Joining Technologies for Nanomanufacturing

Gordon Shaw
U.S. National Institute of Standards and Technology
Manufacturing Engineering Laboratory

Joining Technology for Nanocomponents

- Project's goal is to determine optimum joining methods for nanometer-scale components.

  -Fabrication of nanoscale components

  -Systematically study methods for attaching nanocomponents to substrates and to each other

  -How the joint affects the behavior of the system

The Stakeholders

Industry
- Automotive, Aerospace, Construction, Semiconductor …..

Consultants
- American Welding Society (AWS)
- The Welding Institute (TWI)
- Edison Welding Group (EWG)
- Precision Joining Technologies
- Hobart Institute of Welding Technology
- WJM Technologies
- Materials Resources International
- Thermion
- Joining Technologies

Public
- Materials Joining and Nondestructive Testing Group (ORNL)
- Basic Energy Sciences Welding Science Program (DOE)
- NIST (ATP funding for Reactive NanoTechnologies, Inc.)

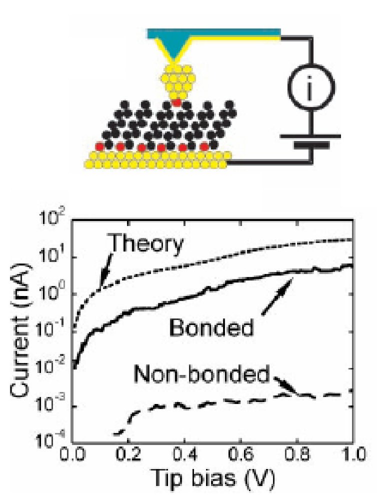
Academic
- Universities, Technical Journals

Standards
- ASTM
- Expansion Joint Manufacturers Association (EJMA)
- NIST

The conference program from Welding and Joining, 2005 contained no presentations on nanotechnology

Selected Prior Work

- Ohmic contacts between an alkanethiol molecule and a scanning probe microscope tip must be made using a gold nanoparticle intermediate, as the gold-thiol bond is too unstable for reliable electronic conduction (1).



1. Cui, X. D., et al., Science, 294, 571-574 (2001)

Nanotechnology at NIST: Nanomanufacturing

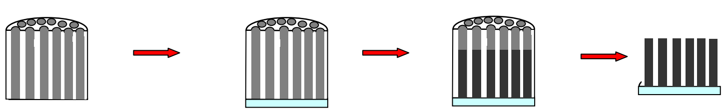
- R&D aimed at enabling scaled-up, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems.

Raw Materials —fabrication→ Discrete Parts —joining→ Useful Object

Two classes of raw materials were examined:
•Metallic nanowires
•Soft biological materials

Fabrication of Nanocomponents

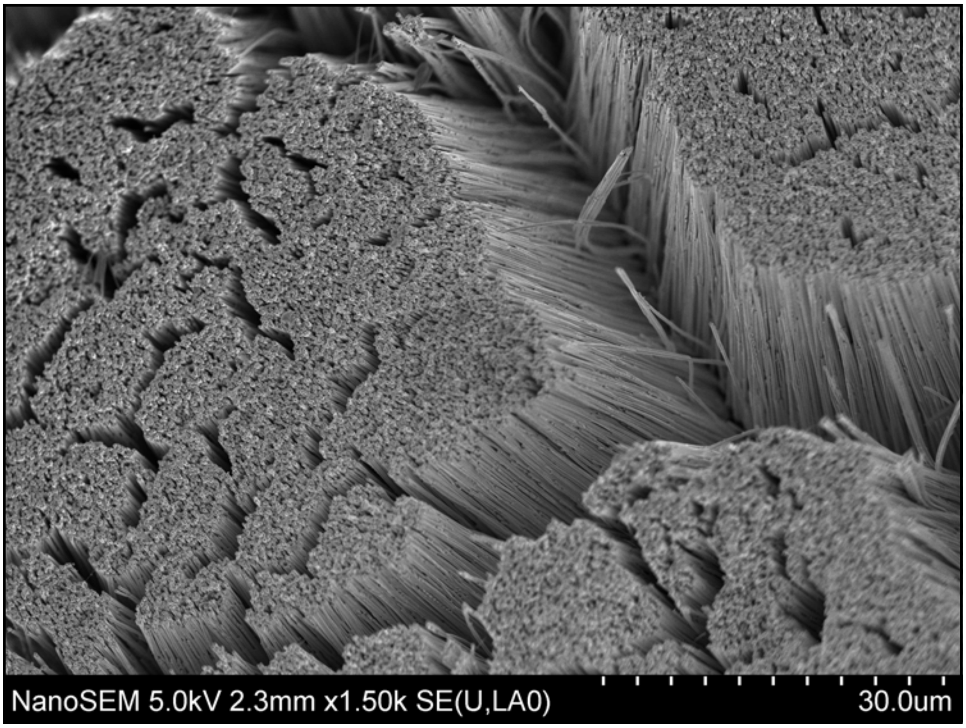
- Inorganic Nanowires: electrochemical template synthesis



