Carbon Nanotube Arrays for Enhanced Thermal and Electrical Interfaces

Tim Fisher
Birck Nanotechnology Center, and
School of Mechanical Engineering

2006 IEEE Holm Conference
27 September 2006

Outline

- Motivation
- Controlled CNT array synthesis by PECVD
- Thermal interfaces
- Electrical interfaces

Carbon Nanotube (CNT) Thermal and Electrical Interfaces

Sponsors: Cooling Technologies Research Center, US Air Force Research Laboratory, Intel Corporation, Nanoconduction Inc.

Motivation and Goals

- Increased density of integrated circuit (IC) devices necessitates improved thermal interface conduction.
- Assemble reliable thermal interface that provides a resistance less than 5 mm^2K/W.

Technical Challenges

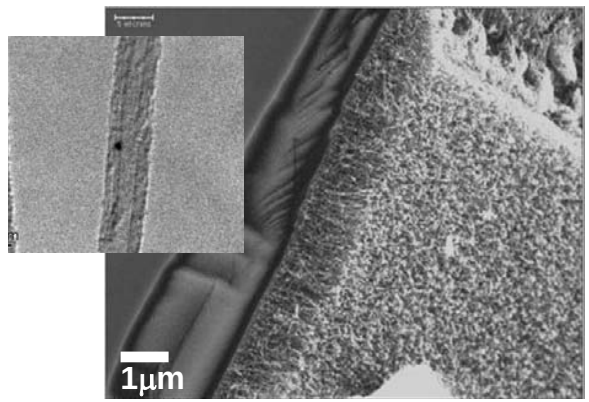
- Precisely measure thermal resistances below 5 mm^2K/W.
- Reduce CNT array free tip interface resistance
- Low temperature (< 500°C) synthesis of CNTs
- Addressability for large-scale integration

Highly conductive CNT interfaces will allow ICs to satisfy the constrained thermal/power budgets needed to maintain acceptable reliability and performance.

Technical Approach

- Microwave plasma CVD to enable dense, vertically oriented CNT array synthesis
- Ti underlayer to provide well anchored CNT arrays
- Substrate plasma shielding to promote low temperature growth
- Various assembly arrangements to facilitate practical implementation
- Photoacoustic (PA) technique to allow precise measurement and component thermal resistance resolution

