SAND2014-20402D

Toward Carbon Nanotube Based Thermal Interface Materials

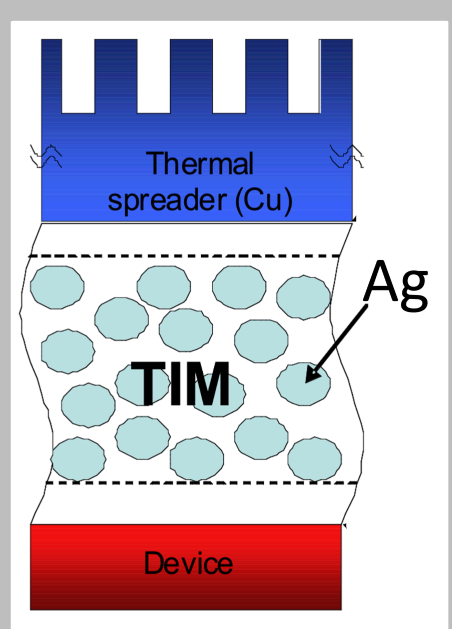
Caitlin Rochford, S. J. Limmer, S. W. Howell, T. E. Beechem, M. P. Siegal
Sandia National Laboratories, Albuquerque, NM

Sandia National Laboratories

Motivation:

Removing heat generated by high power electronics is becoming increasingly important as voltage, current, and frequency scale to increase grid efficiency. Without an efficient thermal interface material (TIM), the advantages of advanced power electronics are obscured.

Traditional TIM (e.g. Ag paste)

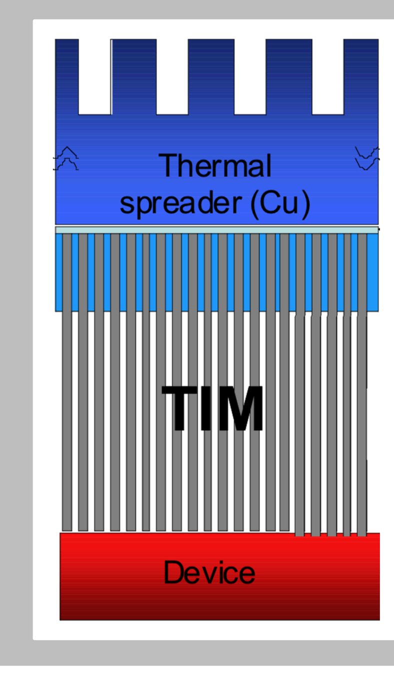


Thermal Conductivities:
Ag: 420 W/m•K, Epoxy: 0.23 W/m•K

The thermal conductivity of metal-filled epoxies are dominated by percolation through the epoxy, resulting in ≈ 1 W/m•K*.

* From commercial data sheets

CNT-based TIM



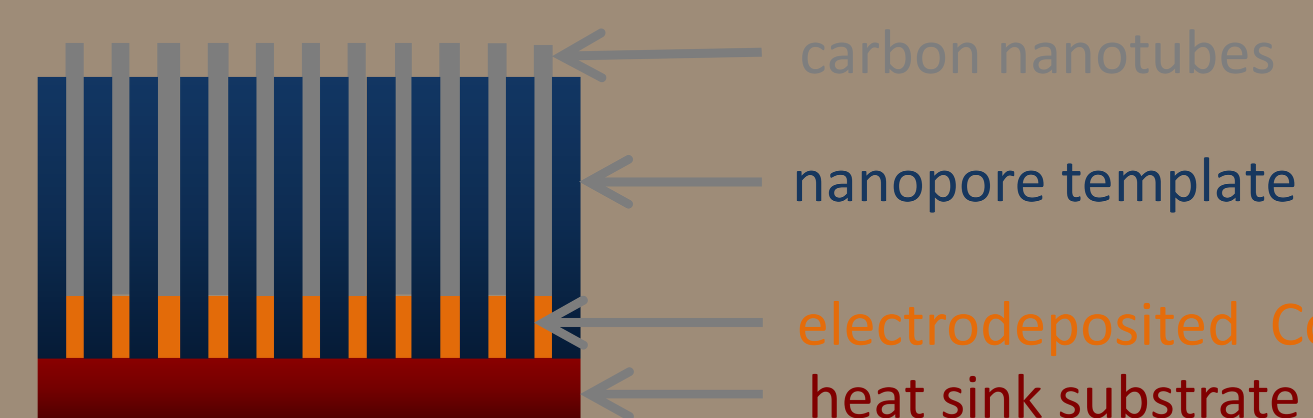
Thermal Conductivities:
CNTs: 10-3000 W/m•K, Eliminate the epoxy

TIM performance is only as good as the carbon nanotubes (CNTs) in the array.

