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Graphene and Carbon Nanotube Hybrid Structure: A Review

Kang Xia, Haifei Zhan, and Yuantong Gu *

School of Chemistry, Physics and Mechanical Engineering, Queensland University of Technology (QUT), Brisbane QLD 4001, Australia

Abstract

Graphene has been reported with record-breaking properties which have opened up huge potential applications. Considerable amount of researches have been devoted to manipulating or modify the properties of graphene to target a more smart nanoscale device. Graphene and carbon nanotube hybrid structure (GNHS) is one of the promising graphene derivate. The synthesis process and the mechanical properties are essential for the GNHS based devices. Therefore, this review will summarise the recent progress of the highly ordered GNHS synthesis/assembly, and discuss the mechanical properties of GNHS under various conditions as obtained from molecular dynamics simulations.

Keywords: Graphene, nanotube, mechanical behaviour, molecular dynamics simulation, Chemical vapor deposition –keep uniform format

1. Introduction

After the discovery of graphene and carbon nanotube hybrid structure[1], extensive researches have been conducted on this structure. To enhance interface thermal conductivity of the 'building blocks' for future nanoscale mechanical and electrical device and bring solution to quick energy dissipation, nanotube-graphene structure is suggested by Vikas et al.[2]. In the electricity perspective, Frederico et al.[3] and Yu et al.[4] also indicated such 'pillared-graphene' system would extend the excellent electrical conductivity of graphene and nanotube to three dimensions. In addition, recently, graphene has been applied as the electrode of supercapacitors because of its significant specific capacitance (135 Fg^{-1}). According to Fan et al.[5], due to the double layer configuration of carbon nanotube (CNT) and graphene hybrid,

* Corresponding author. Tel.: +61731381009
E-mail address: yuantong.gu@qut.edu.au

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the structure is expected to have better electrochemical performance, which indicates that the hybrid structure is suitable to be used as electrode in supercapacitors. What's more, CNT-graphene hybrid structure also shows huge potential in hydrogen storage (hydrogen storage capacity can be as high as 41 gL^{-1}), due to its extremely large surface area[6]. This review is aim to briefly summarize the latest progress in ordered GNHS synthesis, and also the investigations of the mechanical behaviours of GNHSs under various loading, which will shed lights on the design and engineering applications of GNHS.

2. **Synthesis and assemblies of GNHS**

Early researches on GNNH family compounds are focused on the assembly of GNHS into order structure for a specific application. The synthesis/fabrication of GNHSs generally can be categorized into four different approaches, including solution processing/casting[7-12], layer-by-layer deposition[13-15], vacuum filtration[16,17] and chemical vapour deposition (CVD)[5,18-31]. Among all the GNHS synthesis method reported, CVD approaches is shown to build hierarchical nanostructures with reasonable structure stability and mechanical strength[18,32].

In 2012, Yu et al disclosed an approach to synthesise seamless, covalently bonded three-dimensional graphene and carbon nanotube hybrid material with the aid of a floating buffer layer in chemical vapour deposition environment[4], as illustrated in Fig. 1. In detail, graphene is synthesised on the copper foil first, then iron catalyst and alumina buffer layer are deposited on top of graphene respectively using electron evaporation. In the growth stage the buffer is lifted up and CNT carpet grow directly out of the graphene. The density of CNTs forest can be well controlled by the thickness of the iron catalyst layer and the growth rate can be as high as 120 μm in 10 mins. The STEM reveal that the graphene and CNT junction region are well covalent bonded and are suggested to be utilized in the high performance supercapacitor and energy storages.

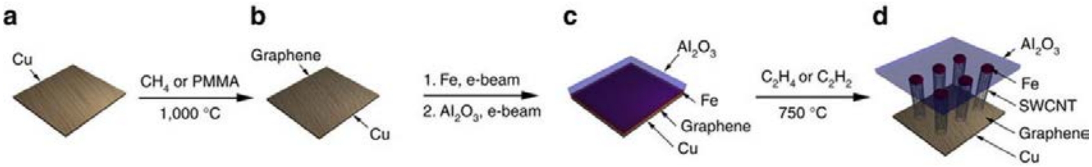

Fig. 1. Scheme for the synthesis of CNT carpets directly from graphene. (a) Copper foil substrate. (b) Graphene is formed on the copper foil by CVD or solid carbon-source growth. (c) Iron and alumina are deposited on the graphene-covered copper foil by using e-beam evaporation. (d) A CNT carpet is directly grown from graphene surface. The iron catalyst and alumina protective layer are lifted up by the CNT carpet as it grows. Reprinted by permission from Macmillan Publisher Ltd: Nature Communications[4], copyright 2016.

To facilitate the application of GNHS in the field of energy storage, Cheng et al.[18] developed a two-step CVD growth method (see Fig. 2). First of all, FeMo/vermiculite composed of exfoliated vermiculite (EV) embedded with FeMo nanoparticles in the interlayer space serves as the bifunctional catalyst to help the synthesis of CNT/Graphene in a low temperature CVD environment of 650 °C. Subsequently, a higher temperature of 950 °C CVD was conducted for uniform graphene layer deposition. To obtain the high carbon purity GNHS, facile acid treatments are applied to remove the FeMo/ vermiculite catalysts. The GNHS which produced via this approach demonstrates outstanding compression and recovery performance which shows the potential in the energy storage industry.