Carbon Nanotube (CNT) Composite Surfaces for Electrical Contact Interfaces

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AIMS AND MOTIVATION

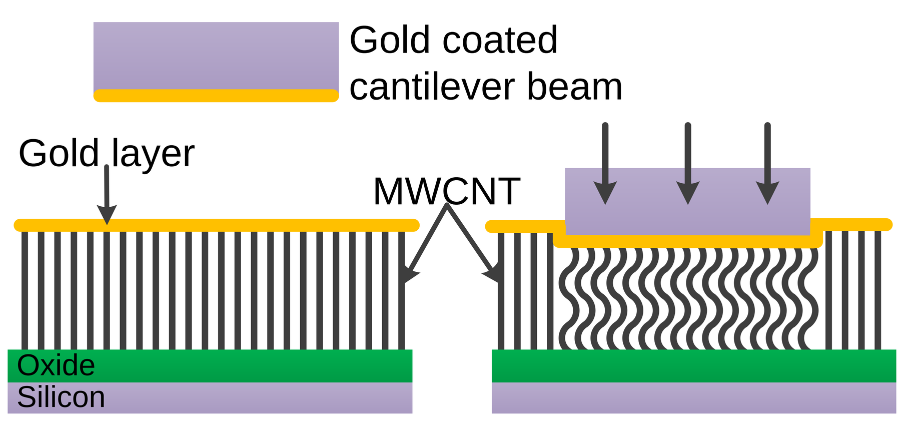
- MEMS switches have high isolation, low on-resistance and are low power, but material transfer between switching contact surfaces in MEMS relay switches causes device failure
- Au/MWCNT composites show resilience to switching damage and yield high lifetimes
- Composite technology has been investigated to enable high lifetime MEMS switches

Deliverables

- Investigate parameters influencing composite manufacture
- Understand contact and impact mechanics of Au/MWCNT composites
- Study the effect of contact force and surface properties on contact resistance
- MEMS relay with $>10^8$ cycles lifetime (load conditions: 4 V >10 mA)

CONCEPT

Schematic illustrating Au/MWCNT composite concept

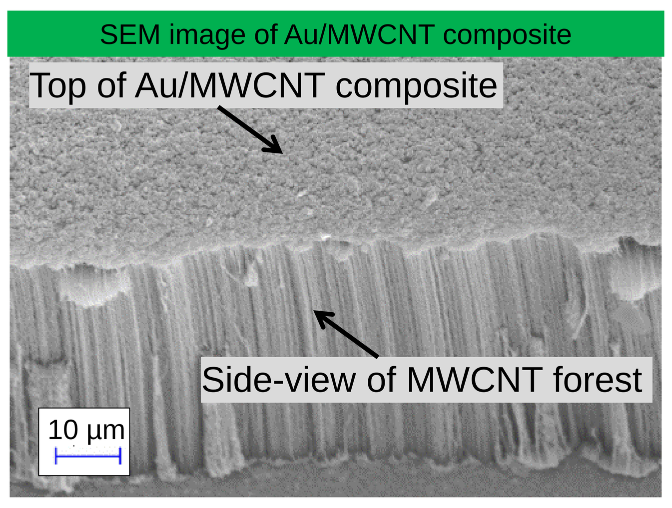


- The MWCNT subsurface provides a soft structure, with high elasticity, which deforms and reforms easily
- Impact energy is dissipated during each switching event
- Au/MWCNT composite conforms to contact yielding larger contact area:
  - → lower contact resistance
  - → higher lifetime

Simplified composite fabrication steps:

1. MWCNT forest grown by thermal CVD
   - buffer and catalyst: Al_2O_3 and Fe
2. Au layer sputtered onto MWCNT forest
3. Au penetrates the composite, electrical conduction is through the Au layer

