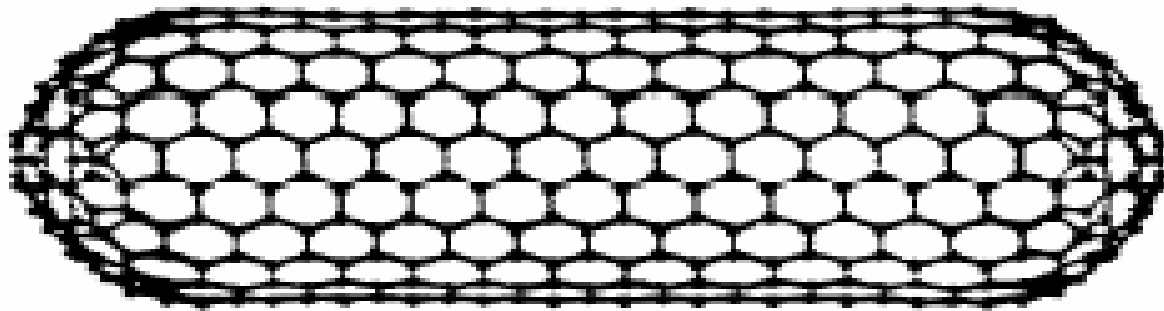


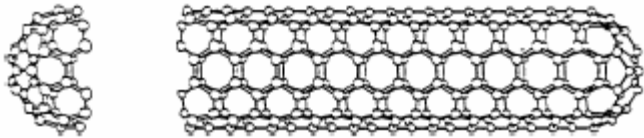
Nanotube Processing and Bioapplications



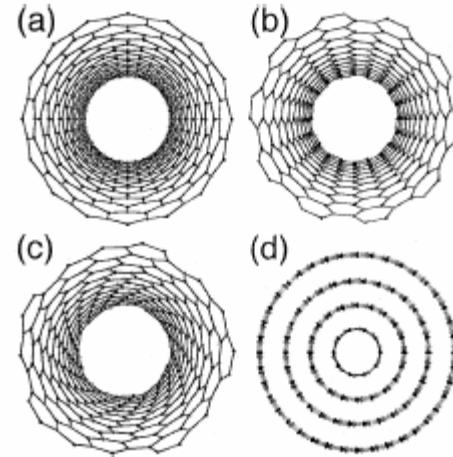
Maxine McClain

Nanotube Structure

- Electronic properties related to diameter and chirality (from semiconducting to metallic)



Above: Tubes may be open ended or capped.



- Nanotubes may be single (a-c) and multi-walled (d)
- Nanotube vs. nanofiber

Applications

- Flat-panel displays
- Nanostructured field effect transistors
- AFM tips
- Composite reinforcement/ mechanical applications
- Hydrogen storage for energy supply

Electron Field Emitter

Vertically aligned carbon nanofibers
(ACNF) cathodes

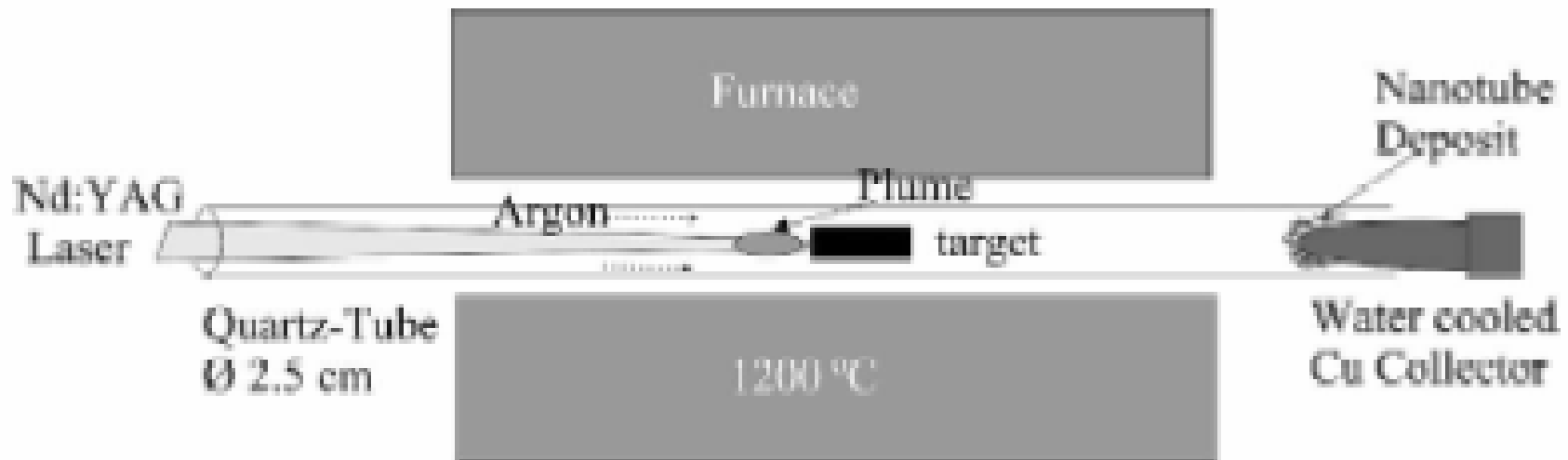
- Stable, resilient
- Low threshold voltage for initiation of FE
- High current densities
- Inexpensive mass fabrication
- High aspect ratio