Dense, Multi-Wall CNTs



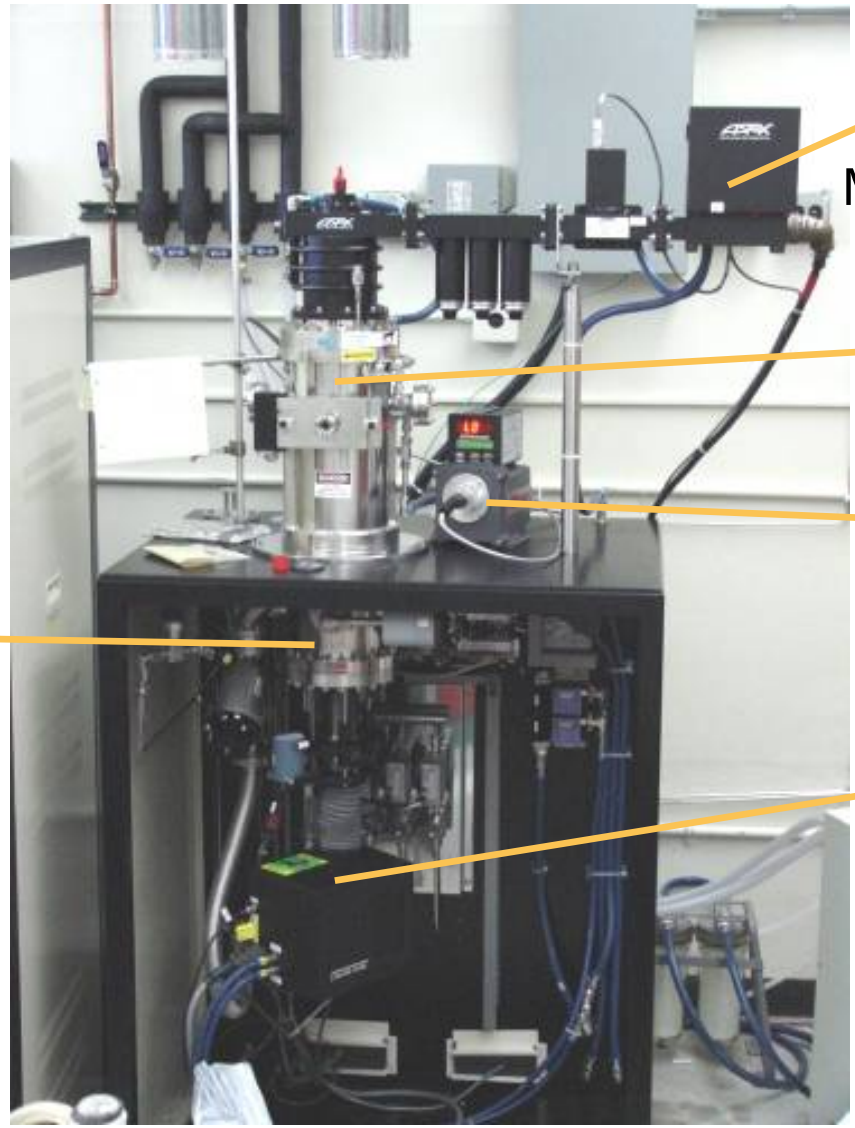
Plasma CVD Deposition System

Process gases:
H_2 – 1000cm^3/min
CH_4 - 10cm3/min
N_2 – 10cm^3/min
Other – O_2, Ar

