PVA-BASED NANOGRAPHENE FILM BY ELECTROSPINNING

by

Jing PANG*[a], *Haiyan KONG*[b], and *Ji-Huan HE*[b]*

[a] College of Science, Inner Mongolia University of Technology, China
[b] National Engineering Laboratory for Modern Silk, College of Textile and Clothing Engineering, Soochow University, Suzhou, China

Original scientific paper
DOI: 10.2298/TSCI13051449P

Two-dimensional polyvinyl alcohol based graphene films with the thickness of less than 20 nm were fabricated directly by using polyvinyl alcohol/graphite solution or polyvinyl alcohol/ash solution by electrospinning. It was found that ash particles are good candidate for substitution of graphite particles to fabricate nanographene films. The relationship between the thickness and width of the film is elucidated, and the periodic morphology of the film is explained.

Key words: *graphene, electrospinning, film*

Introduction

Graphene is a rapidly rising star on the horizon of materials science and thermal science as well [1, 2]. This strictly 2-D material exhibits exceptionally physical and mechanical properties such as high carrier concentration and mobility [3] along with a room temperature quantum Hall effect [4], high thermal conductivity [5, 6], and highest mechanical strength measured to date [7], and it has already revealed a cornucopia of potential applications [8].

Electrospinning is the cheapest and the most straightforward way to produce polymer fibers from polymer solutions, with diameters in the range of 100 nm. Nanofibers with different morphologies have attracted considerable attentions in recent years for their wide potential applications. Among the various structures, film is one of the most attractive classes of structures, whose thickness is only several nanometers, and it is of incredible importance and of wide applications [9-12]. However, little was known that electrospinning can be used for fabricating polymer films with the thickness of several nanometers directly.

This paper is part of exploration of fabricating films by electrospinning and we demonstrate that not only nanographite particles can be used as an additive to fabricate graphene films, but also ash, an assembly of several allotropes of carbon, including graphite and amorphous carbon, an isolated atomic plane of graphite, can also be used to form graphene films.

Experimental procedure

Polyvinyl alcohol (PVA) with a degree of 1750 ± 50 was dissolved into distilled water with the temperature 25.2 °C and the humidity 45%, then the mixture was stirred with the aid of electromagnetic stirrer at 90 °C for 3 hours to get homogeneous and transparent solu-

* Corresponding author; e-mail: hejihuan@suda.edu.cn

tion, and cooled to the room temperature before the experiment. The PVA concentration was 10 wt.%.

There are two spinning experiments. The first is the solution of PVA (10 wt.%) /nano-graphite particle (0.5 wt.%). Nano-graphite particles are added gradually into the PVA solution until its concentration is 0.5 wt.%. The mixed solution is then put into the ultrasonic cell disruption system for 60 minutes to make it homogeneously mixed. The second is to replace nanographite particles by ash (0.5 wt.%).

These solutions were placed in a 10 mL syringe, and the needle tip with a diameter 0.7 mm was connected to a D. C. High voltage generator via an alligator clip. A flat piece of aluminum foil, placed 10 cm before the needle tip was served as the collector for the electrospinning fibers depositing. The voltage applied was maintained at 20 kV. The samples were pasted on a scanning electron microscope (SEM) disk and coated with gold before being observed through SEM, and superthin combined PVA-graphene films were observed (figs. 1 and 2).

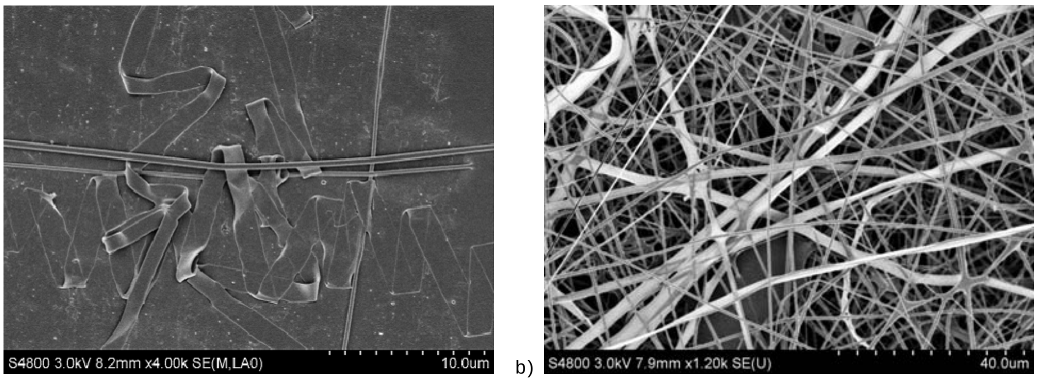
a)