Add a conductive coating to a porous alumina membrane → Electrodeposit metal from solution → dissolve alumina membrane

In collaboration with Daniel Josell, Thomas Moffat and Jon Mallett of the Film and Nanostructure Processing Group

Wide variety of materials can be used



Specialized Probe Fabrication

- Nickel nanowires have been joined to atomic force microscope (AFM) cantilevers
- Small force metrology capability at NIST has been used to test mechanical robustness of joints

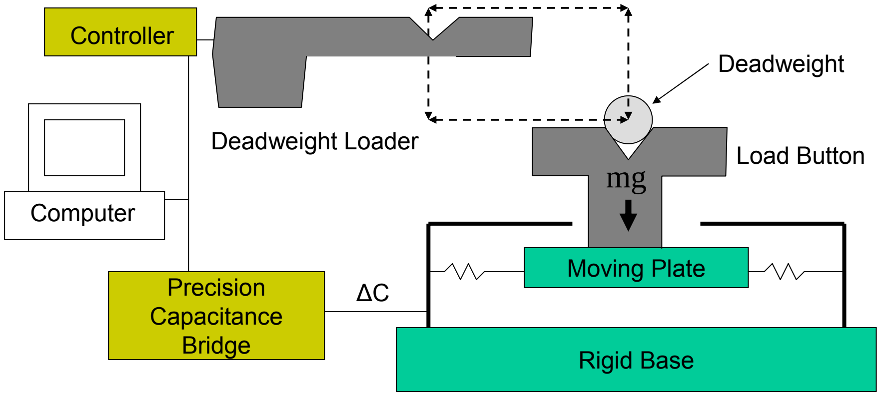
Gordon A. Shaw, Koo-Hyun Chung, Jordan Peck, Ultramicroscopy, In preparation

Traceability Path

- Use traceable deadweight force to calibrate a load cell that can be easily transferred to an instrumented indenter
- Use instrumented indenter to measure joint strength
- Different kinds of tests are required for different kinds of joints (lap vs. butt joint)

Load Cell Calibration

- An automated deadweight loading machine has been developed, and a capacitive load cell used.



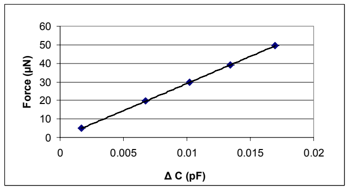
R. M. Seugling, et al., Proc. ASPE, 2004