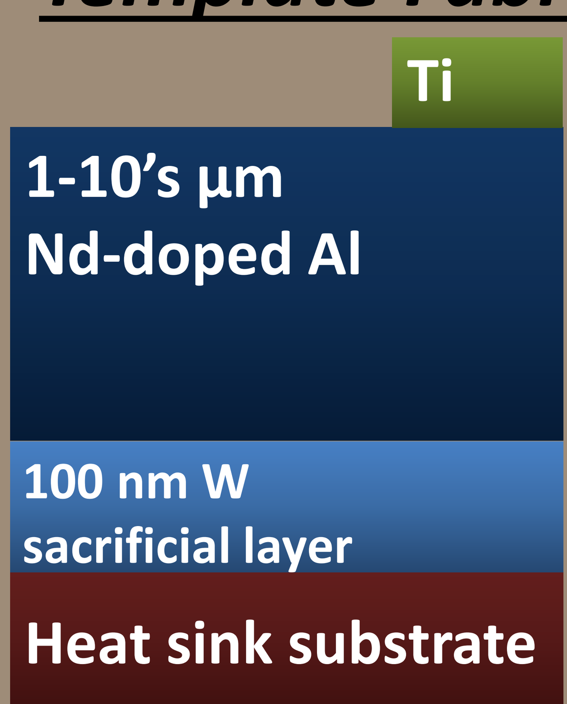
It should be possible to improve TIM performance by multiple orders-of-magnitude.

Strategy:

- Thermal CVD of CNTs from cobalt catalyst → *controlled growth, fewer CNT defects.*
- Use of nanopore template → *vertical alignment, geometric control*
- Grow directly on heat sink material → *eliminate thermal bottleneck of adhesive*
- Cut CNTs to uniform heights → *improve contact to hot device, maximize heat transfer*

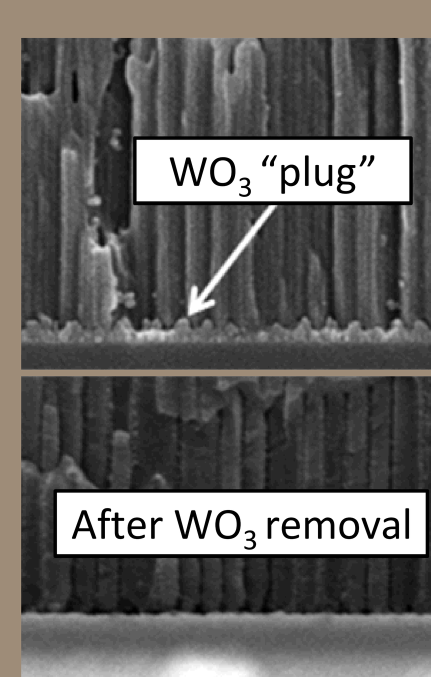


Template Fabrication:



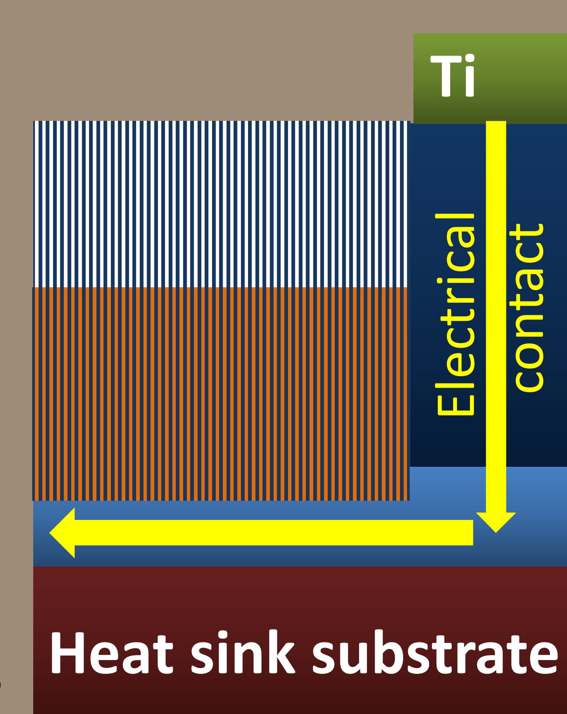
Anodize exposed Nd-doped Al to form pores.

Partially anodize W sacrificial layer. Selectively remove WO_3 plugs.

