Flame Synthesis of Single-walled Carbon Nanotubes

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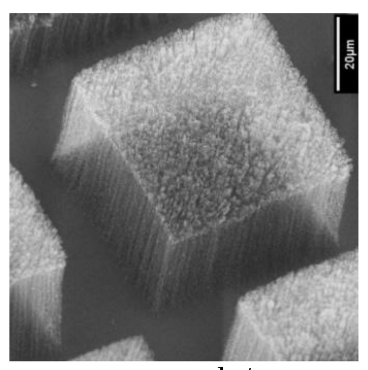
1. Synthesis Approaches and Applications

Supported Catalyst Approach

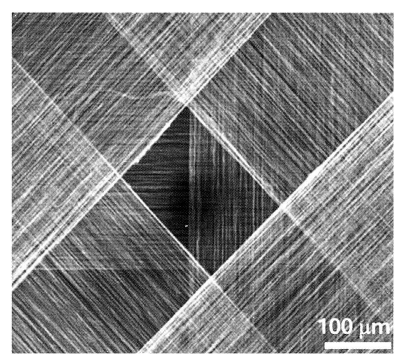


*http://www.nano.mtu.edu/nanocontact.htm

Techniques
- Chemical vapor deposition (CVD)

Applications
- Nano-electronic devices
- Field-emission displays
- AFM tips

Floating Catalyst Approach



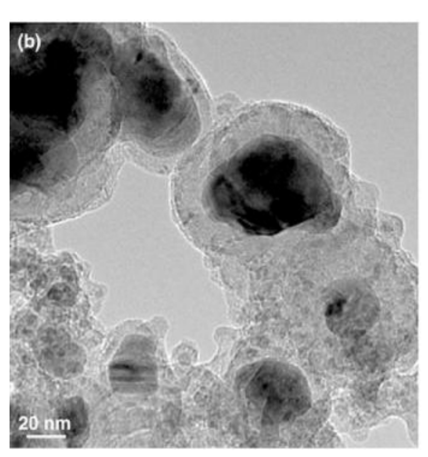
*Baughman et al. (2005) *Science*. 309, 1215-1219

Techniques
- Arc Discharge
- Laser Ablation
- HiPCO
- Spray Pyrolysis
- **Flame Synthesis**

Applications
- Composite materials
- Hydrogen storage
- Catalyst support media

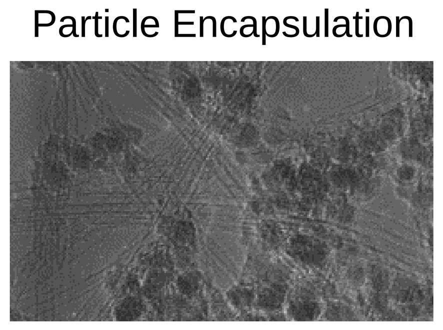
2. Challenges of CNT Flame Synthesis

PAH 'poisoning' of catalyst particles



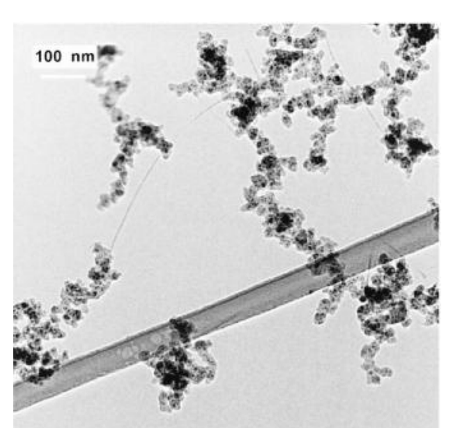
*Vander Wal, R. (2002) *Combust Flame* 130, 37-47

Particle Encapsulation



*Ci et al. (2001) *Chem Phys Lett* 323, 217-223

Soot and Catalyst Particle Contamination



*Vander Wal et al. (2000) *Chem Phys Lett* 323, 217-223

3. Nanotube Characterization

- Current off-line diagnostic tools include TEM, SEM, and Raman Spectroscopy
  - Detailed information about a small number of particles
  - Off-line
  - Long turn around time
- On-line diagnostics are needed for rapid optimization
  - Number concentration
  - Purity
  - Length

