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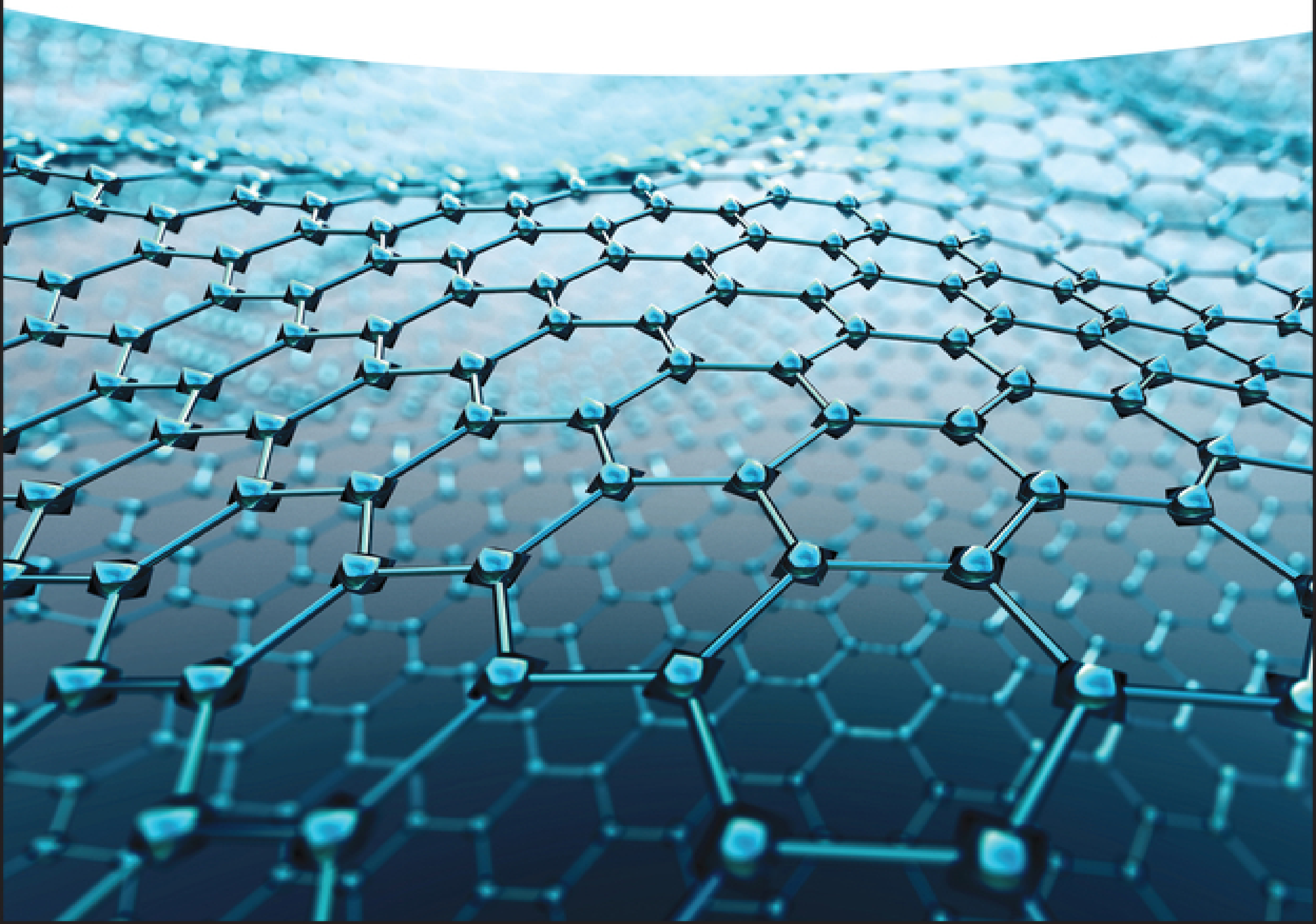
Chunnian He, Naiqin Zhao, and Junwei Sha

Templated Fabrication of Graphene-Based Materials for Energy Applications



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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_3O_4@C@PGC
: 2D porous graphitic carbon nanosheets uniformly embedded with carbon-encapsulated Fe_3O_4 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_2@PCNNs
: few layers MoS_2 nanosheets anchored on 3D porous carbon nanosheet networks

3D G
: 3D graphene architectures

3D GF
: 3D graphene foam

3D GF-FeS_2
: cauliflower-like FeS_2 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_2
3D nanoporous graphene @MnO_2 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$_x$
amorphous manganese oxide

AMs
anode materials

An
aniline

APCVD
atmospheric-pressure CVD

APS
aminopropyltriethoxysilane

APTMS
3-aminopropyl-trimethoxysilane

ASCs
asymmetric supercapacitors

a-TiO$_2$
amorphous TiO_2

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_2RR
: carbon dioxide reduction reaction

Co_3O_4/GS
: Co_3O_4/graphene sheets

Co-MOF/3DGN
: Co-MOF/three-dimensional graphene network

CoS_2/G
: CoS_2/graphene/CoS_2 heterostructure

CoS_2-N-C/3DGN
: CoS_2 encapsulated in N-doped carbon/3DGN

CPD
: critical point dryer

CS-800A
: S-doped carbons synthesized from K_2SO_4 at 800 °C

CS–800B
: S-doped carbons synthesized from $Na_2S_2O_3$ 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 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_2O_3/GS
: Fe_2O_3/graphene sheets

FeS_2/rGO
: FeS_2 microspheres anchored on rGO

G@MoS_2-C
: MoS_2 encapsulated in carbon and coupled on graphene sheets

GAMs
: graphene aerogel microlattices

g-C_3N_4
: carbon nitride

G-CNF film
: carbon nanofiber-stabilized graphene aerogel film

G-Co_3O_4
: graphene-embedded Co_3O_4 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_2-reduced graphene oxide

ML
monolayer

MMT
montmorillonite

MnO_2/e-CMG
graphene–MnO_2 composites

MOF
metal–organic framework

MoS_2/G