# Graphene Materials: Large-Scale Fabrication and Application Explorations

S. F. Pei[1], F. Li[1], W. C. Ren[1], and H. M. Cheng[1*]

[1] Advanced Carbon Division, Shenyang National Laboratory for Materials Science
Institute of Metal Research, Chinese Academy of Sciences, Shenyang 110016, China

Graphene has unique properties and is expected for various applications. There are challenges of how to realize large-scale fabrication of high-quality graphene materials and large-size single crystal graphene domains, which are essential for mass and device applications. In order to commercialize graphene materials, we developed a solid state intercalation-high temperature expansion-liquid phase exfoliation process [1]. With a proto-type production line, 5 kg/day graphene material with high quality can be produced, which will have wide applications in composites, energy storage [2,3], conductive inks, etc (Fig. 1). Second, we developed an ambient pressure CVD to synthesize millimeter-size single crystal graphene grains and films on Pt substrates, and invented an electrochemical bubbling method to transfer these grains and films, which is nondestructive to the Pt substrates that can be repeatedly used for graphene growth with no limit [4]. The single crystal graphene grains have high crystallinity and high electrical mobility. The kinetics and edge control of the graphene grains were elucidated [5,6]. In order to obtain graphene by CVD in a relatively large quantity, we tried to use Ni particles [7] and Ni foams [8] as substrates. With Ni foam as template, a 3D graphene macrostructure, which is called graphene foam (GF), can be synthesized [8]. This porous graphene bulk material consists of an interconnected network of graphene, is flexible, and has outstanding electrical and mechanical properties. And it can be used in elastic conductors [8], sensors, flexible lithium ion batteries [9], Li-S batteries, and electromagnetic interference fielding materials [10].

## References

[1] S. F. Pei, et al, A method for fabricating high-quality graphene material, China Patent filed No. 201110282370.5, 2011.

[2] G. M. Zhou, et al, A graphene-pure sulphur sandwich structure for ultrafast, long-life lithium-sulphur batteries, Adv Mater 26(2014)625.

[3] G. M. Zhou, et al, A flexible sulfur-graphene-polypropylene separator integrated electrode for advanced Li-S batteries, Adv Mater 27(2015)641.

[4] L. Gao, et al, Repeated growth and bubbling transfer of graphene with millimeter-size single crystal grains using platinum, Nature Communications 3:699(2012)DOI: 10.1038/ncomms1702.

[5] T. Ma, et al, Edge-controlled growth and kinetics of single-crystal graphene domains by chemical vapor deposition, PNAS 110(51)(2013)20386.

[6] T. Ma, et al, Repeated growth-etching-regrowth for large-area defect-free single-crystal graphene by chemical vapor deposition, ACS Nano 8(12)(2014)1206.

[7] Z. P. Chen, et al, Bulk growth of mono- to few-layer graphene on nickel particles by chemical vapor deposition from methane, Carbon 48 (12) (2010)3543.

[8] Z. P. Chen, et al, Three-dimensional flexible and conductive interconnected graphene networks grown by chemical vapour deposition, Nature Materials 10(2011)424.

[9] N. Li, et al, Lightweight and flexible graphene-based lithium ion batteries with ultrafast charge and discharge rates, PNAS 109 (43)(2012)17360.

[10] Z. P. Chen, et al, Lightweight and flexible graphene foam composites for high-performance electromagnetic interference shielding, Adv Mater 25(2013)1296.

