Novel Forms of Graphene: Doped Graphenes, Doped Nanoribbons with Atomically Smooth Edges and Graphene-Nanotube Hybrid Structures

Mauricio Terrones

Department of Physics, Department of Materials Science and Engineering and Materials Research Institute. The Pennsylvania State University, University Park, Pennsylvania 16802, USA & Research Center for Exotic Nanocarbons (JST), Shinshu University, Wakasato 4-17-1, Nagano 380-8553, Japan
mut11@psu.edu; mtterrones@shinshu-u.ac.jp

We will describe the synthesis of graphene and graphitic nanoribbons [1-2] via different routes: a) chemical vapor deposition (CVD), and b) by unzipping multi-walled carbon nanotubes using different routes. We have recently developed an innovative route which is able to create graphene and graphitic nanoribbons (Fig. 1) with atomically smooth edges (Fig. 2). These edges exhibited armchair and zigzag edge terminations. The route is environmentally green and involves a mild acid treatment in H_2SO_4 and HNO_3, followed by an abrupt thermal shock using liquid nitrogen and boiling water [3]. We were able to successfully unzip multi-walled carbon nanotubes (MWNTs) and nitrogen-doped multi-walled carbon nanotubes (CNx-MWNTs). More recently, we have been able to synthesize N-doped graphitic nanoribbons via a CVD approach [4]. In particular, the N-doped nanoribbons exhibit semiconducting-like behavior.

Large-area, high-quality monolayer nitrogen-doped graphene sheets were synthesized on copper foils using ambient-pressure CVD [5]. When compared to pristine graphene, nitrogen-doped graphene shows a strong D-band caused by the doping effects or structural defects formed within the lattice. Scanning tunneling microscopy (STM) and spectroscopy (STS) reveal that the defects in the doped graphene samples arrange in different geometrical configurations exhibiting different electronic properties. These experimental results are in agreement with first principles calculations of LDOS of doped graphene. These materials have also been characterized by aberration corrected high-resolution transmission electron microscopy (AC-HRTEM) and X-ray photoelectron spectroscopy (XPS). These doped layers could be used as efficient molecular sensors.

Finally, the synthesis of hybrid carbon materials consisting of sandwich layers of graphene layers and carbon nanotubes have been synthesized by an ionic self assembly route [6]. These films are novel, energetically stable and could well find important applications as catalytic supports, gas adsorption materials [7] and super capacitors.

References

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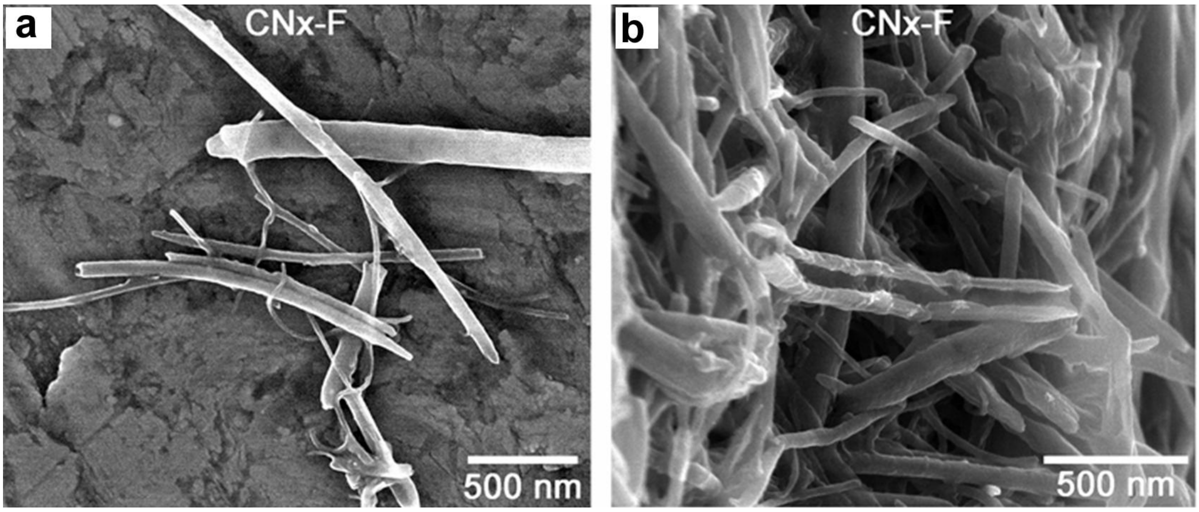