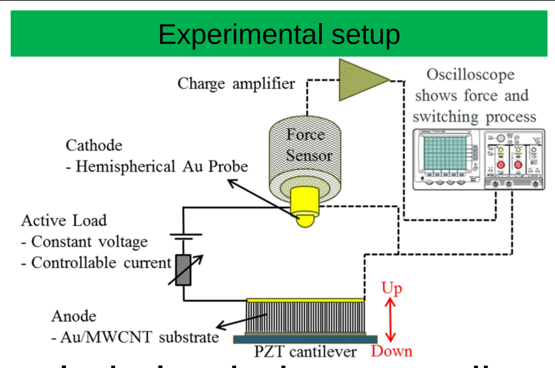
SEM image of Au/MWCNT composite



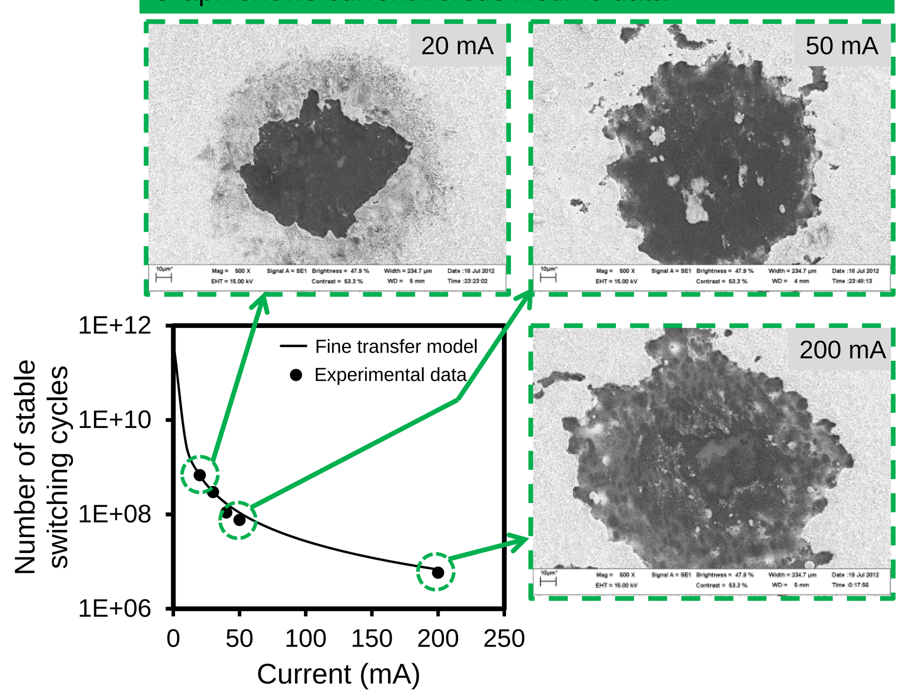
EARLY EXPERIMENTAL WORK

- Initial experiments on a MEMS simulating rig investigated the effect of load current on the lifetime and failure mechanisms of the composites

Experimental setup

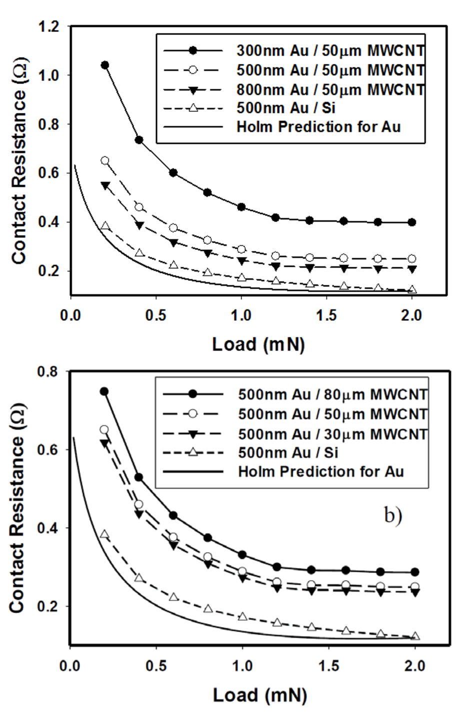


SEM images of Au/MWCNT composites after switching at 4 V, 1 mN until failure; switching current given in legend. Graph shows current versus lifetime data



- Sampled loaded onto vibrating PZT beam repeatedly made contact with an Au-coated ball
- The contact resistance was monitored throughout
- Failure determined by greater than three fold increase in nominal contact resistance
- Material transfer from Au/MWCNT composite to ball
  - Area of failed site related to load current

