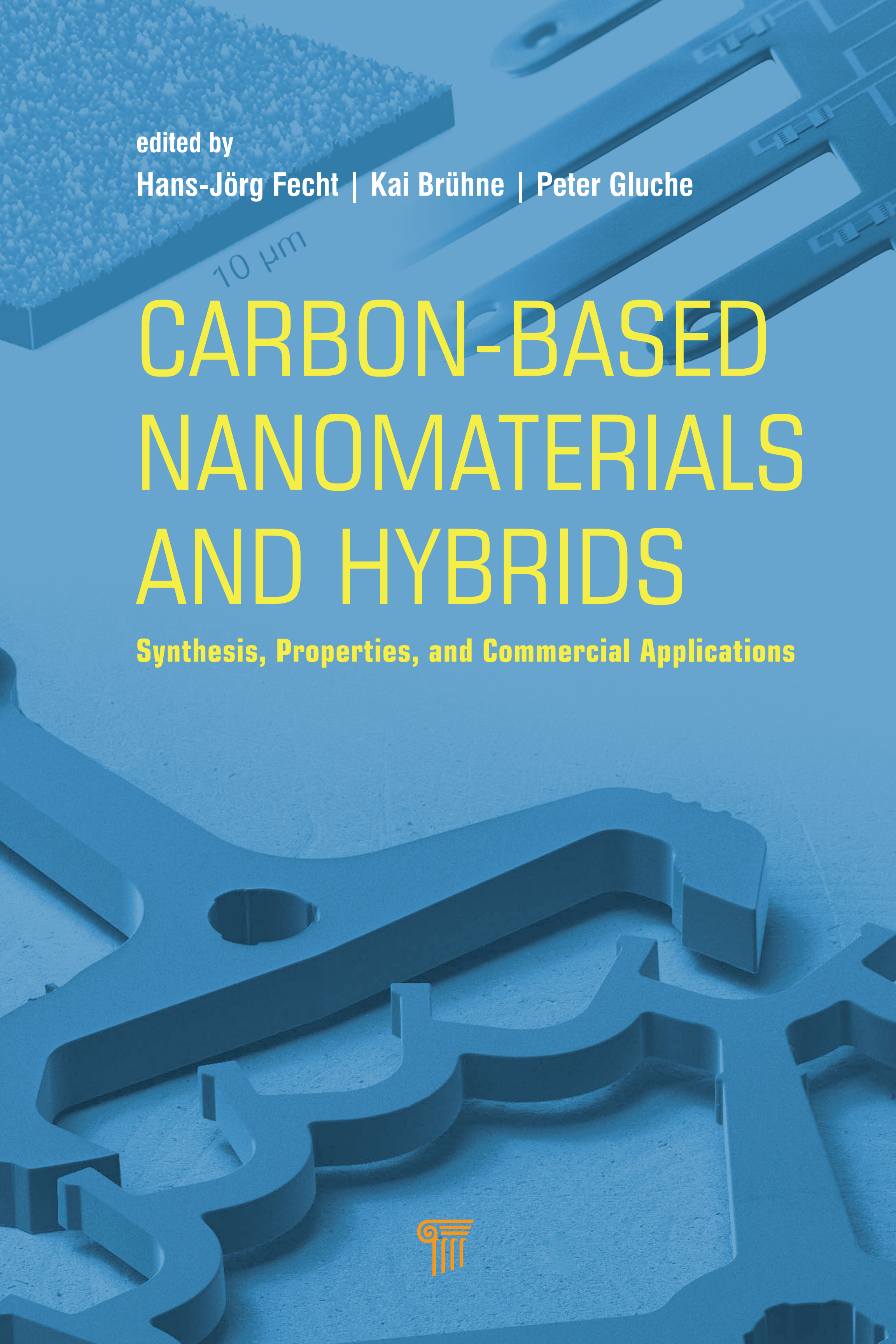


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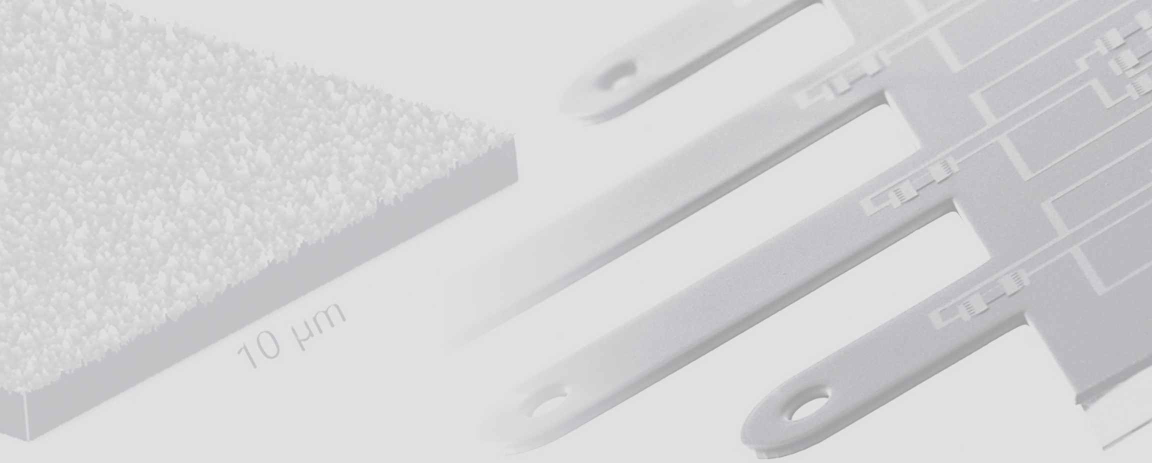
Hans-Jörg Fecht | Kai Brühne | Peter Gluche

# CARBON-BASED NANOMATERIALS AND HYBRIDS

## Synthesis, Properties, and Commercial Applications

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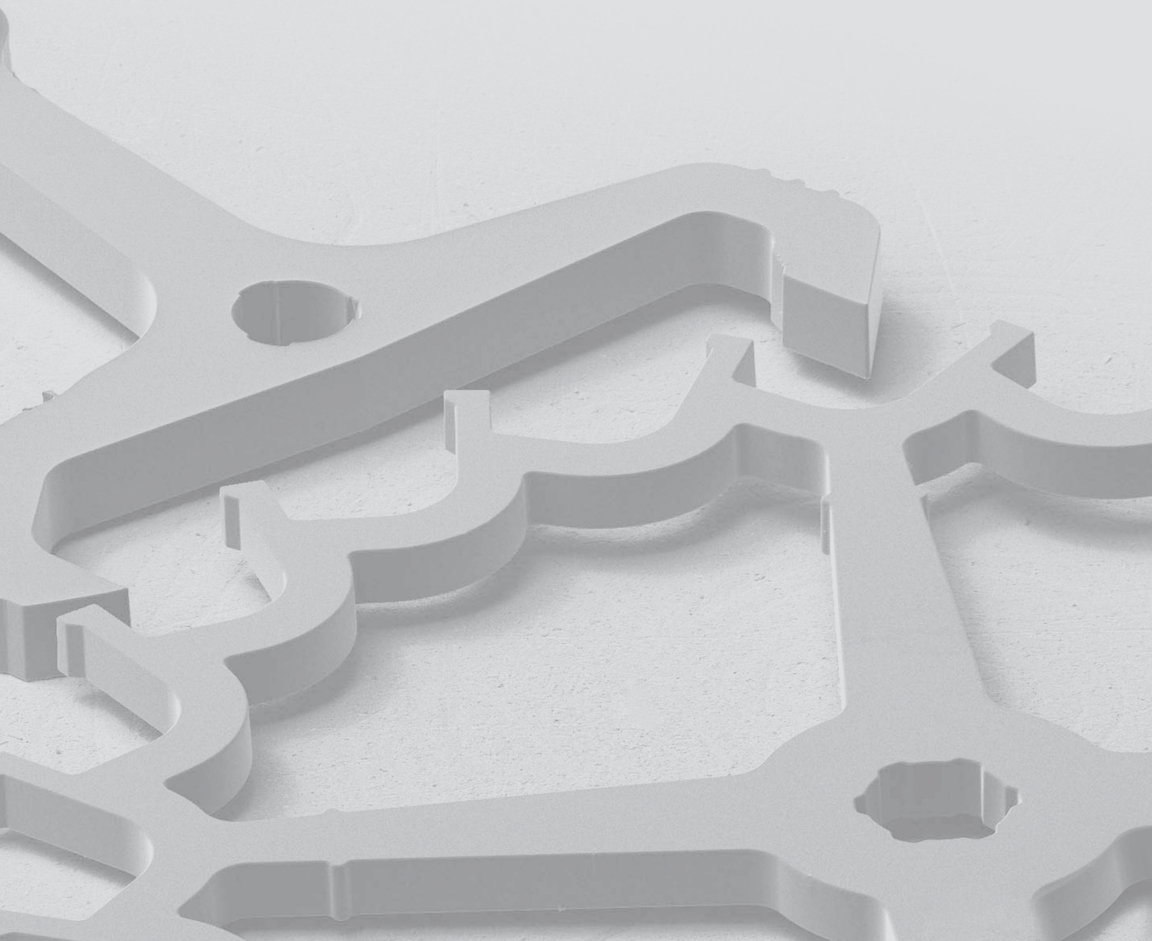

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**Synthesis, Properties, and Commercial Applications**

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Pan Stanford Publishing

*Published by*

Pan Stanford Publishing Pte. Ltd.
Penthouse Level, Suntec Tower 3
8 Temasek Boulevard
Singapore 038988

Email: editorial@panstanford.com
Web: www.panstanford.com

**British Library Cataloguing-in-Publication Data**
A catalogue record for this book is available from the British Library.

