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Fractal characterization of graphene oxide nanosheet

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ABSTRACT

Graphene oxide (GO) nanosheets of planar flake-like structures are fabricated by using a modified Hummers method. Fractal theory is introduced to characterize the topological surfaces and porous structures of the GO nanosheets, the fractal dimensions estimated by using box-counting method are close to 2, indicating that the GO nanosheets possess perfectly smooth surfaces, which agrees well with high resolution transmission electron microscopy (HRTEM) images, and the higher porous fractal dimension of 2.74 determined by using Frenkel-Halsey-Hill (FHH) model suggests a wealth of microporous structures of the GO nanosheets.

1. Introduction

Graphene, an emerging two-dimensional nano-material with a single layer of sp2-bonded carbon atoms packed into a benzene-ring structure, has recently sparked great excitement in academic community given its excellent electronic, mechanical, and thermal properties [1–3]. Both graphene and graphene oxide can be processed into a wide variety of novel materials with versatile morphological features, in which the carbonaceous nanosheets can serve as either the sole component, as in thin films [4], or as fillers in polymer [5] as well as inorganic nanocomposites. One of the advantages of the graphene oxide is its easy dispersability in water and other organic solvents, as well as in different matrixes, due to the presence of the oxygen functionalities.

The surface and pore structure features of graphene-based materials identified from their specific surface area and pore size distribution, have a great impact on their chemical or physical properties [6]. Nitrogen adsorption isotherm is the most common method of surface analysis to estimate the surface and pore structure properties. Apart from gas adsorption, fractal analysis has been widely applied in a few fields of scientific researches to characterize the geometric and structural properties of fractal surfaces and pore structures [7,8]. Fractal dimension is often adopted to quantitatively evaluate the irregularities of the fractal surface and pore structures; its value varies from 2 to 3, in which the lowest value 2 corresponds to a perfectly regular smooth surface, while the upper limit 3 regards to the maximum allowed complexity of the irregular surface [9,10].

In this work, planar flake-like graphene oxide nanosheets have been fabricated by using a modified Hummers method, the mixtures of concentrated H_2SO_4 and H_3PO_4 serve as oxidants instead of the mixtures of concentrated H_2SO_4 and $NaNO_3$ used by traditional Hummers approach [11], the modified method only needs two-stage temperature control operation and produces less toxic gases, therefore it is more convenient and efficient than the traditional approach which needs three-stage temperature control operation and generates more toxic gases. The morphology is analyzed by high resolution transmission electron microscopy (HRTEM), the surface area and pore structure property are acquired by nitrogen adsorption-desorption isotherm. To achieve a deeper understanding of their textural structures or surface characteristics, box-counting method and Frenkel-Halsey-Hill (FHH) model are employed to estimate the fractal dimensions of the graphene oxide nanosheets, which aim to enrich the knowledge on their fractal natures.

2. Fabrication of graphene oxides

The graphene oxides are fabricated via a modified Hummers method which has been described elsewhere [12], typically, 60 mL of concentrated H_2SO_4 as well as 6 mL of concentrated H_3PO_4 are poured into a beaker, 375 mg graphites are subsequently added

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into the aforementioned solution, and then the beaker is shifted into an ultrasonic cleaner for 1 h (10 °C and 200 W). Hereafter, 0.75 g $KMnO_4$ is put into the beaker under slowly stirring and ultrasonic treatment for another 2 h. The beaker is transferred into a water bath at 60 °C for 3 h after adding additional 3 g $KMnO_4$, and then the above solution is poured into a 190 mL ice water accompanying by adding 7.5 mL H_2O_2, the formed colloidal suspension is separated by a centrifugal, the obtained sediments are washed to neutral by using deionized water, and then ultrasonically dispersed at 100 W, eventually, the graphite oxide (GO) nanosheets are attained. The morphologies of the GO nanosheets are acquired by HRTEM (Phillips Model CM200) technique, and the surface area and pore properties are measured at 77 K in a Beishide 3H-2000PS4 apparatus (Beishide Instrument S&T Co., Ltd, China).

