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All-optical analog-to-digital converter based on Kerr effect in photonic crystal

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ABSTRACT

In this paper, a novel all-optical analog-to-digital converter (AOADC) is proposed and simulated for proof of principle. This AOADC is designed to operate in the range of telecom wavelength (1550 nm). A cavity made of nonlinear Kerr material in photonic crystal (PhC), is designed to achieve an optical analog-to-digital conversion with 1 Tera sample per second (TS/s) and the total footprint of 42 μm^2. The simulation is done using finite-difference time domain (FDTD) method.

1. Introduction

Electronic-to-optical conversion and vice versa in integrated optical circuits and networks reduce the bandwidth and limit the speed of operation. One of the best solution proposed is to take advantage of all-optical devices. In recent years, all-optical devices, such as switches [1–3], logic gates [2,4–6], add-drop filters [7,8], and multiplexers [9,10]. based on photonic crystal (PhC) structures have been designed and proposed with appropriate dimensions. Nowadays, in modern communication systems, AOADCs in all-optical networks and processors can lead to increase of speed and bandwidth due to elimination of electronic conversion. However, AOADCs suffer from some limitations that hinder them to be developed commercially. For example, The first generation AOADC was designed based on a hundred-kilometer optical fiber which was not possible to be considered in all-optical integrated circuits [11,12]. Another structures was designed based on Chalcogenide in which although a significant improvement was achieved comparing the former mentioned structure, the dimension still is too large (six centimeters) to be an appropriate candidate for optical integrated circuits [13]. There are various designs for AODCs using PhCs; but operation speed of these devices is not acceptable for ultra-high-speed optical processing [14–16]. In this paper, an AOADC with tiny dimensions and maximum sampling rate up to 1 TS/s is proposed based on nonlinear Kerr effect in PhC. All the calculations and simulations of the designed AOADC are done based on Plane wave expansion (PWE) and finite-difference time domain (FDTD) methods, respectively. While most of the research in this area has been limited to theoretical and numerical analysis, there have also been practical implementation of photonic crystal structures [17,18]. In this work, an analytical and numerical investigation of the novel all-optical analog-to-digital converter (AOADC) is explored and AOADC mechanism is described analytically and findings verified by structure FDTD simulations. The results of this analytical and numerical investigation paves the path and set the direction towards the realization of all-optical AOADC which can find applications in communication and nanoplasmonic circuits. The paper is arranged in following way. In part 2, a defected cavity based on Kerr defect is designed and analyzed. Part 3 introduces the designed ADC based on the discussed defected cavity. Finally, the results are discussed and concluded in part 4.

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2. Defected cavity based to Kerr effect

In recent years, different logic gates and ADCs have been proposed based on cavity and nonlinear properties due to their high-speed performance and low-power consumption [19,20]. In this paper, PhC is designed based on air rods with radii r = 0.3a in GaAs substrate with refractive index of 3.49 at $\lambda = 1550$ nm, and the lattice constant of a = 434 nm. Removing a row of rods in the structure results in the band diagram of PhC, as shown in Fig. 1.

Removing two of the up and down rods along the deleted row as shown in Fig. 2, a cavity is created with a specific resonant frequency. Fig. 3 shows the model of the cavity of the structure. Based on temporal coupled mode theory [21] (TCMT) near the resonant modes, the waveguide transmission can be expressed by:

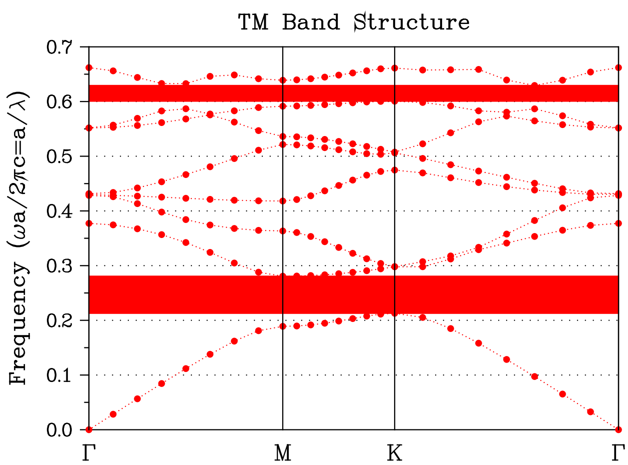

Fig. 1. The simulated band diagram of the designed PhC.

