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Planarized Unentanged Carbon Nanotube Arrays

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The goal:

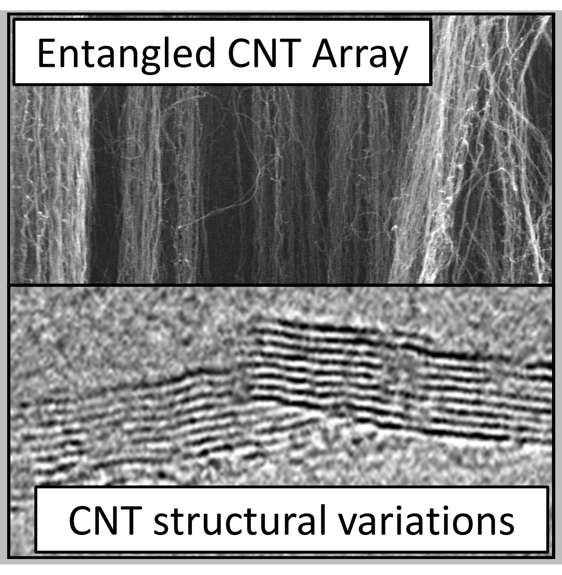
- Array of high quality carbon nanotubes (CNTs)
- Vertical orientation with uniform length
- Electrical and/or thermal contact to substrate, depending on the application
- Controllable site density

The applications:

- Field emission
- Nanoscale transistors
- Sensors
- Thermal interface materials
- High surface area electrodes

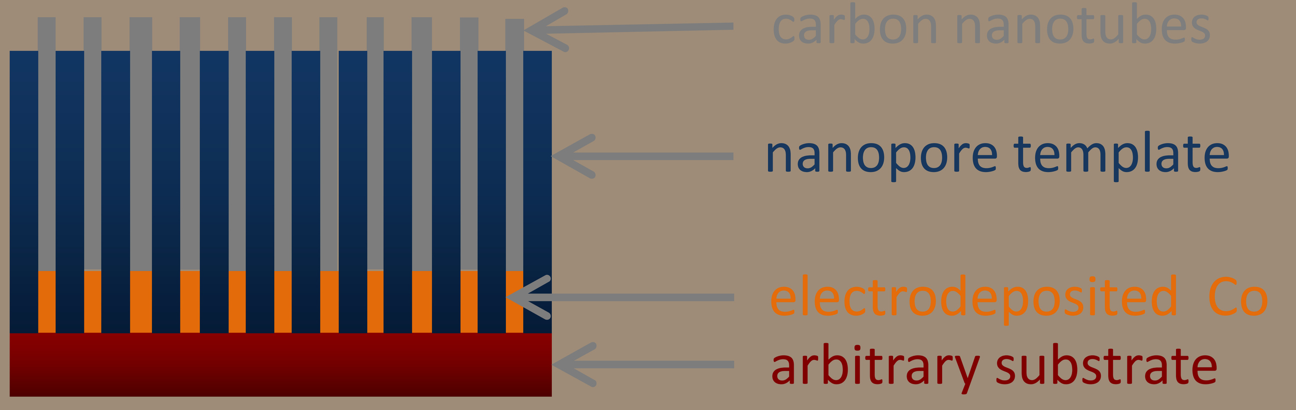
The common pitfalls:

- Defects, kinks, bends in CNTs
- Entangled array, limits applications
- Varying nanotube lengths
- ***Poor electrical & thermal properties***



The approach:

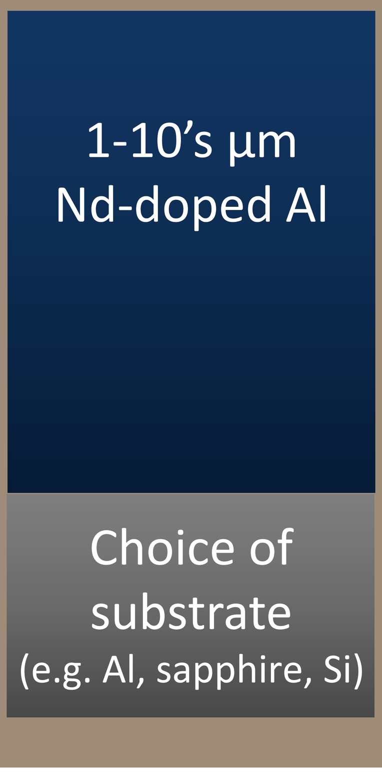
- Thermal CVD of CNTs from cobalt catalyst → ***slower, controlled growth; fewer CNT defects.***
- Use of nanopore template → ***vertical alignment, diameter control, avoids CNT entanglement***
- Low stress deposition of template material → ***choice of substrate and CNT length***
- Ultrasonic cutting → ***uniform length, contact to substrate is maintained***



