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Design and Analysis of Even-Positioned Cavity-Based Optical Amplification Device in Dielectric Metasurface

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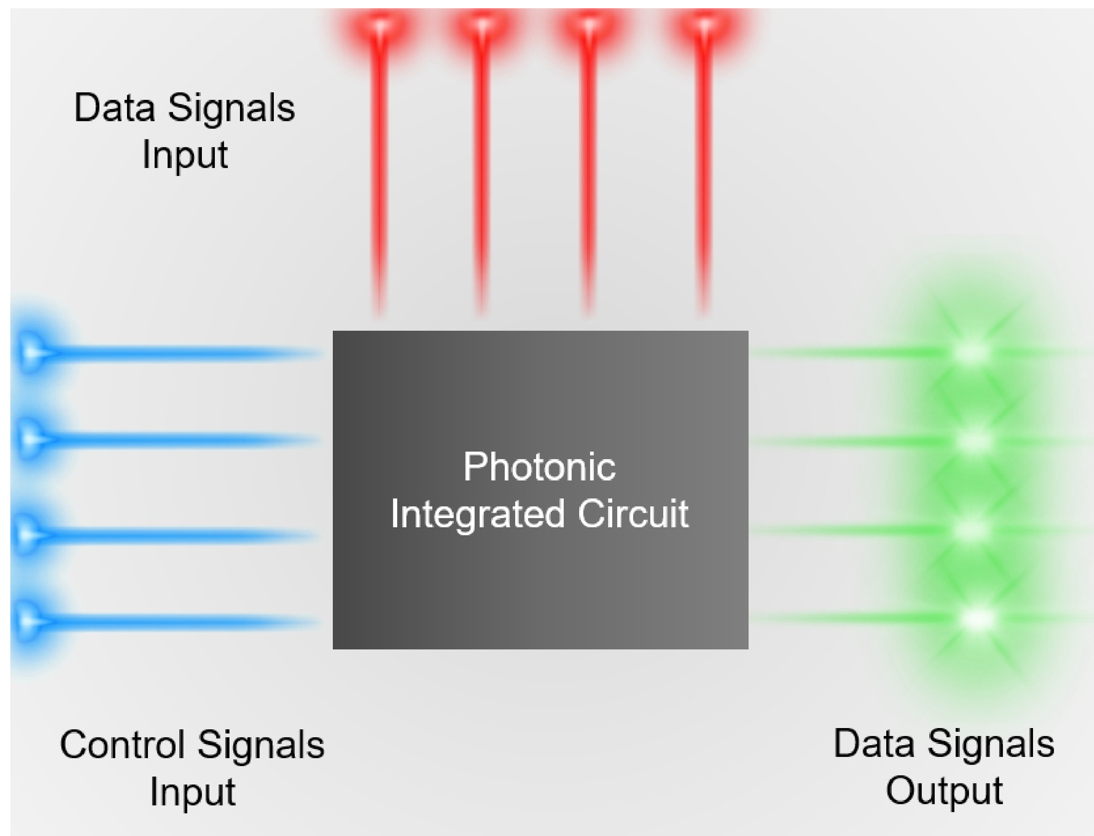
Abstract

Recently, the development in the field of optical technology is exemplary, precisely relating to the design of the components, necessary for optical integrated circuits. This research work investigates optical amplification action in a 2D Photonic Crystals (PhCs) based metasurface with variable radius even-positioned PhC-cavity. Two optical signals are used, i.e., data signal coupled into the optical structure using the phenomenon of the Guided-mode-resonances (GMR) and a pump signal index-guided into the optical structure. The pump signal is used to amplify the data signal and the PhC-cavity is used for spectral tuning of the device operating in the near-infrared (NIR) range. The designed structure comprises of an optical waveguide packed in between the layers of a substrate and cladding. The design and analysis of the proposed device is performed using Finite-difference Time-domain (FDTD) approach in an open-source software package. The investigated results present optical amplification action for a PhC-cavity of radius i.e., greater than the standard radius of the PhC-elements used in the investigated structure. Moreover, as a concluded fact, PhC-cavity nearer to the symmetric point of the optical structure will greatly influence the amplification phenomena and tuning of the GMR modes. The designed device can be used in applications relating to optical transistors, filters, and integrated circuits.

