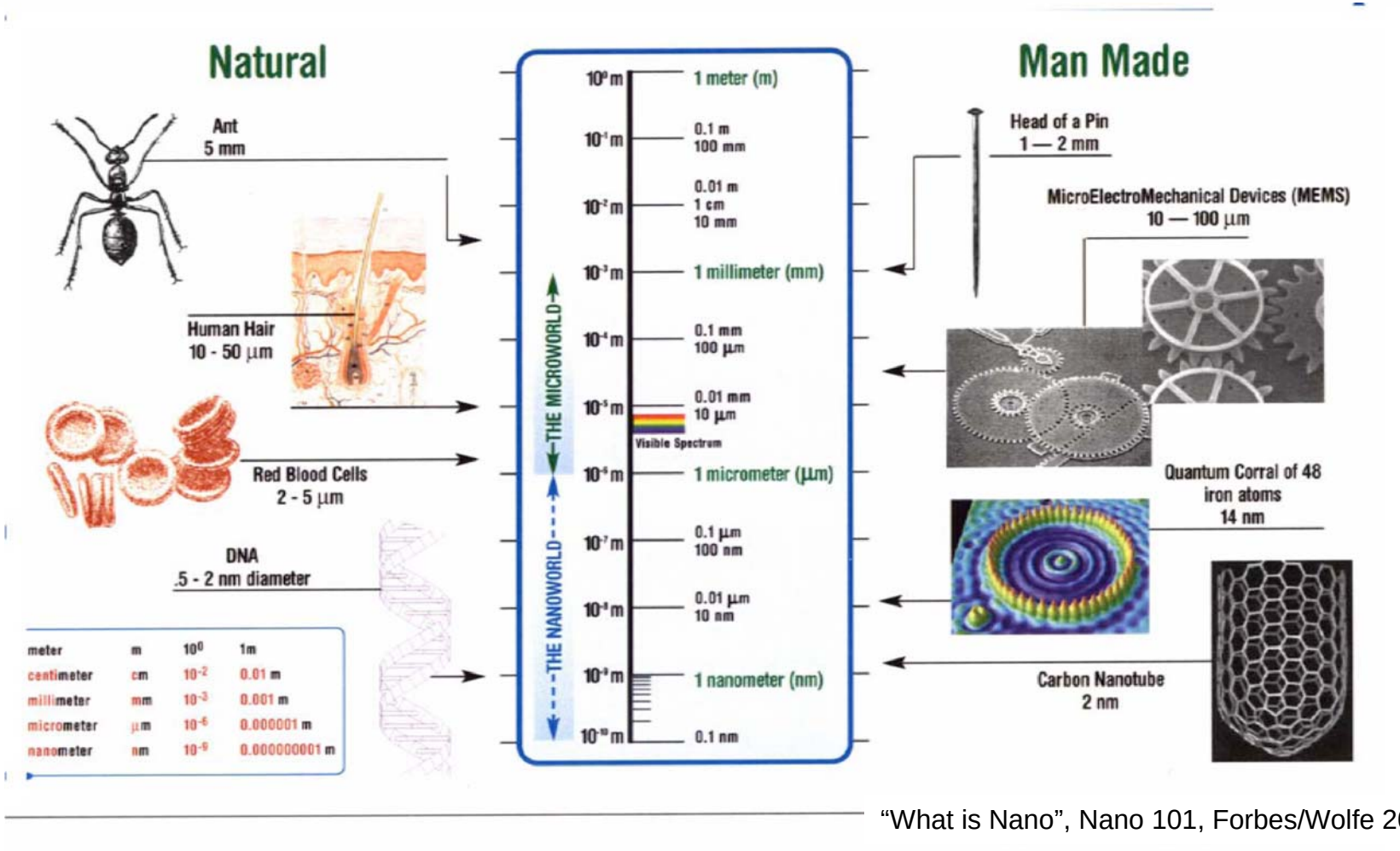
Van der Waals Forces

- intermolecular forces
- present between ***any*** and ***every*** two surfaces
- typical forces between 10 and 1,000 nN per contact point
  - material dependent

Why do two objects tend not to stick together?

