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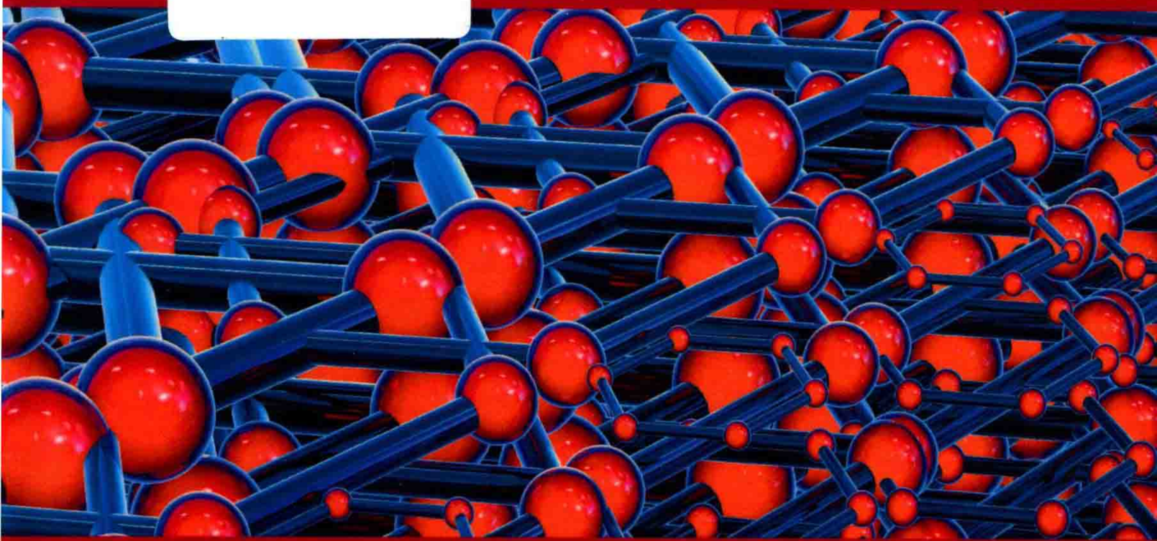

Silicon Carbide One-dimensional Nanostructures

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Silicon Carbide One-dimensional Nanostructures

Foreword

Silicon carbide (SiC) is a wide bandgap semiconductor having factors of merit scaling well above those of well-established semiconductors such as silicon (Si), which became the material of choice of the 20th Century. SiC is a ceramic with very interesting mechanical properties (hardness and composite materials) and a very high thermal conductivity, just like copper. In addition, due to its chemical inertness and its ability to resist radiation damage, this compound semiconductor is an especially suitable electronic material to be used in harsh environments. Furthermore, SiC is also biocompatible, making it promising for interfacing an electronic material with biology. SiC is also very abundant in the interstellar medium and could be a key material in the route toward prebiotic life apparition in the universe. Indeed, SiC was found by Henri Moisan at the end of the 19th Century on a meteorite fallen in the Diablo Canyon, Arizona. The overall properties of SiC have triggered many advanced applications such as high-temperatures, high-power, high-frequencies devices and sensors. Finally, SiC is also an especially interesting material in nanoscience and nanotechnology, such as in the self-organization of massively parallel Si passive/active atomic lines at its surface, or of carbon nanotubes, and an excellent substrate for the epitaxial growth of high-quality graphene. At this point, it is appropriate to mention that the research programs on Si nanowires resulted in about 9,000 publications since the year 2000, while in contrast, similar research on SiC remains rather marginal with no more than 400 publications, despite the much higher performances of SiC when compared to corresponding Si nanowires – see the Introduction section.

In this context, the present book, written by Latu-Romain and Ollivier, brings novel insights in describing a very original and innovative approach to grow SiC nanotubes and nanowires. Indeed, at variance to the well-established methods to grow nanowires, the idea presented here is to grow SiC nanowires/nanotubes using Si nanowires grown through a top-to-bottom approach as an initial template. Then, selective carburization of the external surface core–shell leads to SiC growth covering the outer surface of these Si nanowires. Subsequently, the carburization process leads also to Si removal by out-diffusion, leaving only high-quality SiC nanotubes. These one-dimensional nano-objects potentially open exciting new applications not only in electronics or sensors, but also toward biology and medical applications such as selective drug delivery.

In this book, the authors start with an introduction, and then all the documents are organized into four different chapters, ending up with a conclusion. The Introduction presents the topic of interest, with a short historical background, putting issues and challenges into perspective. Chapter 1, entitled "*Properties of SiC Based One-Dimensional Nanostructures*", provides a thorough presentation of the SiC crystallography, describing the structure of some of the most important SiC polytypes (out of more than 170). It includes cubic 3C, hexagonal 2H, 4H and 6H, and rhomboidal 15R. They also present a general view of their physical, chemical and electronic properties, which are key aspects for understanding SiC, especially at the nanometric and subnanometric scales. Moving next to Chapter 2, entitled "*State of the Art of the Growth of SiC-Based One-Dimensional Nanostructures*", the authors address the key points that make the central issues of their book, namely the growth techniques and challenges. The first section describes the state of the art growth of SiC nanowires. The second section is devoted to the state-of-the-art growth of SiC nanotubes, while the third and last sections move to state-of-the-art growth of SiC-based core–shell nanowires. Chapter 3 is entitled "*An Original Growth Process: the Carburization of Si Nanowires*" and presents the novel approach and key methods that have been developed to do so. It is organized in six sections, respectively, describing Si nanowires, the carburization of bulk silicon, experimental applications, the growth of core–shell Si–SiC nanowires and of SiC nanotubes, and a summary of the study of the carburization of silicon nanowires. Finally, in the last chapter, Chapter 4 entitled "*SiC-Based One-Dimensional Nanostructure Technologies*", the authors describe some promising potential or already existing novel applications. The top-down approach using SiC plasma etching for SiC nanowires is described in the first section, while the mechanics and potentially subsequent novel composites are addressed in the second section. In the third section, energy applications, such as energy storage through super-capacitors, are envisioned, while in the fourth section, novel electronics applications, such as SiC nanowire transistor, are proposed and described. Finally, biology applications and future works are described and commented upon the fifth and six sections, respectively. In the Conclusion, the authors summarize the know-how and the subsequent results for these one-dimensional SiC nanostructures and draw perspectives toward future promising applications covering various high-tech domains of science and technology.

