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Monochromated Low-Dose Aberration-Corrected Transmission Electron Microscopy of Diamondoid Carbon Nanothreads

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Carbon nanothreads are the first in a new class of one-dimensional sp^3 carbon nanomaterials that was recently discovered through compression-induced polymerization of benzene in a Paris-Edinburgh cell [1]. Their diamond-like structure is predicted to have interesting mechanical properties that are on par with or greater than carbon nanotubes [2]. In addition, the solid-state synthesis is entirely driven by kinetic control and devoid of waste, which may open up new routes to fabricate efficient carbon nanomaterials [3,4]. Therefore, it is important to probe the atomic and chemical structure of nanothreads to elucidate the reaction mechanisms that result in their synthesis and determine their macroscale physical and chemical properties.

X-ray diffraction (XRD) studies and density functional theory (DFT) calculations strongly suggest that carbon nanothreads form a well-aligned, hexagonally-packed structure with an inter-thread spacing of ~6.5 angstroms [1]. Likewise, electron diffraction patterns reveal higher order reflections that agree with these experimentally and theoretically-derived models. Direct observation of the atomic structure of nanothreads is complicated by the low threshold of carbon nanomaterials for beam damage in the electron microscope [5]. Similarly, carbon nanothreads' one-dimensional tetrahedral structure is akin to polymers, which makes them susceptible to electron beam damage. In this study, the structural degradation of carbon nanothreads is examined through selected-area electron diffraction, and the critical dose is determined. An electron gun monochromator is then employed to reduce the electron dose and minimize beam irradiation and damage [6] while imaging the nanothreads on a high-resolution aberration-corrected transmission electron microscope. High-resolution images and their Fourier transforms in Figure 1 demonstrate the effect of electron dose on the sample. Figure 1a shows the structural degradation of the nanothreads when exposed to a high electron dose, which is indicated by the amorphous morphology. Figure 1b presents a low-dose image of the highly-oriented nanothread structure, which displays 6.4-angstrom inter-thread spacing and large-scale crystallinity in the sample. These direct observations agree with the predicted 6.5-angstrom hexagonally-packed lattice shown in Figure 1c. This study further employs low-dose imaging techniques to explore a variety of sample preparation techniques, which are intended to separate individual nanothreads in order to determine their atomic and chemical structure.

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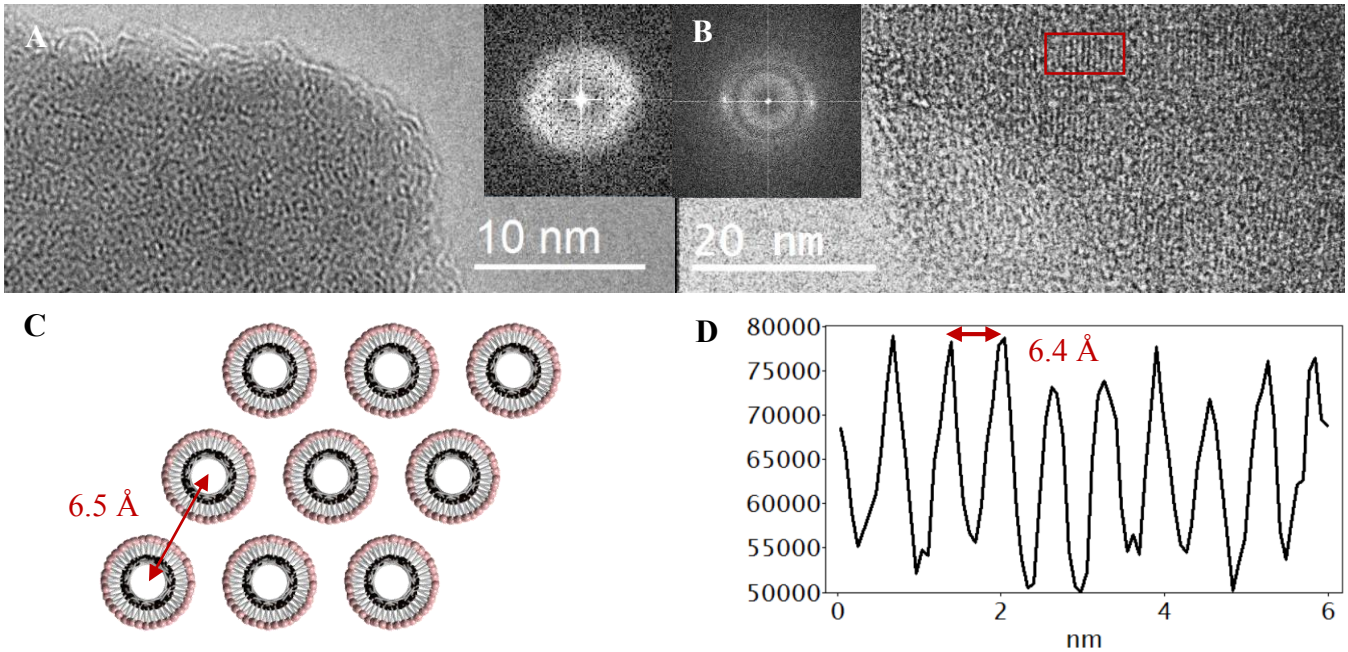

Figure 1. (A) High-dose TEM image of nanothreads taken at 2000 electrons/Å^{2}s with inset Fourier transform shows amorphous morphology, even though (B) a nanothread model predicted from x-ray diffraction data suggests highly-oriented hexagonal packing. (C) A low-dose TEM image taken at 50 electrons/Å^{2}s and (D) a line profile show thread-like features with 6.4 Å spacing, which correlates to the anticipated 6.5 Å interthread spacing.

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