Optical Logic Devices Based on Photonic Crystal for Telecommunication Applications

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Abstract— Semiconductor materials and devices have always dominated the world of electronics in the form of gates, diodes, transistors, etc. In today's world rapidly growing technologies we require advancements in every field specially electronics. So we move in the context of this advancement form electronics to the world of optics. Our effort through this work is to make the semiconductor devices work in the optical field. Hence, we use the most promising optical structure of photonic crystals by implementing optical logic gates instead of analytical electronic gates. Optical components that permit the miniaturization of photonic integrated circuits to a scale comparable to the wavelength of light are good candidates for future optical network and optical computing. All-optical communication is one of the solution for the electronic bottleneck viz speed and size, thanks to their ability to process the information at the speed of light. Optical logic gates are the fundamental components in optical digital information processing.

Key words: All-optical logic gates, telecommunication, photonic, photonic band gap (PBG)

I. INTRODUCTION

All-optical logic gates are key components in all-optical signal processing techniques. In recent years, the demands for all-optical signal processing techniques in telecommunication systems are rapidly increasing. It is now accepted that digital electronics is not able to respond to these demands in the future. In order to response this demands, many efforts have been performed. All-optical logic gates with high performance speed play a main role in signal processing and optical networks. Different structures have so far been presented to recognize the performance of all-optical logic gates. Initially, all optical logic gates based on semiconductor optical amplifier properties (SOA) were reported. However, some limitations such as latency time, power consumption, speed and size of these structures cause it is used less. Various proposed structures differ in the design, material, structure, operation wavelength, operation speed, power consumption and easy to integrated. In order to optimize these characteristics All-optical logic gates based on photonic crystal was considered and investigated.

Photonic crystals are dielectric material that the dielectric constant is periodically varied in space. The light waves could not propagate through the photonic crystals for some frequency ranges, this frequency range is called forbidden band gap. The structures of photonic crystal logic gate benefits various characteristics of photonic crystals.

II. LITERATURE REVIEW

Jae Hun Kim et al.,[1] proposes a novel design of an all-optical XOR gate by using cross-gain modulation of semiconductor optical amplifiers successfully at 10 Gb/s. Kun-Yi Lee et al.,[2] presents a 4×2 encoder logic gate, based on the array of two dimensional triangular lattices photonic crystal composed of cylindrical silicon rods in air. The main structure of the device is a combination of both line defect Y branch and coupler photonic crystal waveguides. I. S. Nefedov et al.,[3] proposes change in the refractive index of GaAs due to the light-induced generation of nonequilibrium charge carriers is shown to substantially change the transmission of a one-dimensional GaAs/GaAlAs photonic band-gap (PBG) structure, allowing low-threshold photonic-crystal optical logic gates. Zhangjian Li et al.,[4] proposes optical pulse controlled all-optical logic gate with multifunctional performance and asymmetric structure theoretically in SiGe/Si materials using multimode interference principle. By switching the optical signal to different input waveguide ports, the device can function as OR, NOT, NAND, and NOR gates simultaneously or individually. Kun-Yi Lee et al.,[5] designed an all-optical AND gate in PPC, as an ultra compact component for planar light wave circuit integration with suitable choice of parameters, perform this task. The PPC waveguides are composed of circular dielectric rods set in two-dimensional triangular lattice. W.-P. Linl et al.,[6] proposes, a novel all-optical NOR logic gate based on 2-D PC. This gate is consisted with two optical T -type switches. Mortaza Noshad et al.,[7] have designed AND, NOT, and NOR logic gates based on photonic crystal structure employing cross-waveguide geometry with nonlinear rods using finite difference time domain (FDTD) method. Masaya Notomi et al.,[8] have demonstrated all-optical bistable switching operation of resonant-tunnelling devices with ultra-small high-Q Si photonic-crystal nanocavities. M. Notomi et al.,[9] have designed , fabrication, and measurement of photonic-band-gap (PBG) waveguides, resonators and their coupled elements in two dimensional photonic crystal (PhC) slabs have been investigated. They have studied various loss mechanisms in PBG waveguides and have achieved a very low propagation loss (~1 dB/mm). Zhiwen Chen et al.,[10] proposed multimode interference principle and free-carrier plasma dispersion effect, a SiGe/Si 2-to-4 decoder switch and simulated. A.P. Kabilan et al.,[11] Have designed and simulated of novel all-optical fundamental X-NOR and NAND logic gates based on two dimensional photonic crystals Adonis Bogris et al.,[12] proposed A simple reconfigurable all-optical logic gate based on cross-phase modulation in highly nonlinear fibers. J.-Y. Kim et al.,[13] 10 Gbit=s all-optical composite logic gates with XOR, NOR, OR and NAND functions using SOA-MZI structures have demonstrated in this paper.

