In-coated Carbon Nanotubes for Flexible Interconnects

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Carbon nanotube (CNT) properties

- Electrical:

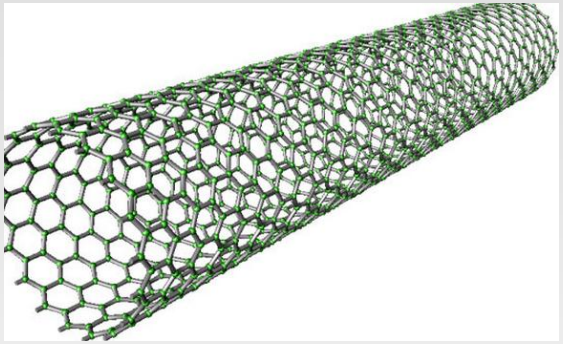
  Semiconducting or metallic

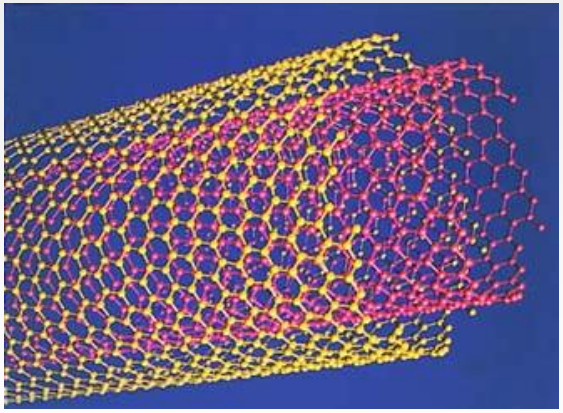
- Thermal:

  Good thermal conductivity

- Mechanical:

  The strongest and stiffest materials yet discovered





CNT as Flexible Electronics and Advanced Packaging Materials

- CNT flexible thin film transistor
- CNTs arrays as thermal interface materials
- Transparent CNT flexible electrodes
- CNT-metal composite to suppress electromigration

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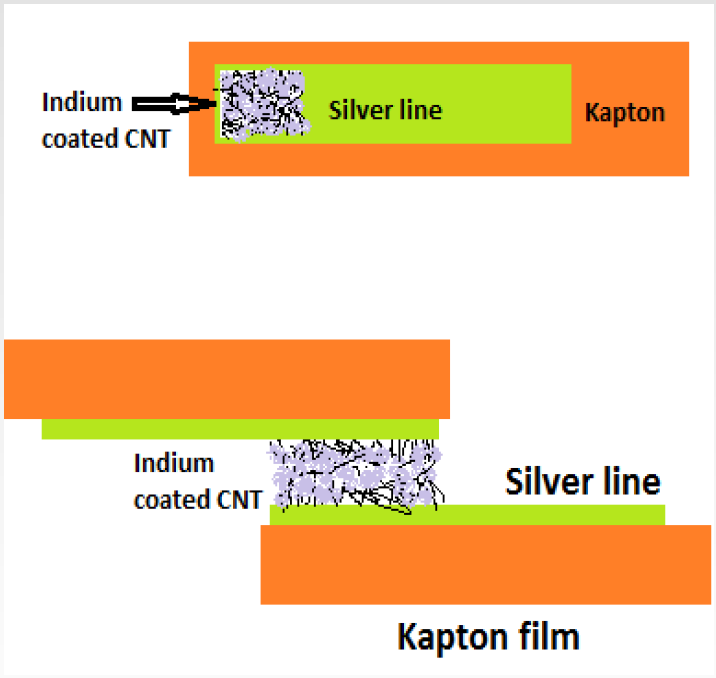
In-coated CNT interconnects