Motivation

- Keeping in view the technological needs of the world in terms of fast processing speed, computational power, and reduced-heating effects, a breakthrough in the existing electronic technology is crucial.
- Recently, devices operating with optical technology are being preferred over electronics for data processing, as they are already being used in long-haul communication systems due to their ability of transferring the data at THz frequencies Fig. 1(a).
- However, as the optical technology is still in its infancy stage, therefore the challenges corresponding to its design and fabrication are higher especially relating to the amplification of the signals and energy confinement .
- Moreover, Photonic Crystals (PhCs) are the periodic-nano-structures, capable of controlling light at wavelength scale.
- In this research, a comparative study corresponding to optical amplification is studied comprising of a PhC-based varying radius (rc) even-positioned cavity targeting the NIR range around 1.55 μm, achieving the phenomenon of the optical amplification by using two optical signals i.e., data signal and pump signal as reflected in Fig. 1(b).



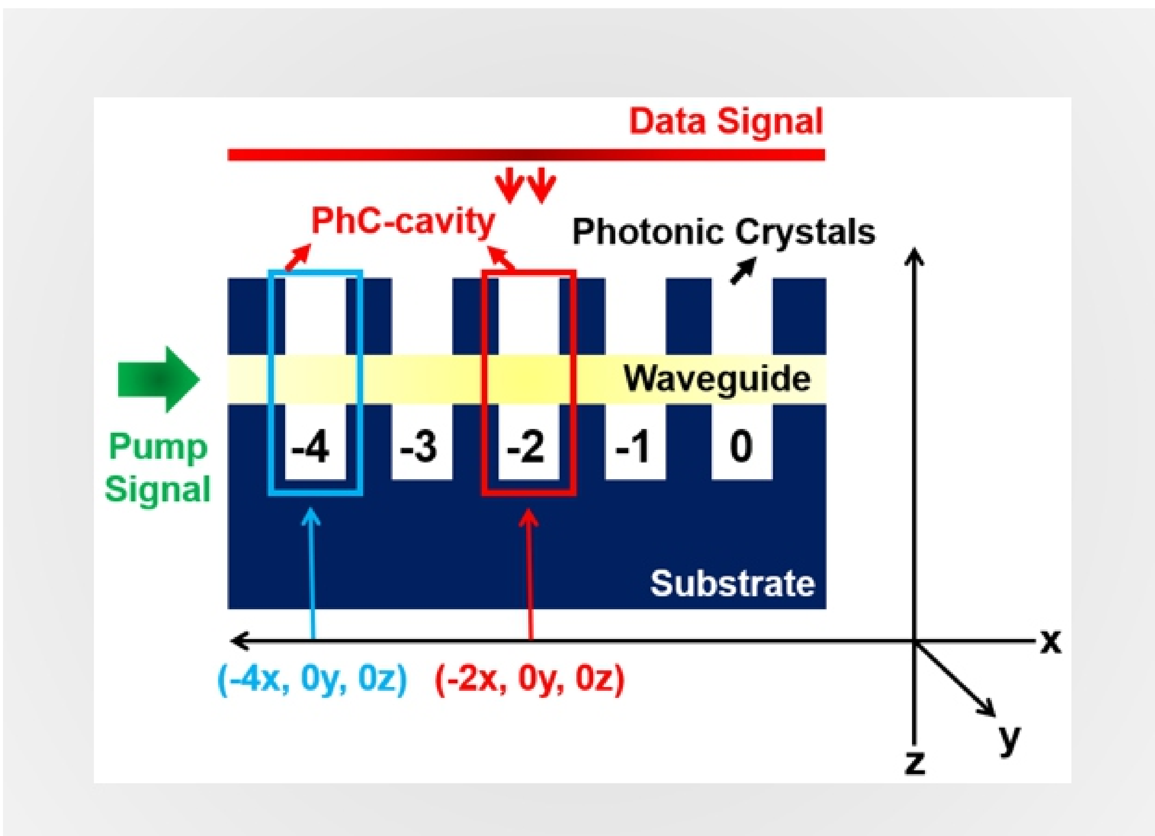


Fig. 1. (a) Photonic integrated circuit (b) Conceptual diagram of optical switch

Methodology