Wen-Piao Lin1et al.,[14] have presented, a novel all-optical NOR logic gate based on two dimension (2-D) photonic crystals (PC) and simulated by a cascade of two all-optical switches. Ye Liu et al.,[15] have demonstrates theoretical design of ultra compact all-optical AND, NAND, OR, and NOR gates with two-dimensional nonlinear photonic crystal slabs. Rekha In 16] it has been have presented the design of All-optical OR logic gate based on 2-D (two dimension) photonic crystals. To realize this, we consider the photonic crystals (PCs) with a square lattice of dielectric rods (refractive index=3.40). Gloria the working of NOT logic gate which is implemented using the 2D photonic crystal instead of using conventional semiconductor devices. Various schemes with and without semiconductor optical amplifiers are discussed and compared. The optical gates are classified according to their design structures. It is divided into two major divisions that is, non-semiconductor optical amplifier based gates and semiconductor optical amplifier based gates. In non-semiconductor optical amplifier based gates, different schemes have been proposed to create non-linearity which is discussed. The semiconductor optical amplifier based gates of different design structures are discussed to show the probe pulse that is modulated in different ways to obtain results. It deals with the compact and high speed OR logic gate design in 2D photonic crystals with size of 77 μm2. To realize this, silicon rod based triangular lattice photonic crystal structure with refractive index 3.4, lattice constant 540nm and rod radius 100 nm is considered.

Photonic crystals (PCs) are engineered structures that have a photonic functionality on the materials level, enabling the complete prohibition or allowance of the propagation of light in certain directions and at certain frequencies. They accomplish this feat by means of a periodic modulation of the refractive index of a suitable host medium. Within these three-dimensionally periodic structures, the distribution of electromagnetic modes and their accompanying dispersion relations differ dramatically from those of bulk media. PCs are, in this regard, highly attractive because they allow the design and manipulation of their photonic properties based on a so-called band-structure engineering.

In particular, it swiftly turns out from a pertinent modal analysis that PCs possess photonic band gap (PBG) regions, i.e., regions in which the propagation of photons is forbidden and the density of allowed electromagnetic states vanishes. These regions can be designed to exist in one-, two- or three-dimensional structures, depending on whether the dielectric constant is periodic along one direction and homogeneous in the others (1D PCs), periodic in a plane and homogeneous in the third direction (2D PCs), or periodic in all three directions (3D PCs).

Although 1D PCs have been known and well-studied for decades in the form of highly reflecting dielectric (Bragg) mirrors, the idea of constructing a 2- or 3D PC is no more than about two decades old. From the start, 3D PCs have attracted enormous attention by scientists, owing to the prediction that they posses highly unusual features, such as full 3D PBGs, and also because of the conceivable applications of these structures. Some of the best known 3D PCs are the Yablonovite structure, the layer-by-layer structure, the silicon woodpile structure, and the opal and inverse-opal PC structures.

Photonic crystal (PhC) is a promising candidate as a platform on which to construct devices with dimensions of a few wavelengths of light for future photonic integrated circuits. The photonic crystal concept was proposed in 1987 , and the first 3D experimental photonic crystal with full band gap was manufactured in 1991. The existence of band gap in PhC structures led to many prominent applications in integrated optics. Photonic crystals are nowadays used for different applications such as filters , modulators , switches, beam splitters, and super prisms for multiplexing and demultiplexing for example. All-optical switching is one of the most important targets for photonics. However, this goal has been considered difficult to achieve because of the inefficiency of optical nonlinearity in materials.

In Ref 15, we attempted to overview the current status of QD based ultrafast devices which may find ways for their application to future optical networks. From the viewpoint of integrating devices to realize a compact, energy-efficient photonic system, major advantages of QD-based photonic devices include:

A. High Energy Efficiency

QD ridge-waveguide lasers were demonstrated with a threshold current density of 17 A/cm2 [16]. All optical QD switches were operated at an energy density of 0.1-1.0 fJ/μm2 [17]. Both values are smaller than those for their quantum well (QW) counterparts.

B. High Thermal Stability

QD lasers, combined with p-type modulation doping technique, achieved temperature insensitivities from 0 to 85oC [18-22]. QD semiconductor optical amplifiers (SOAs) were reported to exhibit ultralow noise figure [23] and negligible pattern effect [24], due to the absence of carrier heating effects in spatially separated QDs.

C. Broad Bandwidth

QD-based external cavity lasers can be tuned within a wavelength range larger than 70 nm because of the inhomogeneous broadening of the gain spectra [25]. For the same reason, self-assembled QDs are employed as saturable absorbers for mode-locked lasers [26, 27].

D. Compatibility with An Si-Platform

Recent research has proven that QD lasers can be monolithically grown on Ge/Si substrates using a special capability of dot layers to filter out anti-phase boundaries and threading dislocations [28-30].

III. CONCLUSION

Photonic crystal (PhC) is a promising candidate as a platform on which to construct devices with dimensions of a few wavelengths of light for future photonic integrated circuits. Photonic crystals (PCs) are engineered structures that have a photonic functionality on the materials level, enabling the complete prohibition or allowance of the propagation of light in certain directions and at certain frequencies. All-optical communication is one of the solution for the electronic bottleneck viz speed and size, thanks to their ability to process the information at the speed of light. Optical logic gates are the fundamental components in optical digital information processing.

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