Lack of surface contact points

What is Nanotechnology?



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

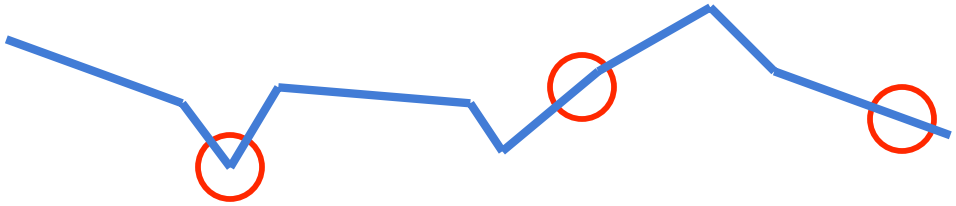
Human hair: 50,000 – 100,000 nm

How does nanotechnology help?

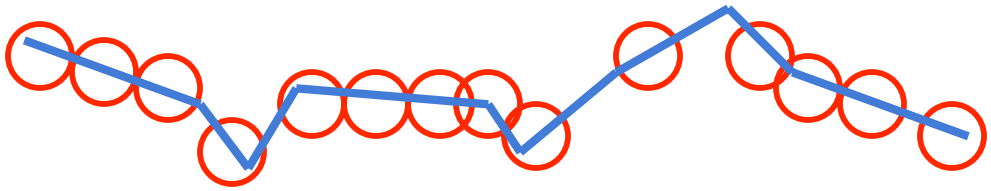
Why do two surfaces tend not to stick together?

- surface roughness

Without nanotechnology:



With nanotechnology:



Contact Points:

1,000,000 /cm^2

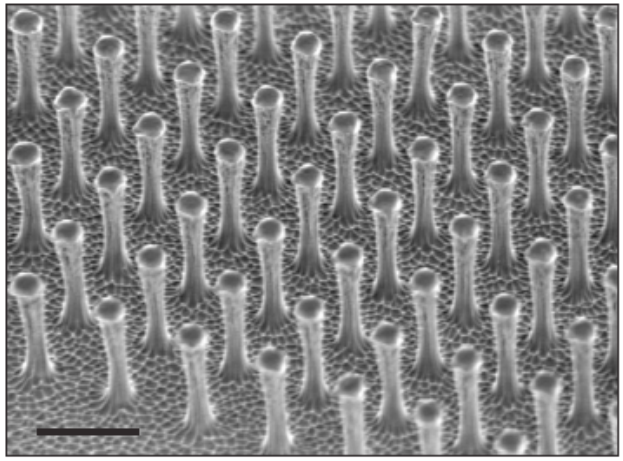
1,000,000,000 /cm^2

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:

adhere to glass slide

- 20 kg preload
- **0.01 N/cm^2 adhesion**
- < 1% of hairs in contact
- height of 2 μm
- density of 1E7 /cm^2

control

- unstructured surface
- **<10^{-3} N/cm^2**

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: Polymer

transfer polyimide hairs to tape

- adhere to glass slide
- 3 N/cm^2 adhesion
- 70 nN / hair
- independent of preload force (up to 50 N/cm^2)
- all hairs already attached
- repeated attach/detach resulted in fallen and broken hairs

Control:

<0.001 N/cm^2

Nanostructures on Silicon:

0.01 N/cm^2

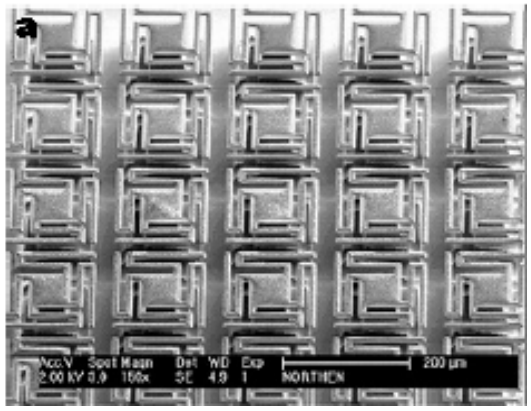
Nanostructures with flexible substrate:

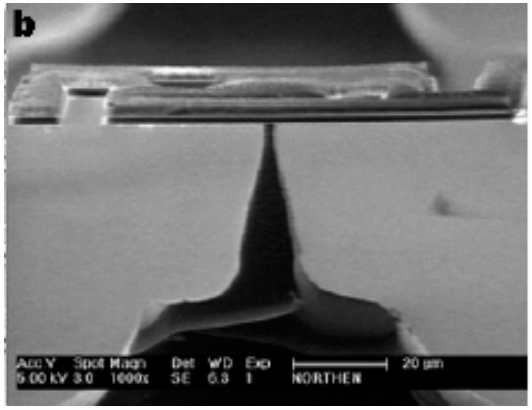
3 N/cm^2

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: Hierarchical Structures





Platform

- MEMS approach
- 2 mm thick wet oxidation of Si to create SiO_2
- dry etching to undercut Si
- 150 mm x 150 mm platform

Control: 0.00001 N/cm^2

Nanostructures: 0.00065 N/cm^2

Nanostructures on platform: 0.00218 N/cm^2

conformal contact by hierarchical structure

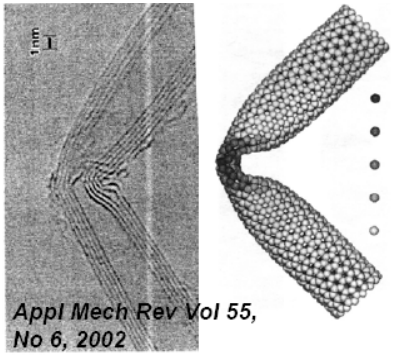
M.T. Northen and K.L Turner, “A Batch Fabricated Biomimetic Dry Adhesive”, *Nanotechnology*, 16, 1159 (2005).

Carbon Nanotube Properties

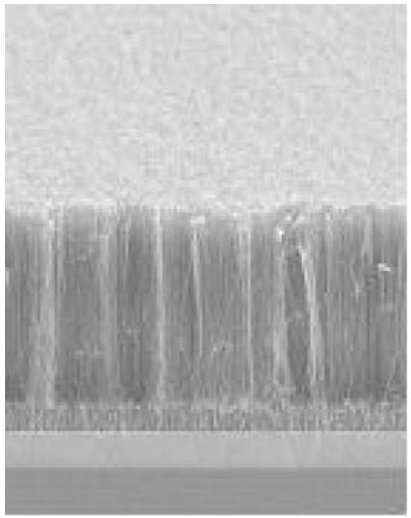
	Current Performance	Current Material Systems	Carbon Nanotubes
Tensile Strength	~2 GPa	High-strength steel alloys	~45 GPa
Current Carrying Capacity	~1E6 A/cm^2	Copper wires	1E9 A/cm^2 (estimated)
Thermal	3,320 W/m*K	Diamond	6,000 W/m*K (predicted)

Other Properties:

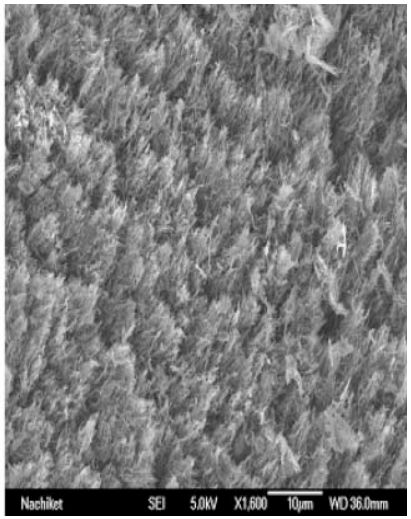
- temperature stability up to 2,800^{o}C in vacuum, 750^{o}C in air
- extremely flexible and reversible



Synthetic Gecko: Carbon Nanotube



side view



top view

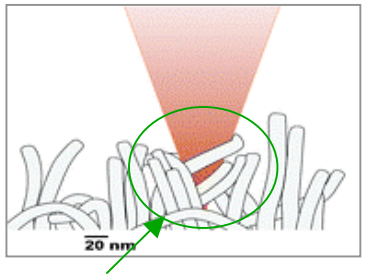
vertical probe

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

control

- negligible adhesion without CNTs

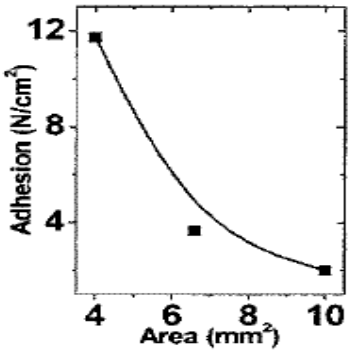
does it scale to larger surfaces?



