Flame Synthesis of Single-walled Carbon Nanotubes

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1. Synthesis Approaches and Applications

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<th>Supported Catalyst Approach</th>
<th>Floating Catalyst Approach</th>
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<tr>
<td><img src="image1.png" alt="Supported Catalyst Approach Image" /></td>
<td><img src="image2.png" alt="Floating Catalyst Approach Image" /></td>
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Techniques: Applications
- Chemical vapor deposition (CVD)
- Nano-electronic devices
- Field-emission displays
- AFM tips

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

2. Challenges of CNT Flame Synthesis

PAH ‘poisoning’ of catalyst particles

![Particle Encapsulation Image](image3.png)


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

\[ Z_\text{a} = \left( 1 + \frac{Y_F W_F}{Y_O W_O} \right)^{-1} \]

- Fuel/Air, \( Z_\text{a} = 0.064 \)
- Diluted fuel/O₂, \( Z_\text{a} = 0.78 \)

6. Experimental Approach with Online Diagnostics

- 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**

![Typical Size Distribution Image](image4.png)

7. Effect of \( Z_\text{a} \) at \( T = 1920 \text{ K} \)

- Equivalent Mobility Diameter (nm)
- Number Concentration (#/cm³)

8. SWNT Growth Rate

- The electrical mobility of a carbon nanotube is given by:

\[ Z = \frac{nc(d)}{3\pi\eta L(D_d)} \]

- 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 \( \mu \text{m/s} \)

9. Composite Catalysts: Addition of Si

- FeO Catalyst Synthesis
- FeSiO Catalyst Synthesis

- HREM image below showing single walls and a diameter of only 1.0-1.1 nm

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