4. Objectives

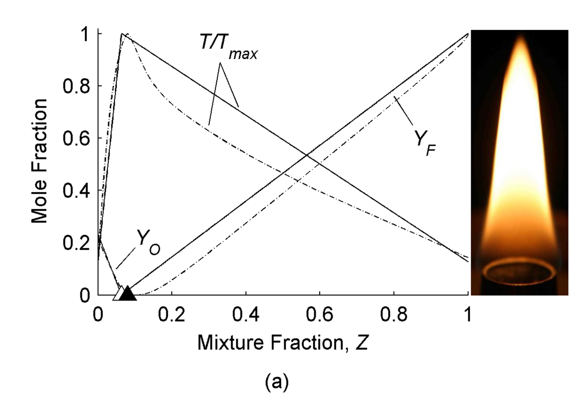
1. Develop a diffusion flame process for synthesizing single-walled carbon nanotubes (SWNTs) that minimizes carbonaceous contaminates.
2. Develop a method to obtain on-line information using a Scanning Mobility Particle Sizer (SMPS).
3. Employ the SMPS system to characterize the flame process
4. Improve catalyst yield using composite catalyst particles

5. Soot-Free Flames by Fuel Dilution and Oxygen-Enrichment

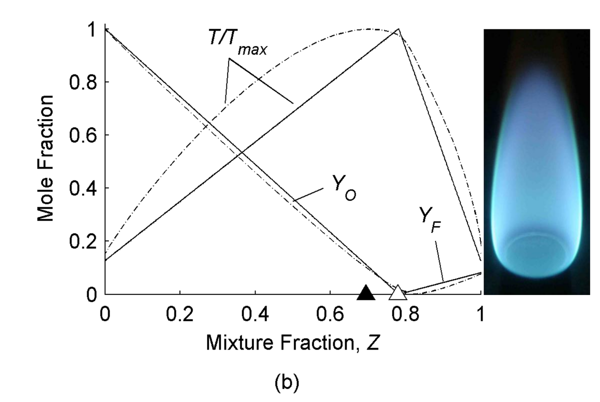
- Flame structure is characterized by the stoichiometric mixture fraction