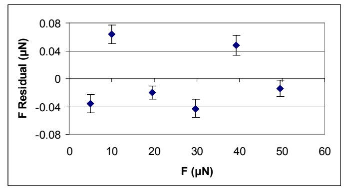
Calibration Results

•Dominated by interpolation uncertainty above 50 µN

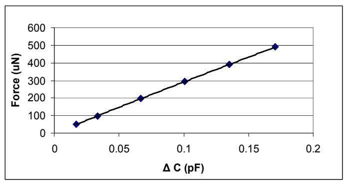
Calibration Curve | Residuals

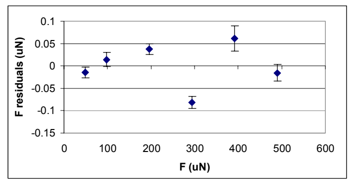
5 to 50 µN



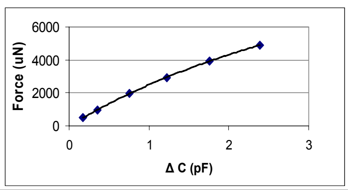


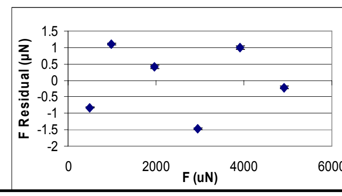
50 to 500 µN





500 to 5000 µN



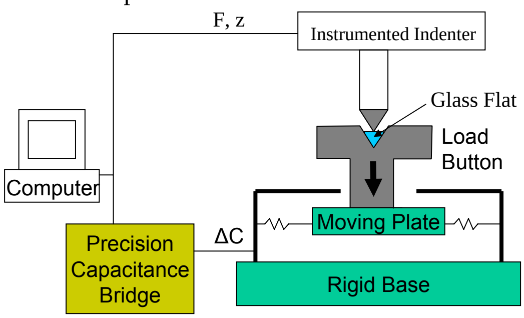


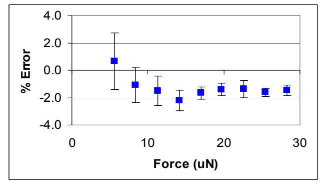
Uncertainty Analysis

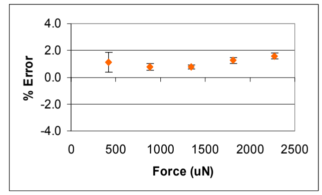
Source of uncertainty	Magnitude of uncertainty / 10^{-3}
Statistical Uncertainty	2.0
Mass (1 mg)	2.0
Gravity	0.001
Dielectric constant	0.1
Buoyancy	0.015
Capacitance	0.01
Load Position	0.1
Interpolation	1
Combined Standard Uncertainty	3

Transfer to Indenter

- The load cell was then used as a sample during an indentation experiment.







Source of uncertainty	Magnitude of uncertainty (%)
Load cell force	0.3
Load position	0.1
Indenter force (10 μN)	1
Combined Standard Uncertainty	1

Testing Mechanical Stability

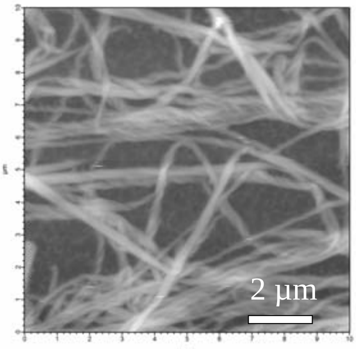
- Prerequisite for any joining technology.

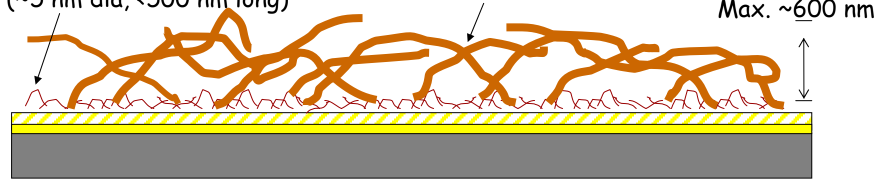
  -Use nanoindentation AFM to mechanically shear test individual nanowire lap joints qualitatively

  -Use instrumented indentation to perform preliminary tensile testing of microwire butt joints

Soft Biological Materials: Collagen

- Collagen is the major connective tissue protein. It consists of triple-helical peptides organized into fibrils (shown to the right).
- Type 1 collagen fibril network fabricated on alkanethiol-functionalized gold surfaces
- Provide highly reproducible environment for cell growth which closely mimics cells' natural environment
- Cell response to ECM can be tuned based on processing conditions, especially level of hydration