- **Goal:**

a) Better contact for high electrical conductivity

b) Reusability

- **Role of CNT:**

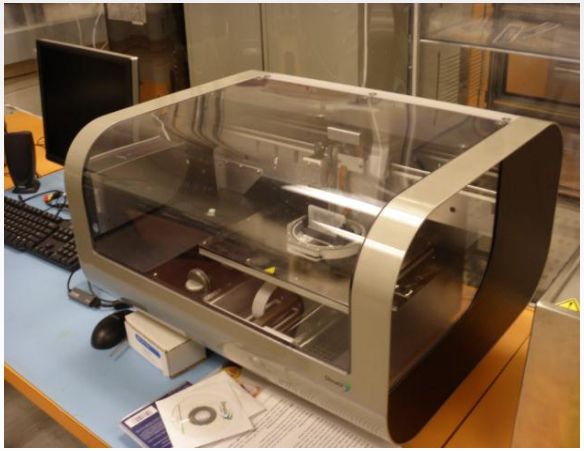
a) Strengthen the contact to make it more durable and repeatable.

b) Enhance electrical conductivity.

CNT ink preparation and printing

- 0.125 wt.% of single walled nanotube (SWNT) & 0.33 wt.% of sodium dodecyl sulfate (SDS, used as *surfactant*) in DI water

CNT dispersion



Dimatix DMP-2800 material deposition ink-jet printer

- Stir SDS in DI water for 10 min
- Add CNT into solution and ultrasonicate (VC 750 Max. Power: 750W. Amplitude: 25% sonication time: one hour)
- Centrifugation (3000 rpm. 30 min)

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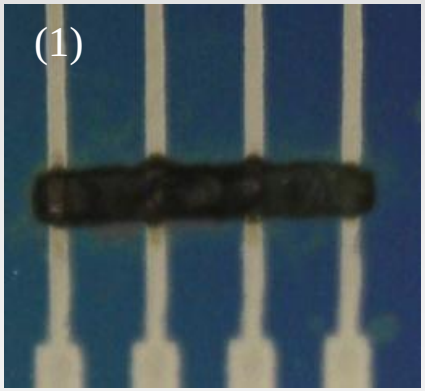
Printing CNT and electroplating indium on CNT

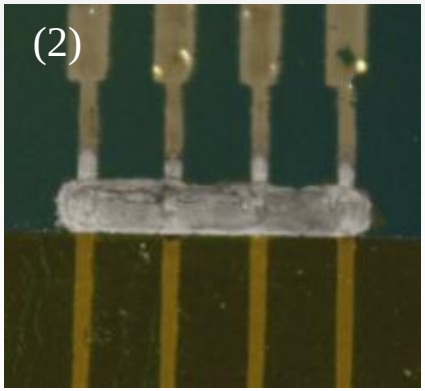
Printing CNT:

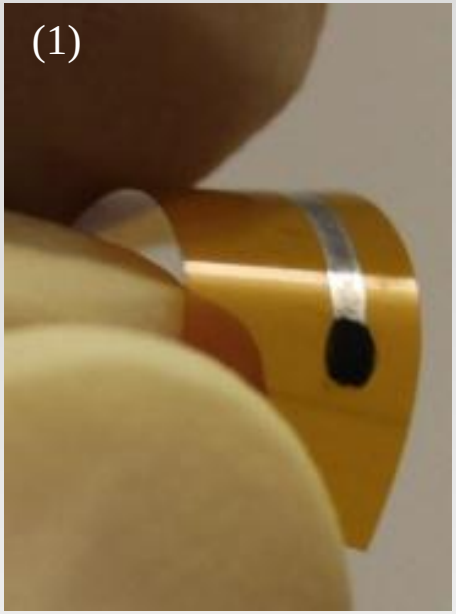
- Drop spacing: 10um
- Cartridge ink-jetting voltage: 30V



Electroplating indium:

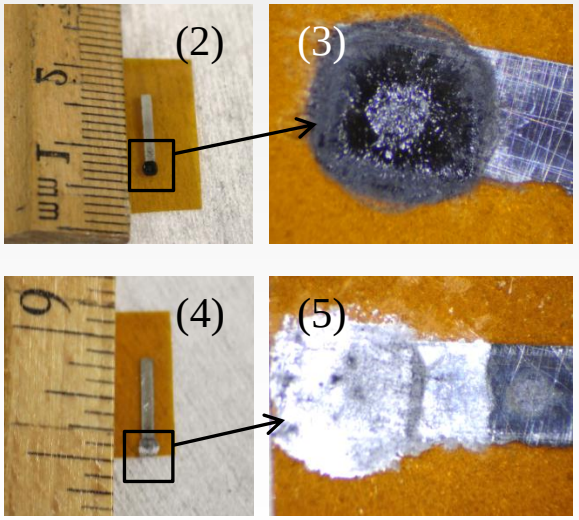
- Current density: 30mA / cm^2
- Anode: Indium
- Cathode: CNT on substrate