- The arrangement of proposed 2D-based simulation comprises of excitation sources, transmission, and reflection EM-waves monitoring points below and above the optical waveguide respectively.
- The data signal is acting out-of-plane to the optical structure, while the pump signal is acting in-plane to the structure.
- The investigated structure uses a lattice constant of a = 1 μm. Therefore, all the parameters are expressed in terms of 'a', making the structure re-scalable to any range of the wavelength having optimized values for cylindrical shape of the PhCs, in 11 PhC-elements-based structure.
- In the end, the effect of each of the varying radius PhC-cavity in the structure one at a time is investigated with data signal for tunning of the GMR-modes and then along the pump signal for optical-amplification action.

Results

- The field distribution of the structures comprising of PhC-cavities located at (-4x, 0y, 0z) and (-2x, 0y, 0z) are shown in Fig. 2(a-b).
- Similarly, the output reflection spectra of the investigated structure with varying radius PhC-cavity located at position (-2x, 0y, 0z) and (-4x, 0y, 0z) simulated by data signal only, are shown in Fig. 3(a-b)., with Fig. 3(c-d) investigating the structure simulated by both of the signals i.e., data and control simultaneously for optical switching mechanism.

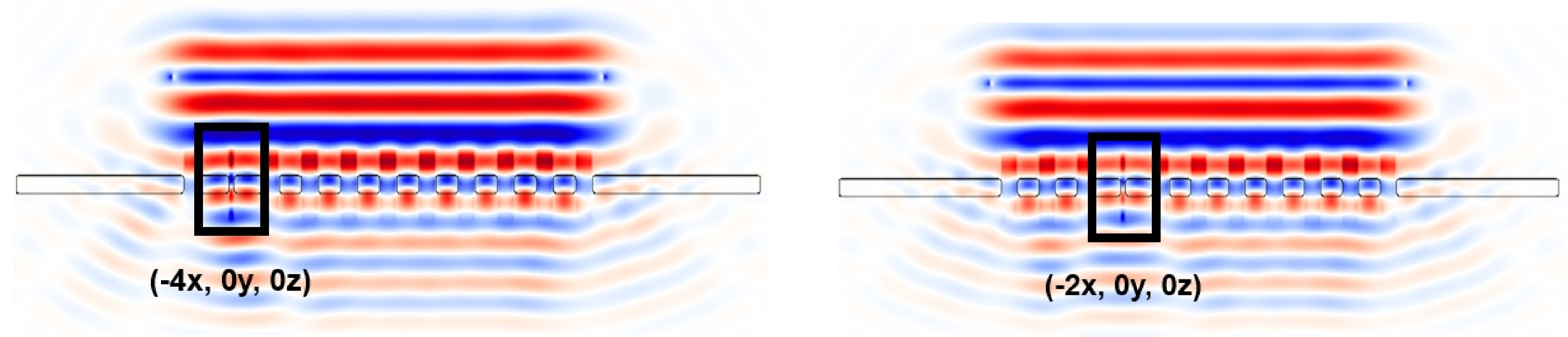


Fig. 2. Field distribution of the structures (a) (-2x, 0y, 0z) data signal (b)(-4x, 0y, 0z) data signal

