We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Introductory Chapter: Unique Applications of Silicon Photonics

Lakshmi Narayana Deepak Kallepalli

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.78963>

1. Introduction

Current technological demands require two key components: miniaturization of devices and integration of multifunctional components onto a single chip offered at low cost. The continuous improvement in meeting the demands of integrated circuits has been enabled by incremental efforts of miniaturization of the transistor [1]. Moore's law states that the minimum feature size shrinks by a factor of 0.7 every 2 years [2, 3]. There has been tremendous growth in the areas of semiconductors and electronics to meet these requirements. However, the research on silicon photonics started only in the 1980s [4]. The advantage of silicon is that its properties can be tailored by doping, which makes it suitable for applications both in electronics and photonics. For useful applications, the technology also plays a major role along with the material. Here, a few applications in photonics domain have been demonstrated.

2. Silicon photonics: a brief overview

Silicon photonics is a disruptive technology, in contrast to conventional technology, as it is vast and has diverse applications. Some important applications include high-performance computing, sensors, and data centers. The photonics industry is rapidly growing to meet the semiconductor and electronics industry. One key advantage can be that of the accessible bandwidth. Most of the electronic devices are limited to GHz speeds in contrast to higher speeds accessible to optical devices. This has spurred researchers develop optical devices operated with faster speeds and at low cost. Silicon photonics is accepted as the next-generation communication systems and data interconnects as it brings the advantages of integration and

photonics-high data densities and transmission over longer distances. One potential application was of waveguides in silicon-on-insulator (SOI) wafer structures in 1985 [5, 6], which was commercialized later in 1989 by Bookham Technology Ltd. [7].

The commercialization for sensor applications began in the 1990s, with integrated gyroscopes and pressure sensors being the first prototype products. Later on, commercialization changed to wavelength-division-multiplexing (WDM) telecommunications products. Here, the low-cost integration capabilities of the platform enabling high-density chips that can perform the multiplexing of many channels of high-speed data onto a single fiber demonstrated the fundamental commercial promise of the technology. The later versions of the data communications advanced the realization of SOI-waveguide p-i-n junction modulators [6] and Ge-, SiGe-based photodetectors, and modulators [8].

3. Role of ultrafast lasers

Ultrafast lasers are known to tailor the properties of materials locally anywhere in 3D to explore salient functionalities. When ultrafast laser pulses (femto and pico) are tightly focused into a material, large peak intensities at the focal volume result in nonlinear absorption and ionization (e.g., multiphoton, tunneling, or avalanche type) guiding to an array of changes in material physical and optical properties. These include negative refractive index (RI) change, positive RI change, or simply void formation. This highly controlled modification endows fs LDW a unique two-dimensional/three-dimensional (2D/3D) microfabrication capability without the use of any phase mask or special sample preparation. Large-scale structures can be fabricated easily by placing the material on a stacked 3D translation stages and control the motion in 3D pattern. In the past, several optical components such as structures for MEMS [9], 2D and 3D gratings [10–17], optical data storage [18–22], waveguides [23–26], photonic band gap materials [27–29], and microfluidic structures/devices [30–34]. Ultrafast lasers have been used to change the properties (optical, electrical, chemical, and physical) of silicon toward different applications like surface-enhanced Raman scattering (SERS) for sensors, and waveguides [35, 36]. Silicon also has been tested for its wettability for diverse applications in biophotonics and tissue engineering [36]. There is a need to integrate all these optical components like sensor and waveguides onto Si wafer.

4. Conclusions

The unique combination of properties of silicon combined with photonics technology has been demonstrated in several applications in the past and current. Tailoring the properties of material (silicon) such as bandgap and properties of light such as wavelength, energy, and pulse duration are shown to be the key components in several applications. In this book, some of the key applications in the area of sensors and waveguides have been highlighted.

