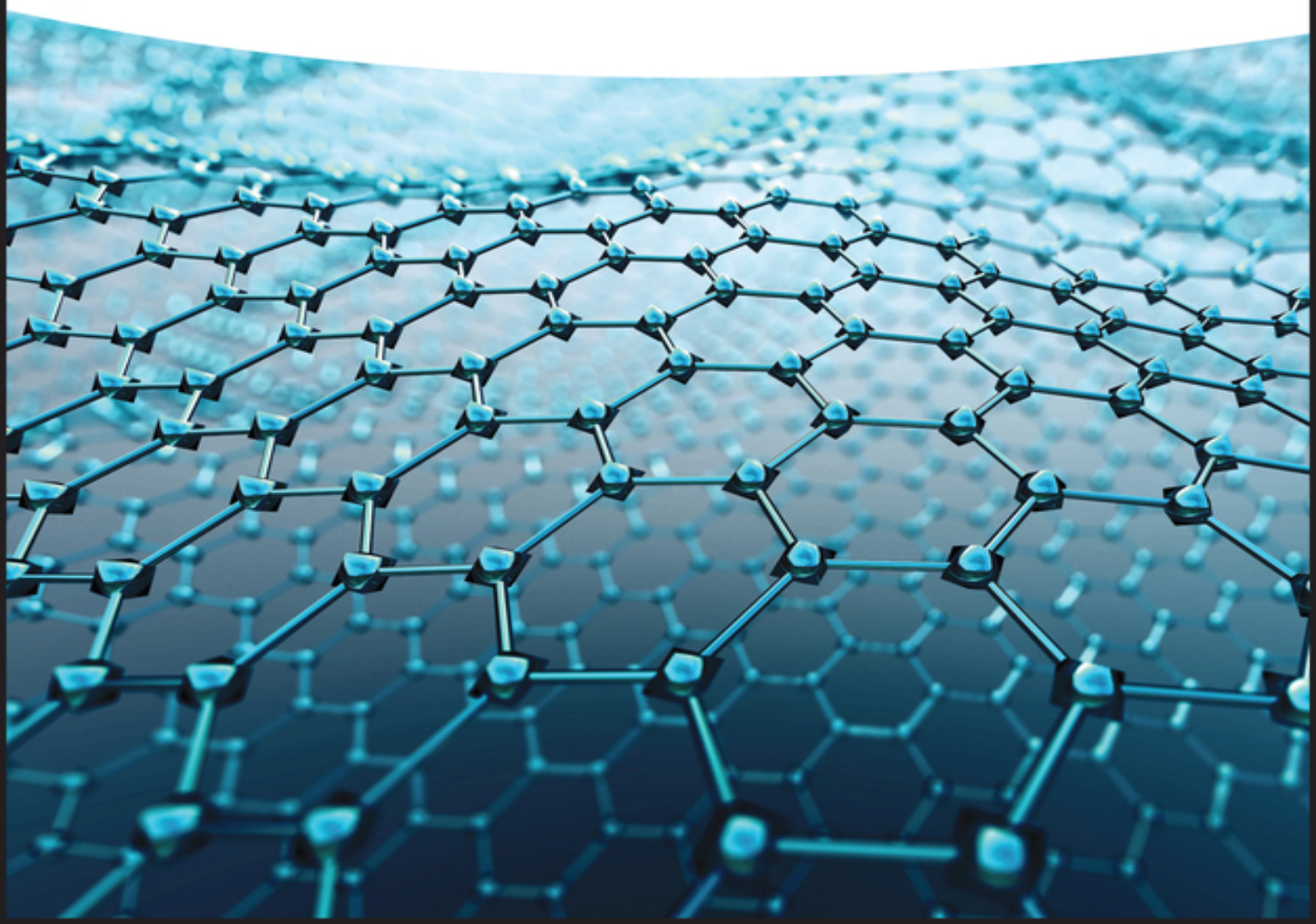


Edited by  
Chunnian He, Naiqin Zhao, and Junwei Sha

# Templated Fabrication of Graphene-Based Materials for Energy Applications



# Table of Contents

[Cover](#)

[Title Page](#)

[Copyright](#)

[Preface](#)

[List of Abbreviations](#)

[1 Graphene-Based Materials: Structure and Properties](#)

[1.1 Introduction to Carbon Materials](#)

[1.2 History of Graphene](#)

[1.3 Structure of Graphene](#)

[1.4 Properties of Graphene](#)

[1.5 Structure Defects of Graphene](#)

[1.6 Different Dimensional Graphene](#)

[1.7 Graphene Composites](#)

[1.8 Applications of Graphene](#)

[References](#)