Ink-jet printed Silver trace and CNT based interconnect on flexible Kapton substrate

CNT based interconnect before and after indium plating



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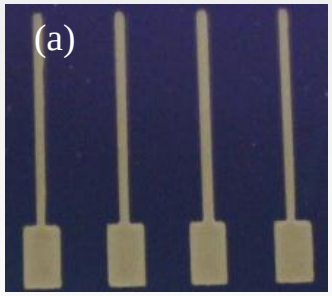
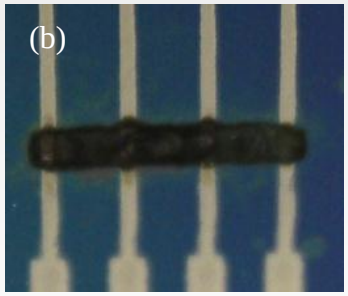
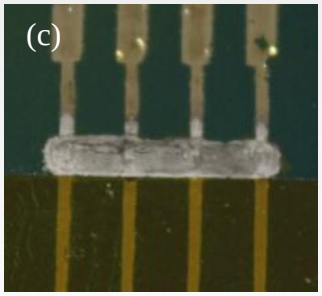
Experimental results and analysis

- A revised four-point probe method is adopted because a standard four point probe doesn't give reliable and repeatable result.







$$R_s = Rm * W/d$$

R_s: Sheet resistance
R_m: Measured resistance
W: CNT film width

d: distance between two silver electrodes

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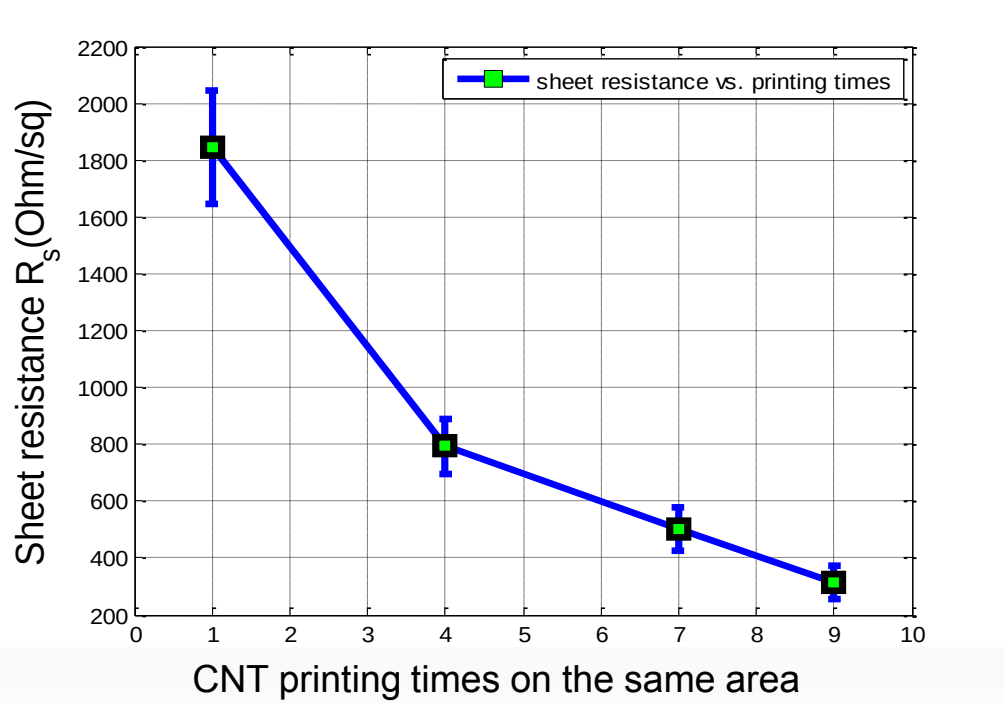
CNT film sheet resistance variation after multiple times of overwriting