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



Adhere to glass slide

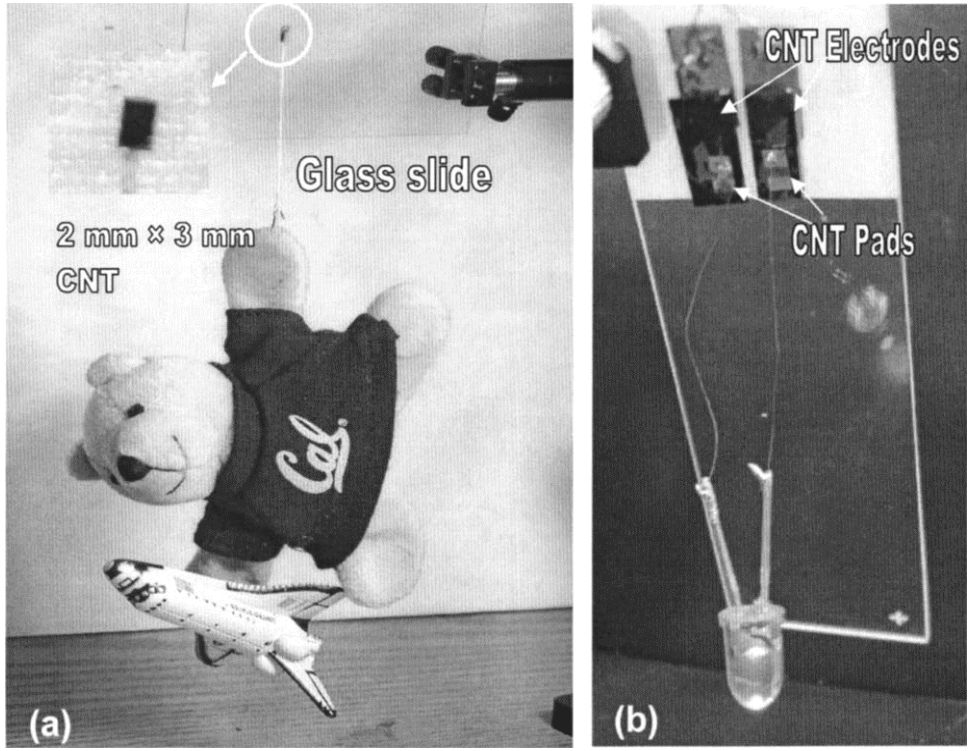
- **11.7 N/cm²** with 4 mm² contact area
- decreases with larger sample size
- negligible adhesion at 20 mm² contact area
- surface roughness?

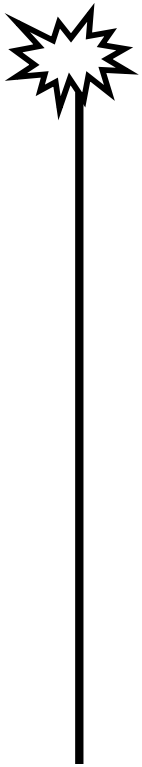
Advantages of Nano-Attach:

- attractive properties of CNTs
- extremely stable to high temperatures, environmental conditions such as chemical exposure, UV radiation, humidity, etc.
- multiple attach/detach without loss of adhesion properties
- no residue after detachment

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).