[2 Graphene Synthesis: An Overview of Current Status](#)

[2.1 Top-Down Approaches](#)

[2.2 Bottom-up Approaches](#)

[References](#)

[3 Nanoporous Metal Template Methods](#)

[3.1 Introduction](#)

[3.2 Dealloying Method for the Preparation of Nanoporous Metal Foil](#)

[3.3 Nanoporous Ni as the Substrate for the Growth of 3D Nanoporous Graphene](#)

### [3.4 Nanoporous Cu as the Substrate for the Growth of 3D Nanoporous Graphene](#)

#### [References](#)

## [4 Soluble-Salt-Template Methods](#)

### [4.1 Salt-Template Methods](#)

### [4.2 Salt-Template-Directed Graphene-Based Materials](#)

### [4.3 Outlook](#)

#### [References](#)

## [5 Powder Metallurgy Templates Methods](#)

### [5.1 Powder Metallurgy](#)

### [5.2 Powder Metallurgy Templates Methods](#)

### [5.3 Mechanism of Powder Metallurgy Templates Method](#)

### [5.4 3D GM and Its Composites Prepared by PMT Method](#)

### [5.5 Additive Manufacturing](#)

### [5.6 Outlook for PMT and Additive Manufacturing Method](#)

#### [References](#)

## [6 Graphene-Based Materials for Lithium/Sodium-Ion Batteries](#)

### [6.1 Introduction](#)

### [6.2 Graphene-Based Insertion Composites](#)

### [6.3 Graphene-Based Alloying-Type Composites](#)

### [6.4 Graphene-Based Conversion-Type Composites](#)

### [6.5 Summary and Outlook](#)

#### [References](#)

## [7 Graphene-Based Materials for Lithium-Metal Batteries](#)

[7.1 Graphene-Based Nanoscale Layers](#)

[7.2 Graphene-Based Hosts for Li Storage](#)

[7.3 Heteroatom-Doped Graphene for Uniform Lithium Nucleation](#)

[7.4 Graphene Combined with Other “lithiophilic” Materials](#)

[7.5 Outlook](#)

[References](#)

[8 Graphene-Based Materials for Li-S Batteries](#)

[8.1 Development History of Li-S Batteries](#)

[8.2 Working Mechanism of Li-S Battery](#)

[8.3 Challenges of Li-S Batteries](#)

[8.4 Overview of the Graphene as Host for S](#)  
[References](#)

[9 Graphene-Based Materials for Supercapacitors](#)

[9.1 Supercapacitor](#)

[9.2 Graphene-Based Supercapacitor](#)

[9.3 Future Prospects](#)

[References](#)

[10 Graphene-Based Materials for Electrocatalysis](#)

[10.1 Introduction](#)

[10.2 Preparation of Graphene-Based Materials for Electrocatalysis](#)

[10.3 Application of Graphene-Based Electrocatalysts](#)

[10.4 Outlook](#)

[References](#)

[Index](#)

[End User License Agreement](#)

# List of Tables

## Chapter 8

[Table 8.1 Overview of the materials used to modify the separator.](#)

## Chapter 9

[Table 9.1 Common considerations for optimizing the performance of supercapac...](#)

## Chapter 10

[Table 10.1 HER mechanism in acid and alkaline electrolytes.](#)

[Table 10.2 Reaction and equilibrium potentials \( \$E^0\$ \) of ECR pathways.](#)

# List of Illustrations

## Chapter 1

[Figure 1.1 Typical carbon materials, such as charcoals, pencil lead, diamond...](#)

[Figure 1.2 Carbon family based on carbon-carbon bonding.](#)

[Figure 1.3 Timeline of selected events in the history of the preparation, is...](#)

[Figure 1.4 \(a\) Graphene structure and \(b\) mother of all graphitic forms.](#)

[Figure 1.5 Atomic and electronic structures of graphene. \(a\) Graphene lattic...](#)

[Figure 1.6 Ambipolar electric field effect in single-layer graphene. The rap...](#)

[Figure 1.7 TEM image.\(a\) and \(b\) atomic structure of Stone-Wales defect ...](#)

[Figure 1.8 Atomic structures and TEM images of single-vacancy  \$V\_{1\(5-9\)}\$ -\(a, d\)...](#)

[Figure 1.9 Atomic structures of carbon adatoms: \(a, d\) single adatom in the ...](#)

[Figure 1.10 TEM image and corresponding atomic structure of GO films. The in...](#)

[Figure 1.11 \(a\) The schematic representation of cutting the two-dimensional ...](#)

## Chapter 2

[Figure 2.1 Classification of graphene preparation methods.](#)

[Figure 2.2 Four typical methods for graphene by exfoliation of bulk graphite...](#)

