

Preface

This is the third volume in the Silicon Photonics series, which we started in 2004 with a book simply entitled Silicon Photonics. At that time, the field was in its infancy and the research was concentrated on the basic building blocks for integrated photonic circuits. Then in 2011, we edited the second volume, Silicon Photonics II: Components and Integration. This volume was devoted to the description of the different requirements needed to integrate the basic building blocks into integrated circuits. Today, we present this book where we focus on the state of the art of silicon photonics in industry and also make comparisons with other competing technologies. It is impressive to see the paradigmatic change that the field has witnessed in just 5 years. Specifically, silicon photonics has moved from the research laboratory to manufacturing companies. Indeed, in the first books, the contributors were mainly from academia, while in the present volume, more than half of them are from companies.

In Chap. 1, the use of silicon photonics to solve the bandwidth bottleneck of inter-chip interconnects is addressed. Fully hybrid integrated systems are described and a bandwidth density of 30 Tbps/cm² is demonstrated. In addition, the problem of the temperature reliability of the system is addressed with the discussion of error-free data links operating up to 125 °C at 25 Gbps. The use of quantum physics and its integration in silicon photonics is at the heart of Chap. 2. Quantum technologies promise to revolutionize the way we handle information. Though the control of quantum systems remains extraordinarily challenging, silicon quantum photonics, with its density and manufacturability, is a credible challenger.

One still open issue in silicon photonics is the temperature dependence of many of its components. Chapter 3 reviews the various approaches to overcome the high temperature dependence of wavelength-filtering devices such as ring resonators and arrayed waveguide gratings. Based on specific designs, athermal devices are presented. Key to this achievement is a proper simulation software that enables the development of athermal geometries. Chapter 4 discusses the challenges and the opportunities in photonic integrated circuit design software tools, examines existing design flows for photonic design, and how these fit different design styles.

Modeling of chip-scale interconnects is presented in Chap. 5 with reference to high-performance computer systems that need to distribute extremely large amounts of data in an energy efficient manner. A fully functional co-integrated hardware–software system is presented to encompass device functionality, control schema, and software logic seamlessly. Each layer, ranging from individual device characterization, to higher layer control of multiple devices, to arbitration of networks of devices, and ultimately to encapsulation of subsystems to create the entire computing system is explored.

Silicon photonics is going to enable more and more commercial applications as the technology matures. This will increase the demand for foundries to produce the photonic integrated chip. The accessibility to foundries becomes then a critical aspect for any business models. Chapter 6 reports on the foundry services for multi-project wafer shuttles, customized process runs, and small volume production. Results and challenges in setting up a CMOS manufacturing foundry line for silicon photonics research and development along with commercialization are also presented. A specific aspect is the move from the chip to the packaged device. In Chap. 7 the path from a device-by-device packaging to automatic packaging, which allows scaling to high volumes, is described. Packaging challenges still remain in areas such as fiber array coupling, laser source and electronic integration, and efficient thermal management. The problems and the challenges to automatize the fiber array pigtailling and the laser integration in relation to silicon photonics devices are addressed in Chap. 8. Solving these manufacturing issues, whether silicon photonics needs a dedicated fab or not, still remains an open topic. Megafabs produce 10,000–25,000 12" wafers per week in their normal capacity. The silicon photonics industry has the potential for approximately 25,000 wafers per year or ~500 wafers per week by 2021. This volume forethought and the path to low-volume production of silicon photonics devices are presented in Chap. 9. With growing production volume, dedicated fabs are needed. Chapter 10 presents the development of silicon photonics within a CMOS line. Cost process issues, efficient electronic and photonic integration, a usable design kit, an industrial testing strategy, and a low cost packaging strategy are discussed and presented from the perspective of a complete industrialization of silicon photonics.

Applications of silicon photonics are diverse. Chapter 11 reports on the use of silicon photonics for signal processors in microwave photonic frontends. These are especially attractive for their compact size and performance. Silicon photonics for optical interconnect applications is addressed in Chap. 12. The development of transceivers is presented starting from wafer process technology to photonic device libraries, to integration with electronic circuits and optical probing technology. An alternative approach to silicon photonics transceivers is discussed in Chap. 13. The heterogeneous integration of InP into a silicon photonics platform enables the inclusion of all photonic elements in a cost-effective manufacturing process. Chapter 14 compares the two technologies and reviews the technical merits of silicon photonics devices and integrated circuits. Various applications such as chip-scale optical interconnects, short-reach communications in datacenters and supercomputers, and metro/long-haul optical transmissions are enabled by the

technical merits of silicon photonics. Specifically, in Chap. 15 silicon photonics for telecom and datacom is reviewed. Detailed architectures to enable high-performance systems are discussed. Chapter 16 focuses on the fundamental and high-speed characteristics of small-footprint integrated optical modulators designed and fabricated with silicon photonics. Here the application framework is digital coherent communication in optical fiber links and the demonstration of long-haul transmission of up to 1000 km in length at a bit rate as high as 128 Gbps is reported. Datacenters are the application discussed in Chap. 17. An overview of optical interconnect requirements for large-scale datacenters is presented here together with a comparison between silicon photonics technologies and more traditional options in meeting these requirements. Finally, Chap. 18 unfolds a technology roadmap of VLSI photonics applications for datacenters from an industrial perspective. The roadmap of the microelectronics industry development indicates that Si will remain the prime microelectronics material. Therefore, sophisticated silicon photonics devices will serve as the backbone for new architecture to bring the next generation of datacenters to the world soon.

We feel honored to be the editors of this series of volumes on Silicon Photonics, because we have witnessed the evolution of this field from a privileged point of view and could accompany it from its infancy to full maturity. Nevertheless, in these volumes, we have also tried to perceive the future of silicon photonics in terms of both industrial applications and fundamental research. We thank all the authors of the present volume for their invaluable contributions, the staff of Springer for their support, and our co-workers for sharing with us their research in this field. We look forward to further excitement ahead and new developments in silicon photonics, and we hope to share them with you, our esteemed readers, in the next volume of this series.

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