Multiple times of printing on the same area:

- Increase CNT film thickness and enhance electrical conductivity
- Average out non-uniformity and reduce “coffee-ring effect”



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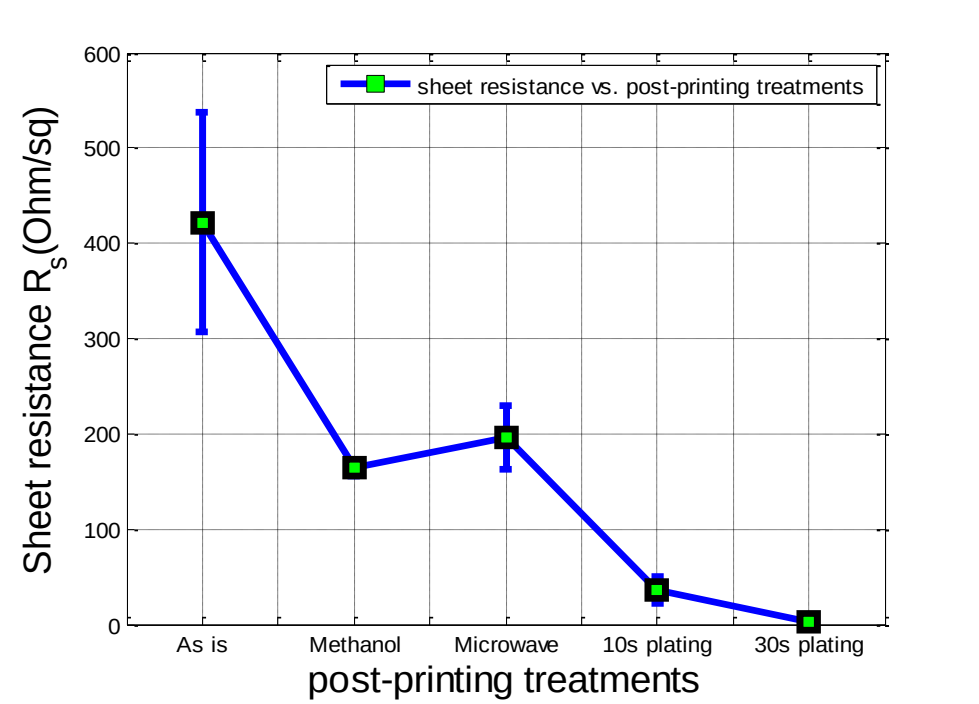
Sheet resistance variation after various treatment

- Methanol treatment:
  To wash off surfactant (SDS)
- Microwave treatment:
  Improve adhesion between CNT and substrate



