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All-Optical Switch Based on Nonlinear Kerr Effect in Photonic Crystal Micro Ring Resonators

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Abstract

This paper presents theoretical and applied information in the field of alkali-aggregate reactivity (AAR) in concrete. The aspects discussed include basic concepts of the reaction and expansion mechanisms, conditions conducive to the development and the sustainability of AAR in concrete, field and laboratory investigation programs for evaluating the potential alkali-reactivity of concrete aggregates, selection of preventive measures against AAR, and the management of structures affected by AAR. Lithium Nitrate inhibitor in the form of liquid solution was used in the concrete mix as an admixture to prevent ASR. This substance will react with silica gel and produces a non-expansive material when absorbing water to prevent cracking. In addition Lithium inhibitor, ground granulated furnace slag, a well-known cement substitution pozolan was used in the specimens as a less expensive material. Silica fume as a cement replacement material was also used to observe its ASR inhibiting effect. Slag and silica fume have a lower Alkali content in comparison to ordinary Portland cement and can reduces the rate of ASR. In this study Effective recommendations to produce durable concrete resistant to ASR are proposed for the new concrete structures.

Keywords: nonlinear Kerr effect, photonic crystal, ring resonator, switch.

INTRODUCTION

All-optical switch 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. In order to response this demands, many efforts have been performed. 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 switches based on photonic crystal was considered and investigated [1-5].

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. Since the wave can be localized in the ring resonator, lower optical intensity is require to actuate the nonlinear effect and achieve the switching mechanism. Hence, nonlinear properties of ring resonators were used widely in all-optical integrated circuits [6-9].

In this paper, we demonstrate an intensity switch based on nonlinear photonic crystal T-type ring resonator. Our photonic crystal consists of dielectric rods in air substrate. As we will show this structure is applicable for photonic integrated circuits. Plane wave expansion (PWE) method is used for calculating photonic band gap and Finite difference time domain (FDTD) is used for analyzing propagation of electromagnetic wave in the time domain [10-11].

Theory of the nonlinear ring resonator

Photonic crystals are dielectric materials that the dielectric constant is periodically varied in space and thus the light waves with frequency in the forbidden band gap range could not propagate through the photonic crystals. When we create a line defect in the photonic crystal, a single mode waveguide can obtained. In addition, a T-type waveguide and a ring create a T-type photonic crystal ring resonator.

The light power couples to the photonic crystal ring resonator at the resonant frequency and hence we are in drop state. On the other hand, at a non-resonant frequency, the wave does not couple to the photonic crystal ring resonator and hence we are in through state. When low intensity light at the resonant wavelength of the photonic crystal ring resonator, applied to the structure the light will be coupled to the ring, whereas if the light intensity increases, Kerr nonlinear effect cause the refractive index of the ring to increase based on Eq. (1).

$$n = n_0 + n_2 I \tag{1}$$

Where n is total refractive index, n_0 is linear refractive index n_2 is Kerr effect coefficient and I is intensity of applied. Also by considering new refractive index, the permittivity coefficient comes from Eq. (2).

$$\varepsilon = n^2 = (n_0 + n_2 I)^2 \tag{2}$$

Increasing refractive index in turn make the resonant wavelength of ring resonator to red shifted.

Thus by increasing the input light intensity the resonant wavelength of ring resonator will change. For example, we can tune the input light intensity in the T-type ring resonator so that all the energy coupled to the resonator and guided in the drop waveguide, all the energy transmitted to the through waveguide, or a fraction of energy guided in the drop waveguide and another fraction in the through waveguide. This will help us in the designing of all-optical switches by applying proper light intensity.

All-Optical switching

In this paper, a square lattice of Chalcogenide glass rods with refractive index of 3.1 in air substrate is used for designing the structure [12-13]. The dielectric rods have a high Kerr nonlinear coefficient of $n_2 = 9.0\times10^{-17} m^2/W$. We have designed our Switch with a square lattice nonlinear photonic crystal consisting of two input waveguide and a T-type ring resonator. The schematic of a nonlinear T-type ring resonator is illustrated in fig. (1)**Hata! Başvuru kaynağı bulunamadı.**. The radius of the ring is 3a and the radius of the rods are 0.2a where "a" is the lattice constant.

The plane wave expansion (PWE) method is used to derive the dispersion diagram of the Photonic crystal structure. We should consider the structure without any defects to calculate photonic band gap. The first Brillion zone and dispersion diagram of the structure is shown in Fig. (2).