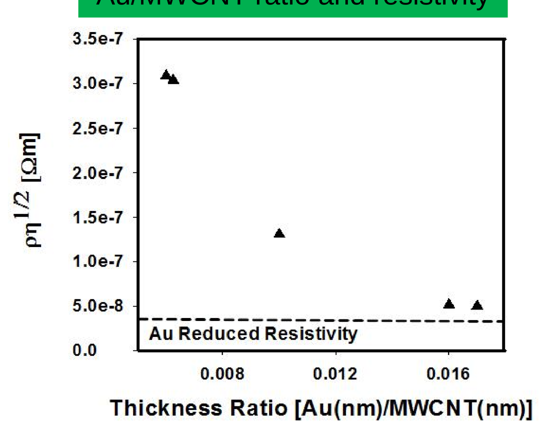
ELECTROMECHANICAL CHARACTERISATION



Electromechanical characterisation using a modified nanoindenter

- Integrating a NI data acquisition card and modified indenter tip on a NanoTest Vantage nanoindenter system enabled accurate monitoring of the electrical potential during nanoindentation
- Electromechanical results demonstrate trends similar to those of bulk conducting materials highlighting the influence of the penetration of the Au into the MWCNT composite on the material properties

Relationship between Au/MWCNT ratio and resistivity



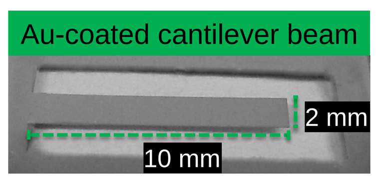
- The electrical influence of the MWCNT on the properties of the composite can be directly observed. Longer MWCNTs allow for deeper Au penetration slightly increasing resistivity
- The observed electrical resistivities of the samples are comparable to the more common Au/Si samples

RECENT MEMS EXPERIMENTS

Simplified cantilever fabrication steps:

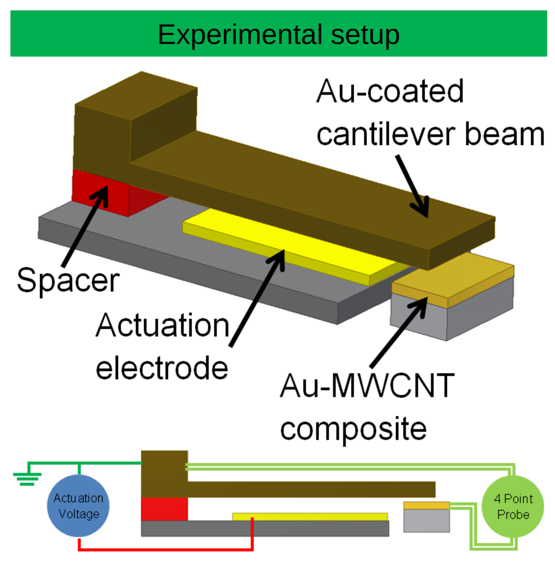
1. Photolithograph to define beam dimensions
   - Width 2 mm
   - Length 10 mm
   - Thickness 20 µm

Au-coated cantilever beam

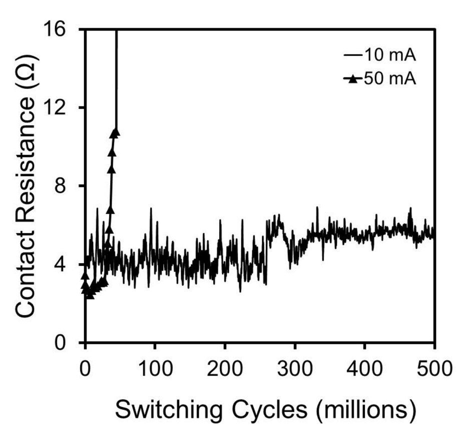


2. ICP-RIE of silicon to release cantilever beam
3. Au layer [500 nm] sputtered onto cantilever beam

Experimental setup



Contact resistance over lifetime for composites for two values of load current: 10 and 50 mA



Results

- With 50 mA, tests with the composite showed failure after 25–45 million cycles
- The experiment at 10 mA, maintained a stable contact for over 500 million hot switched cycles
  - exceeding the deliverable specification
- SEM analysis of the cantilever beam after 500 million switching cycles showed no visible signed of material transfer

CONCLUSIONS

- Au/MWCNT composites significantly improve the lifetime of electrical contacts
- Model for describing the effect of load current on lifetime developed
- Electromechanical performance of composite modelled and experimentally investigated
- Feasibility of use of Au/MWCNT composites to enable MEMS switch technology proven
- MEMS developmental device hot-switched for over 500 million cycles with stable contact resistance

Industrial Engagement

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