**Carbon-based Nanomaterials and Hybrids: Synthesis, Properties, and Commercial Applications**

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Cover image: The atomic force microscope image (AFM) demonstrates the ultra-smooth surface of a nanocrystalline diamond layer with a root mean square roughness of 16 nm (top left/courtesy Matthias Wiora, Ulm University).
Free standing piezoresistive (*n*-type) diamond microcantilevers with a thickness of typically 10 µm and a length between 500 µm and1000 µm (top right/courtesy Neda Wiora, Ulm University).
Diamond-based escapement wheel and anchor—the heart of a lubrication-free mechanical watch (bottom/courtesy Diamaze Microtechnology SA, La Chaux-de-Fonds, CH).

ISBN 978-981-4316-85-9 (Hardcover)
ISBN 978-981-4411-41-7 (eBook)

Printed in the USA

# Contents

# Preface

Carbon-based materials date centuries back in their synthesis and usage and comprise a whole realm of different crystallographic structures, chemical bonds and geometries, such as natural and synthetic diamond, different variations of graphite, carbon fibers, and their composites. Over the past few years however, the controlled reduction of sample size into the range of a few nanometers at least in one dimension has received growing interest and a renaissance of the field.

Diamond is renowned as a material with superlative physical qualities, most of which originate from the strong covalent bonding between its atoms. Diamond has the highest hardness and highest thermal conductivity of any bulk material and those properties determine the major industrial applications of diamond in cutting and polishing tools, windows, heat spreaders, and the scientific applications in diamond knives, diamond anvil cells, and as an optical detector material. Although diamond is thermodynamically less stable than graphite, the conversion rate from diamond to graphite is negligible at standard conditions.

Graphite generally can be considered as a well-ordered kind of coal and represents an electrical conductor, a semimetal that is mechanically rather soft due to its weak Van der Waals interlayer bonds and thus forms a two-dimensional structure. The basic unit of graphite is one layer of carbon, which is called graphene.

Furthermore, carbon nanotube or generally carbon fiber is a material consisting of fibers typically 5–10 μm in diameter. To produce carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber. This alignment gives a high strength-to-volume ratio with carbon fibers exhibiting furthermore high stiffness, high tensile strength, low weight, high chemical resistance, and low thermal expansion. Carbon fibers are usually combined with other materials to form a composite. When combined with a plastic resin, it forms a carbon fiber–reinforced polymer that has a very high strength-to-weight ratio, is lightweight, and is extremely rigid although somewhat brittle with an abundance of applications in aerospace, automotive, and civil engineering; motorsports; and others.

Considering more recent developments, the miniaturization of material dimensions, components, and structures nowadays is reaching dimensions of a few nanometers—a development which generally is termed nanotechnology. In general, most materials properties are changed dramatically when reaching nanometer sizes and thus nanoscaled materials can be engineered through the controlled and size-selective synthesis of nanoscale building block with tunable and improved physical and chemical properties.

This trend over the last decades has been taken up here and represents the main focus of the present book applied to C-based materials. Nano-sized C-based materials include several modifications and geometries, such as nanocrystalline diamond, amorphous diamond-like carbon (DLC), C-based aerogels, and carbon nanotubes (CNTs), while some other new developments including fullerenes and graphene are still in their infancy. The book compiles and details cutting-edge research, and several applications are described within the fields of energy, microelectronics, biomedicine, and beyond. Furthermore, a perspective is given, including a diversity of industrial applications and market opportunities for C-based nanoscale materials and devices in the future.

With eight chapters contributed by world-class scientists and engineers, this book covers most recent developments in the science and technology of C-based nanomaterials for a number of industrial applications. It addresses both academia and industry research and engineering in this fast-developing field.

**Hans-Jörg Fecht**
**Kai Brühne**
**Peter Gluche**
Spring 2014

# Acknowledgment

The financial and intellectual support of BMBF-VDI/VDE IT (C-HYBRID 16SV5320K and VIP-DiM 16SV6053) as well as Ulysse Nardin, Le Locle, Switzerland, and Audemars Piguet, Le Brassus, Switzerland, are gratefully acknowledged.

We would also like to thank the publishers, in particular, Stanford Chong and Shivani Sharma; and a number of graduate students working in the group, including M. Mertens, M. Mohr, N. Wiora, and D. Zhu for their excellent contributions; and Helga Faisst and Carolyn Kotlowski for their expert technical support.