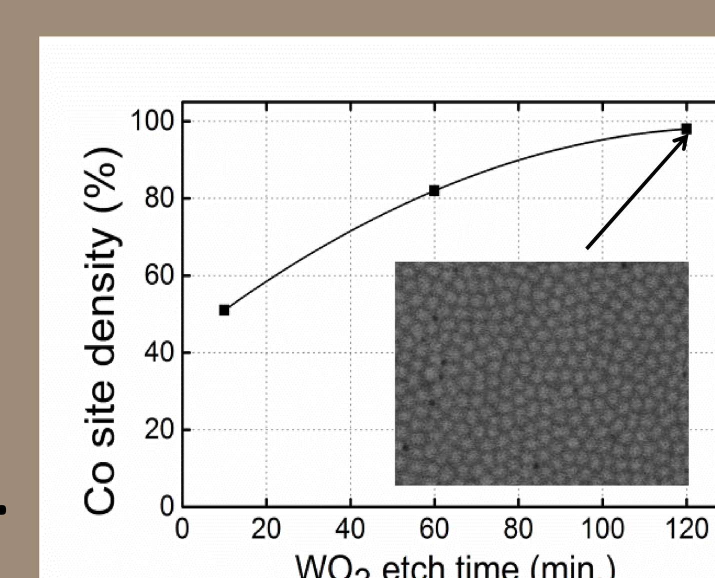


Metallic W remains at pore bottoms.

This facilitates electrodeposition of the catalyst, even on insulating substrates.



Near 100% site density of cobalt catalyst can be achieved.

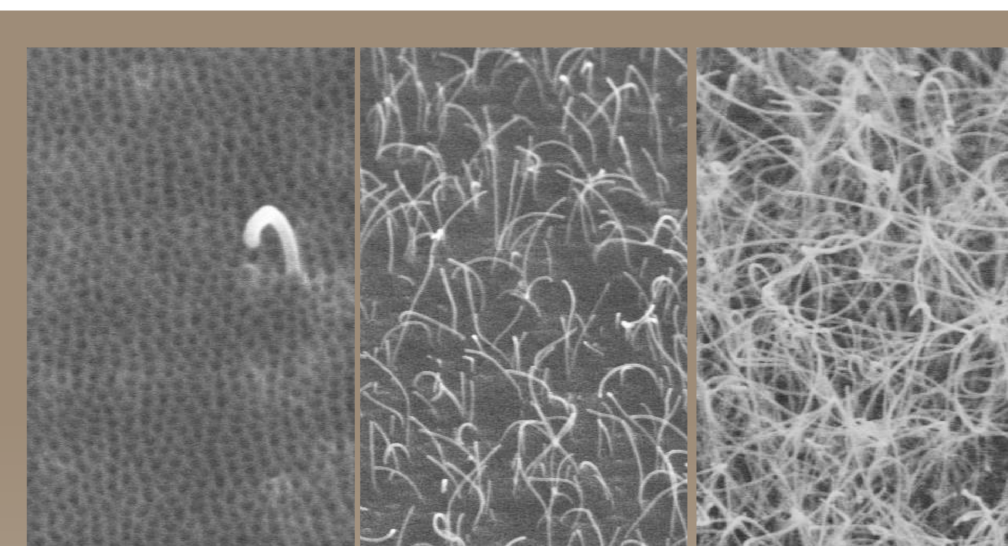


Inset: top view of filled pores flush with template surface

Nanotube Growth

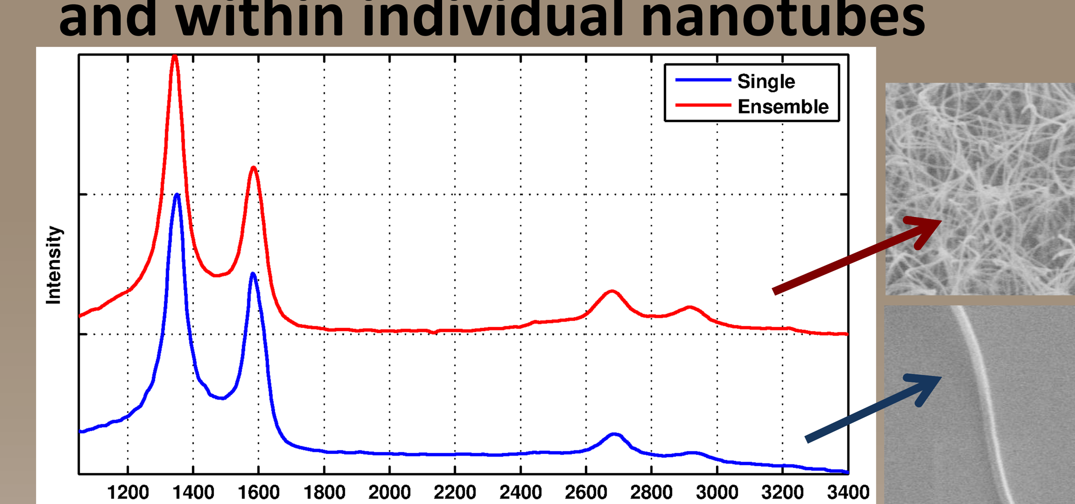
Nanotubes are grown by CVD at temperatures between 450 - 650 °C in a flowing mixture of C_2H_2, H_2, and N_2. .