[11] W. C. Ren, H. M. Cheng, The global growth of graphene, Nature Nanotechnology 9(10)(2014)72.
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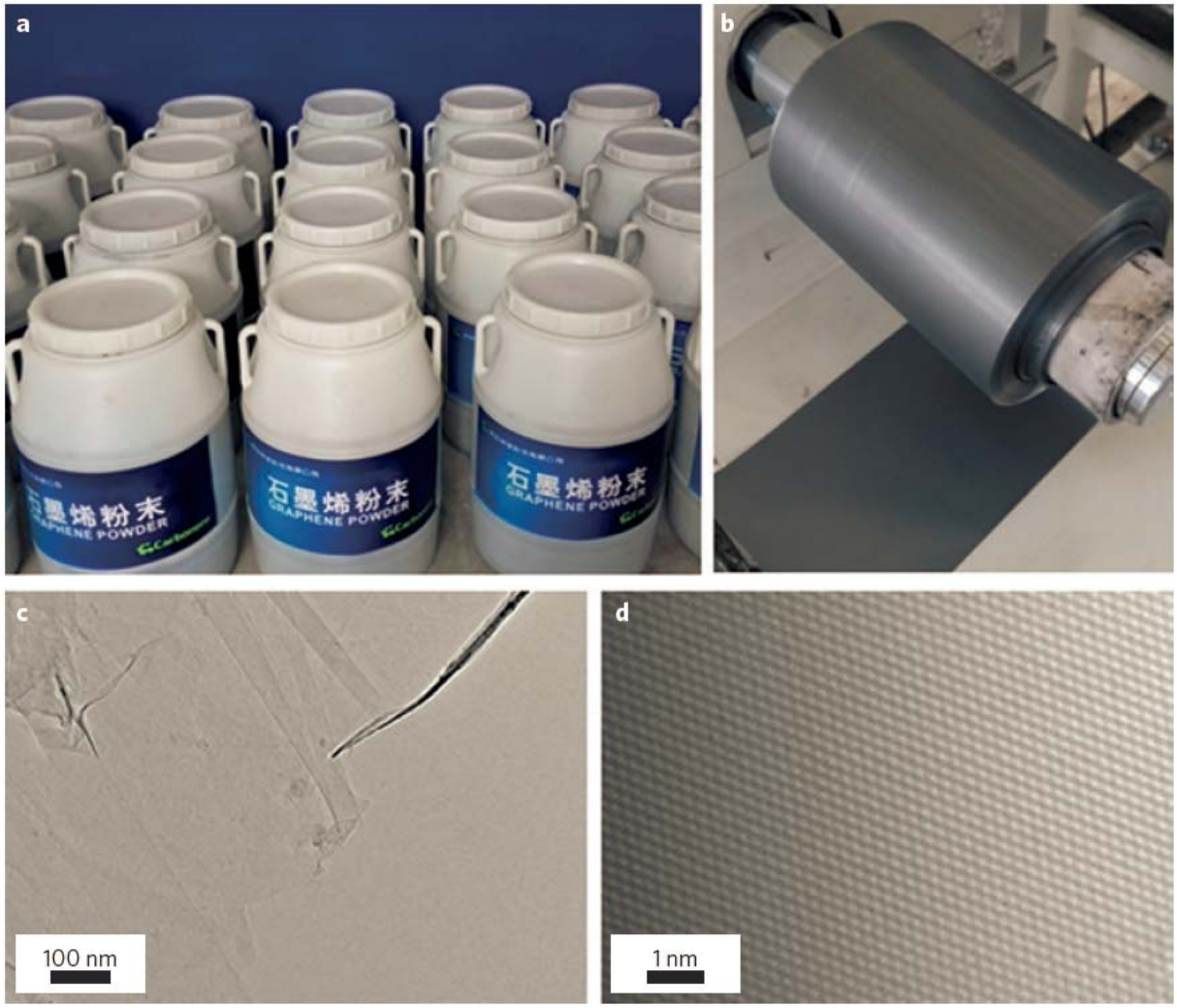


Figure 1: Mass production and application of small graphene sheets. **a**, A shipment of few-layer graphene product manufactured by Deyang Carbonene Technology. **b**, TEM, and **c**, aberration-corrected HRTEM images of the product in **a**, showing its very high quality. **d** and **e**, Graphene-coated Al current collectors for lithium ion batteries.[11]

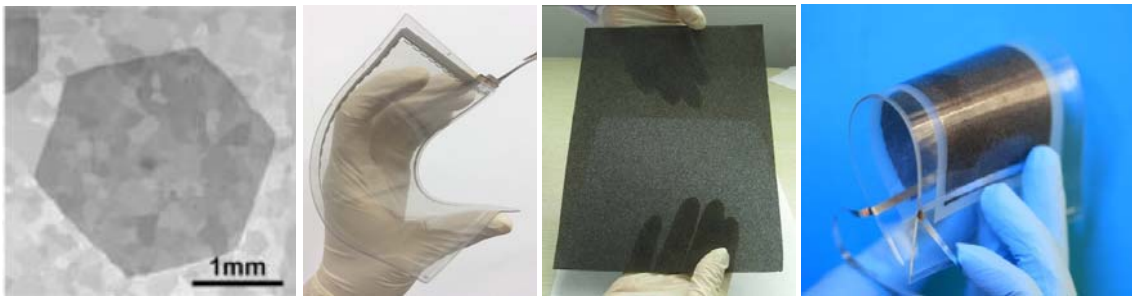


Figure 2 (from left to right): A high-quality single crystal graphene domains with a size of about 3 mm [5]; a flexible CVD-grown graphene touch panel with a size of 7.5”; a semi-transparent free-standing 3D graphene interconnected network by CVD [8]; and a flexible graphene-based lithium ion full battery [9].