331e Single-Walled Carbon Nanotubes from a Premixed Flame

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Flames offer potential as a means of producing bulk quantities of carbon nanotubes in a continuous, economically favorable process. Single-walled nanotubes have been observed in a premixed acetylene/oxygen/argon flame operated at 50 torr with iron pentacarbonyl vapor used as a source of metallic catalyst necessary for nanotube growth. Samples taken from the flame using a thermophoretic sampling method were analyzed via transmission electron microscopy in order to characterize the solid material present at various heights above burner (HAB), giving resolution of formation dynamics within the flame system. Catalyst particle formation and growth is observed in the immediate post-flame region, 10 to 40 mm HAB, with coagulation leading to typical particle sizes on the order of 5 to 10 nm. Nanotubes were observed to be present after 40 mm (34 ms) with nanotube inception occurring as early as 30mm HAB (~25 ms). Between 40 and 70 mm HAB (period of approx. 30 ms), nanotubes are observed to form and coalesce into clusters. Based on the rapid appearance of nanotubes in this region, it appears that once initiated, nanotube growth is quite rapid, on the order of 10 μm per second. A nanotube formation ‘window' is evident with formation limited to fuel equivalence ratios between a lower limit of 1.5 and an upper limit of 1.9. A continuum of morphologies ranging from relatively clean clusters of nanotubes to disordered material is observed between the lower and upper limits.