Substrate Bias:
0 – 600 V; 0 – 1.7 A

Stage Temperature Control with Heating up to 1000^{o}C

External Interlocks for Safe Operation



1.5kW@2.5GHz Microwave Generator

Vacuum Chamber

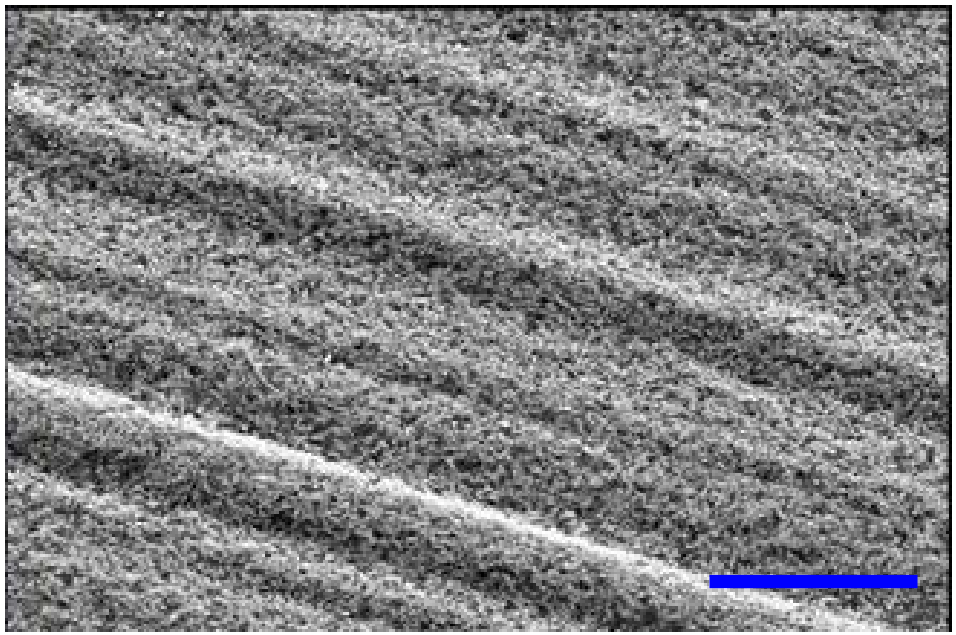
Dual Wavelength Pyrometer

75 mm of Stage Translation