[Figure 2.3 Growth kinetics in CVD-produced graphene on various catalysts: ca...](#)

[Figure 2.4 Schematic of the fabrication process of 3D-DG@MnO<sub>2</sub> film.](#)

[Figure 2.5 Schematics of powder metallurgy.](#)

[Figure 2.6 Schematic illustration of the in situ CVD process for the one-ste...](#)

[Figure 2.7 Methods for unzipping carbon nanotubes. \(a\) Treated with sulphuri...](#)

[Figure 2.8 Schematic illustration of femtosecond laser direct writing for on...](#)

[Figure 2.9 Monolayer graphene is derived from solid PMMA films on Cu substra...](#)

## Chapter 3

[Figure 3.1 \(a\) Schematic illustration of the synthetic procedure of 3D bimod...](#)

[Figure 3.2 \(a\) Schematic diagram of the fabrication of NO-3DNG film. \(b\) SEM...](#)

[Figure 3.3 Microstructural and chemical characterization of amorphous and cr...](#)

[Figure 3.4 \(a\) Schematic diagram of the fabrication process of the hnp-G. \(b...](#)

[Figure 3.5 \(a\) SEM image of the nanoporous copper \(NPC\) coated with HG, the ...](#)

[Figure 3.6 \(a\) Schematic illustrations of the fabrication of 3DCu@NG. \(b\) Th...](#)

[Figure 3.7 Schematic of the fabrication process of the NO-3DG@CNC films. \(a\)...](#)

[Figure 3.8 \(a\) SEM image of the cross-section of the NPC@N-3DG/CNCs grown at...](#)

[Figure 3.9 Schematic of the fabrication process of 3D nanoporous graphene@Mn...](#)

[Figure 3.10 \(a, b\) SEM and TEM images of 3D nanoporous graphene after removi...](#)

[Figure 3.11 Schematic illustration of the fabrication of H-3DRG@NiCo-LDH and...](#)

[Figure 3.12 \(a, b\) SEM images of the cross section of H-3DRG film with diffe...](#)

## Chapter 4

[Figure 4.1 \(a\) Schematic view of graphene growth on a NaCl crystal. \(b, c\) s...](#)

[Figure 4.2 \(a\) Schematic of NaCl template, \(b\) SEM image of carbon-coated mi...](#)

[Figure 4.3 \(a\) Schematic of the preparation procedure of the heteroatom-dope...](#)

[Figure 4.4 \(a\) Schematic of the synthesis of porous 2D nanosheet-shaped carb...](#)

[Figure 4.5 \(a\) Schematic of the production process for porous carbon materia...](#)

[Figure 4.6 \(a\) SEM, \(b\) TEM \(the inset is the electron diffraction pattern\),...](#)

[Figure 4.7 \(a\) Schematic of the preparation process of Fe<sub>3</sub>C/PG.\(b\) Schem...](#)

[Figure 4.8 \(a\) Schematic of the in situ technique to fabricate 2D Fe<sub>3</sub>O<sub>4</sub>@C@PG...](#)

[Figure 4.9 \(a\) Schematic for the formation of N- and S-doped porous carbon s...](#)

[Figure 4.10 \(a\) Schematic representation of the preparation of ferrite/carbo...](#)

[Figure 4.11 \(a\) Schematic illustration of the in situ technique to fabricate...](#)

[Figure 4.12 \(a\) Schematic of the preparation process for the SHG. \(i\) Melami...](#)

[Figure 4.13 \(a\) TEM \(upper row\) and SEM pictures \(lower row\) of N-dCs using ...](#)

[Figure 4.14 \(a\) Schematic illustration of shape fixing via salt recrystalliz...](#)

[Figure 4.15 \(a\) Schematic illustration of the 3D NaCl assembly-assisted synt...](#)

[Figure 4.16 \(a\) Schematic illustration of the top-down in situ synthesis of ...](#)



[Figure 4.17 \(a\) Schematic illustration of an in situ strategy for the prepar...](#)

[Figure 4.18 \(a\) Scheme for the synthesis of freestanding, flexible, transpar...](#)

## Chapter 5

[Figure 5.1 Schematics of powder metallurgy templates method with Ni powder a...](#)

[Figure 5.2 Schematics of the possible distribution of C isotopes on \(a\) Ni a...](#)

[Figure 5.3 \(a, b\) SEM images and \(c, d\) TEM images of 3D GM prepared by PMT ...](#)

[Figure 5.4 \(a\) Raman spectrum, \(b\) XRD pattern, \(c\) TGA curve, and \(d\) XPS d...](#)

[Figure 5.5 Schematic diagram of the formation process of in situ grown 3D-GN...](#)

