Dr. Rajen B. Patel
Energetics Research Branch – US Army
B3028, Picatinny Arsenal
New Jersey 07806, USA

Boron-filled Hybrid Carbon Nanotubes

A new type of nanostructure synthesized using a one-step chemical vapor deposition process will be discussed, a boron-filled hybrid carbon nanotube (BHCN). The method of synthesis of these structures is a modification of a method successfully used to grow pure boron nanowires. The process was originally a thermal vapor deposition reaction, performed in an inert gas atmosphere, which was altered by the addition of methane gas. The following analytical techniques have been used to characterize BHCNs: electron microscopy, Raman spectroscopy, 2 point electrical probe measurement, and compressive stress strain mechanical property tests (performed in the radial direction). The product of this reaction, when imaged by electron microscopy, was found to be a core-shell hybrid nanotube, where the interior of the structure consists of a boron nanowire and the exterior is essentially a distorted multiwalled carbon nanotube (CNT). The interior boron nanowire has lattice spacings of 0.38, 0.48, and 0.44-0.45 nm, indicating it is similar to the product obtained without the addition of methane. The layers of the carbon nanotube which formed on the outside of the BHCN are distorted and corrugated, most likely because of a lattice mismatch and the presence of excessive missing carbon atoms. This distortion is further manifested in the spacing between the layers of carbon, which range from 0.36 to 0.39 nm, as opposed to regular, straight carbon nanotubes which have a spacing of 0.34 nm. The boron nanowire interiors have a thickness of 20-30 nm, and are each surrounded by a 10-20 nm layer thick coating of carbon. The length of the entire hybrid-nanotube is a few microns. Each hybrid-nanotube has a bulbous tip filled with catalyst, indicating a vapor-liquid-solid growth. The carbon layer on the outside of the hybrid structure was found to be insulating, which is unusual for a layered carbon. Modeling was used to confirm a connection among defects and the waved structure of the BHCN. From a scientific standpoint, BHCNs are exciting because they could be considered to be a novel form of boron carbide and carbon. Furthermore, they may portend the discovery of other hybrid-nanotube structures.

Practically, BHCNs have some important differences from CNTs. They are highly insulating, making them suitable for applications where that is a requirement. More impressively, BHCNs are expected to have a number of uses exploiting their mechanical properties, as they address several problems with CNTs. CNTs are weak in compression and in the radial direction, and do not bond easily to each other or to matrices. BHCNs are shown to be up to 31% stiffer and 233% stronger than CNTs and maintain superior mechanical properties at elevated temperatures. BHCNs are corrugated, which may help with bonding in composites and bundling. Due to their unique properties and structure, BHCNs are a significant advance in the field of nanocarbon science and engineering.

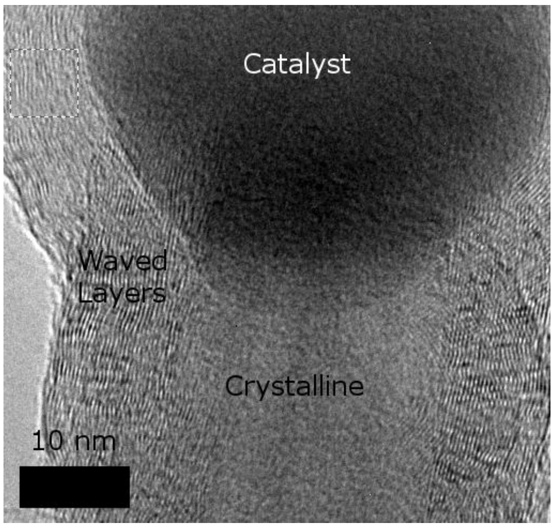

Figure 1. TEM image of BHCN