Fabrication Methods

- Principle:
 - bulk carbon material brought to gas phase for self-assembly into tubular structures
 - Requires high temperatures
 - Growth variables: tube diameter, height, orientation, density, single/multi-walled tubes, tube capping, uniformity, by-products (amorphous carbon, catalytic nanoparticles)
- Arc discharge
 - High voltage arc between two graphite electrodes in a gas (He, H₂, or Ar)
 - Primarily multi-walled carbon nanotube bundles
 - Metal catalysts (cobalt, iron or nickel) may be used for single-walled nanotubes

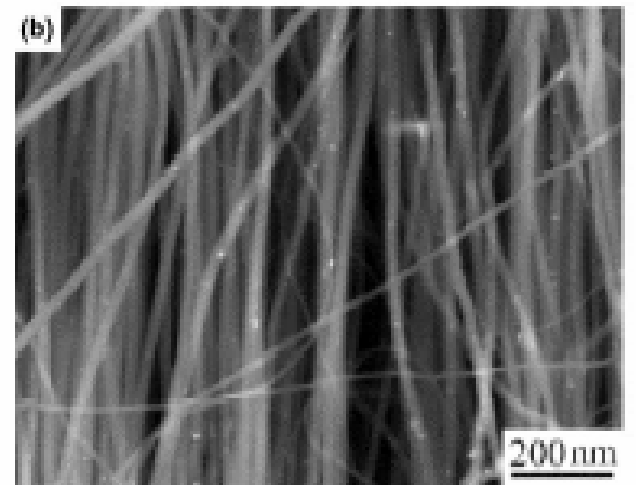
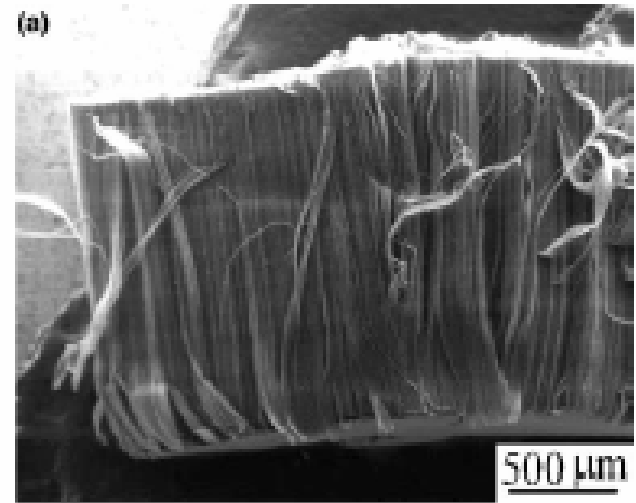
Laser Irradiation