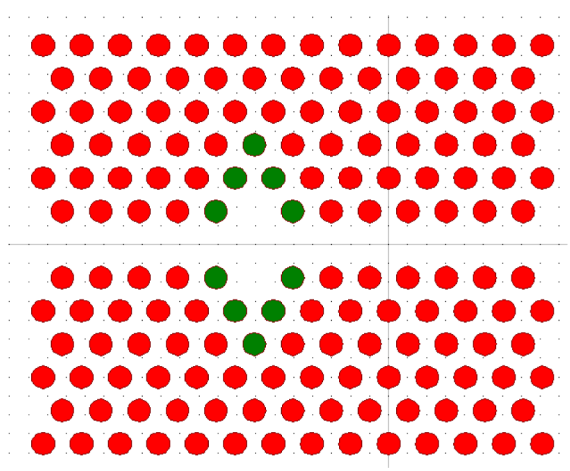

Fig. 2. Schematic of the designed PhC including removed rods and green dots creating the cavity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

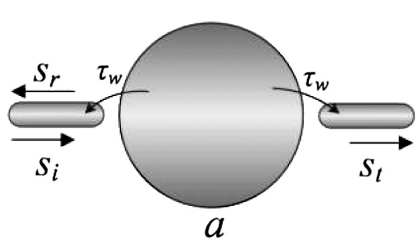

Fig. 3. Schematic of photonic crystal cavity model

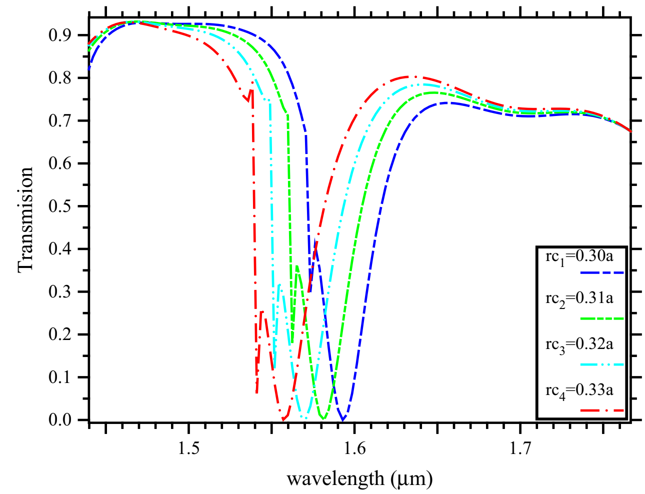

Fig. 4. Simulated transmission vs. wavelength for the PhC with the radii of the rods around the defect of $r_{C1} = 0.30a$, $r_{C2} = 0.31a$, $r_{C3} = 0.32a$, and $r_{C4} = 0.33a$.

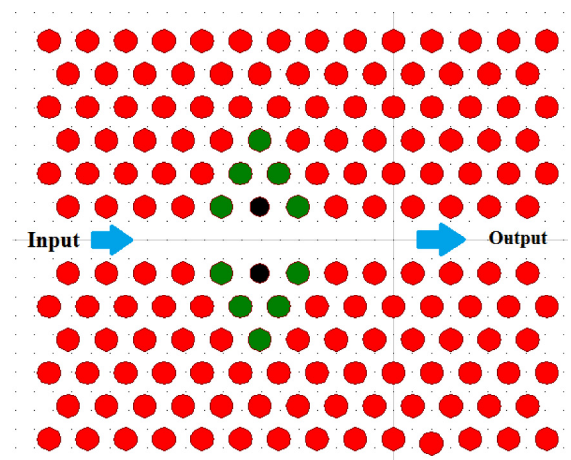

Fig. 5. Schematic of the designed PhC including the located nonlinear Kerr material (black dots) within the cavity.

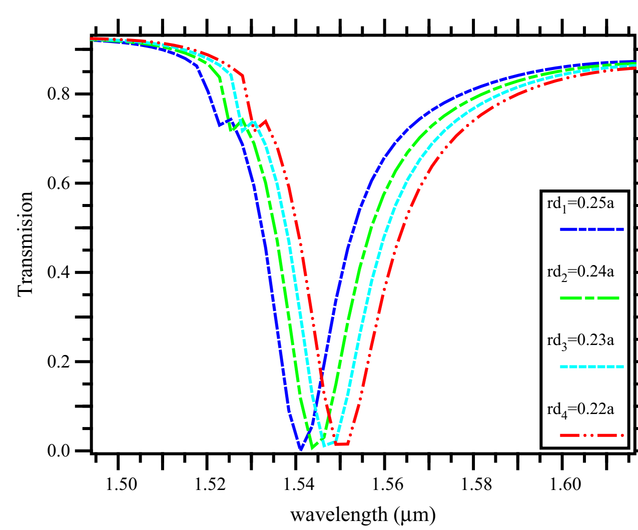

Fig. 6. Simulated transmission vs. wavelength for the PhC with the nonlinear Kerr defects with radii of $r_{d1} = 0.25a$, $r_{d2} = 0.24a$, $r_{d3} = 0.23a$ and $r_{d4} = 0.22a$.