$$Z_{st} = \left(1+\frac{Y_{F,0}W_O\nu_O}{Y_{O,0}W_F\nu_F}\right)^{-1}$$

Fuel/Air, $Z_{st} = 0.064$



Diluted fuel/O_2, $Z_{st} = 0.78$

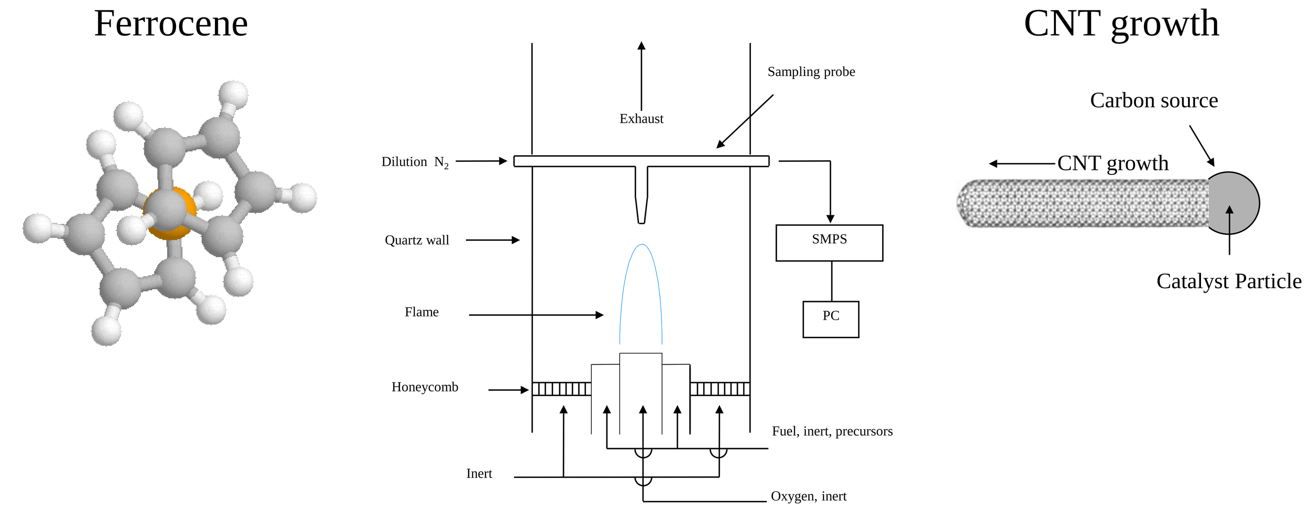


6. Experimental Approach with Online Diagnostics

Ferrocene

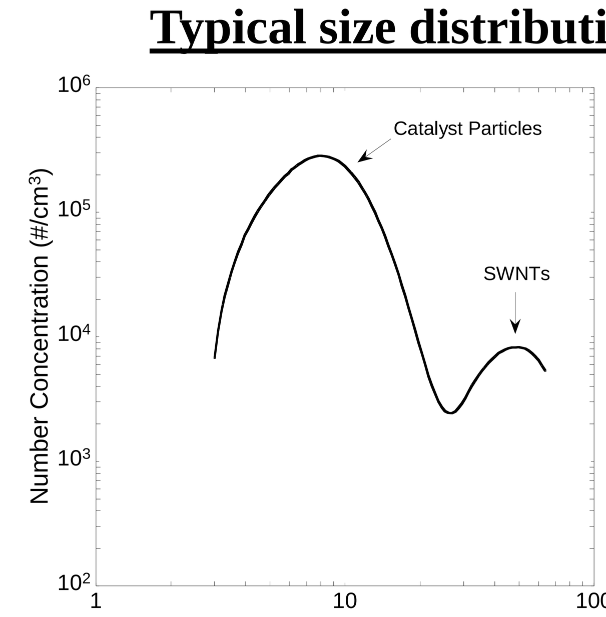
High Z_{st} inverse diffusion flame

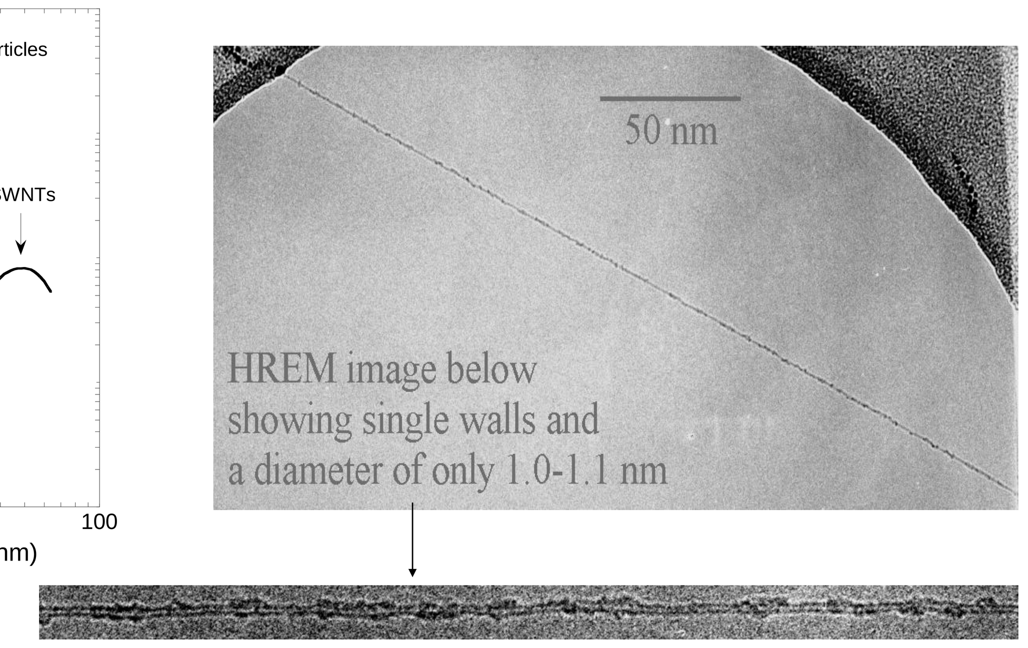
CNT growth



- A Scanning Mobility Particle Sizer is employed as an online diagnostic tool
- Due to the difference in drag force, catalyst particles and carbon nanotubes will be classified separately by their electrical mobility
- Thus, flame conditions were adjusted until a bimodal distribution appeared, indicating nanotube formation