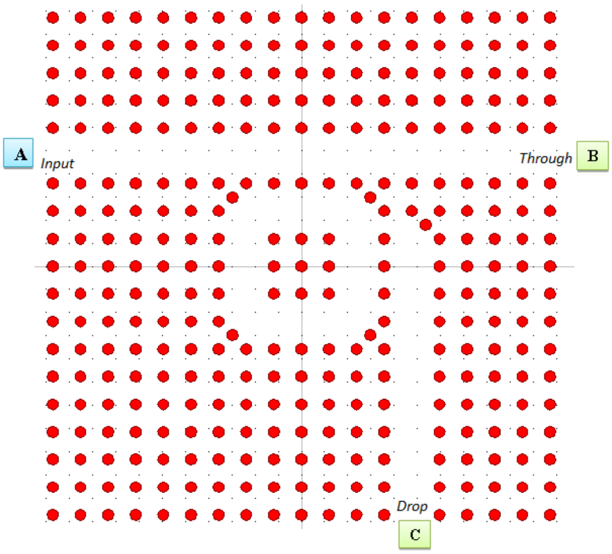

Figure 1. The schematic of a nonlinear T-type ring resonator

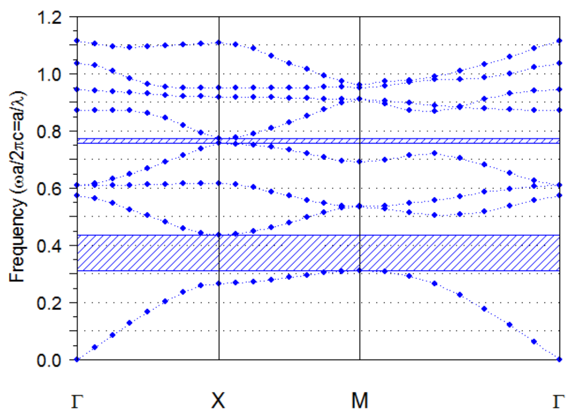

Figure 2. Band diagram in a square lattice of Chalcogenide glass rods (ε = 9.61) in the air substrate for TM mode.

The TM Band structure shows that this structure has band gap in the range of $0.3116 \leq a/\lambda \leq 0.4365$, where "a" is the lattice constant, and λ indicates the optical wavelength in free space. Therefore, the light with frequency in this rang cannot propagates in the photonic crystal lattice.

As depicted in the normalized transmission spectra of the structure in Fig. (3), the T-type ring resonator has two resonant frequencies of 0.3834a/λ and 0.4222a/λ. We select 0.3834a/λ as operational frequency.

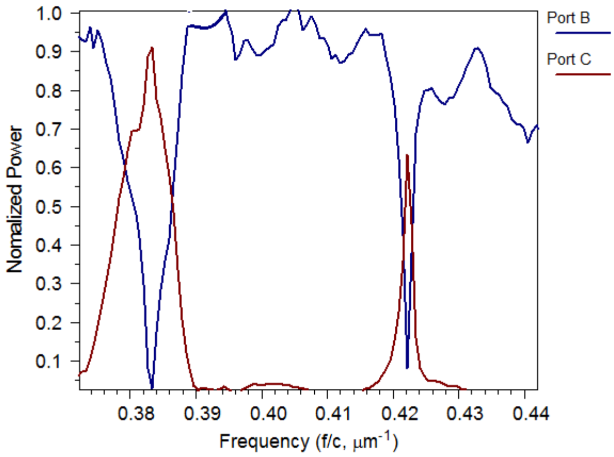

Figure 3. Transmission spectrum of T-type ring resonator

In addition, in the Fig. (3), we can see that at the frequency of 0.3863a/λ, approximately half of energy is in the port B and another half is in the port C and at the frequency of 0.39a/λ, all of energy transmitted to the port B.

As theoretically described in the previous section with low light intensity at the resonant frequency of 0.3834a/λ the energy transmitted toward port C. By increasing the light intensity, due to nonlinear Kerr effect, the transmission spectrum shown in Fig. 3 shifts to the left. We increased and tuned the input intensity so that the frequency of 0.39a/λ (frequency that the energy transmitted toward port B) shifts to the operational frequency of 0.3834a/λ. We do this in order to have the energy at the port B and therefore be able to design switch. The optical field pattern in the low and high intensities for the T-type ring resonator shown in Fig. (4).

The output power levels in these two states are shown in Fig. (5). At the low intensity, the power of port B reaches to the power level of 0.94 after cT=100μm (0.34ps). Also, the power of port C reaches to the power level of 0.05 after cT=140μm (0.47ps). At the high intensity, the power of port B reaches to the power level of 0.2 after cT=150μm (0.5ps). Also, the power of port C reaches to the power level of 0.98 after cT=255μm (0.85ps). Thus, the maximum delay time obtained about 0.85ps and the T-type ring resonator has a lower switching time of about 0.85ps.

Fig. (6) depicts the transmission ratio of the T-type ring resonator versus the input power. The blue curve shows output at port B and the red curve shows output at port C. As we see in the Fig. (6) at the first power is at the port C and as the power increases the power of port C decreases and the power of port B increases. At the threshold power of 2.77mW, the transmission ratio is about 0.5. With input power more than threshold power the transmitted power to port B is greater than port C.