Figure 1. Nanographene film fabricated by electrospinning

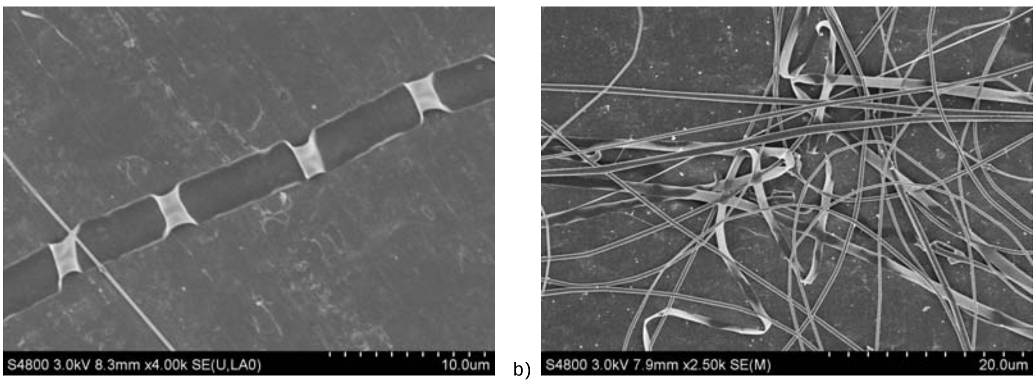
a)


Figure 2. Nanographene film fabricated by electrospinning, the solution is PVA (10 wg.%)/ash (0.5 wt.%) solution

Results and discussion

Figure 1 shows the SEM photos of PVA-graphite fibers and films. Figure 2 shows PVA-ash fibers and films. Both cases show similar structure of fibers and films, hinting that the cheapest ash might be a good candidate for substituting for most expensive nano-graphites.

Graphene, a 2-D allotrope of carbon, is made out of carbon atoms arranged on a honeycomb structure made out of hexagons [13]. Graphite, a 3-D allotrope of carbon, became widely known after the invention of the pencil in 1564, and its usefulness as an instrument for writing comes from the fact that graphite is made out of stacks of graphene layers that are weakly coupled by van der Waals forces [14]. Ash is the grey or black powdery substance that is left after something is burned, which is an assembly of several allotropes of carbon, including graphite and amorphous carbon, an isolated atomic plan of graphite. The graphite, made out of stacks of graphene layers, might move onto a sheet under a high electronic force in the mixed solution, and this is very reason to form a very long but extremely thin film.

From fig. 1(a) we can obtain that the width of the PVA-graphene film is about 1.5 micrometers and its thickness is about 50 nm; while the width of the PVA-ash film is about 3 micrometers and its thickness is about 20 nm as shown in fig. 3. This can be approximately explained by the mass conservation:

$$A\rho = hL\rho = Q \tag{1}$$

where A is the section area of the film, h – the thickness, L – the width, ρ – the density, and Q – the flow rate. Assume the density of PVA-graphene solution and PVA-ash solution is approximately same, this results in:

$$(hL)_{\text{PVA-graphene}} = (hL)_{\text{PVA-ash}} \tag{2}$$

Equation (2) implies that:

$$(50\ \text{nm} \times 1.5\ \mu\text{m}\ L)_{\text{PVA-graphene}} \approx (20\ \text{nm} \times 3\ \mu\text{m})_{\text{PVA-ash}} \tag{3}$$

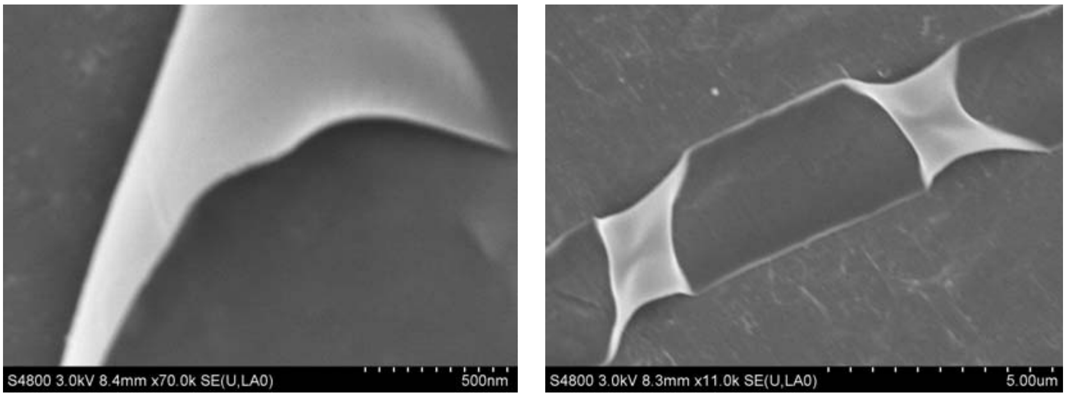


Figure 3. PVA-ash film

The obtained nano-film seems to have a periodic structure as that in beaded fibers [15, 16]. The liquid surface before solidification oscillates due to thermally excited capillary waves. The capillary waves typically have small amplitudes (~1 nm) and small wavelength (~100 μm). For a cylindrical jet, the oscillation frequency can be expressed:

$$\omega = \frac{I\rho}{2Q\sqrt{k\mu}} \tag{4}$$

where I is the current, ρ – the liquid density, Q – the flow rate, k – the dimensionless conductivity of the fluid, and μ – the viscosity coefficient.

The oscillating of the cylindrical jet results in periodic beads on the fiber's surface, similarly the oscillating of a film yields a periodic necking as illustrated in figs. 1 and 2.

Conclusions

This paper provides a simple way to produce PVA-based nanographene films with many potential applications. The mathematical explanation is given to reveal the relationship between the width and thickness of the film, and the periodic structure of the film. We demonstrate that ash is an excellent candidate for replacement of nano-graphite particles.

Acknowledgments

The work is supported by Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD), National Natural Science Foundation of China under grant No. 11071159 and No. 11372205 and Project for Six Kinds of Top Talents in Jiangsu Province under grant No. ZBZZ-035, Science & Technology Pillar Program of Jiangsu Province under grant No. BE2013072.

References

[1] Novoselov, K. S., *et al.,* Electric Field Effect in Atomically Thin Carbon Films, *Science, 306* (2004), 5696, pp. 666-669
[2] Kong, H. Y., He, J.-H., Superthin Combined PVA-Graphene Film, *Thermal Science, 16* (2012), 5, pp. 1660-1661
[3] Morozov, S. V., *et al.*, Two-Dimensional Electron and Hole Gases at the Surface of Graphite, *Physical Review B, 72* (2005), 20, pp. 201401-201404
[4] Novoselov, K. S., *et al.,* Room-Temperature Quantum Hall Effect in Graphene, *Science, 315* (2007), 5817, pp. 1377-1378
[5] Balandin, A. A., *et al.*, Superior Thermal Conductivity of Single-Layer Graphene, *Nano Letters, 8* (2008), 3, pp. 902–907.
[6] Ghosh, S., *et al.*, Extremely High Thermal Conductivity of Graphene: Prospects for Thermal Management Applications in Nanoelectronic Circuits, *Applied Physics Letters, 92* (2008), 15, pp. 151911-151913
[7] Lee, C. G., *et al.*, Measurement of the Elastic Properties and Intrinsic Strength of Monolayer Graphene, *Science, 321* (2008), 5887, pp. 385–388
[8] Geim, A. K., Novoselov, K. S., The Rise of Graphene, *Nature Materials, 6* (2007), 3, pp. 183–191
[9] Chen, Z. Y., *, et al.*, Augmentation of Transgenic Expression by Ultrasound Mediated Liposome Microbubble Destruction, *Mol. Med. Rep., 5* (2012), 4, pp. 964-970
[10] Akimov, V. V., *et al.*, Mass Transfer in the Chemosorption of CO(2) in a Membrane Microbubble Apparatus, *Theoretical Foundations of Chemical Engineering, 45* (2011), 6, pp. 811-817
[11] Steiner, E., *, et al.*, Protein Changes During Malting and Brewing with Focus on Haze and Foam Formation: a review, *European Food Research and Technology, 232* (2011), 2, pp. 191-204
[12] Gibbs, J. G., Zhao, Y. P., Autonomously Motile Catalytic Nanomotors by Bubble Propulsion, *Applied Physics Letters, 94* (2009), 16, pp. 163104-163106
[13] Castro Neto, A. H., *et al.*, The Electronic Properties of Graphene, *Reviews of Modern Physics, 81* (2009), 1, pp. 109-162
[14] Petroski, H., *The Pencil: A History of Design and Circumstance,* Knopf, New York, USA, 1989
[15] He, J.-H., *et al.*, *Electrospun Nanofibers and Their Applications*, Smithers Rapra Update, Shawbury, UK, 2008
[16] He, J.-H., *et al.*, Review on Fiber Morphology Obtained by Bubble Electrospinning and Blown Bubble Spinning, *Thermal Science, 16* (2012), 5, pp. 1363-1379

Paper submitted: January 2, 2013
Paper revised: June 2, 2013
Paper accepted: June 3, 2013