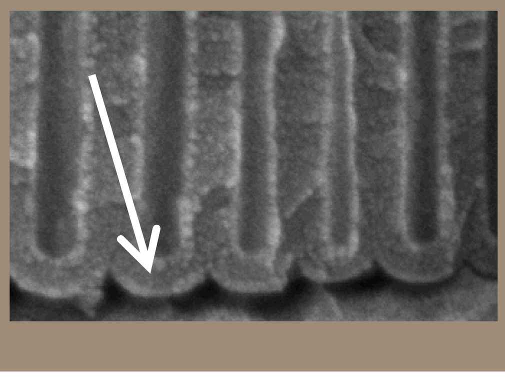
Starting Material: Anodized Aluminum Oxide (AAO) Nanopore Templates on Substrates

Instead of anodizing a sheet of aluminum, a low-stress, mirror-smooth Nd-doped Al film is deposited onto the desired substrate.

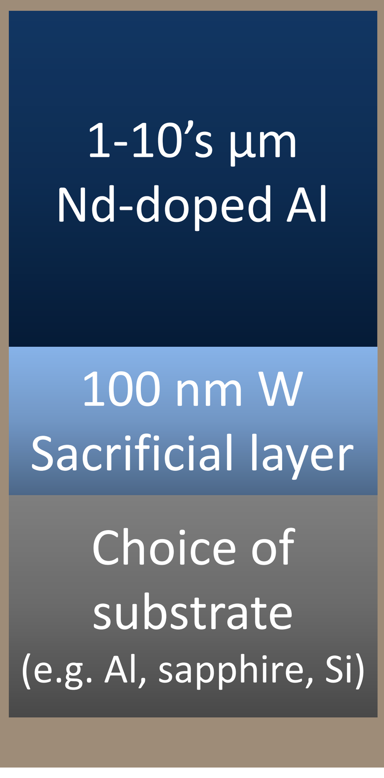
This film is anodized to create the nanopore template.



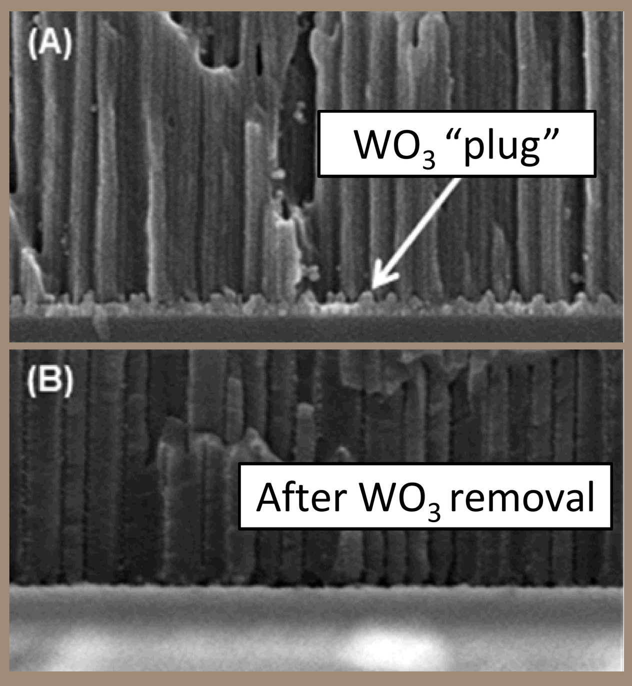
Problem: Anodization leaves an oxide barrier at pore bottoms, which prevents electro-deposition of the catalyst



Solution:



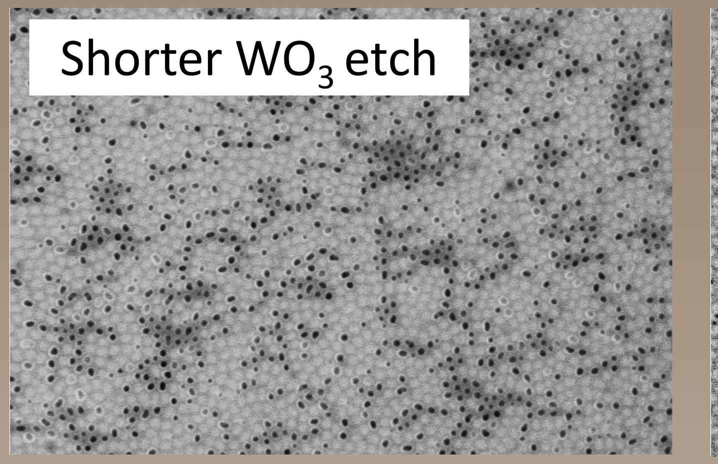
A sacrificial W "valve" layer oxidizes partially through during anodization. The WO_3 is selectively removed to leave a conductive W layer at the pore bottoms. This facilitates catalyst electrodeposition, even on insulating substrates.