Typical size distribution and single-walled carbon nanotube





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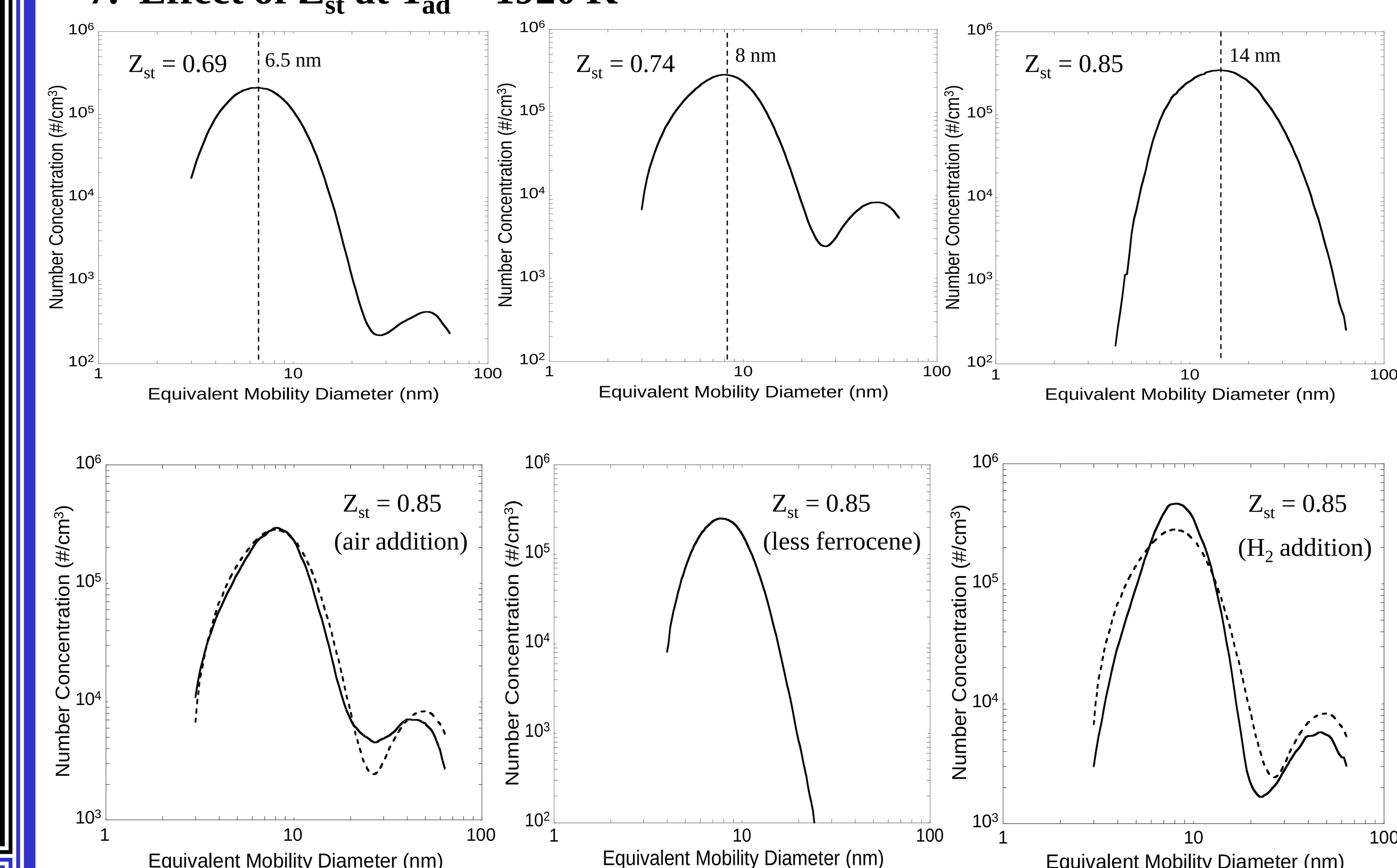
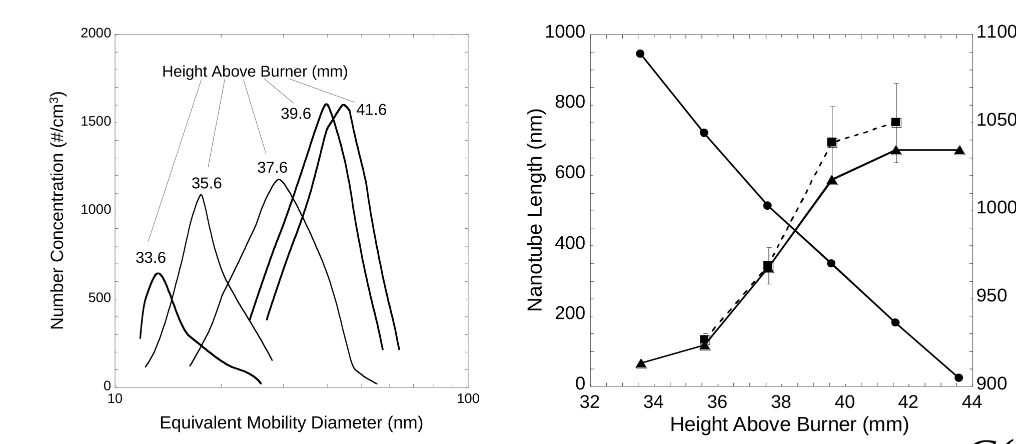
7. Effect of Z_{st} at T_{ad} = 1920 K