- Properties and uniformity highly dependent on laser and temperature



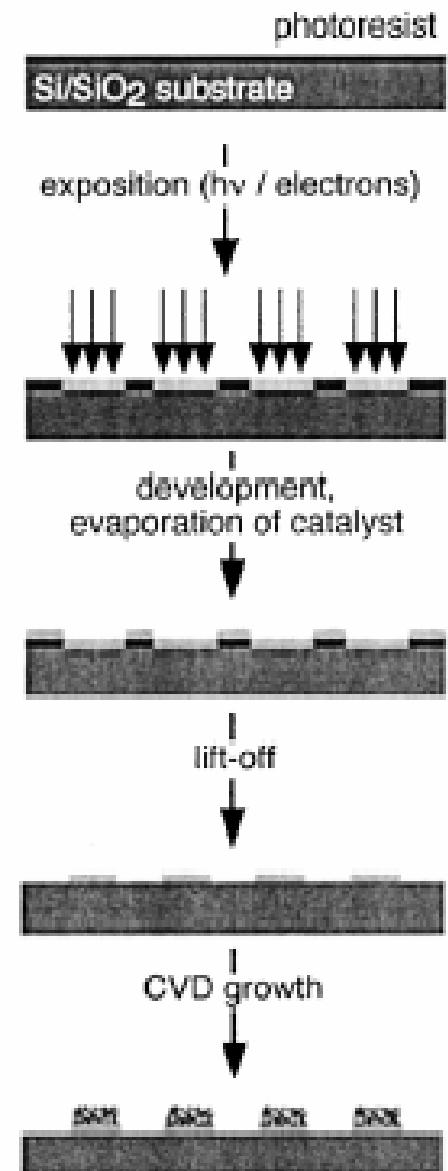
Chemical Vapor Deposition

- Catalytic
 - Organized monolayer structure
 - Catalytically controlled- presence of fiber determined by deposition of catalyst
 - High purity, high yield, vertical alignment
 - Growth rates of 50 $\mu\text{m}/\text{min}$



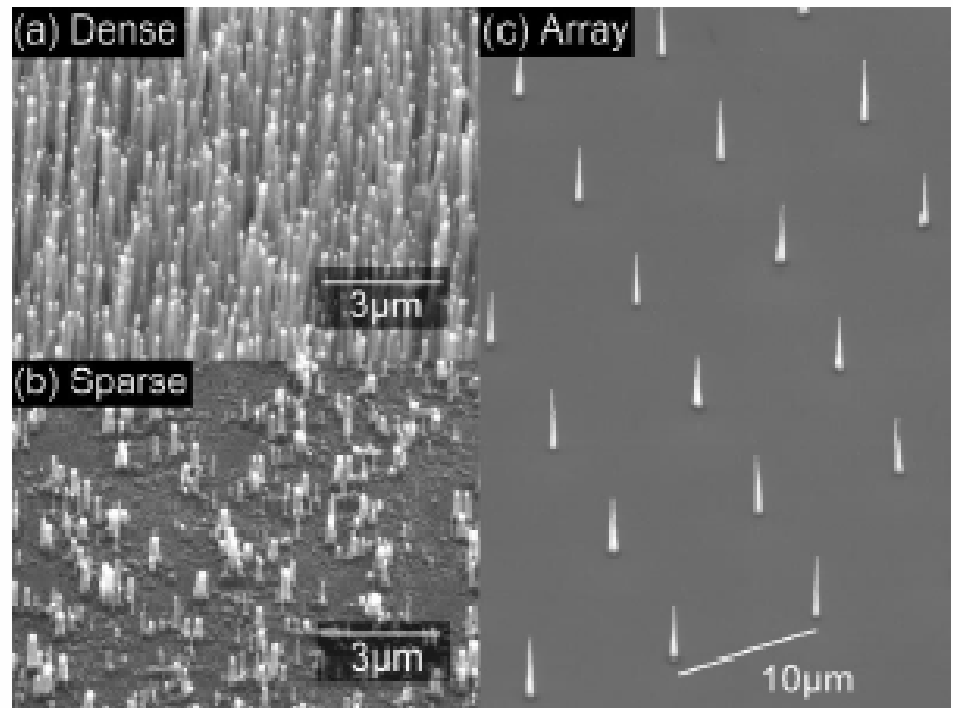
CVD

- Pattern exposure
- Material deposition (PECVD/PVD)
- Pattern transfer (lift off metallization/RIE)
- Nanotube growth (CVD)



Nanotube Density

- Closely packed arrays generate electric field shielding effects which compromise field emission characteristics
- Implement barrier layer to increase spacing
- Place catalyst so that growth is isolated