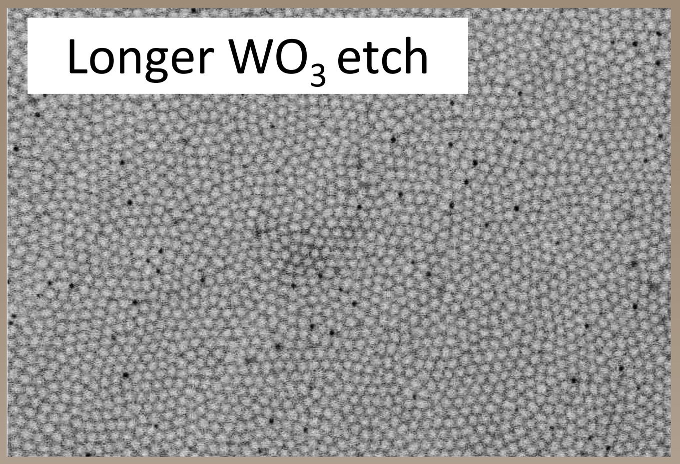


__Growing Nanotubes__: Control the Site Density

Nanotubes will only grow from catalyst-filled pores

Controlling the duration of the WO_3 etching step allows control over the catalyst site density.





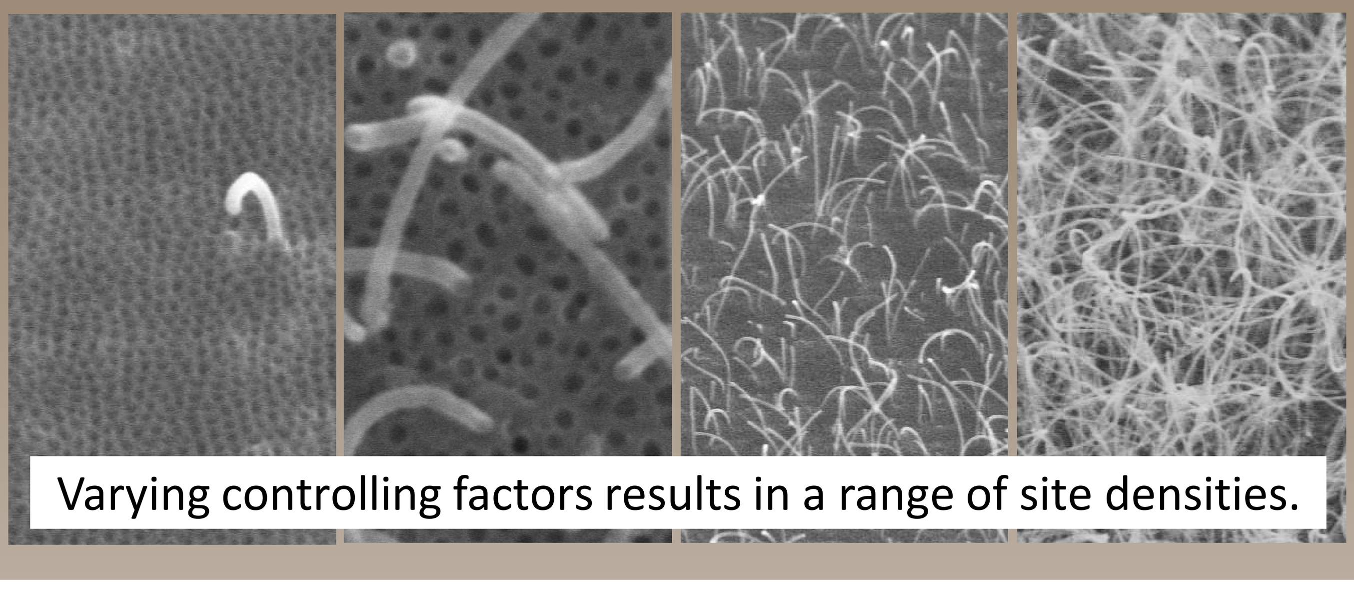
Ion milled pores expose Co catalyst. Empty pores appear dark.
Scale: pore diameter is 75 nm

Nanotube growth competes with amorphous carbon deposition on the AAO

Nanotubes are grown by CVD at temperatures between 450 - 650 °C in a flowing mixture of C_2H_2, H_2, and N_2. AAO also catalyzes the decomposition of C_2H_2, and amorphous carbon deposition on pore walls and over pore openings can block the Co-nucleated growth.