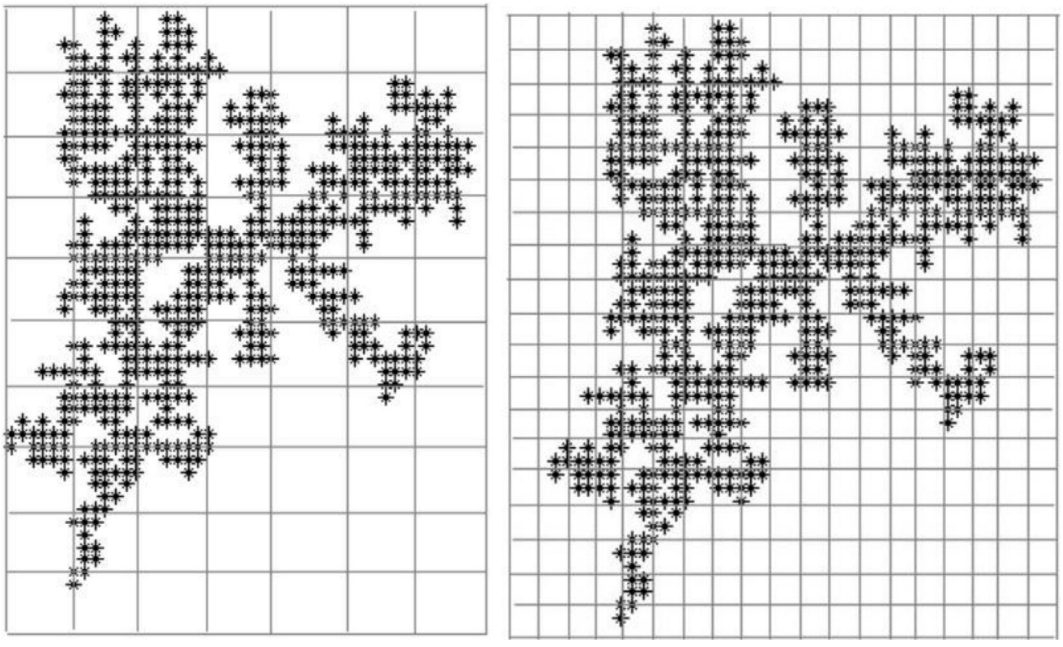

Fig. 1. Sketch of fractal dimensions determined by using box-counting method.

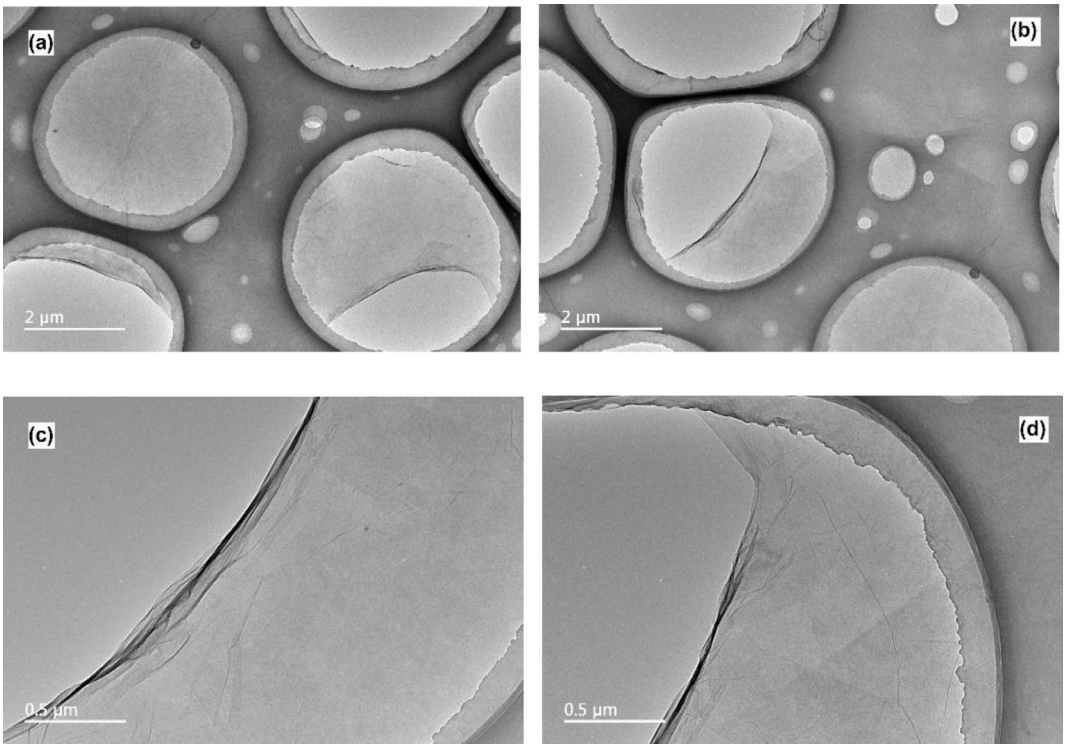

Fig. 2. HRTEM images of graphene oxide nanosheets.