Synthesis, Length Classification, and Growth Kinetics of Aerosol Carbon Nanotubes

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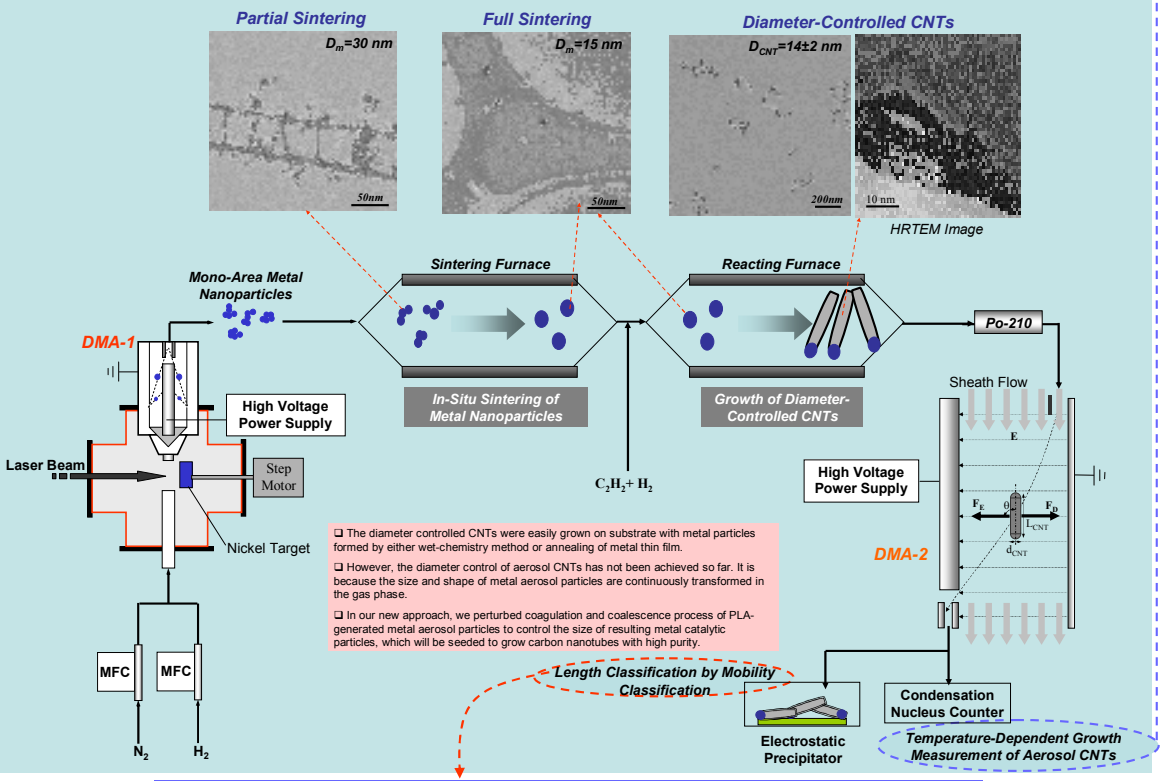
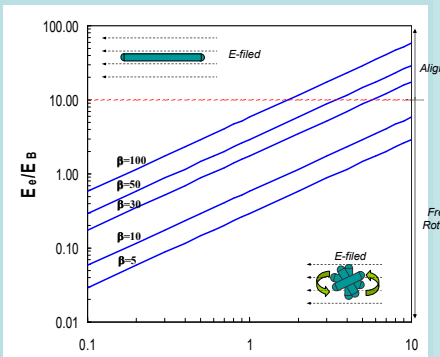
[1] Synthesis of Diameter-Controlled CNTs in the Gas Phase



- The diameter controlled CNTs were easily grown on substrate with metal particles formed by either wet-chemistry method or annealing of metal thin film.
- However, the diameter control of aerosol CNTs has not been achieved so far. It is because the size and shape of metal aerosol particles are continuously transformed in the gas phase.
- In our new approach, we perturbed coagulation and coalescence process of PLA-generated metal aerosol particles to control the size of resulting metal catalytic particles, which will be seeded to grow carbon nanotubes with high purity.