We can therefore envision that this book is providing a very suitable document based on sound grounds that will be especially useful for scientists and engineers performing research and developing technological applications. Furthermore, this same book will also serve as a very appropriate, pertinent and well-focused tutorial for graduate master as well as for PhD students.

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Introduction

Increasing communication requirements, as well as the need for processing of data or diagnostics in general, which we have experienced for several decades now, have allowed several sectors, such as microelectronics, information technology (IT) or even telecommunications and biotechnology to become strategic, globalized and recognized industrial sectors. These different technological domains have greatly benefited from scientific progress, notably in the domains of materials and microelectronics.

The discovery of semiconducting materials, for example, materials whose behavior with regard to current can be modified by adding impurities, is definitely one of the advances that allowed for the revolutionizing of most of the domains named above. Among these materials, silicon has become an emblem, to the point of becoming nearly hegemonic. Despite this, its physical properties limit its use to certain sectors such as optoelectronics, or hinder the obtaining of satisfactory results, like the low yields of solar cells, for example.

On top of the materials-related physical limitations, there are also technological limitations, when for reasons of space, yield or mobility, new technologies reach nanometric sizes.

This scale change has brought new challenges for those involved in the industry and researchers, the main ones being the creation of nanometric objects and the control of the physical and chemical properties of these objects. This book fits into the general scope of this challenge.

One-dimensional (1D) nanostructures, such as nanowires or nanotubes, are of interest to the scientific community with regard to their growth, characteristics and their potentially exceptional properties compared to the bulk material. Semiconducting 1D nanostructures are widely studied, mainly those made of silicon and III-V materials for their electronic and optic properties.

In this book, we will look at the unique case of the growth of 1D nanostructures of silicon carbide (SiC). In the literature, this subject has not been explored greatly as the synthesis of nanostructures is difficult. The polytypism of SiC – and therefore its structural stability – is indeed an additional difficulty in the growth of such structures.

Figure I.1 illustrates the growing interest of researchers for semiconducting 1D nanostructures since the 2000s. The number of publications recorded in *Isi Web of Knowledge,* which include the keywords *Si nanowire* and *SiC nanowire,* is shown. The number of publication reaches 9,000 in the first case and only 400 in the second case. Only half of these works are on the study of the growth of these nanostructures. Finally, the studies related to the synthesis of SiC nanowires are 20 times less common than those on silicon nanowires. However, we will see that the unique properties of SiC merit that time be spent on the study of the growth of these nano-objects. The different techniques used in the synthesis of SiC nanowires and nanotubes are reviewed. We have also elected to study an original growth process based on the carburization of SiC nanowires. This approach has allowed for work on the growth of SiC 1D nanostructures from the excellent base that is the single crystalline silicon nanowire. Original nanostructures, such as Si-SiC core-shell nanowires and SiC nanotubes, have thus been obtained. The different application domains for mechanics, energy, electronics and the biology of the use of these structures are finally described.

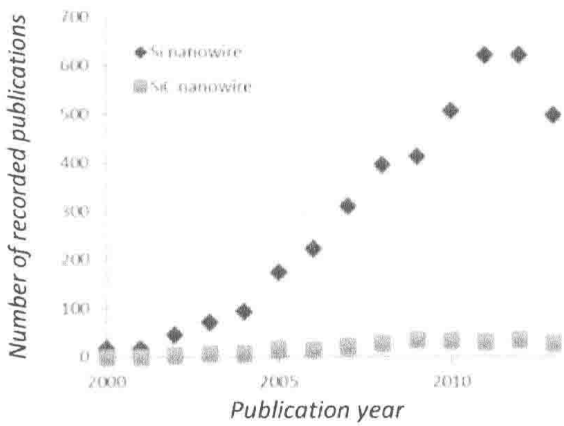

Figure I.1. *Number of publications recorded in Isi Web of Knowledge by the year from 2000 to 2013 containing the words Si nanowire and SiC nanowire (statistics carried out December 9th 2013)*

List of Acronyms

1D	One-dimension
CVD	Chemical vapor deposition
FET	Field Effect Transistor
FIB-SEM	Focused ion beam-scanning electron microscope
HR-TEM	High-resolution transmission electron microscope
IT	Information technology
JFET	Junction Field Effect Transistor
LA	Longitudinal acoustic
LO	Longitudinal optic
MEMS	Micro-electro-mechanical systems
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
NS	Nanostructure
NT	Nanotube
NW	Nanowire

SEM	Scanning electron microscope
SF	Stacking fault
SGPS	Solid and Gases Pure Substances
SiC	Silicon carbide
STEM	Scanning transmission electron microscope
TA	Transverse acoustic
TEM	Transmission electron microscope
TMS	Tetramethylsilane
TO	Transverse optic
VLS	Vapor-Liquid-Solid
VS	Vapor-Solid
VSS	Vapor-Solid-Solid

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