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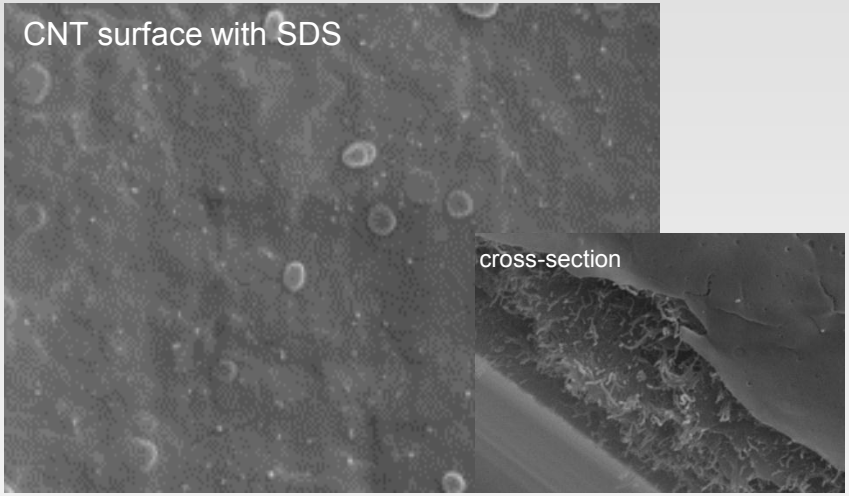
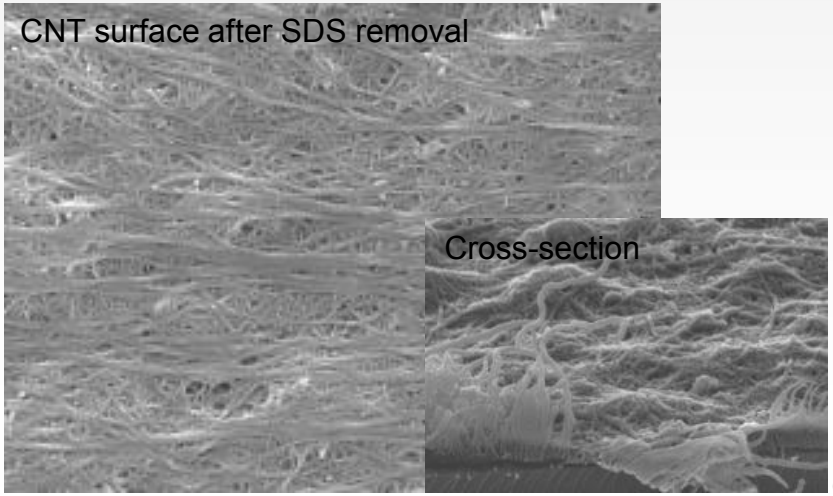
SEM pictures of CNT and In-coated CNT films



- Before SDS removal, a smooth surface of SDS covers CNT film.



- After SDS removal, CNTs are exposed.

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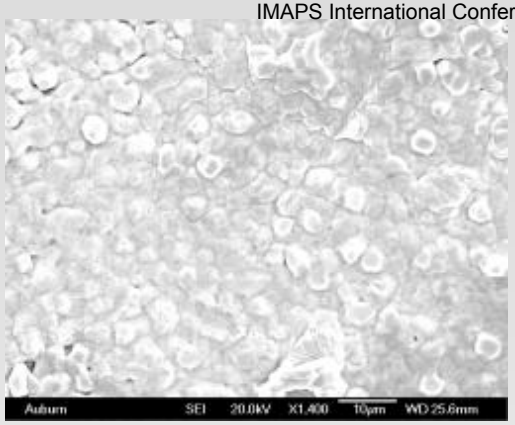
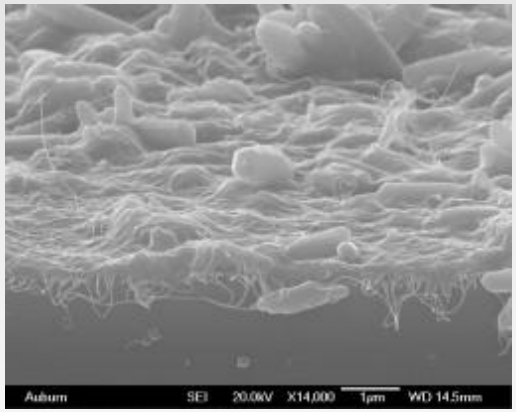
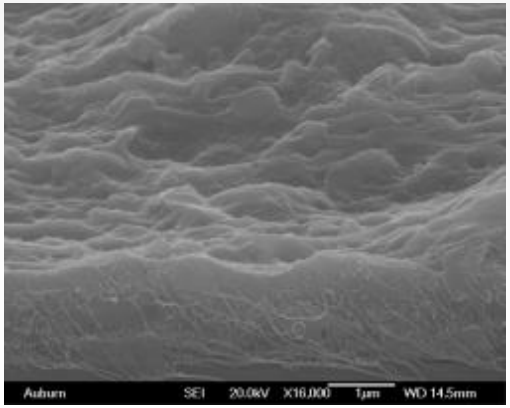