[Figure 5.6 Raman spectra of as-obtained graphene by using Cu powder as the t...](#)

[Figure 5.7 The synthesis steps for the preparation of 3D porous cellular car...](#)

[Figure 5.8 Scheme of metal-powder-assisted soluble salt templates method to ...](#)

[Figure 5.9 Raman spectrum surface scanning \( \$I\_D/I\_G\$ \) of 3D bmG. Source: Sha et...](#)

[Figure 5.10 Scheme of the synthesis of 3D N-doped GM.](#)

[Figure 5.11 Scheme of the preparation of ruGF and ruGF-epoxy composites.](#)

[Figure 5.12 Photographs of Ni/sucrose half-articles before and after growth:...](#)

[Figure 5.13 \(a\) Photographs of pellets prepared with 3 g of Ni and 0.5 g of ...](#)

[Figure 5.14 SEM images of 3D GMs prepared under \(a, b\) 749 MPa, \(c, d\) 125 M...](#)

[Figure 5.15 \(a\) Photograph and \(b\) SEM image of as-prepared LPM-3D rebar GF...](#)

[Figure 5.16 Mechanism schematic of preparation of 3D GM by PMT method. \(a\) S...](#)

[Figure 5.17 Schematic of Ni particle interspace as a microreactor during col...](#)

[Figure 5.18 \(a\) Schematic of preparation of 3D rebar GF. \(b\) Schematic of tu...](#)

[Figure 5.19 \(a\) Photographs of 3D rebar GF before and after loading 540 g we...](#)

[Figure 5.20 \(a-e\) Performance testing data of 3D N-doped GM as the electrode...](#)

[Figure 5.21 The cycling performance of the as-prepared PCCF/S with different...](#)

[Figure 5.22 Scheme of the preparation process of the 3D GF/graphene “eggshel...](#)

[Figure 5.23 Schematic of the preparation of LPM-3D rebar GF as the anode of ...](#)

[Figure 5.24 Schematic of the synthesis of metal graphene foams.](#)

[Figure 5.25 Schematic diagram of the fabrication of NO-3DNG film.](#)

[Figure 5.26 The sheet resistance profiles of as-prepared graphene/Ag film, g...](#)

[Figure 5.27 Schematic of GO nanowire fabrication.](#)

[Figure 5.28 Resistance of the fabricated rGO nanowire as a function of strai...](#)

[Figure 5.29 \(a-d\) Fabrication process of 3D printed hydroxyapatite and GO na...](#)

[Figure 5.30 Photograph of as-printed samples. HG0 refers to 0 wt% of GO to h...](#)

[Figure 5.31 \(a and c\) Schematic of laminated object manufacturing process fo...](#)

[Figure 5.32 The fabrication of soft electrothermal actuators based on laser-...](#)

[Figure 5.33 \(a-c\) The fabrication of the laser printing 3D porous graphene a...](#)

## Chapter 6

[Figure 6.1 A schematic representation of the different reaction mechanisms o...](#)

[Figure 6.2 \(a\) Schematic illustration of the formation and \(b\) TEM image of ...](#)

[Figure 6.3 \(a\) Schematic illustration of the formation and \(b\) SEM image of ...](#)

[Figure 6.4 Side views of the models with an increase of Na coverage from 0.1...](#)

[Figure 6.5 \(a\) Schematic illustration of the formation and \(b\) TEM image of ...](#)

[Figure 6.6 The comparison of rate \(a\) and cycling \(b\) performances of the Sb...](#)

[Figure 6.7 \(a\) Schematic illustration of the formation process and \(b\) SEM i...](#)

[Figure 6.8 \(a\) First reversible specific capacity of the graphene, NiO NSs, ...](#)

[Figure 6.9 \(a\) Schematic illustration of the formation process and \(b\) TEM i...](#)

[Figure 6.10 \(a\) TEM image of MoS<sub>2</sub>/G \(1 : 2\). \(b\) Cycling performance of \(1\)...](#)

[Figure 6.11 Schematic illustration of the formation process of freestanding ...](#)

## Chapter 7

[Figure 7.1 Bar chart of the practical specific energy density \(pink\) and ene...](#)

[Figure 7.2 An illustration of the morphological phenomena and failure mechan...](#)

[Figure 7.3 Scheme of dilemma for LMA in rechargeable batteries.](#)

[Figure 7.4 \(a\) Illustration of Li/Na plating on the Cu foil coated with conv...](#)

[Figure 7.5 \(a\) Illustration of Li deposition on an electrode with a PP separ...](#)

[Figure 7.6 \(a\) Illustration of Li deposition on the lithium metal electrode ...](#)