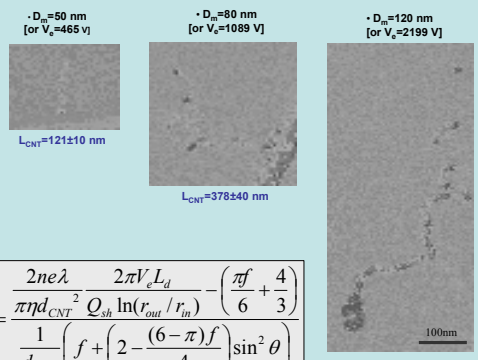
[2] In-Flight Length Classification of Diameter-Controlled Aerosol CNTs



• Relative electrical energy (E_e) to Brownian rotation energy (E_B) as a function of applied electric filed and aspect ratio (β) of carbon nanotubes

where,

$$E = \int_0^{\pi/2} \frac{1}{2} L_f F_E \sin\theta d\theta = \frac{1}{2} L_f neE \quad \text{and} \quad E_B = \frac{1}{2} k_B T$$

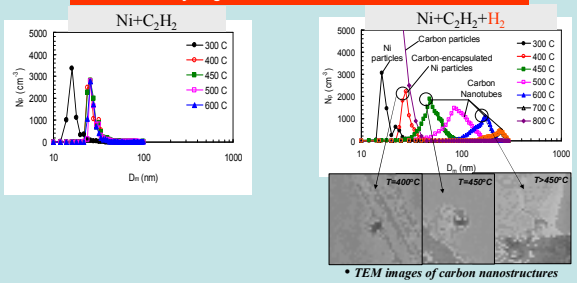


$$L_{CNT} = \frac{2ne\lambda}{\pi\eta d_{CNT}^2} \frac{2\pi V_e L_d}{Q_{sh} \ln(r_{out}/r_{in})} - \left(\frac{\pi f}{6} + \frac{4}{3}\right) \Big/ \frac{1}{d_{CNT}} \left(f + \left(2 - \frac{(6-\pi)f}{4}\right)\sin^2\theta\right)$$

where, L_{CNT}=Nanotube length, d_{CNT}=Nanotube diameter, f=accommodation coefficient, θ=angle between moving direction and asymmetric axis, V_e=applied voltage, L_d=DMA electrode length, r_{in} and r_{out}=radius of inner and outer electrode, Q_{sh}=sheath flow rate

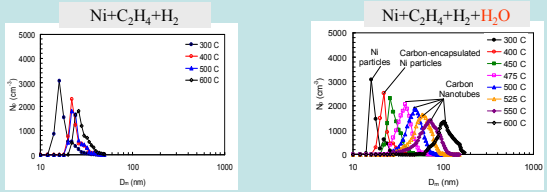
[3] Growth Kinetics of Aerosol CNTs

The Role of Hydrogen in the Growth of Carbon Nanostrucutres

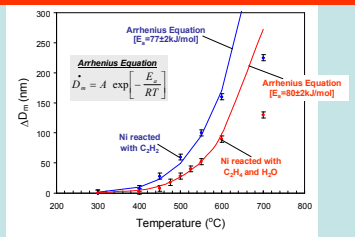


• TEM images of carbon nanostructures

The Role of Oxidizer in the Growth of Carbon Nanostrucutres

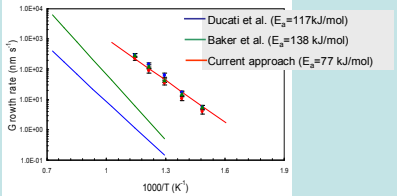


Kinetic Parameters of Aerosol CNTs Based on TDMA Measurement



- TDMA measurement was non-linear least-square fitted to Arrhenius equation to find kinetic parameters for the growth of carbon nanostructures.
- The measured activation energy (E_a=~77kJ/mol for C_2H_2 and E_a=~80kJ/mol for C_4H_4. A=~1.4x10^6 nm/s) fall between the reported activation energy of surface (29 kJ/mol) and bulk (145 kJ/mol) diffusion of carbon in nickel.

Comparison of Growth Rate of Aerosol CNTs with Selected Substrate-Grown CNTs



- Growth rate of aerosol grown CNTs is ~100 times higher than substrate grown CNTs. It is presumably because (1) the mass transfer rate of substrate-growth material is slower, and (2) reduced solubility of carbon on possible poisoning of catalysts from the substrate.
- No significant catalysts size-dependent growth was observed. This suggests the dominant factor for determining growth rate of CNTs are growth temperature, presence of hydrogen and weak oxidizer, and diffusion and solubility of carbon on catalysts.