Indium coated CNT surface



CNT surface after 10 sec of plating

- Indium fills in CNT mesh



CNT surface after 30 sec of plating

- After longer time of plating, In-CNT composite forms

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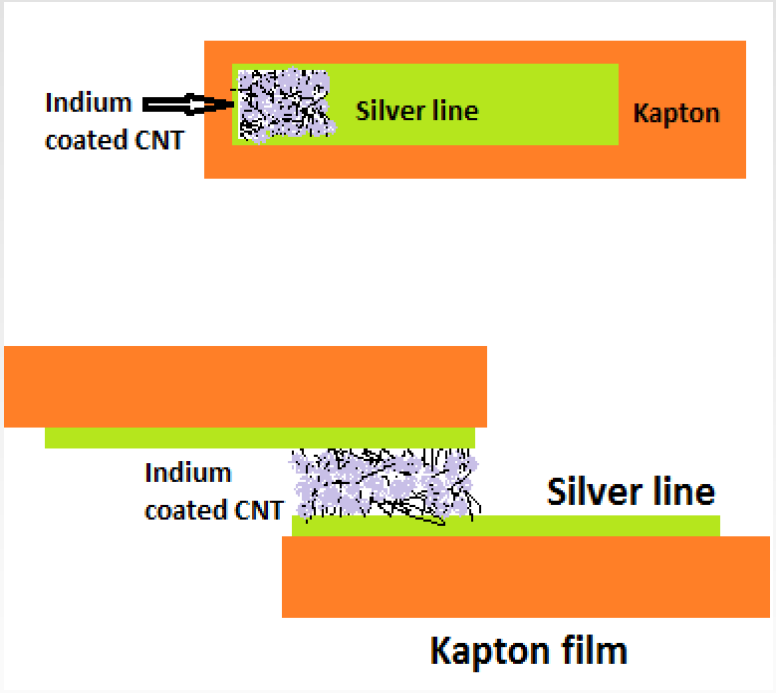
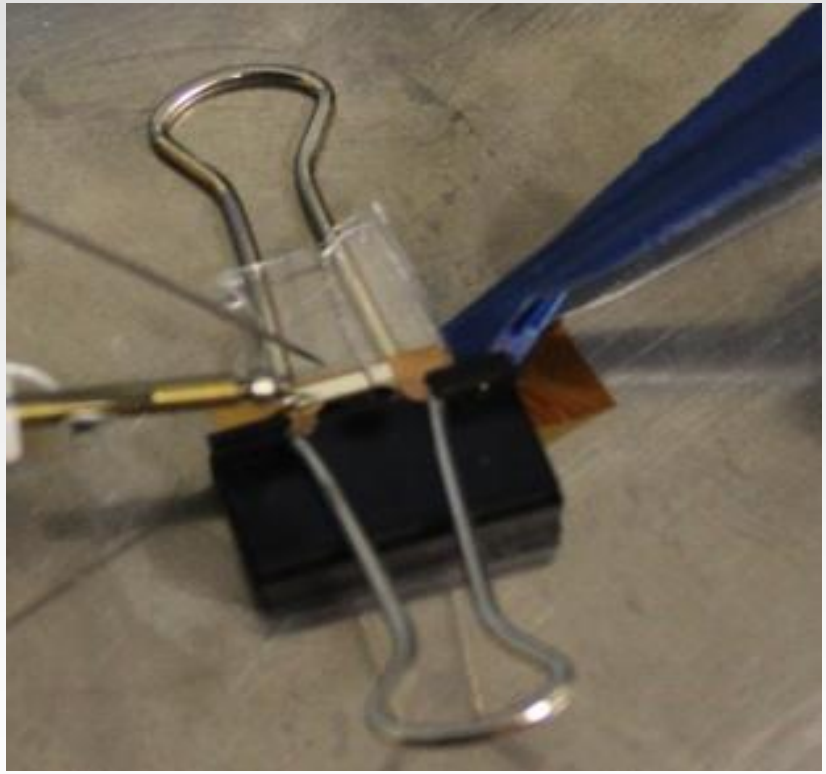
In-coated CNT flexible interconnect experimental results