[Figure 7.7 \(a, b\) Schematic diagrams of Li depositing/stripping process on o...](#)

[Figure 7.8 \(a, b\) Fabrication process of layered Li-rGO composite LMA; From ...](#)

[Figure 7.9 \(a\) Li plating process on 3DCG. \(b-e\) The cross-section SEM image...](#)

[Figure 7.10 \(a\) Modeling of different heteroatom-doped carbons. \(b\) Modeling...](#)

[Figure 7.11 \(a, b\) Li adsorption energy distribution mapping and illustratio...](#)

[Figure 7.12 \(a\) Schematic illustration of Li plating/stripping on 3DCu@NG. T...](#)

[Figure 7.13 Fabrication process of the N-doped porous graphene-Li anode. SEM...](#)

[Figure 7.14 \(a\) Voltage-capacity profiles of Li deposition on Cu substrate a...](#)

[Figure 7.15 \(a\) Schematic and \(b\) SEM image of WGC. \(c\) Schematic and SEM im...](#)

[Figure 7.16 Schematic of Li deposition on the \(a\) 3D ZnO@PCCM and \(b\) ZnO/3D...](#)

## Chapter 8

[Figure 8.1 Illustration of the working mechanism of Li-S batteries.](#)

[Figure 8.2 The anode corrosion and structure collapse in Li-S batteries. Sch...](#)

[Figure 8.3 Schematic of the hierarchical design principle for Li-S batteries...](#)

[Figure 8.4 \(a\) Schematic for the synthesis of unstacked DTG and the TEM imag...](#)

[Figure 8.5 \(a\) The EF-TEM image and corresponding electron energy loss spect...](#)

[Figure 8.6 TEM bright-field \(BF\) image \(a\) and the corresponding elemental m...](#)

[Figure 8.7 \(a\) Schematic process of fabricating free-standing rGO-S composit...](#)

[Figure 8.8 \(a\) A schematic showing the preparation of L-GPC material.\(b\)...](#)

[Figure 8.9 \(a\) Schematic illustration of the NG/S-TiO<sub>2</sub> preparation process a...](#)

[Figure 8.10 Schematic illustration of the discharge process in sulfur cathod...](#)

[Figure 8.11 \(a\) Schematic of the fabrication of a porous VN/G composite and ...](#)

[Figure 8.12 \(a\) Synthesis of the 3DTSC composite. \(b\) Advantages of the 3DTS...](#)

[Figure 8.13 Schematic of the fabrication process of the hierarchical archite...](#)

[Figure 8.14 \(a\) Schematic of a Li-S battery with electrode configuration and...](#)

[Figure 8.15 Schematic diagram of synergistic adsorption reduction of polysul...](#)

[Figure 8.16 Schematic of the preparation of the Co<sub>9</sub>S<sub>8</sub>/CoO heterostructures a...](#)

## Chapter 9

[Figure 9.1 Ragone plot supercapacitors and other energy-storage devices.](#)

[Figure 9.2 Comparison between double-layer capacitor, pseudocapacitor, and l...](#)

[Figure 9.3 The relation between capacitance and \(a\) specific surface area, \(...](#)

[Figure 9.4 \(a\) Graphene-based supercapacitor device and \(b\) its optical imag...](#)

[Figure 9.5 Schematic illustration of the N-doping process.](#)

[Figure 9.6 The different types of hard templates and their corresponding len...](#)

[Figure 9.7 \(a, d, g\) Schematic of NaX template, \(b, e, h\) SEM image of carbo...](#)

[Figure 9.8 \(a\) Schematic illustration of producing the MnO<sub>2</sub>/e-CMG process. \(...\)](#)

[Figure 9.9 Electrochemical characterization of a-MEGO electrodes in the elec...](#)

[Figure 9.10 \(a\) Schematic diagram of asymmetric supercapacitors configuratio...](#)

[Figure 9.11 \(a\) Scheme of LIC, \(b\) Galvanostatic charge-discharge curve at 0...](#)

[Figure 9.12 Schematic of a LIG-MSD device and the digital photograph.](#)

[Figure 9.13 The schematics and graphene-electrode patterns of laser photonic...](#)

## Chapter 10

[Figure 10.1 Schematic representation of the gas-involving electrocatalysis. ...](#)

[Figure 10.2 \(a\) Periodic table and the corresponding electronegativity of el...](#)

[Figure 10.3 Typical nitrogen species in N-doped graphene and their binding e...](#)

[Figure 10.4 Schematic illustrations of the proposed P-doping \[20\] \(a\), S-dop...](#)

[Figure 10.5 \(a\) Schematic of the N-X co-doped graphene nanoribbons \(X = B, P...](#)