Nanotube growth competes with amorphous carbon deposition on the AAO. The nanotube must get up and out before amorphous carbon blocks the uplift.



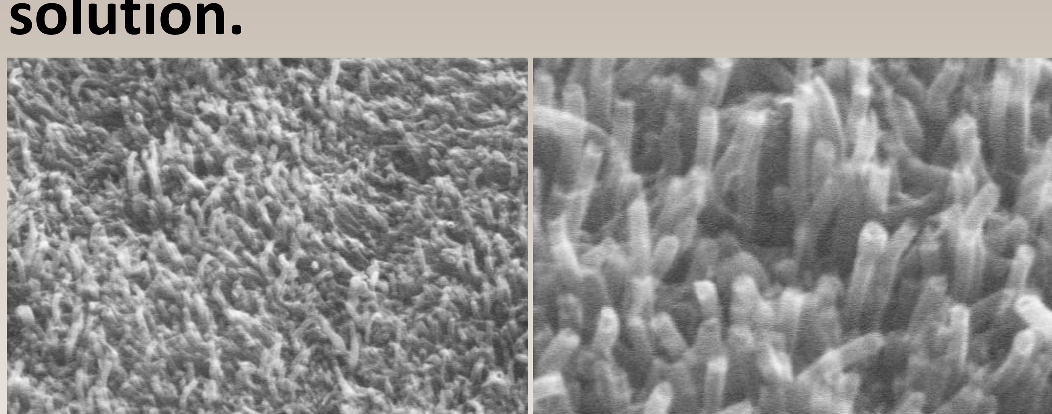
Nanotube density varies with the aspect ratio of the open pore above the Co

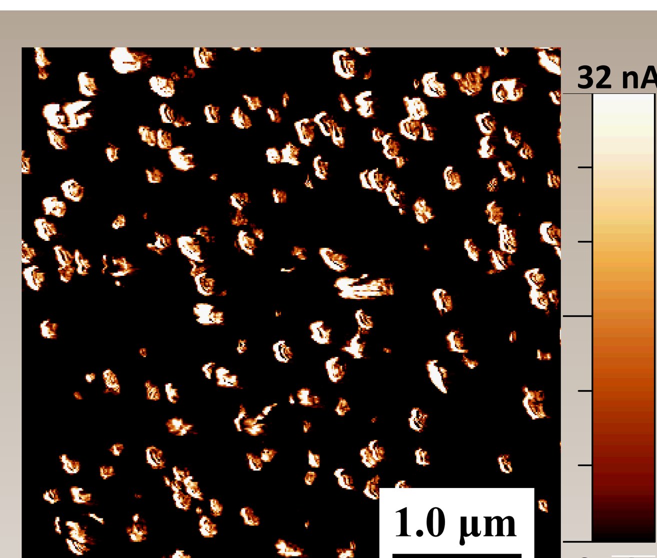
Raman spectroscopy shows very little variation between nanotubes and within individual nanotubes

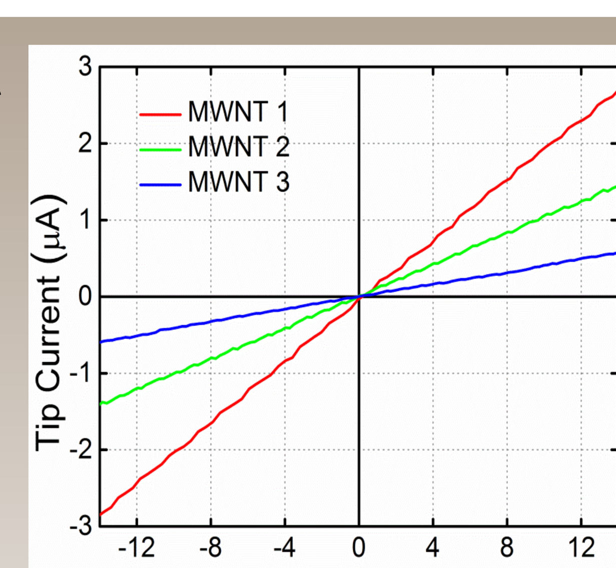


Planarizing Nanotube Arrays:

CNTs can be cut to uniform height above the AAO by ultrasonication in solution.







Conductive AFM confirms electrical (and therefore thermal) contact to the substrate is preserved.

Summary and Ongoing Work:

- Carbon nanotube arrays may improve thermal interface material performance by orders of magnitude.
- Template growth and ultrasonic cutting provide control over geometry, alignment, and planarization while maintaining robust contact to the heat sink substrate.
- Ongoing work is focused on optimizing nanotube quality and measuring thermal conductivity of nanotubes and arrays.

U.S. DEPARTMENT OF ENERGY   NNSA National Nuclear Security Administration

This work is supported by the Laboratory Directed Research and Development Program and Sandia National Laboratories. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.