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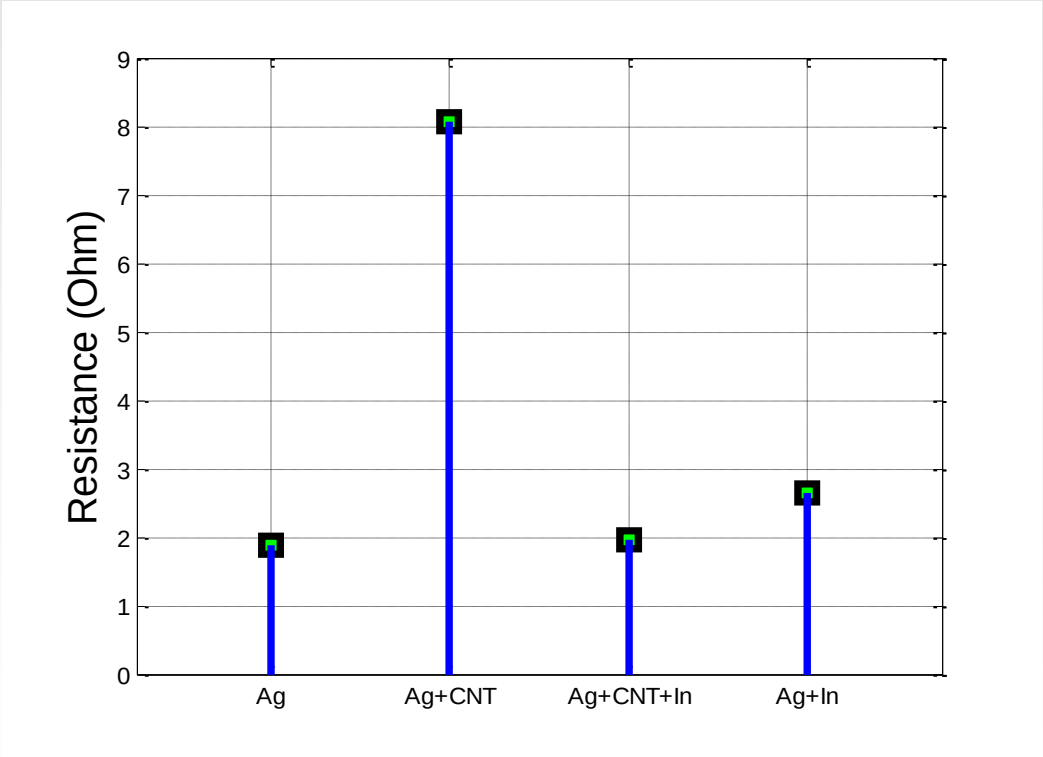
Resistance of interconnects using different contact



Ag + CNT + In interconnect has a resistance lower than both Ag + CNT & Ag + In interconnect.