[Figure 10.6 Defects in carbon nanostructures for catalysis. \(a-e\) Representa...](#)

[Figure 10.7 \(a, b\) The simulated free energy along the reaction step and the...](#)

[Figure 10.8 The schematics of different carbon lattice structures: \(a\) 5-8-5...](#)

[Figure 10.9 \(a\) Free energy plots of ORR and optimized configurations of the...](#)

[Figure 10.10 Schematic representation of a HER volcano plot.](#)

[Figure 10.11 \(a\) Linear sweep voltammetry \(LSV\) for the ORR for graphene, N-...](#)

[Figure 10.12 \(a\) Illustration of the electrochemical CO<sub>2</sub> reduction process a...](#)

[Figure 10.13 Schemes of the NRR via different pathways.](#)



# **Templated Fabrication of Graphene-Based Materials for Energy Applications**

*Edited by*

*Chunnian He, Naiqin Zhao, and Junwei Sha*

**WILEY-VCH**

## **Editors**

### ***Prof. Chunnian He***

Tianjin University  
Materials Science and Engineering  
Peiyang Park Campus  
No.135 Yaguan Road  
Haihe Education Park  
300350 Tianjin  
China

### ***Prof. Naiqin Zhao***

Tianjin University  
Materials Science and Engineering  
Peiyang Park Campus  
No.135 Yaguan Road  
Haihe Education Park  
300350 Tianjin  
China

### ***Assoc. Prof. Junwei Sha***

Tianjin University  
Materials Science and Engineering  
Peiyang Park Campus  
No.135 Yaguan Road  
Haihe Education Park  
300350 Tianjin  
China

**Cover Image:** © Neon\_dust/Shutterstock

All books published by **WILEY-VCH** are carefully produced. Nevertheless, authors, editors, and publisher do not warrant the information contained in these books, including this book, to be free of errors. Readers are advised to keep in mind that statements, data, illustrations, procedural details or other items may inadvertently be inaccurate.

**Library of Congress Card No.:** applied for

### **British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

### **Bibliographic information published by the Deutsche Nationalbibliothek**

The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <<http://dnb.d-nb.de>>.

© 2022 WILEY-VCH GmbH, Boschstr. 12, 69469 Weinheim, Germany

All rights reserved (including those of translation into other languages). No part of this book may be reproduced in any form – by photoprinting, microfilm, or any other means – nor transmitted or translated into a machine language

without written permission from the publishers. Registered names, trademarks, etc. used in this book, even when not specifically marked as such, are not to be considered unprotected by law.

**Print ISBN:** 978-3-527-34600-4

**ePDF ISBN:** 978-3-527-82209-6

**ePub ISBN:** 978-3-527-34625-7

**oBook ISBN:** 978-3-527-82208-9

# Preface

With carbon neutrality being raised as the high-priority mission for human society, there is an urgent need for technological development in related fields. In particular, the demand for energy storage and conversion applications, represented by batteries, is increasing rapidly. Moreover, their development of energy-related applications greatly boosted the requirements for new materials.

Among various new materials, graphene is undoubtedly the most popular one. Since its discovery, graphene has become a star material due to its excellent mechanical, electrical, and chemical properties. However, in energy-related fields such as batteries, supercapacitors, and electrocatalysis, the demand for materials has a different focus. How to manufacture and improve the graphene-based materials to meet different needs is a question worth exploring. Among the many strategies to prepare graphene-based materials, the template method is one of the most popular methods. The advantage of the template method is that it can effectively regulate the microstructure of graphene. Also, such a method can introduce heteroatoms or other phases in graphene by the interaction between the template and precursors during the preparation process. There are more and more researchers recognizing the benefits of the template method for graphene-based materials production. There has been a rapid growth in research in this area and many promising applications have emerged. Therefore, we think it is necessary to summarize and review the development in this field, which is the main reason why we have written this book.

The framework of this book can be broadly divided into three parts. Firstly, we will start with a basic introduction

to graphene-based materials ([Chapters 1](#) and [2](#)); the second part is the frontier of template methods for the preparation of graphene-based materials ([Chapters 3-5](#)); the third part is the research progress of graphene-based materials in different energy-related applications ([Chapter 6-10](#)).

