Chapter 10

THREE DIMENSIONAL (3D) GRAPHENE NETWORKS: SYNTHESIS METHODS

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1. Introduction

Graphene is a "a miracle two-dimensional (2D) material" with a single sheet of carbon atoms packed into a honeycomb lattice. It has been the focus of intense interest of physics, chemistry, material science, and engineering since its discovery in 2004. Due to its outstanding physicochemical properties, graphene demonstrates a great potential for various applications such as composite materials, nanoelectronics, energy storage, sensors, environment, catalysis and biomedical (Fang et al., 2015).

The fabrication of graphene into 3D hierarchical architectures for practical applications is still a challenge in nanotechnology. Generally, 2D graphene is synthesized through thermal or chemical reduction of graphene oxide (GO) exfoliated from graphite. In such cases, as a result of the strong π- π interactions between the graphene sheets 2D graphene structure tend to agglomerate or to restack, which causes to the decreasing of electrochemically active surface area. Furthermore, due to the abundant existence of defects and oxygen-containing functional groups, and numerous non-ideal contacts between graphene layers, the resulting graphene structure exhibit severely compromised conductivity (Fang et al., 2015; Lu, 2018). These shortcomings severely limit the performance of graphene-based energy storage systems, sensors and other electronic applications. In order to fully exploit the theoretical properties of graphene, different strategies have been de-

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and exciting potential applications. In this chapter, a variety of approaches based on self-assembly and template-assisted methods to produce three dimensional graphene architectures have been presented briefly. However, all of these techniques have both pros and cons in point of the ease of production method and the quality of obtained graphene structure. The fabricated 3D graphene networks have various superior merits which enable us to use in different promising fields such as energy conversion/storage, environment, biomedical, electronic and so on. Therefore, although many efforts have been devoted for the fabrication of 3D graphene structures, many challenges still remain for their further commercialization. Even though these 3D graphene structures exhibit excellent characteristics in the laboratory, more researches are still required to meet the demand for commercial application. Moreover, the structures and properties of 3D graphene require further optimization for specific applications. So, it should be investigated the way of low-cost and eco-friendly large scale production methods of fabricating 3D graphene networks. Ultimately, it can be concluded that 3D graphene architectures with optimized structures, controlled morphologies, and tailored properties will bring more exciting results in various extended fields such as energy storage, environment, electrochemistry, actuator, artificial organ, biosensors, wearable electronics.

Keywords: Graphene, Three Dimensional Graphene, Syhntesis, Decoration, Mechanism

References

Chabot, V., Higgins, D., Yu, A., Xiao, X., Chen, Z., & Zhang, J. (2014). A review of graphene and graphene oxide sponge: material synthesis and applications to energy and the environment. *Energy & Environmental Science*, *7*(5), 1564-1596.

Chakravarty, D., Tiwary, C. S., Woellner, C. F., Radhakrishnan, S., Vinod, S., Ozden, S., ... & Galvao, D. S. (2016). 3D Porous Graphene by Low-Temperature Plasma Welding for Bone Implants. *Advanced Materials*, *28*(40), 8959-8967.

Chen Z., Jin L., Hao W., Ren W., Cheng H.M. (2019). Synthesis and applications of three-dimensional graphene network structures, *Materials Today Nano,* 5, 100027.

Chen, W., & Yan, L. (2011a). In situ self-assembly of mild chemical reduction graphene for three-dimensional architectures. *Nanoscale*, *3*(8), 3132-3137.

Chen, Z., Ren, W., Gao, L., Liu, B., Pei, S., & Cheng, H. M. (2011b). Three-dimensional flexible and conductive interconnected graphene networks grown by chemical vapour deposition. *Nature materials*, *10*(6), 424.

Choi, B. G., Yang, M., Hong, W. H., Choi, J. W., & Huh, Y. S. (2012). 3D macroporous graphene frameworks for supercapacitors with high energy and power densities. *ACS nano*, *6*(5), 4020-4028.

Compton, O. C., An, Z., Putz, K. W., Hong, B. J., Hauser, B. G., Brinson, L. C., & Nguyen, S. T. (2012). Additive-free hydrogelation of graphene oxide by ultrasonication. *Carbon*, *50*(10), 3399-3406.