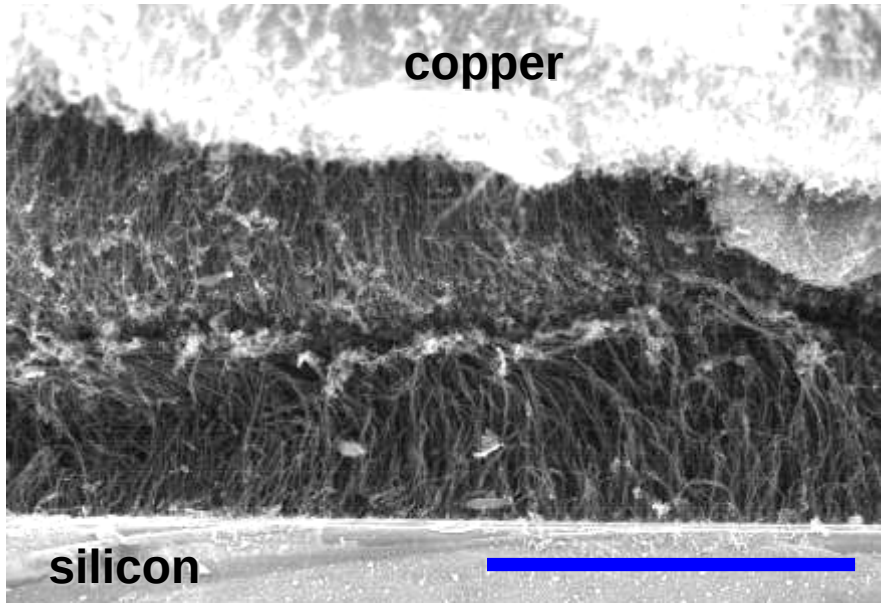
Seki Technotron Corp. AX5200 Series

Types of Interfaces

One-sided (post test)



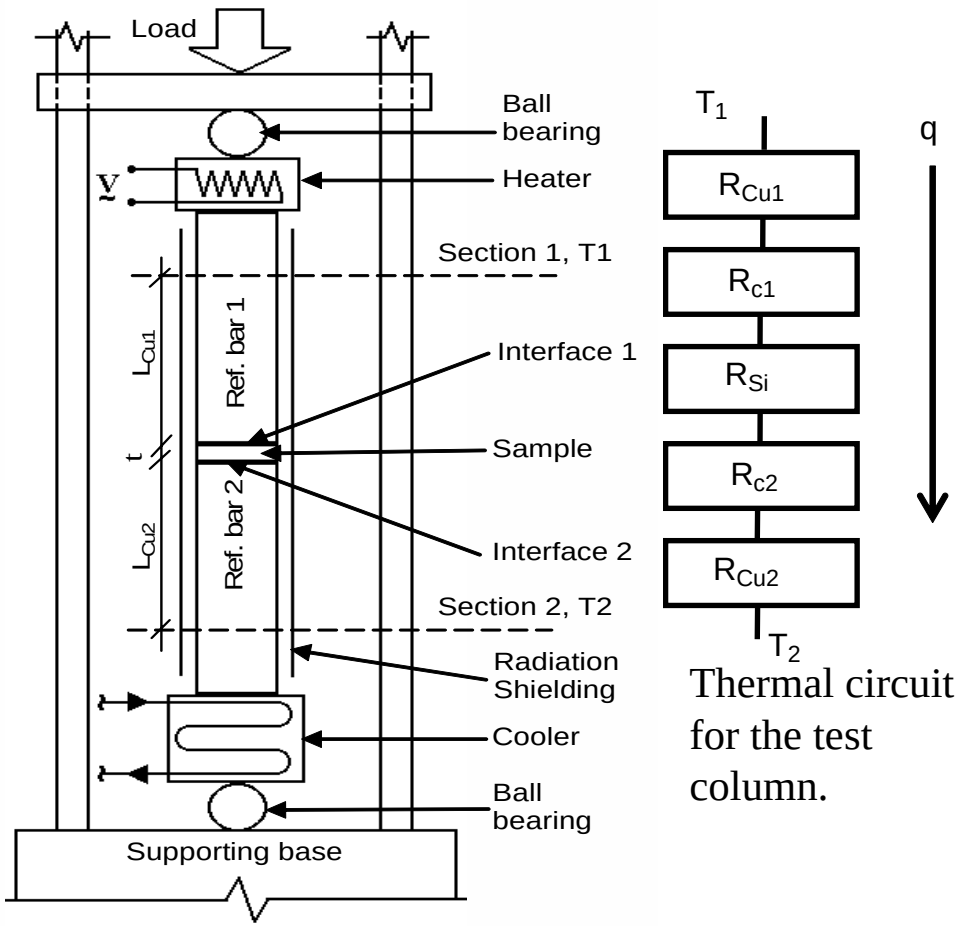
Two-sided



Scale bar = 5 μm

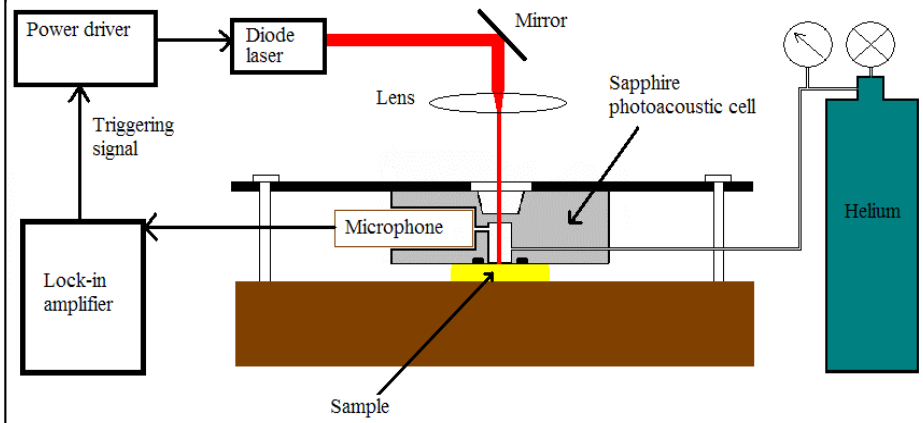
Thermal Metrology

1D Reference Bar Method
Student: Jun Xu (now with Honeywell)