Figure 1. *SEM images of* ***(a-b)*** *unzipped CNx-MWNTs using the technique involving a mild acid treatment followed by an abrupt thermal shock involving liquid nitrogen and boiling water.*

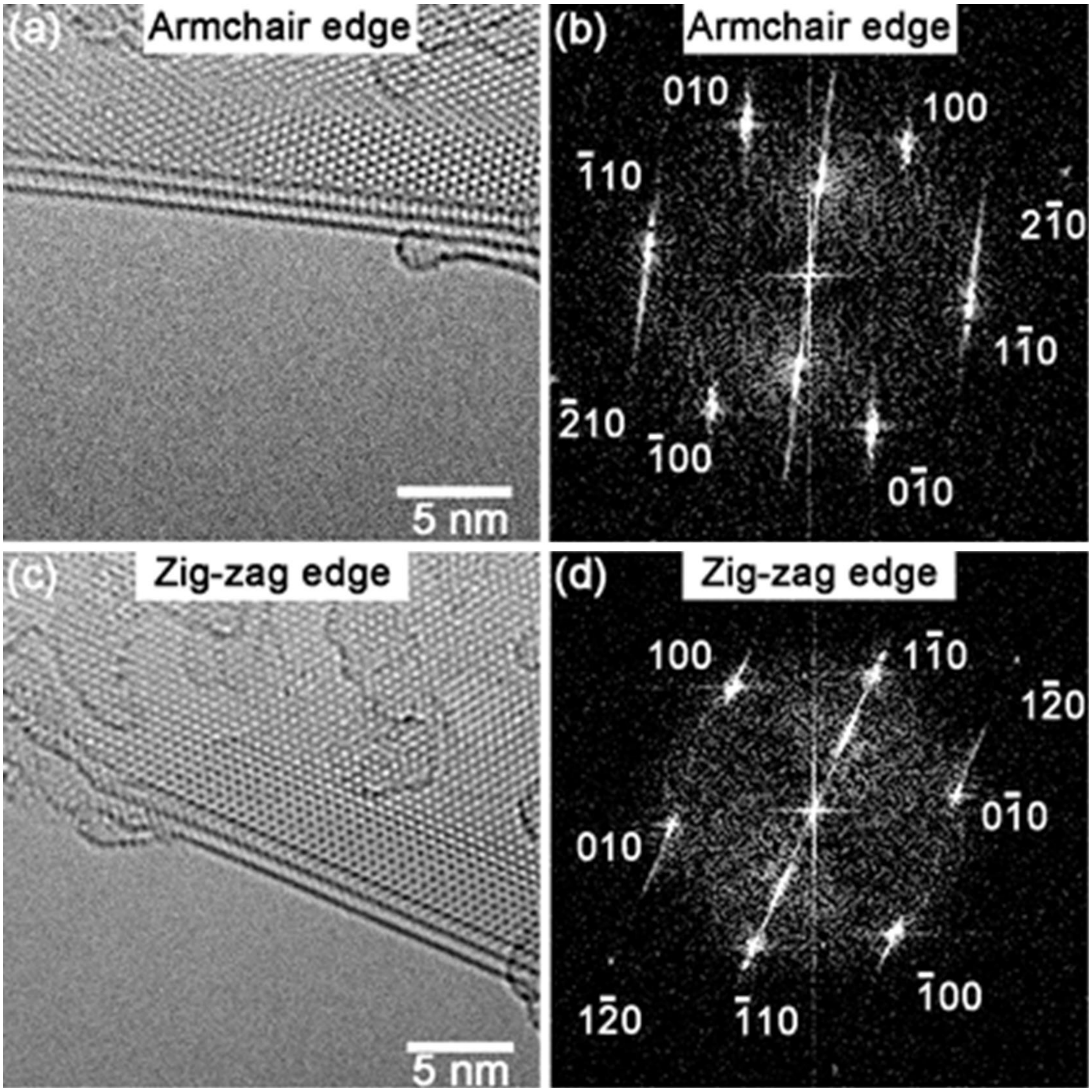

Figure 2. *(a), (c) HRTEM images and (b),(d) fast Fourier Transformations of the edges of CNx-MWNT nanoribbons with (a,b) armchair and (c,d) zig-zag edges.*