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Cryogenic Transmission Electron Microscopy Investigation of Carbon Nanothreads

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The ability of the element carbon to form many types of chemical bonds enables it to exist as a variety of allotropes, including diamond, graphite/graphene, and fullerenes [1]. Recently, a new class of hydrocarbon materials has been discovered, called carbon nanothreads [2]. Nanothreads have been created by the controlled compression of aromatic molecules, such as benzene and its derivatives, and the resulting structure consists largely of one-dimensional sp3-bonded carbon networks saturated with hydrogen.

X-ray diffraction (XRD) and a variety of chemical characterization techniques have helped to establish the structure and bonding in nanothreads [2], but transmission electron microscopy (TEM) is uniquely able to determine the local, real-space structure [3]. XRD measurements show that benzene-derived nanothreads pack into a pseudohexagonal lattice, with a [10-10] spacing equal to 5.6 Å [2]. However, under the electron beam, damage occurs so quickly that even low-dose TEM conditions (5 e/Å2s) at room-temperature only capture images of an expanded lattice spacing of 5.9 Å after the initiation of beam damage in the lattice [4].

For this reason, analysis at cryogenic temperatures (cryo-TEM) is an attractive avenue to pursue. Here, we show that cryo-TEM has enabled the significant reduction of beam damage in carbon nanothreads. This allows the native structure of benzene-derived carbon nanothreads to be imaged successfully, both in real space and in diffraction mode. This presentation will show successes from using cryo-TEM and a comparison with high-resolution nanothread imaging at room temperature.

Nanothreads can also be synthesized with a variety of compositions, using benzene derivatives as precursors [5-8]. Recently reported precursors have included pyridine [5], thiophene [6], furan [7], and cocrystals [8,9]. Beyond what has been achieved for benzene-derived nanothreads, this presentation will further highlight recent results on the structural analysis via TEM of other nanothread chemistries.

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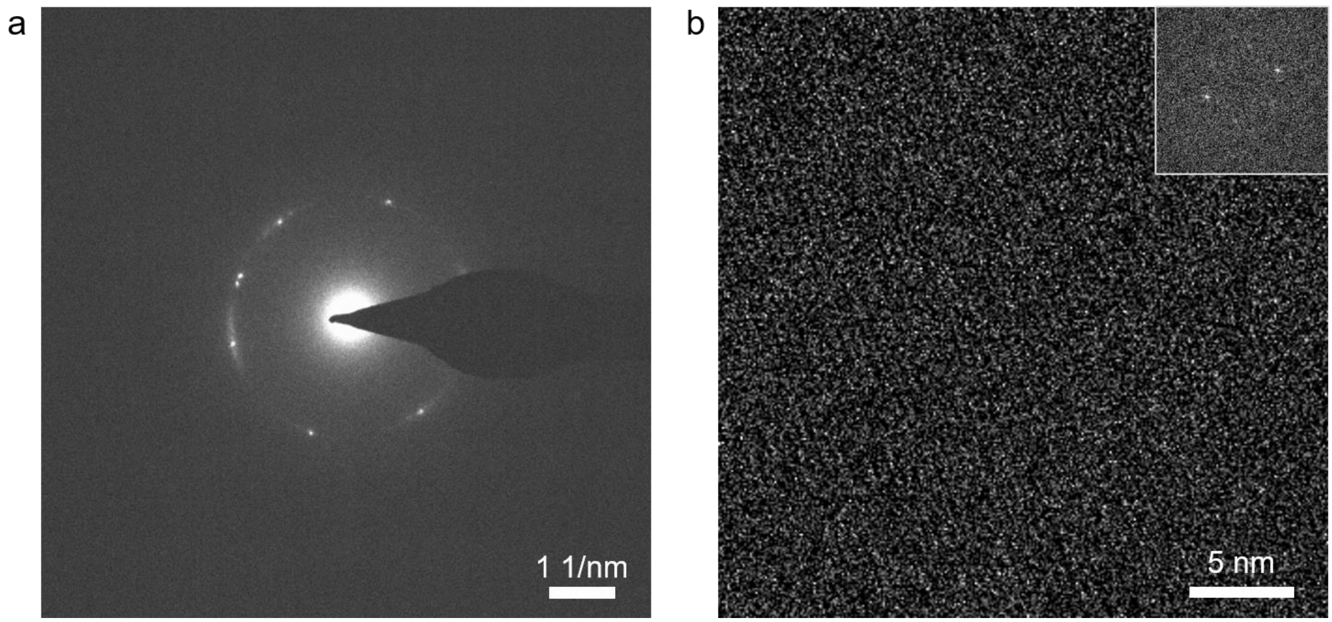

Figure 1. Cryo-TEM characterization of benzene-derived carbon nanothreads. (a) A representative cryo-electron diffraction pattern. (b) Low-dose cryo-high-resolution imaging (inset: FFT).

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