8. SWNT Growth Rate

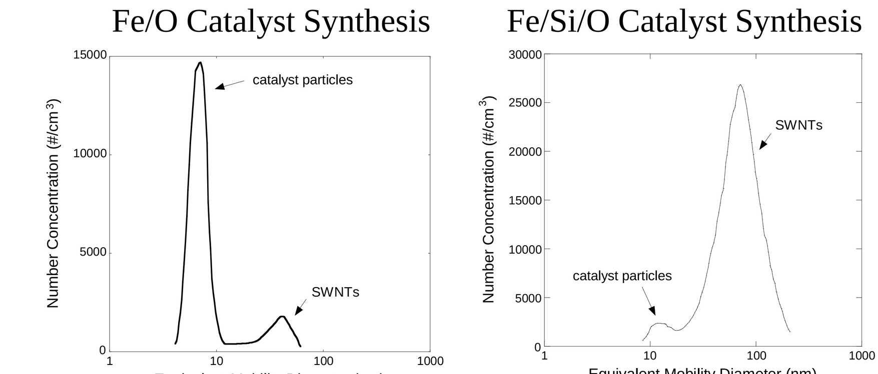


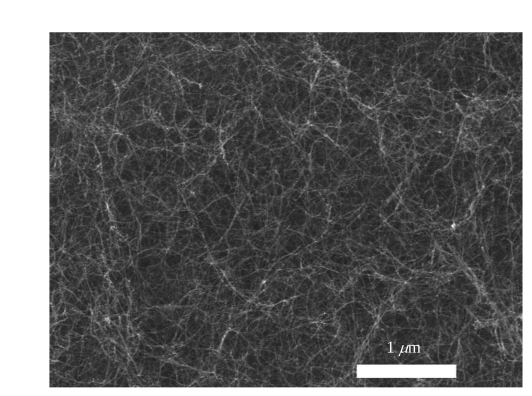
- The electrical mobility of a carbon nanotube is given by: $Z = \frac{neC(d_a)}{3\pi\mu k_0(L,D)d_v}$
- To obtain a length measurement, we assume a charge of unity, an average diameter of 2 nm, a cylindrical shape, and an orientation parallel to the electric field in the DMA
- Average growth rate of 125 μm/s

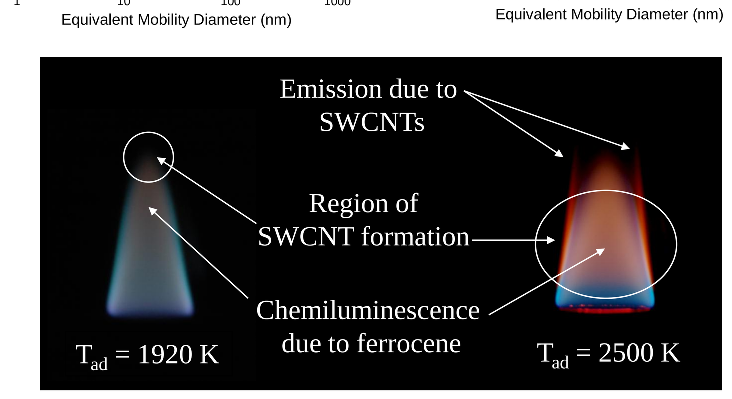
9. Composite Catalysts: Addition of Si

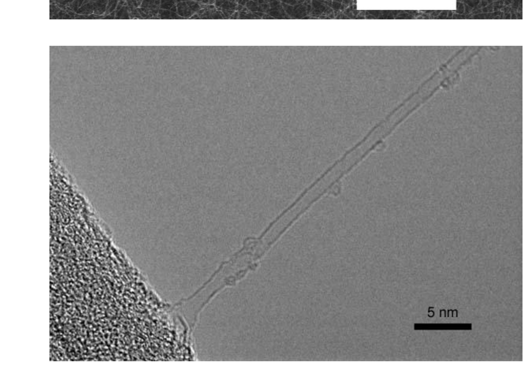
Fe/O Catalyst Synthesis

Fe/Si/O Catalyst Synthesis









Acknowledgements

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