Synthetic Gecko Demonstrations

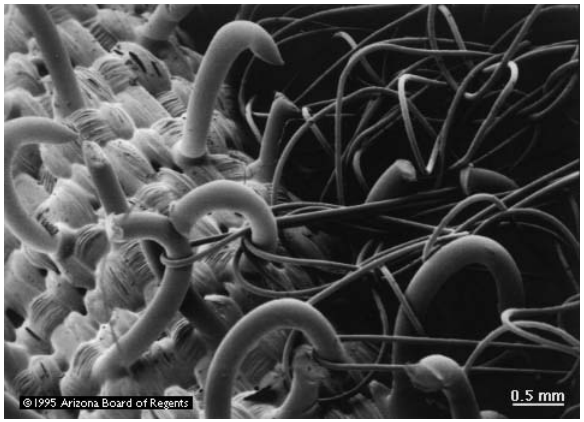




Y. Zhao, T. Tong, L. Delzeit, A. Kashani, M. Meyyappan, and A. Majumdar, “Interfacial Energy and Strength of Multiwalled-Carbon-Nanotube-Based Dry Adhesive”, *J. Vac. Sci. Technol. B*, 24, 1071 (2006).

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).

Nano-Velcro

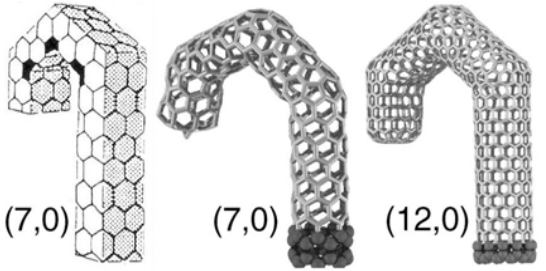


Velcro:

- two-sided attachment scheme as need for nanostructures on both surfaces
- hook & loop
- 2 hooks

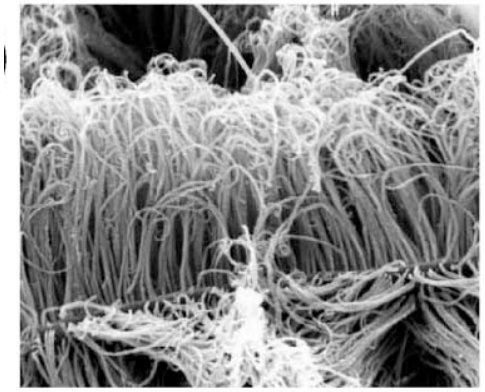
Carbon nanotube hooks

- substitution of hexagon structure with heptagon-pentagon structures
- energetically unfavorable
- system is flexible enough to redistribute strain

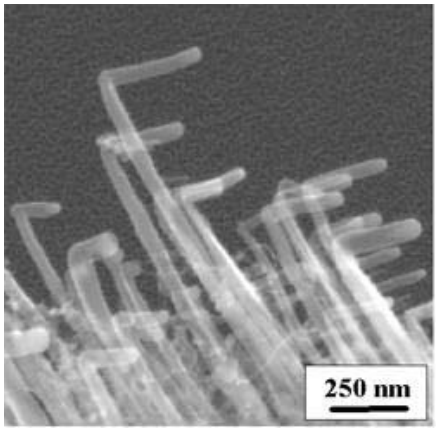


S. Berber, Y-K. Kwon, and D. Tomanek, "Bonding and Energy Dissipation in a Nanohook Assembly", *Phys. Rev. Lett.*, 91, 165503 (2003).

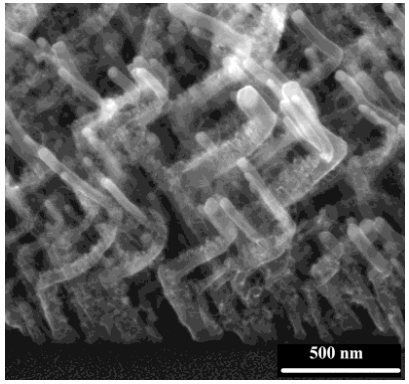
Examples of Nano-Hooks



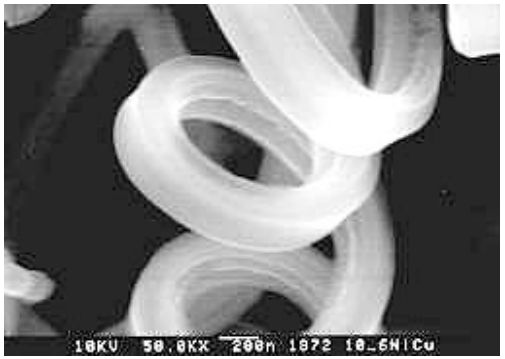
S. Berber et al., *Phys. Rev. Lett.*, 91, 165503 (2003).
ref 13 [private communications]



