Chapter 1

Introductory Chapter: Unique Applications of Silicon Photonics

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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.

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