<u>The density of CNTs emerging from the pores depends on:</u>

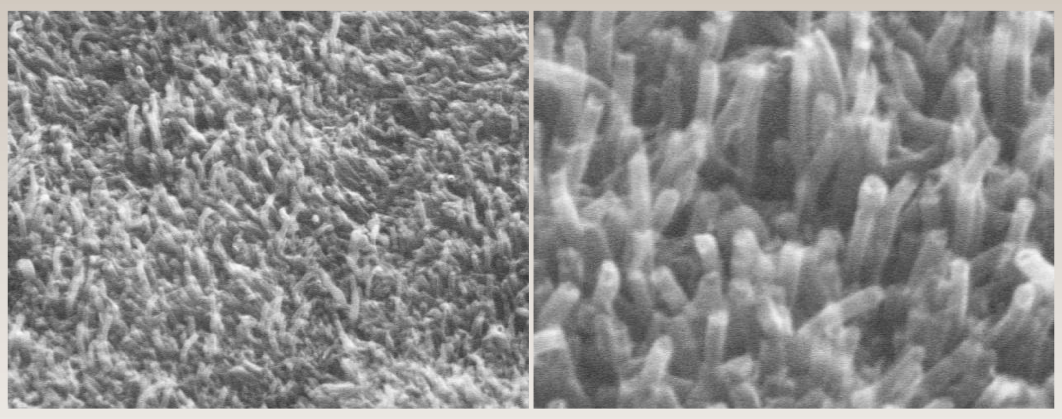
- Open pore aspect ratio
- Ratio of C_2H_2 to H_2
- Growth temperature



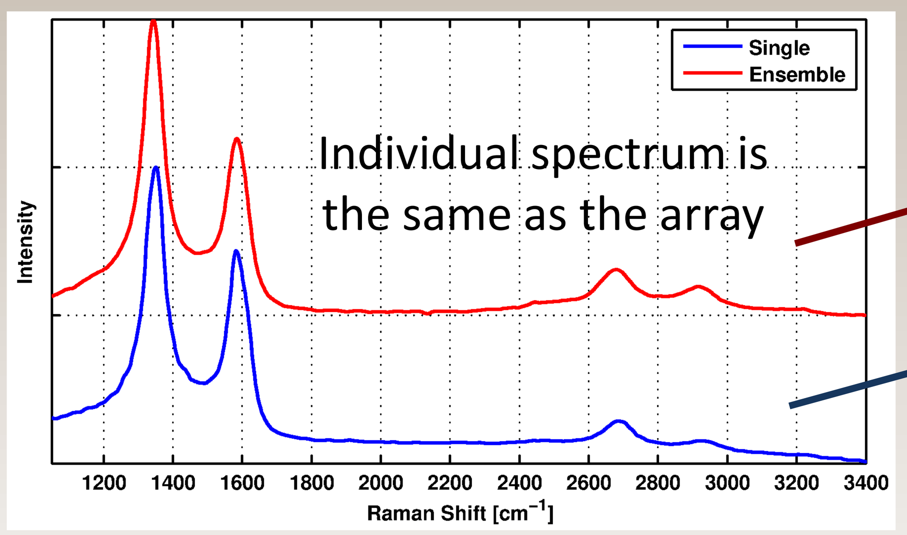
Varying controlling factors results in a range of site densities.

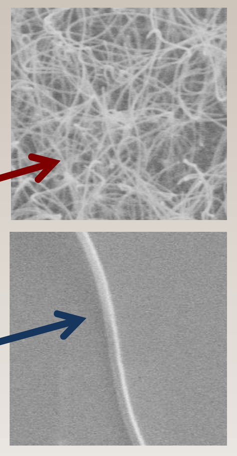
__Processing Nanotube Arrays__:

CNTs can be cut to uniform height above the AAO by ultrasonication in acetone, *retaining electrical contact to the substrate.*



Raman confirms growth of uniform MWNTs. Individual CNTs can be harvested for device fabrication or characterization.





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NNSA National Nuclear Security Administration

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Summary

- Vertically aligned, planarized CNT arrays have many possible applications, but commonly used fabrication techniques lead to poor quality.
- The above technique produces tunable (e.g. diameter, length, site density), high quality CNT arrays suitable for a variety of applications.
- Future directions: optimize site density control, characterize CNT electrical and thermal properties.