Author details

Lakshmi Narayana Deepak Kallepalli

Address all correspondence to: lkallepa@uottawa.ca

National Research Council Laboratory for Attosecond Science, Joint University of Ottawa,
Ottawa, Ontario, Canada

References

- [1] Shin C. State-of-the-art silicon device miniaturization technology and its challenges. *IEICE Electronics Express*. 2014;**11**(10):1-11. DOI: 10.1587/elex.11.20142005
- [2] Moore GE. Cramming more components onto integrated circuits. *Proceedings of the IEEE*. 1998;**86**:82. DOI: 10.1109/JPROC.1998.658762
- [3] International Technology Roadmap for Semiconductors (ITRS). Available from: <http://public.itrs.net>
- [4] Thomson D, Zilkie A, Bowers JE, Komljenovic T, Reed GT, Vivien L, Marris-Morini D, Cassan E, Virot L, Fédéli J-M. Roadmap on silicon photonics. *Journal of Optics*. 2016; **18**:073003
- [5] Soref RA, Lorenzo JP. Single-crystal silicon: A new material for 1.3 and 1.6 μm integrated-optical components. *Electronics Letters*. 1985;**21**:953
- [6] Reed G, Headley W, Png C. Silicon photonics: The early years. *Proceedings of SPIE*. 2005;**5730**:596921
- [7] Rickman A. The commercialization of silicon photonics. *Nature Photon*. 2014;**8**:579-582
- [8] Liu J, Cannon DD, Wada K, Ishikawa Y, Jongthammanurak S, Danielson DT, Michel J, Kimerling LC. Tensile strained Ge p-i-n photodetectors on Si platform for C and L band telecommunications. *Applied Physics Letters*. 2005;**87**:011110
- [9] Juodkazis S, Yamasaki K, Marcinkevicius A, Mizeikis V, Matsuo S, Misawa H, Lippert T. Microstructuring of silica and polymethylmethacrylate glasses by femtosecond irradiation for MEMS applications. *Materials Research Society Symposium Proceedings*. 2002;**687**:B5-B25
- [10] Higgins DA, Everett TA, Xie AF, Forman SM, Ito T. High-resolution direct-write multi-photon photolithography in poly(methyl methacrylate) films. *Applied Physics Letters*. 2006;**88**:184101
- [11] Scully PJ, Jones D, Jaroszynski DA. Femtosecond laser irradiation of polymethylmethacrylate for refractive index gratings. *Journal of Optics A: Pure and Applied Optics*. 2003;**5**:S92-S96

- [12] Wochnowski C, Cheng Y, Meteva K, Sugioka K, Midorikawa K, Metev S. Femtosecond-laser induced formation of grating structures in planar polymer substrates. *Journal of Optics A: Pure and Applied Optics*. 2005;**7**:493-501
- [13] Baum A, Scully PJ, Basanta M, Thomas CLP, Fielden PR, Goddard NJ, Perrie W, Chalker PR. Photochemistry of refractive index structures in poly (methyl methacrylate) by femtosecond laser irradiation. *Optics Letters*. 2007;**32**:190-192
- [14] Baum A, Scully PJ, Perrie W, Jones D, Issac R, Jaroszynski DA. Pulse-duration dependency of femtosecond laser refractive index modification in poly (methyl methacrylate). *Optics Letters*. 2008;**33**:651-653
- [15] Hirono S, Kasuya M, Matsuda K, Ozeki Y, Itoh K, Mochizuki H, Watanabe W. Increasing DE by heating phase gratings formed by femtosecond laser irradiation in poly(methyl methacrylate). *Applied Physics Letters*. 2009;**94**:241122
- [16] Katayama S, Horiike M, Hirao K, Tsutsumi N. Structures induced by irradiation of femtosecond laser pulse in polymeric materials. *Journal of Polymer Science: Polymer Physics*. 2002;**40**:537-544
- [17] Katayama S, Horiike M, Hirao K, Tsutsumi N. Structure induced by irradiation of femtosecond laser pulse in dyed polymeric materials. *Journal of Polymer Science: Polymer Physics*. 2002;**40**:2800-2806
- [18] Glezer EN, Milosavljevic M, Huang L, Finlay RJ, Her TH, Callan JP, Mazur E. Three-dimensional optical storage inside transparent materials. *Optics Letters*. 1996;**21**:2023-2025
- [19] Cumpston BH, Ananthavel SP, Barlow S, Dyer DL, Ehrlich JE, Erskine LL, Heikal AA, Kuebler SM, Lee IYS, McCord-Maughon D, Qin JQ, Rockel H, Rumi M, Wu XL, Marder SR, Perry JW. Two-photon polymerization initiators for three dimensional optical data storage and microfabrication. *Nature*. 1999;**398**:51-54
- [20] Nie Z, Lee H, Yoo H, Lee Y, Kim Y, Lim K-S, Lee M. Multilayered optical bit memory with a high signal-to-noise ratio in fluorescent polymethylmethacrylate. *Applied Physics Letters*. 2009;**94**:111912
- [21] Tang H, Jiu H, Jiang B, Cai J, Xing H, Zhang Q, Huang W, Xia A. Three-dimensional optical storage recording by microexplosion in a doped PMMA polymer. *Proceedings of SPIE*. 2005;**5643**:258-263
- [22] Kallepalli DLN, Alshehri AM, Marquez DT, Andrzejewski L, Scaiano JC, Bhardwaj R. Ultra-high density optical data storage in common transparent plastics. *Nature Scientific Reports*. 2016;**6**:26163. DOI: 10.1038/srep26163
- [23] Watanabe W, Sowa S, Tamaki T, Itoh K, Nishii J. Three-dimensional waveguides fabricated in poly(methyl methacrylate) by a femtosecond laser. *Japanese Journal of Applied Physics*. 2006;**45**:L765-L767
- [24] Zoubir A, Lopez C, Richardson M, Richardson K. Femtosecond laser fabrication of tubular waveguides in poly (methyl methacrylate). *Optics Letters*. 2004;**29**:1840-1842