[Chapter 1](#) mainly introduces the basic knowledge of graphene, including its history and physical properties. The purpose of this chapter is to give the reader a background for the following chapters. [Chapter 2](#) will give readers a grasp of the current synthesis strategies for graphene. To this regard, the classification of graphene preparations is described and some typical researches are introduced in this chapter. [Chapters 3](#) to [5](#) will focus on a brief overview of different kinds of template methods for graphene production. The study of porous metals for graphene preparation is presented in [Chapter 3](#). Nanoporous graphene shows excellent physics and electrochemical performance in the fields of energy storage and conversion due to its high-quality and unique interconnected structure. [Chapter 3](#) presents an overview of the recent research about the nanoporous graphene-based materials using nanoporous metal as the substrates. Then, [Chapter 4](#) focuses on how to prepare graphene in large quantities, in particular. Considering the cost of graphene preparation with the potential for a large number of applications, substantial efforts have been devoted to developing a facile and versatile method, and several low-cost template methods will be reviewed in this part. In [Chapter 5](#), the strategy of powder metallurgy and additive manufacturing procedures to prepare graphene materials is highlighted, which is one of the current research interests of our group. Subsequent chapters will discuss the various applications of graphene-based materials, such as lithium-ion batteries ([Chapter 6](#)), lithium-metal batteries ([Chapter 7](#)), lithium-

sulfur batteries ([Chapter 8](#)), supercapacitors ([Chapter 9](#)), electrocatalysis ([Chapter 10](#)), and so on. [Chapters 6 to 10](#) all follow a similar framework of discussion. At first, we will give the background of these fields, such as the basic concepts in energy applications and the physicochemical principles for different devices. Then, the discussion of the current bottlenecks in materials encountered in these applications will be presented. Consequently, we will describe why graphene-based materials are promising in these fields and how graphene should be improved to suit the different requirements. Meanwhile, we will review the specific applications of graphene-based materials prepared by the template methods in these fields and give the properties that can be achieved or the performance in practical cases. At the end of each chapter, we will discuss the current challenges of these graphene-based materials in each energy-related application, as well as possible improvement strategies and directions.

In these chapters, relevant content includes both the authors' studies and the research of others. This content has been reorganized and reviewed to form systematic frameworks. It is my pleasure to write and edit this book on graphene-based materials and their energy applications. It is hoped that the publication of this book will be helpful to researchers in this field and provide guidelines for related researches. Special thanks go to my students, colleagues, and the publisher's editors for their discussions and help.

# List of Abbreviations

## **0D**

zero-dimensional

## **1D**

one-dimensional

## **2D Fe<sub>3</sub>O<sub>4</sub>@C@PGC**

2D porous graphitic carbon nanosheets uniformly embedded with carbon-encapsulated Fe<sub>3</sub>O<sub>4</sub> nanoparticles

## **2D**

two-dimensional

## **3D BMG**

three-dimensional bi-functional modular graphene network

## **3D CG**

3D graphene-based hosts with continuous ductlike structure

## **3D FL-MoS<sub>2</sub>@PCNNs**

few layers MoS<sub>2</sub> nanosheets anchored on 3D porous carbon nanosheet networks

## **3D G**

3D graphene architectures

## **3D GF**

3D graphene foam

## **3D GF-FeS<sub>2</sub>**

cauliflower-like FeS<sub>2</sub> anchored on three-dimensional graphene foams

## **3D GM**

3D graphene monolith

**3D GN**

three-dimensional graphene foams

**3D GNs**

3D porous graphene-like networks

**3D PG**

3D porous graphene

**3D Rebar GF**

CNTs-reinforced 3D graphene foam

**3D S@PGC**

sulfur nanoparticles in three-dimensional (3D) porous graphitic carbon (PGC)

**3D SnSb@N-PG**

SnSb in-plane nanoconfined three-dimensional N-doped porous graphene composite microspheres

**3D ZnO@PCCMs**

ZnO nanoparticle-confined 3D porous carbon composite microspheres

**3D**

three-dimensional

**3DCu@NG**

nanoporous Cu@N-doped graphene

**3D-DG**

free-standing 3D duct-like graphene

**3D-DG@MnO<sub>2</sub>**

3D nanoporous graphene @MnO<sub>2</sub> composite

**ΔG**

Gibbs free energy

**AFM**

atomic force microscopy

**AGNRs**

armchair graphene nanoribbons

**ALD**



atomic layer deposition

**a-MEGO**

KOH-activated microwave-exfoliated graphite oxide

**a-MnO<sub>x</sub>**

amorphous manganese oxide

**AMs**

anode materials

**An**

aniline

**APCVD**

atmospheric-pressure CVD

**APS**

aminopropyltriethoxysilane

**APTMS**

3-aminopropyl-trimethoxysilane

**ASCs**

asymmetric supercapacitors

**a-TiO<sub>2</sub>**

amorphous TiO<sub>2</sub>

**BET**

Brunauer-Emmett-Teller

**BF-STEM**

bright-field scanning transmission electron microscopy

**B-LIG-MSCs**

flexible supercapacitors based on boron-doped laser scribing graphene

**BN-GAs**

nitrogen and boron co-doped monolithic graphene aerogels

**C**

capacitance

**C60**

fullerene

**carbide@CNS**

vertically aligned 2D N-doped carbon nanosheets  
embedded with uniform nanosized metal carbides