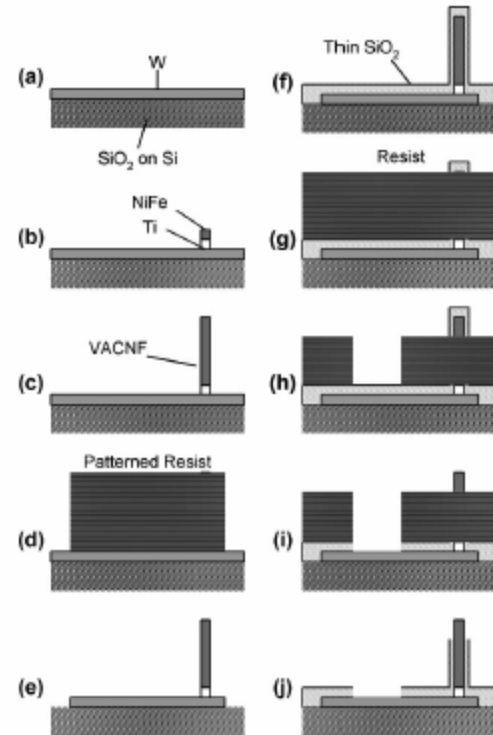


Bioapplications of Nanotubes

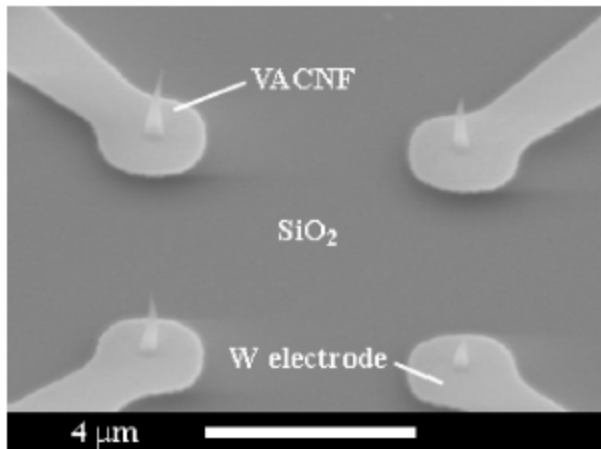
- Separations
 - Thin film membranes
- Ion-channel mimetic sensors
- Sensors of cellular activity
 - Single cell interrogation
- Microinjection of bioactive compounds
 - Useful for non-cell permeable compounds compared to other technologies.

VACNF Probes

- VACNF- vertically aligned carbon fiber
- At size scale to detect cellular level electrochemical activity
- System tested with oxidation/reduction. Current range was $\cong 100$ pA

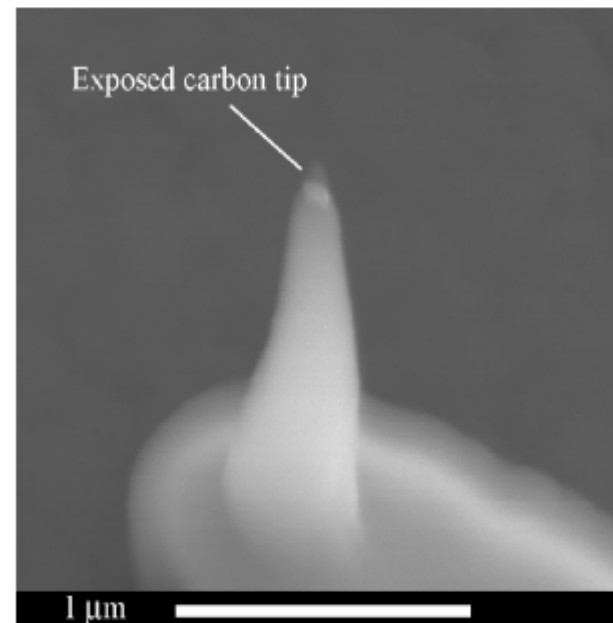


VACNF Probes



SEM micrograph of four VACNF probes on individual W pads.

Probe tip: shows contrast between probe tip and passivated body.



Summary

- CNTs can be grown using a variety of methods.
- Nanotube density in a monolayer may be finely tuned to maximize properties.
- CNTs have multiple applications, including single cell interrogation.