Estevez, L., Kelarakis, A., Gong, Q., Da'as, E. H., & Giannelis, E. P. (2011). Multifunctional graphene/platinum/nafion hybrids via ice templating. *Journal of the American Chemical Society*, *133*(16), 6122-6125.

Fang, Q., Shen, Y., & Chen, B. (2015). Synthesis, decoration and properties of three-dimensional graphene-based macrostructures: a review. *Chemical Engineering Journal*, 264, 753-771.

Farahani, R. D., Dubé, M., & Therriault, D. (2016). Three-dimensional printing of multifunctional nanocomposites: manufacturing techniques and applications. *Advanced Materials*, *28*(28), 5794-5821.

Geim, A. K., & Novoselov, K. S. (2010). The rise of graphene. In *Nanoscience and Technology: A Collection of Reviews from Nature Journals* (11-19).

He, Y., Liu, Y., Wu, T., Ma, J., Wang, X., Gong, Q., ... & Gao, J. (2013). An environmentally friendly method for the fabrication of reduced graphene oxide foam with a super oil absorption capacity. *Journal of hazardous materials*, *260*, 796-805.

Hummers, J. R., William, S., & Offeman, R. E. (1958). Preparation of graphitic oxide. *J. Am. Chem. Soc*, *80*(6), 1339-1339.

Hu, H., Zhao, Z., Wan, W., Gogotsi, Y., & Qiu, J. (2013). Ultralight and highly compressible graphene aerogels. *Advanced materials*, *25*(15), 2219-2223.

Huang, X., Qian, K., Yang, J., Zhang, J., Li, L., Yu, C., & Zhao, D. (2012). Functional nanoporous graphene foams with controlled pore sizes. *Advanced Materials*, *24*(32), 4419-4423.

Jiang, X., Ma, Y., Li, J., Fan, Q., & Huang, W. (2010). Self-assembly of reduced graphene oxide into three-dimensional architecture by divalent ion linkage. *The Journal of Physical Chemistry C,* 114(51), 22462-22465.

Kurra, N., Jiang, Q., Nayak, P., & Alshareef, H. N. (2019). Laser-derived graphene: A three-dimensional printed graphene electrode and its emerging applications. *Nano Today,* 24, 81-102.

Lee, S. H., Kim, H. W., Hwang, J. O., Lee, W. J., Kwon, J., Bielawski, C. W., ... & Kim, S. O. (2010). Three-dimensional self-assembly of graphene oxide platelets into mechanically flexible macroporous carbon films. *Angewandte Chemie International Edition*, 49(52), 10084-10088.

Li, D., Müller, M. B., Gilje, S., Kaner, R. B., & Wallace, G. G. (2008). Processable aqueous dispersions of graphene nanosheets. *Nature nanotechnology*, *3*(2), 101.

Liu, F., & Seo, T. S. (2010). A controllable self-assembly method for large-scale synthesis of graphene sponges and free-standing graphene films. *Advanced Functional Materials*, *20*(12), 1930-1936.

Liu, L., Yang, J., & Meng, Q. (2013). Graphene cross-linked phenol–formaldehyde hybrid organic and carbon xerogel during ambient pressure drying. *Journal of sol-gel science and technology*, *66*(1), 1-5.

Liu, T., Huang, M., Li, X., Wang, C., Gui, C. X., & Yu, Z. Z. (2016). Highly compressible anisotropic graphene aerogels fabricated by directional freezing for efficient absorption of organic liquids. *Carbon*, *100*, 456-464.

Lu, L. (2018). Recent advances in synthesis of three-dimensional porous graphene and its applications in construction of electrochemical (bio) sensors for small biomolecules detection. *Biosensors and Bioelectronics*, *110*, 180-192.

Nguyen, S. T., Nguyen, H. T., Rinaldi, A., Nguyen, N. P., Fan, Z., & Duong, H. M. (2012). Morphology control and thermal stability of binderless-graphene aerogels from graphite for energy storage applications. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *414*, 352-358.

Qin, S. Y., Liu, X. J., Zhuo, R. X., & Zhang, X. Z. (2012). Microstructure-Controllable Graphene Oxide Hydrogel Film Based on a pH-Responsive Graphene Oxide Hydrogel. *Macromolecular Chemistry and Physics*, *213*(19), 2044-2051.