- [25] Wang K, Klimov D, Kolber Z. Waveguide fabrication in PMMA using a modified cavity femtosecond oscillator. *Proceedings of SPIE*. 2007;**6766**:67660Q
- [26] Ohta K, Kamata M, Obara M, Sawanobori N. Optical waveguide fabrication in new glasses and PMMA with temporally tailored ultrashort laser. *Proceedings of SPIE*. 2004;**5340**:172
- [27] Mendonca CR, Cerami LR, Shih T, Tilghman RW, Baldacchini T, Mazur E. Femtosecond laser waveguide micromachining of PMMA films with azoaromatic chromophores. *Optics Express*. 2008;**16**:200-206
- [28] Zhou G, Ventura MJ, Vanner MR, Gu M. Use of ultrafast-laser-driven microexplosion for fabricating three-dimensional void-based diamond-lattice photonic crystals in a solid polymer material. *Optics Letters*. 2004;**29**:2240-2242
- [29] Straub M, Gu M. Near-infrared photonic crystals with higher-order bandgaps generated by two-photon photopolymerization. *Optics Letters*. 2002;**27**:1824-1826
- [30] Farson DF, Choi HW, Lu C, Lee LJ. Femtosecond laser bulk micromachining of microfluidic channels in poly (methyl methacrylate). *Journal of Laser Applications*. 2006;**18**: 210-215
- [31] Haiducu M, Rahbar M, Foulds IG, Johnstone RW, Sameoto D, Parameswaran M. Deep-UV patterning of commercial grade PMMA for low-cost, large-scale microfluidics. *Journal of Micromechanics and Microengineering*. 2008;**18**:115029-115035
- [32] White YV, Parrish M, Li X, Davis LM, Hofmeister W. Femtosecond micro- and nano-machining of materials for microfluidic applications. *Proceedings of SPIE*. 2008;**7039**: 70390J
- [33] Gómez D, Goenaga I, Lizuain I, Ozaita M. Femtosecond laser ablation for microfluidics. *Optical Engineering*. 2005;**44**:05110
- [34] Day D, Gu M. Microchannel fabrication in PMMA based on localized heating by nano-joule high repetition rate femtosecond pulses. *Optics Express*. 2005;**13**:5939-5946
- [35] Merlen A, Sangar A, Torchio P, Kallepalli LND, Grojo D, Utéza O, Delaporte P. Multi-wavelength enhancement of silicon Raman scattering by nanoscale laser surface ablation. *Applied Surface Science*. 2013;**284**:545-548
- [36] Zorba V, Persano L, Pisignano D, Athanassiou A, Stratakis E, Cingolani R, Tzanetakis P, Fotakis C. Making silicon hydrophobic: Wettability control by two-lengthscale simultaneous patterning with femtosecond laser irradiation. *Nanotechnology*. 2006;**17**(13): 3234-3238