S. Jin's group, UCSD



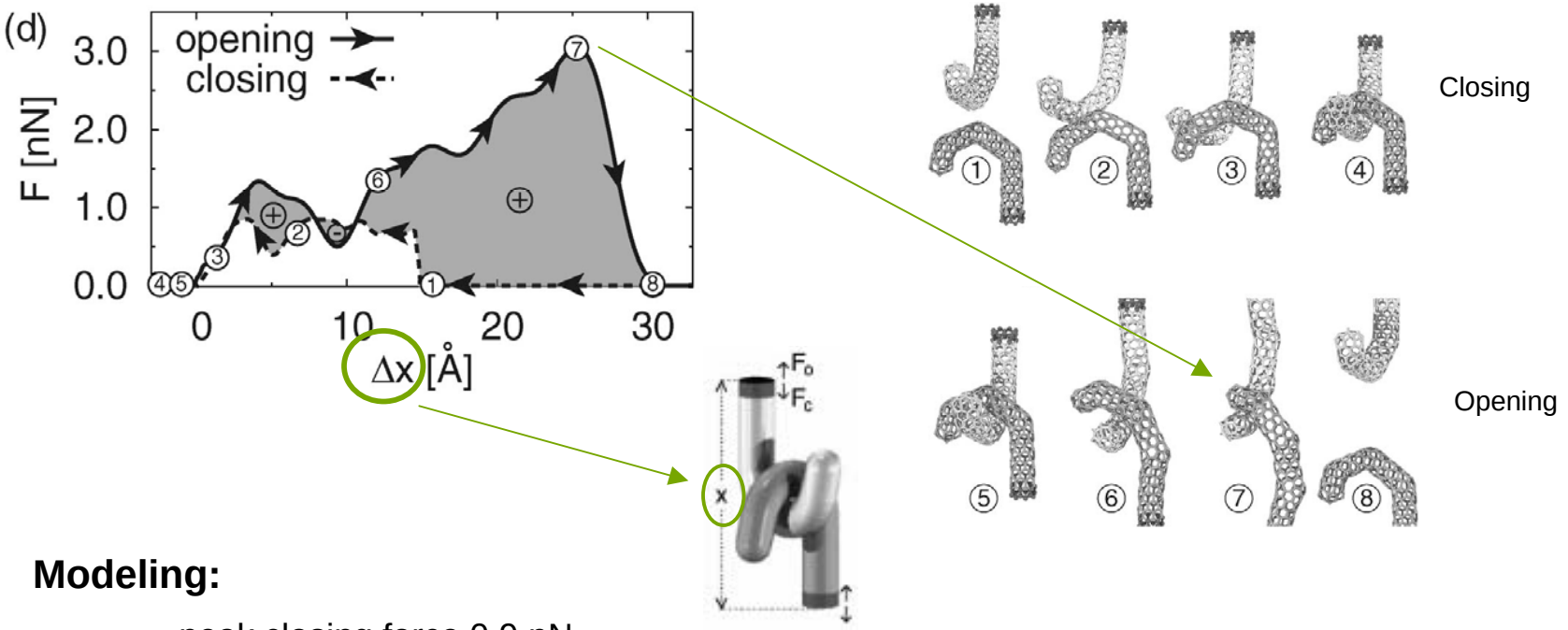
J. AuBuchon et al., *Nano Lett.*, 4, 1781 (2004).