Samad, Y. A., Li, Y., Alhassan, S. M., & Liao, K. (2015). Novel graphene foam composite with adjustable sensitivity for sensor applications. *ACS applied materials & interfaces*, *7*(17), 9195-9202.

Sheng, K. X., Xu, Y. X., Chun, L. I., & Shi, G. Q. (2011). High-performance self-assembled graphene hydrogels prepared by chemical reduction of graphene oxide. *New Carbon Materials*, *26*(1), 9-15.

Sheng, K., Sun, Y., Li, C., Yuan, W., & Shi, G. (2012). Ultrahigh-rate supercapacitors based on eletrochemically reduced graphene oxide for ac line-filtering. *Scientific reports*, *2*, 247.

Sudeep, P. M., Narayanan, T. N., Ganesan, A., Shaijumon, M. M., Yang, H., Ozden, S., ... & Roy, A. K. (2013). Covalently interconnected three-dimensional graphene oxide solids. *Acs Nano*, *7*(8), 7034-7040.

Vickery, J. L., Patil, A. J., & Mann, S. (2009). fabrication of graphene–polymer nanocomposites with higher-order three-dimensional architectures. *Advanced Materials*, *21*(21), 2180-2184.

Wang, X., Zhang, Y., Zhi, C., Wang, X., Tang, D., Xu, Y., ... & Bando, Y. (2013). Three-dimensional strutted graphene grown by substrate-free sugar blowing for high-power-density supercapacitors. *Nature communications*, *4*, 2905.

Worsley, M. A., Pauzauskie, P. J., Olson, T. Y., Biener, J., Satcher Jr, J. H., & Baumann, T. F. (2010). Synthesis of graphene aerogel with high electrical conductivity. *Journal of the American Chemical Society*, *132*(40), 14067-14069.

Worsley, M. (2018, December). 3D Printing Electrodes for Electrochemical Energy Storage and Conversion. In *2018-Sustainable Industrial Processing Summit* (Vol. 2, pp. 159-160). Flogen Star Outreach.

Wu, X., Zhou, J., Xing, W., Wang, G., Cui, H., Zhuo, S., ... & Qiao, S. Z. (2012). High-rate capacitive performance of graphene aerogel with a superhigh C/O molar ratio. *Journal of Materials Chemistry*, *22*(43), 23186-23193.

Yang, X., Qiu, L., Cheng, C., Wu, Y., Ma, Z. F., & Li, D. (2011). Ordered gelation of chemically converted graphene for next-generation electroconductive hydrogel films. *Angewandte Chemie International Edition*, *50*(32), 7325-7328.

Yavari, F., Chen, Z., Thomas, A. V., Ren, W., Cheng, H. M., & Koratkar, N. (2011). High sensitivity gas detection using a macroscopic three-dimensional graphene foam network. *Scientific reports*, *1*, 166.

Xu, Y., Wu, Q., Sun, Y., Bai, H., & Shi, G. (2010a). Three-dimensional self-assembly of graphene oxide and DNA into multifunctional hydrogels. *ACS nano*, *4*(12), 7358-7362.

Xu, Y., Sheng, K., Li, C., & Shi, G. (2010b). Self-assembled graphene hydrogel via a one-step hydrothermal process. *ACS nano*, *4*(7), 4324-4330.

Zhang, W., Zhu, J., Ang, H., Zeng, Y., Xiao, N., Gao, Y., ... & Yan, Q. (2013). Binder-free graphene foams for O_2 electrodes of Li–O_2 batteries. *Nanoscale*, *5*(20), 9651-9658.

Zhou, H., Yao, W., Li, G., Wang, J., & Lu, Y. (2013). Graphene/poly (3, 4-ethylenedioxythiophene) hydrogel with excellent mechanical performance and high conductivity. *Carbon*, *59*, 495-502.

Zhu, C., Han, T. Y. J., Duoss, E. B., Golobic, A. M., Kuntz, J. D., Spadaccini, C. M., & Worsley, M. A. (2015). Highly compressible 3D periodic graphene aerogel microlattices. *Nature communications*, *6*, 6962.