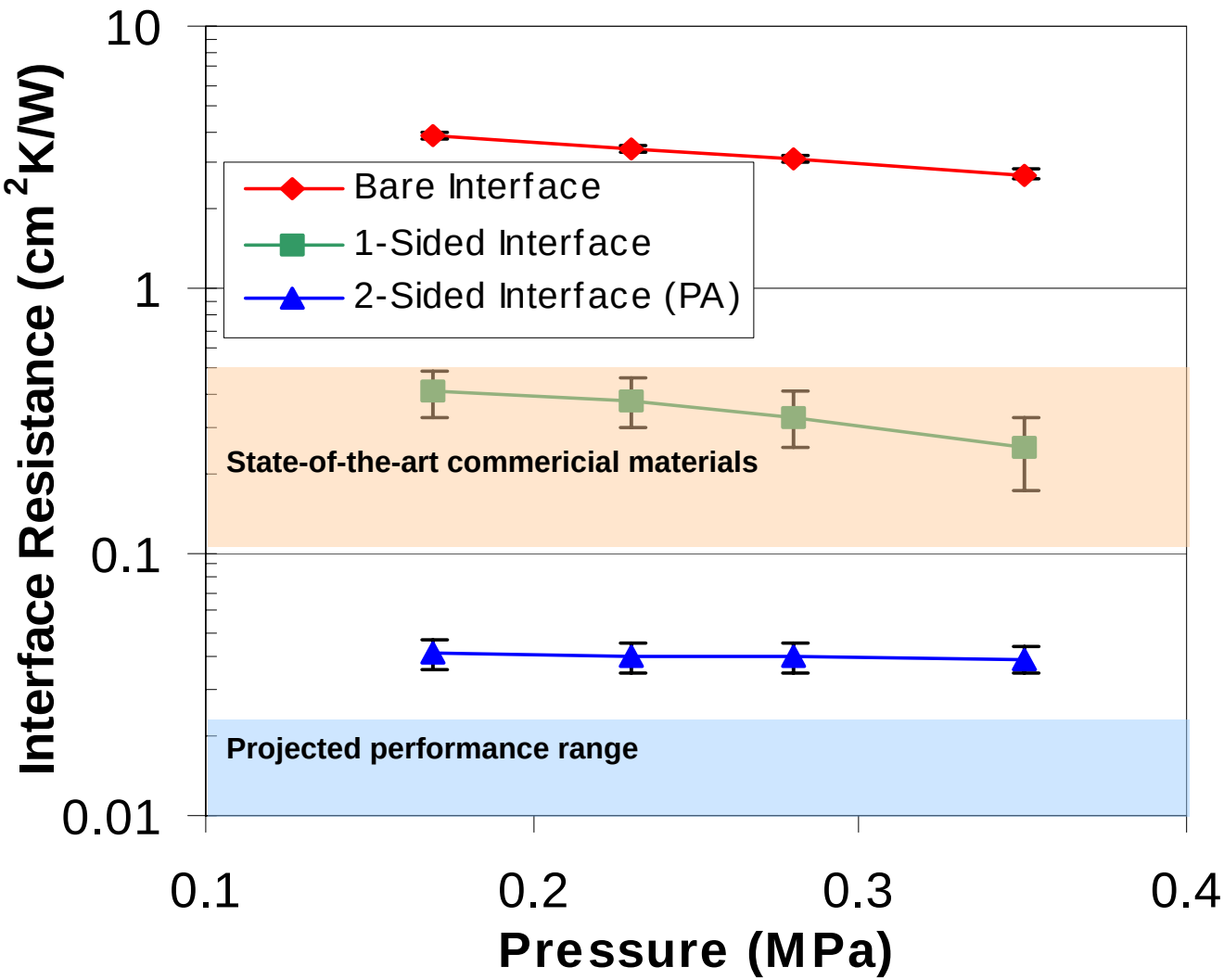
Thermal circuit for the test column.