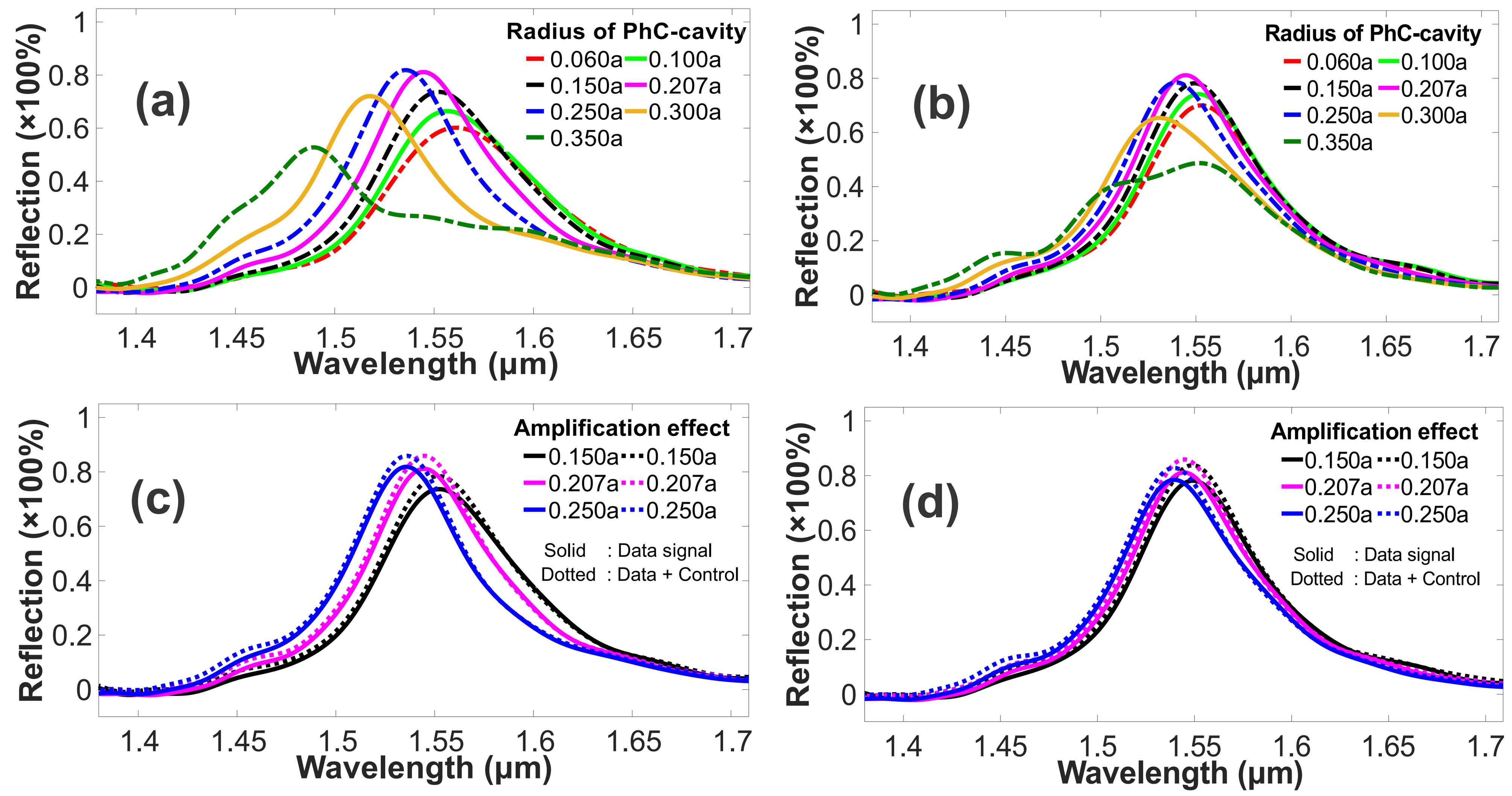


Fig. 3. (a) (-2x, 0y, 0z) data signal (b)(-4x, 0y, 0z) data signal (c) (-2x, 0y, 0z) both signals (d) (4x, 0y, 0z) both signals

Conclusions

- A comparative-study corresponding to varying radius PhC-cavity implemented at even-positions is investigated for the phenomenon of all optical amplification action in the presence of the two-optical signals. At first, the optimal radius of the PhC-cavity is studied using data signal only, corresponding to its different positions in the optical structure where a radius of PhC-cavity i.e., r_c = 0.250a and r_c = 0.207a with a reflection peak of 82% and 81% were determined for its placement in the optical structure.
- Secondly, both positions of the PhC-cavity are investigated for optical amplification using data signal along the pump signal simultaneously, where amplification of 6%, and 5% are achieved for the radius of the PhC-cavity i.e., r_c =0.250a, and 0.207a implemented at (x = -2 and x = -4), respectively.
- Therefore, it observed that the PhC-cavity implemented near the symmetric point of the optical structure i.e., (x = -2), provides better confinement of the GMR-modes.

References

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