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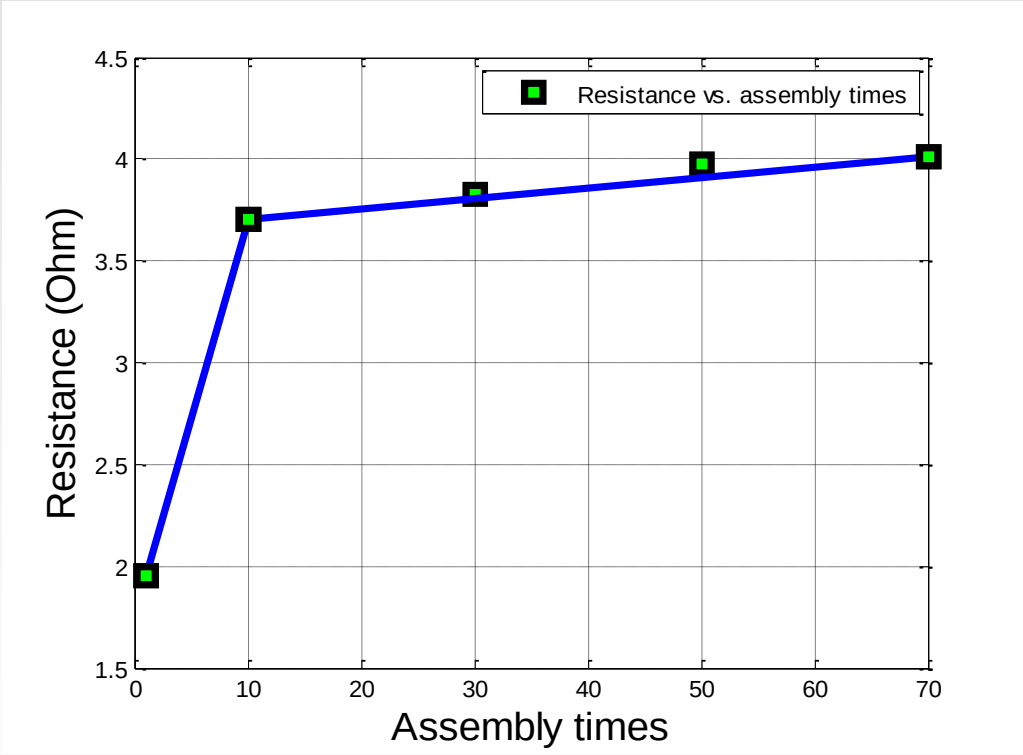
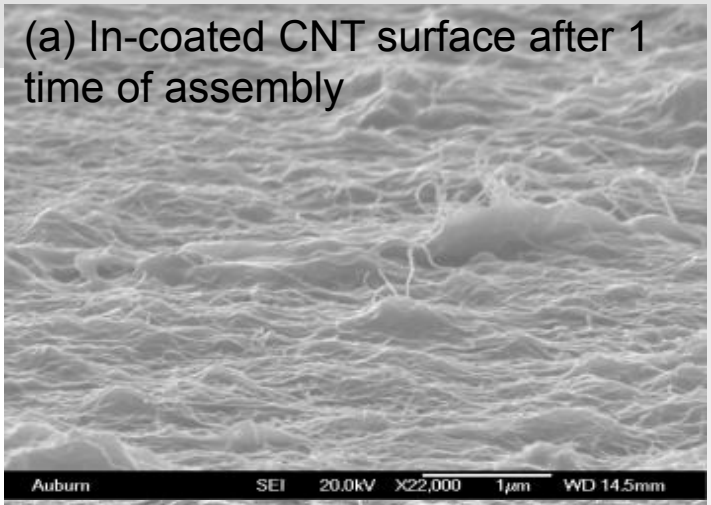
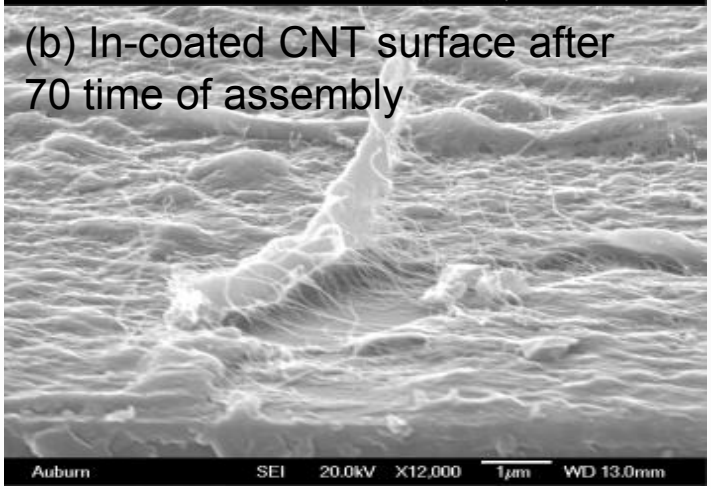
In-coated CNT interconnect resistance degradation after multiple times of assembly







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Conclusion

- Inkjet printing is an effective way to print out CNT.
- Sheet resistance of printed CNT film can be greatly reduced by plating metal to fill in the CNT mesh.
- In-coated CNT interconnects degrade after many times of assembly.
- Future work includes more reworkablity research, performance research in power & signal distribution and RF structures.

Acknowledgement

- We thank Dr. Virginia Davis and Geyou Ao in the Auburn chemical engineering department for their help in making carbon nanotube dispersion.

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Questions?

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