POROUS SILICON

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PREFACE

The recent discovery of room temperature (RT) visible luminescence from porous silicon has raised a great deal of interest and effort on porous Si and related materials. Traditionally, crystalline silicon (c-Si), the heart of modern computer and electronic industry, is an indirect semiconductor with a band gap near 1.1 eV at room temperature and can emit weak light via phonon assistance only in the near infrared region. This fact limits silicon applications in optoelectronics, where compound semiconductors with direct band gaps, such as GaAs, InP, and so on, are the dominant materials at present. The difficulties in combining these compounds with the well-developed Si integrated technology hinder further applications and developments. However, the observations of bright visible photoluminescence and electroluminescence from porous Si and related materials have changed this trend. Since 1990, investigation of porous silicon, with more than 1000 papers and reports has opened the door for silicon to play a role in optoelectronics.

In order to present a review of these recent important achievements and to promote further research and applications, we have invited scientists, professors, and engineers working on the frontiers of this field to contribute to this review book. The book, *Porous Silicon*, contains twenty-two chapters and is grouped into five sections: *General Topics*, *Light Emission Mechanism*, *Optical and Multi-technique Study*, *Surface-Chemistry and Theory*, and *Application and Si-based Materials*. This division is primarily for the readers' convenience. It is almost impossible to avoid overlapping discussions in these chapters dealing with various topics related to fundamental mechanisms. Each one in the book focuses on a special subject and is prepared by one or more experts in the field. Each is a comprehensive review of the achievements and contributions from the authors in their field of expertise. From this book, readers can delve into the up-to-date research results on porous Si, including luminescence, fabrication, surface and electro-chemistry, structures, optics and lattice dynamics, various mechanisms for visible light emission, theories, device applications, Si-based nanocrystallites and organosilicon, and so on. Some historical review and introductory materials are also included to acquaint students and new scientists and engineers with the field.

The *General* section includes four chapters. C. Pickering, who pioneered the visible photoluminescence from porous Si at low temperature ten years ago, presents Chapter 1, *Optical properties of porous silicon*

(1984-1993): *correlation with microstructure*. U. Gösele and V. Lehmann, who first observed the shifts of the transmission curve from porous Si and associated the blue shifts to a quantum confinement effect, contribute their review, *Porous silicon quantum sponge structures: formation mechanism, preparation methods and some properties*. In Chapter 3, *Doping in silicon nanocrystallites*, which may serve as a self-limiting process in electrochemical etching, is reviewed by R. Tsu and D. Babic from theoretical points of view. S. S. Iyer and Y. H. Xie give their review, *Light emission from silicon*, in Chapter 4.

Section II, ***Light Emission Mechanism***, contains four reviews concerning various mechanisms of the visible light emission from porous silicon. X. Wang from Fudan University presents, *New insight on the luminescence mechanism of light-emitting porous silicon* in Chapter 5. T. Motohiro et al. from Toyota-Labs wrote, *An oligosilane bridge model: nanocomposite nature of the origin of the intense visible photoluminescence of porous silicon* in Chapter 6. F. Koch and V. Petrova-Koch, of München, contribute *The surface state mechanism for light emission from porous silicon* in Chapter 7. F. Kozlowski et al. from Fraunhofer Institut present *Micro Raman investigations and a structure model for electroluminescent porous n-silicon* in the last chapter of this section. Four different types of mechanisms or models of the origins of light emission from porous silicon are presented and reviewed here. Additional mechanisms and models are described in other chapters of this book.

Section III, ***Optical and Multi-technique study***, involves four contributions. Chapter 9, *Multi-technique study of porous silicon membranes by Raman scattering, FTIR, XPS, AES and SIMS*, is contributed by Z. C. Feng and A. T. S. Wee from National University of Singapore. Chapter 10, *The photo excitation and luminescence processes in porous silicon*, is presented by G. G. Qin at Peking University. Chapter 11, *Photoluminescence excitation spectroscopy of porous silicon*, is given by N. M. Haegel of Fairfield University and L. Wang of University of California, Los Angeles. Chapter 12, *Formation and optical properties of porous silicon*, is presented by Q. S. Li and R. C. Fang from University of Science and Technology of China.

In Section IV, ***Surface, Chemistry and Theory***, K. H. Li et al. presents Chapter 13, *Porous silicon: surface chemistry*. S. M. Prokes of Naval Research Laboratory contributes Chapter 14, *The relationship of structure and surfaces to light emission properties in porous silicon*. V. P.

Parkhutik at Madrid Autonomous University gives Chapter 15, *Morphology of porous silicon layers: experimental studies and theoretical modeling*. Two theorists, C. G. Van de Walle and J. E. Northrup from Xerox Palo Alto Research Center prepare Chapter 16, *First principles calculations of light emission from Si-based materials*.

Section V, *Application and Si-based Materials*, consists of device applications and investigation of other Si-based materials, such as microcrystalline Si, SiGe alloy and siloxene. Chapter 17, *Device Applications of porous and nanostructured silicon*, is contributed by Y. S. Tsuo, Y. Xiao and C. A. Moore from Denver. Chapter 18, *Porous silicon: microstructure, optical properties and application to light emitting diodes* is presented by Y. Kanemitsu et al. from Japan. R. W. Fathauer of Jet Propulsion Laboratory, California Institute of Technology, presents Chapter 19, *Properties of light-emitting porous Si and $\text{Si}_{1-x}\text{Ge}_x$ alloys produced by stain etches*. M. Stutzmann and M. S. Brandt at Walter Schottky Institut, Germany, prepare Chapter 20, *Spin resonance investigations of porous silicon and siloxene*. The last section, Chapter 21, *Silicon-interface adsorbed gas superlattices*, representing a latest development in light emission from silicon-based materials, is presented by the Charlotte group. And finally Chapter 22, *Light-emitting porous silicon: a status report*, is presented by P. Fauchet from Rochester.

The weak optical transition in silicon is the consequence of an indirect fundamental bandgap which necessitates a relaxation in the conservation of crystal momentum for any appreciable light emission. Most researchers attribute the observation of strong light emission to quantum size effects. However, quantitatively, a drastic size reduction to a few nanometers is needed. Since an appreciable fraction of the silicon atoms appears on the surface, surely surface species, including silicon-oxide interface and even siloxene molecules must play a significant role. For this reason, a great debate ensued. From the technological viewpoint, the high porosity required in effecting efficient luminescence presents a formidable drawback, however, no one has shown that high porosity is required. It is quite obvious to us, as the editors of this review book, that quantum confinement and surface effects are both present and together play a role in promoting porous silicon as a potential answer to silicon optoelectronic devices. Rather than focusing on the poor mechanical and structural aspects of porous

silicon, it is important to recognize the achievements in porous silicon research in optical properties and as a stepping stone to new types of composites with nanostructures.

The academic points of view from different chapter authors in this book might differ very much. We have made no attempt to comment on these reviews; instead, we list the detailed contents below. The list of subject matter can serve to orient the readers.

In the recent years, American Physical Society (APS), Materials Research Society (MRS), and other academic societies and organizations have organized several successful symposiums, workshops and meetings on porous silicon and related materials, which greatly helped us to organize the authors for this book. Many current results also appeared in various academic journals and magazines, which also served in the identification of active researchers in the field. Nonetheless, the editors would like to express regrets for possible omissions. We would also like to compliment and to thank all the scientists, engineers, professors, and students for their effort in making this review possible. The editors are thankful to National University of Singapore and University of North Carolina at Charlotte for their support in editing this book.

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