Toyohashi University of Technology

Lack of nano-loops

Nano-Hooks



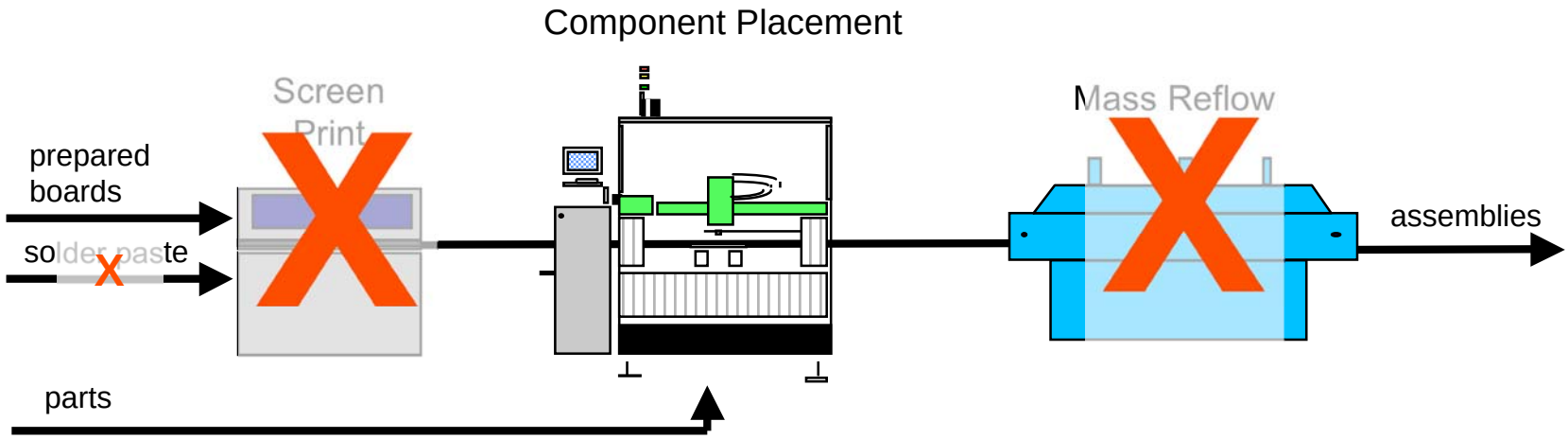
Modeling:

- 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

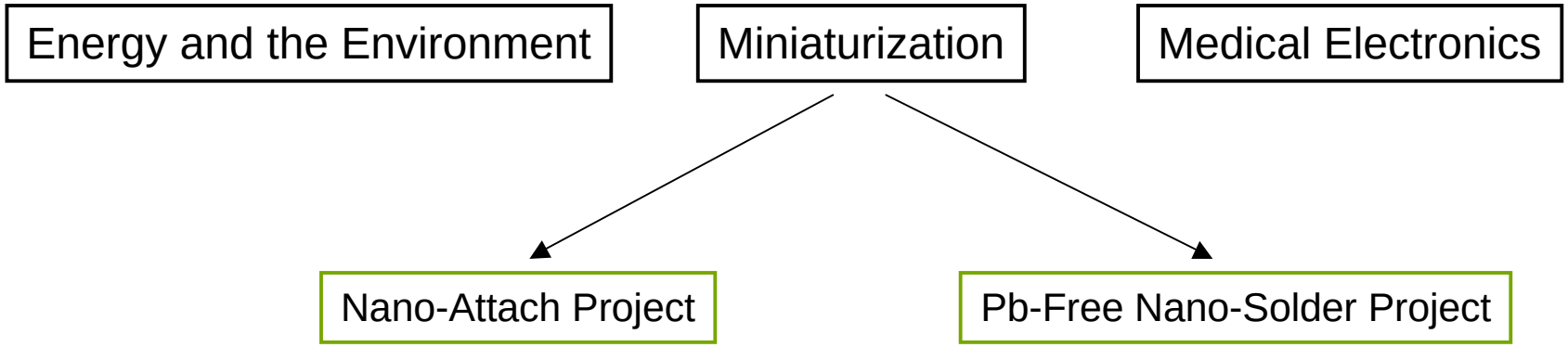


Potential benefits with nanotechnology approach:

- room temperature process
- improve field reliability
- streamline manufacturing
- reduce cost
- simplified rework

iNEMI Roadmap

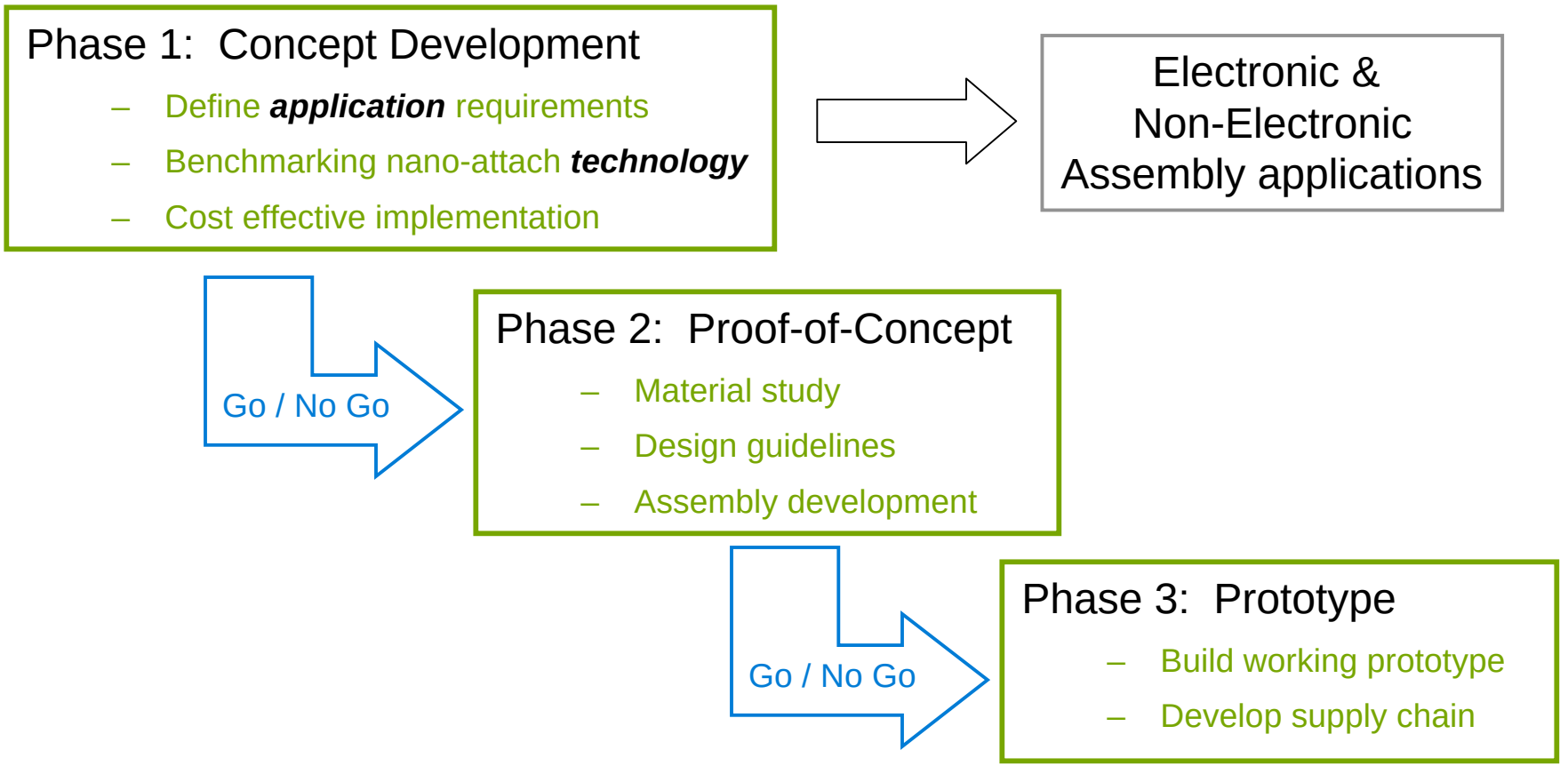
Primary Technology Focuses:



Research Projects:

- established for first time
- leverage emerging nanotechnologies
- alternatives to SAC alloy soldering

Nano-Attach Project Goals



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

Team Members

www.inemi.org

Hope Chik

hope.chik@motorola.com

iNEMI

Advancing manufacturing technology