**Cat**

catecho

**CE**

coulombic efficiency

**CNF**

carbon nanofiber

**CNFs**

carbon nanofibers

**CNs**

carbon nanosheets

**CNTs**

carbon nanotubes

**CO<sub>2</sub>RR**

carbon dioxide reduction reaction

**Co<sub>3</sub>O<sub>4</sub>/GS**

Co<sub>3</sub>O<sub>4</sub>/graphene sheets

**Co-MOF/3DGN**

Co-MOF/three-dimensional graphene network

**CoS<sub>2</sub>/G**

CoS<sub>2</sub>/graphene/CoS<sub>2</sub> heterostructure

**CoS<sub>2</sub>-N-C/3DGN**

CoS<sub>2</sub> encapsulated in N-doped carbon/3DGN

**CPD**

critical point dryer

**CS-800A**

S-doped carbons synthesized from K<sub>2</sub>SO<sub>4</sub> at 800 °C

**CS-800B**

S-doped carbons synthesized from  $\text{Na}_2\text{S}_2\text{O}_3$  at 800 °C

**CTAB**

cetyltrimethylammonium bromide

**CV**

cyclic voltammogram

**CVD**

chemical vapor deposition

**DA**

dopamine hydrochloride

**DFT**

density functional theory

**DMA**

dynamic mechanical analysis

**DOS**

density-of-states

**E**

energy density

**ECR**

electrochemical  $\text{CO}_2$  reduction

**EDLCs**

electrical double-layer capacitors

**EELS**

electron energy-loss spectroscopy

**EIS**

electrochemical impedance spectroscopy

**EOG**

edge-oriented multilayer graphene

**Fe@C@PGC**

2D porous graphitic carbon nanosheets uniformly embedded with carbon-encapsulated Fe nanoparticles

**Fe<sub>2</sub>O<sub>3</sub>/GS**

Fe<sub>2</sub>O<sub>3</sub>/graphene sheets

**FeS<sub>2</sub>/rGO**

FeS<sub>2</sub> microspheres anchored on rGO

**G@MoS<sub>2</sub>-C**

MoS<sub>2</sub> encapsulated in carbon and coupled on graphene sheets

**GAMs**

graphene aerogel microlattices

**g-C<sub>3</sub>N<sub>4</sub>**

carbon nitride

**G-CNF film**

carbon nanofiber-stabilized graphene aerogel film

**G-Co<sub>3</sub>O<sub>4</sub>**

graphene-embedded Co<sub>3</sub>O<sub>4</sub> rose-spheres

**GF separator**

glass fibers separator

**GF**

graphene fiber

**GNR**

graphene nanoribbons

**GO**

graphene oxide

**H-3DRG**

heteroatom-doped edge-enriched 3D rivet graphene

**HAADF-STEM**

high-angle annular dark-field scanning transmission electron microscopy

**HAH**

hydroxylamine hydrochloride

**HER**

hydrogen evolution reaction

**HG**

hydrogenated graphite

**HIP**

hot isostatic pressing

**hnp-G**

hierarchical nanoporous graphene

**HOPG**

highly oriented pyrolytic graphite

**HPC-BMS**

hierarchical porous carbons with different size of pores (-B, -M, S, meaning big, medium, and small, respectively.)

**HPGN**

layered porous graphene nanoparticles

**HR-TEM**

high-resolution TEM

 **$I_D/I_G$** 

The ratio of D-band and G-band in the Raman spectroscopy

**ITO**

indium tin oxide

**K**

thermal conductivity

**LCGO**

liquid crystalline graphene oxide

**LDH**

layered double hydroxide

**LEG**

light-emitting diode

**LIBs**

lithium-ion batteries

**LIC**

lithium-ion capacitors

**LMA**

lithium metal anode

**LMB**

lithium metal battery

**LMO**

lithium transition-metal oxide

**LOG**

laterally oriented graphene

**LPCVD**

low-pressure CVD

**LPM-3D Rebar GF**

3D rebar GF prepared via a loose powder metallurgy  
templates method

**LSG**

laser scribing graphene

**MBE**

molecular beam epitaxy

**MG**

MoS<sub>2</sub>-reduced graphene oxide

**ML**

monolayer

**MMT**

montmorillonite

**MnO<sub>2</sub>/e-CMG**

graphene-MnO<sub>2</sub> composites

**MOF**

metal-organic framework

**MoS<sub>2</sub>/G**