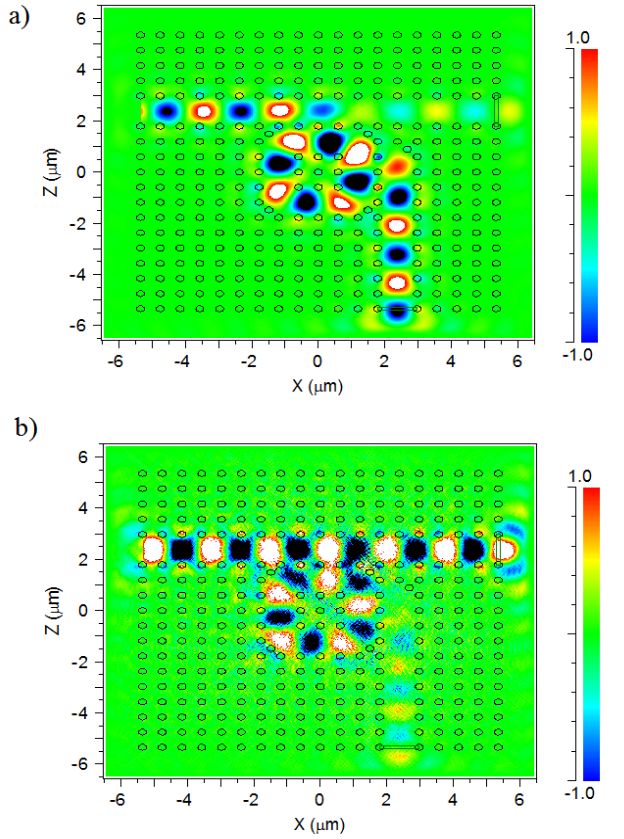

Figure 4. The optical field pattern of the T-type ring resonator for two states, (a) low intensity input; port B is “OFF” and port C is “ON” (b) high intensity input; port B and C is “ON”.

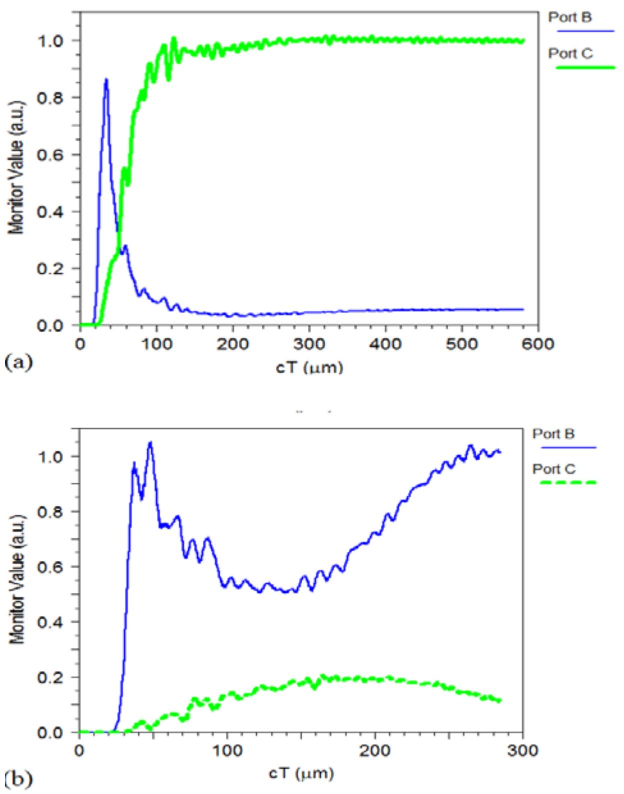

Figure 5. The output power levels of the T-type ring resonator for two states, (a) low intensity input (b) high intensity input.

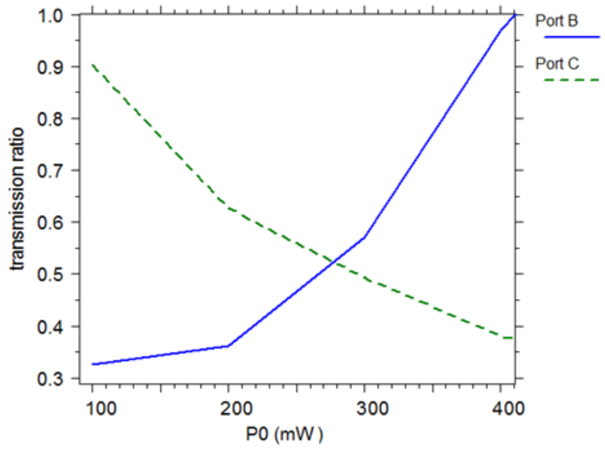

Figure 6. The transmission ratio of the T-type ring resonator versus the input power.

CONCLUSION

A new scheme for implementation of all-optical switch based on nonlinear photonic crystal T-type ring resonator had been demonstrated in this study. The photonic crystal structure has a square lattice of Chalcogenide glass rods with a high Kerr nonlinear coefficient in the air substrate. The T-type ring resonator had a low switching time of less than 1ps, which was about 0.85ps. The performance of the structure for central wavelength was derived equal to 1.55µm. As the structure had a simple geometric shape with clear operating principle and sizes of about 14.4µm×14.4µm, it is suitable in constructing photonic integrated circuits systems as well as future optical computing components.

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