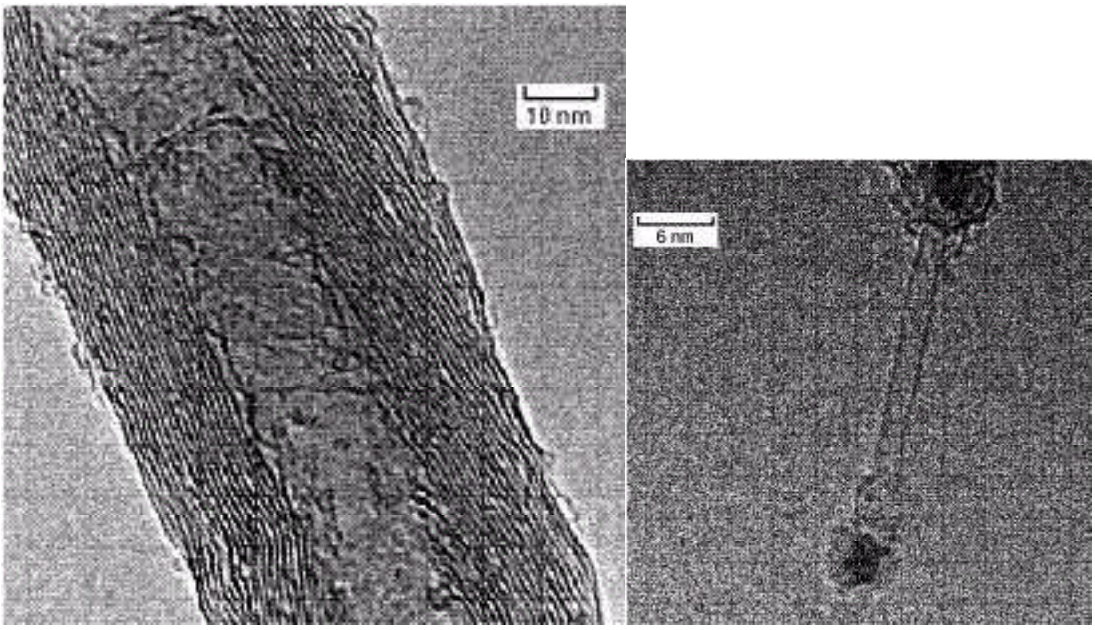
Flame Synthesis Used to Create Metal-Catalyzed Carbon Nanotubes

Metal-catalyzed carbon nanotubes are highly ordered carbon structures of nanoscale dimensions. They may be thought of as hollow cylinders whose walls are formed by single atomic layers of graphite. Such cylinders may be composed of many nested, concentric atomic layers of carbon or only a single layer, the latter forming a single-walled carbon nanotube. This article reports unique results using a flame for their synthesis.

Only recently were carbon nanotubes discovered within an arc discharge and recognized as fullerene derivatives. Today metal-catalyzed carbon nanotubes are of great interest for many reasons. They can be used as supports for the metal catalysts like those found in catalytic converters. Open-ended nanotubes are highly desirable because they can be filled by other elements, metals or gases, for battery and fuel cell applications. Because of their highly crystalline structure, they are significantly stronger than the commercial carbon fibers that are currently available (10 times as strong as steel but possessing one-sixth of the weight). This property makes them highly desirable for strengthening polymer and ceramic composite materials.

Current methods of synthesizing carbon nanotubes include thermal pyrolysis of organometallics, laser ablation of metal targets within hydrocarbon atmospheres at high temperatures, and arc discharges. Each of these methods is costly, and it is unclear if they can be scaled for the commercial synthesis of carbon nanotubes. In contrast, flame synthesis is an economical means of bulk synthesis of a variety of aerosol materials such as carbon black. Flame synthesis of carbon nanotubes could potentially realize an economy of scale that would enable their use in common structural materials such as car-body panels.

The top figure is a transmission electron micrograph of a multiwalled carbon nanotube. The image shows a cross section of the atomic structure of the nanotube. The dark lines are individual atomic layer planes of carbon, seen here in cross section. They form a nested series of concentric cylinders, much like the growth rings on a tree. This sample was obtained by the supported catalyst method, whereby the nanoscale catalysts are dispersed on a substrate providing their support. The substrate with catalyst particles was immersed within an acetylene diffusion flame to which nitrogen had been added to eliminate soot formation. Upon removal from the flame, the nanotubes were dispersed on a holder suitable for electron microscopy. Although not seen in the figure, the tube diameter reflects that of the catalyst particle.



Left: Cross section of a multiwalled carbon nanotube. Right: Single-walled carbon nanotube showing that a single atomic layer of graphite forms the hollow cylinder.

The bottom figure is a transmission electron micrograph of a single-walled carbon nanotube. Only a single graphite layer of carbon (one layer plane of graphite) is rolled upon itself so as to form a seamless cylinder. The nanotube was obtained by sampling material from a flame using a probe that was rapidly inserted and retracted from the flame to minimize flame perturbations. In these experiments, catalyst particles were seeded into the flame by thermal decomposition of a suitable precursor compound. Upon reaching a suitable temperature within the flame, the catalyst particle initiated nanotube formation. Given buoyancy-induced convection, the total residence time for the catalyst particle within the flame environment is less than 1/10 of a second, limited by buoyancy-induced convection. Experiments conducted in a low-gravity environment will help us understand the limitations imposed by such short residence times upon nanotube growth and structure.

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