Photoacoustic (PA) Method
Student: Bara Cola
Collaborator: Prof. Xianfan Xu



Photoacoustic method reduces experimental uncertainty by approximately one order or magnitude.

Summary Results



References:

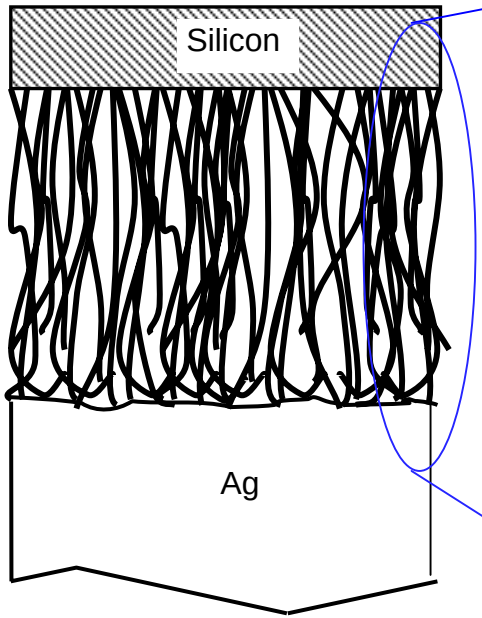
B.A. Cola, J. Xu, C. Cheng, H. Hu, X. Xu, and T.S. Fisher, J. Appl. Phys. in review (2006).

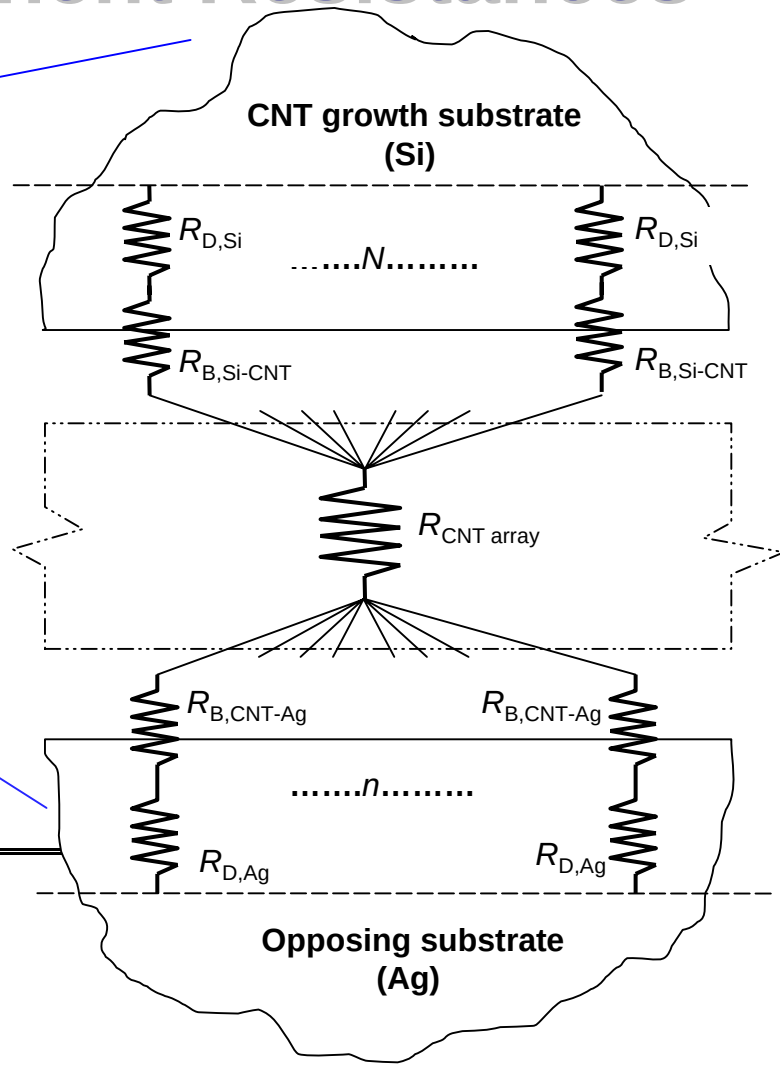
J. Xu and T.S. Fisher, IEEE Trans. Comp. Pack. Tech. 29, 261 (2006).