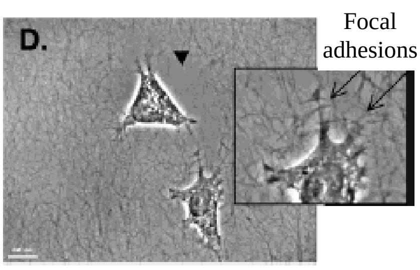




J. T. Elliott, et. al., Langmuir, 19, 2003

Cells Join to Collagen

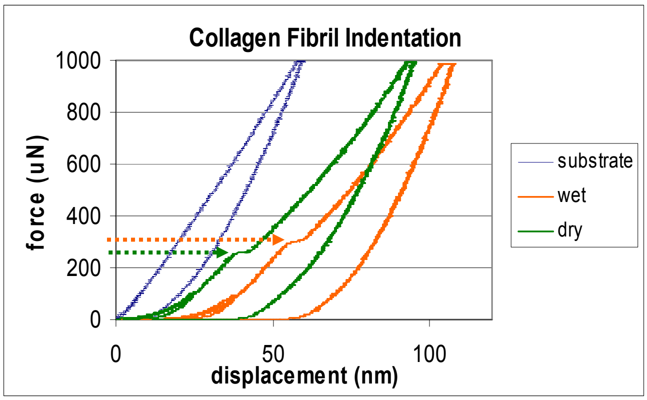
- At the joint between a cell and a collagen fibril, a focal adhesion forms.
- Focal adhesions have a high concentration of integrin proteins which sense collagen, and may direct cell behavior (mechanotransduction).
- Cells behave differently depending on the mechanical properties of the collagen environment.

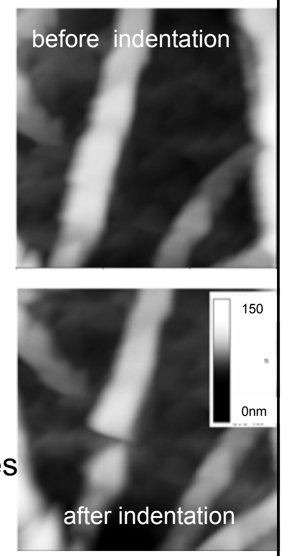


Fibril Rupture Events

submerged in water

AFM in air



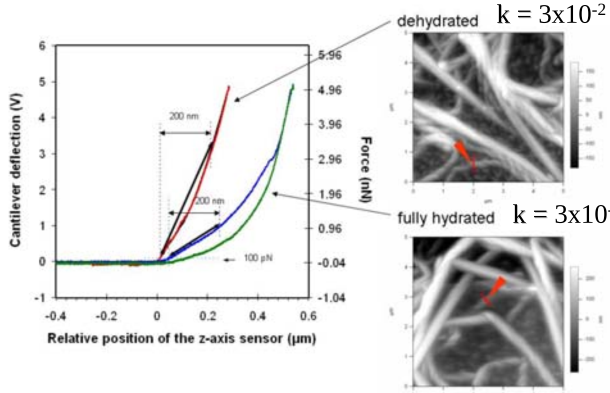


The collagen fibrils rupture at well-defined forces

Wet fibrils 322 ± 18 μN

Dry fibrils 266 ± 17 μN

Qualitative Difference in Fibril Behavior



dehydrated $k = 3x10^{-2} \pm 2x10^{-2}$ N/m

fully hydrated $k = 3x10^{-3} \pm 2x10^{-3}$ N/m

•k is "apparent contact stiffness," calculated from slope of force curve

•Adhesion of wet fibers mimics that observed in AFM force spectroscopy experiments

Dennis P. McDaniel, Gordon A. Shaw, John T. Elliott, Kiran Bhadriraju, Curt Meuse, Koo-Hyun Chung, and Anne L. Plant, Biophysical Journal, In Press, 2007

Conclusions

- Joining is an active field of industrial research, but nanotechnology is not yet a focus
- Electrochemical joining of nickel nanowires to an AFM tip can be used to fabricate high-aspect ratio probes.
- Qualitative measurements of joint strength were performed using instrumented indentation
- Small force measurement was used to understand the role of collagen-cell joints on cell behavior

Acknowledgments

•Mass and Force Group
•Jon Mallett, Daniel Josell, and Thomas Moffatt of the Metallurgy Division
•Dennis McDaniel, John Elliott, Anne Plant of the Biotechnology Division
•U.S. National Research Council, Research Associates Program
•Canadian National Research Council, Institute for National Measurement Standards