J. Xu and T.S. Fisher, Int. J. Heat Mass Trans. 49, 1658 (2006).

X. Hu, A.A. Padilla, J. Xu, T.S. Fisher, K.E. Goodson, in press, J. Heat Transfer (2006).

Toward Resolving Component Resistances



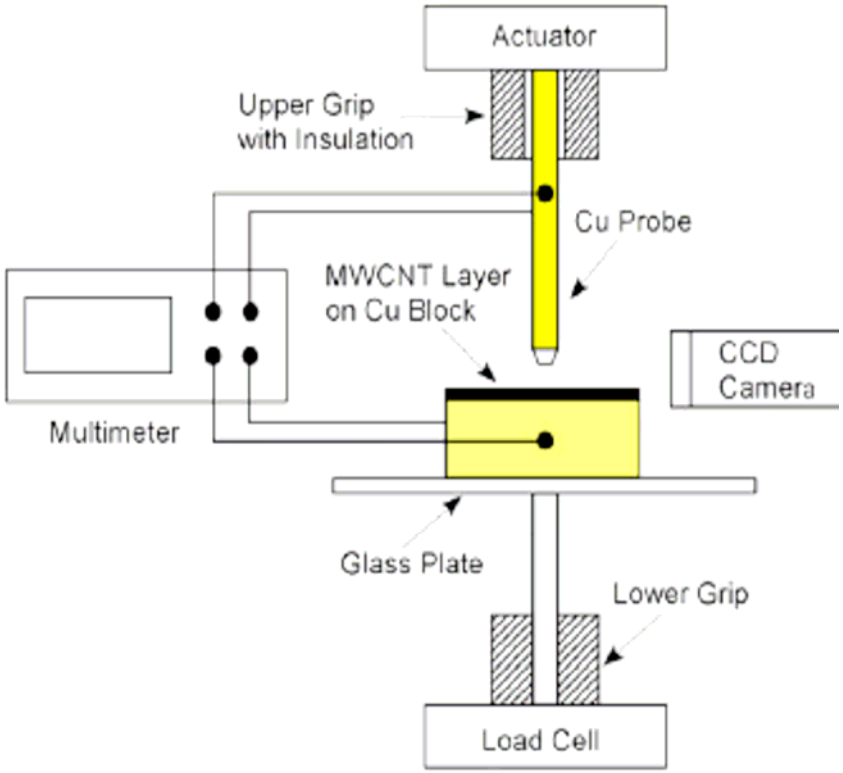


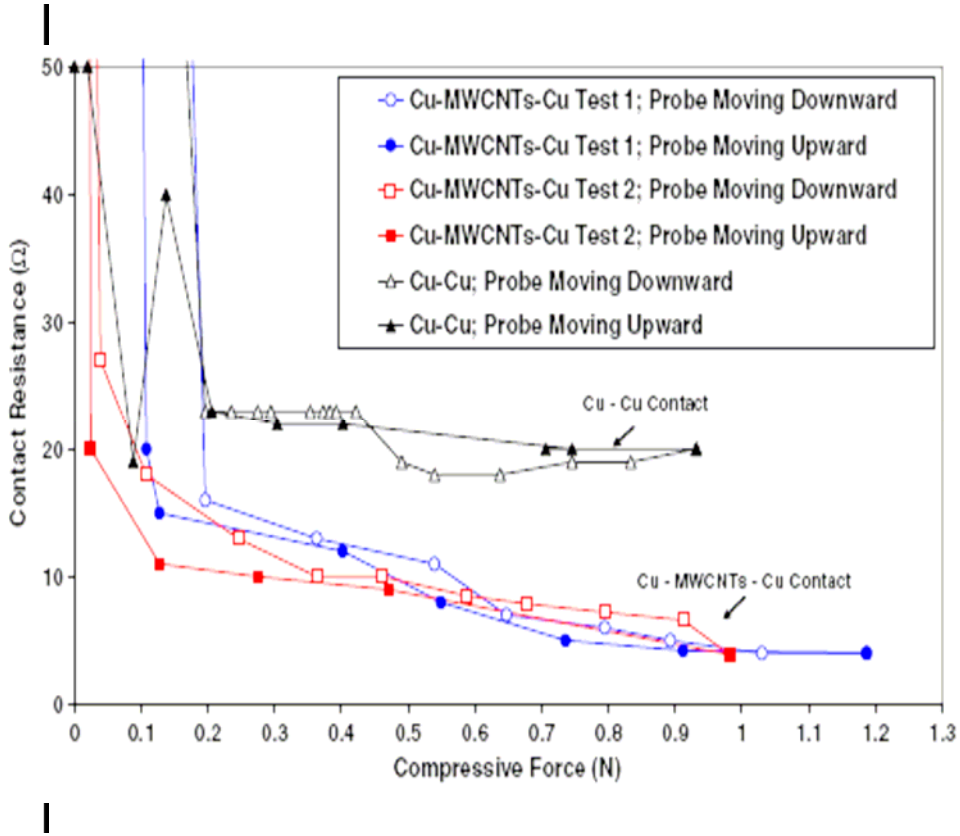
Fitted parameters	Measured values at 241 kPa
$R_{Si\text{-}CNT}$ (mm^2W/K)	2.3 ± 0.4
$R_{CNT\text{-}Ag}$ (mm^2W/K)	13.4 ± 0.2
**R_{Total} ($R_{Si\text{-}Ag}$) (mm^2W/K)	15.8 ± 0.2
$\alpha_{CNTs\text{-}on\text{-}Si}$ (m^2/s)	$1.7 \pm 0.3 \times 10^{-4}$

**Obtained from data fit where the CNT arrays are not considered as a layer in the PA model

Cola et al., in review

Electrical Interfaces





Apparent area of probe tip = 0.3 mm^2

Park et al., Nanotechnology 17, 2294 (2006)

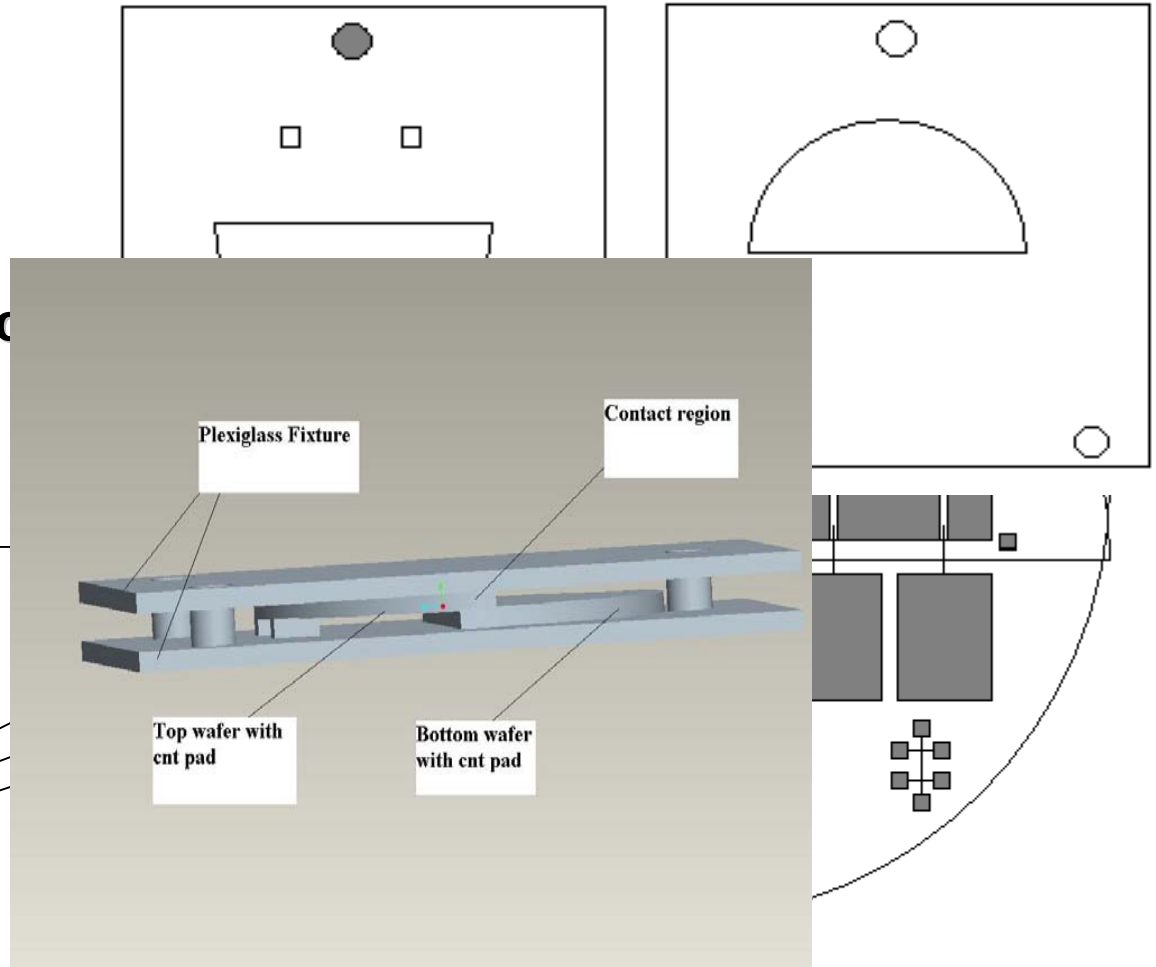
Improved Experiments

Experimental details

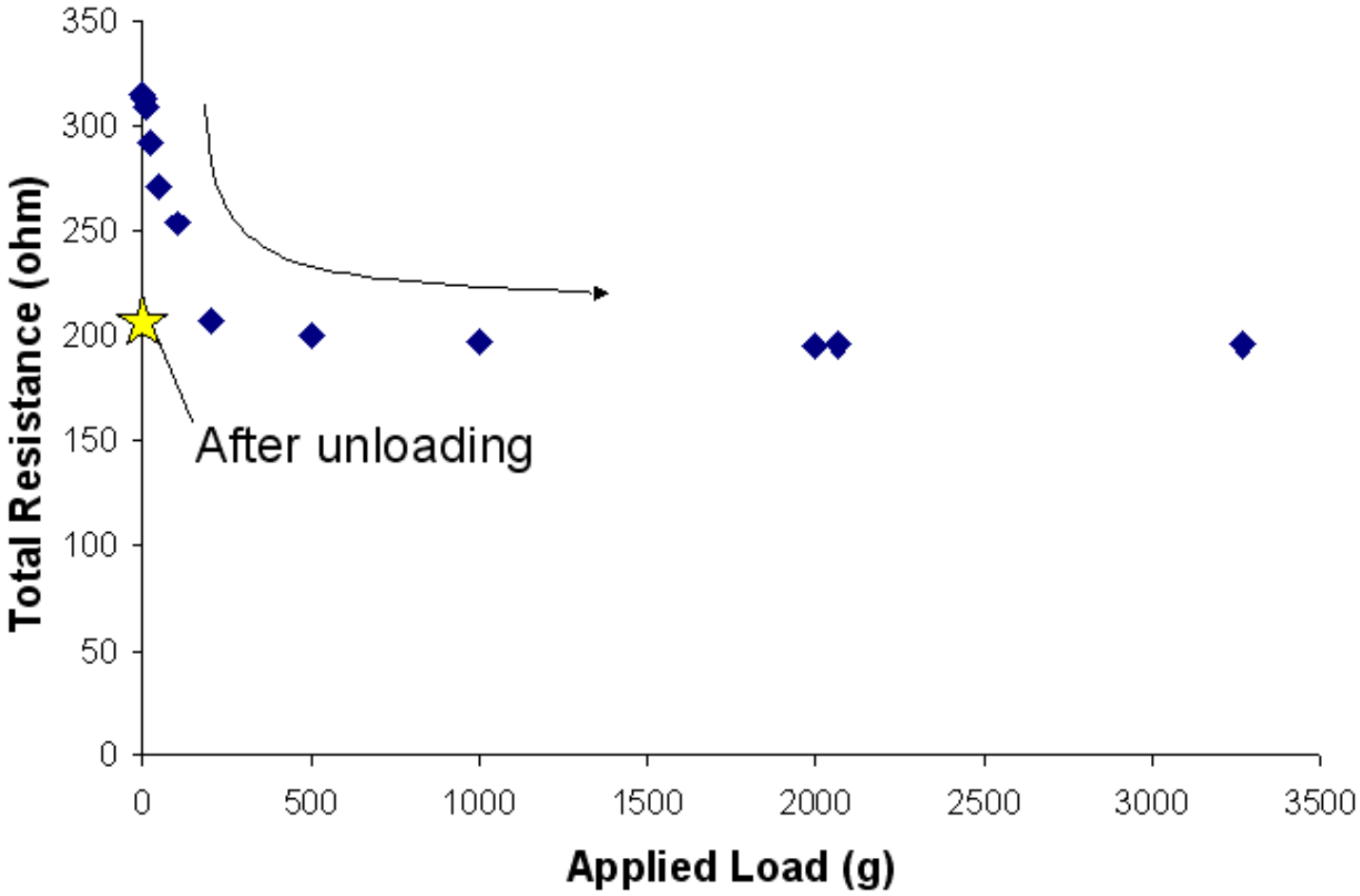
- **4”x4” Transparent Plexiglass**
- **500X optical microsc used for optical alignment**

Optical alignment

CNT-CNT contacts of varying area



Preliminary Results



Conclusions

- CNTs offer the promise of ultra-high conductance (both electrically and thermally)
  - Metrology for both is a major challenge
  - Deterministic contact conductance is, in general, poorly understood for nanomaterials—stochastic transport through many such contacts is even less so
- Thermal conductance through dry CNT array contacts can approach that of bonded metals
- Electrical contacts made from CNT arrays are relatively less developed, but offer similar promise