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Demonstration of temperature resilient properties of 2D silicon carbide photonic crystal structures and cavity modes

Jiten Boruah*, Yogita Kalra, R.K. Sinha

TIFAC-Centre of Relevance and Excellence in Fiber Optics and Optical Communication, Department of Applied Physics, Delhi Technological University (Formerly Delhi College of Engineering, Faculty of Technology, University of Delhi), Bawana Road, Delhi 110042, India

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ABSTRACT

In this paper, photonic crystal (PhC) based on two dimensional (2D) square and hexagonal lattice periodic arrays of Silicon Carbide (SiC) rods in air structure have been investigated using plane wave expansion (PWE) method. The PhC designs have been optimized for telecommunication wavelength ($\lambda = 1.55\,\mu$m) by varying the radius of the rods and lattice constant. The result obtained shows that a photonic band gap (PBG) exists for TE-mode propagation. First, the effect of temperature on the width of the photonic band gap in the 2D SiC PhC structure has been investigated and compared with Silicon (Si) PhC. Further, a cavity has been created in the proposed SiC PhC and carried out temperature resiliency study of the defect modes. The dispersion relation for the TE mode of a point defect A1 cavity for both SiC and Si PhC has been plotted. Quality factor (Q) for both these structures have been calculated using finite difference time domain (FDTD) method and found a maximum Q value of 224 for SiC and 213 for Si PhC cavity structures. These analyses are important for fabricating novel PhC cavity designs that may find application in temperature resilient devices.

1. Introduction

Photonic Crystals exhibit photonic band gaps (PBG) in which electromagnetic fields cannot propagate in given directions, if the geometrical parameters and dielectric contrast of the photonic lattices are chosen appropriately [1]. Photonic Crystals can be used to control light propagation through it by using different geometry and dielectric contrast. Because of the strong photon confinement shown by these crystals they can be used in variety of applications. A special attractive application of PhCs is to construct localized electromagnetic modes by introducing defects in the periodic structure. These confined modes could be used in optical resonators, laser cavities, etc.

Investigating photonic structures which are less sensitive to environmental fluctuations is a valuable area of research, hence, we here propose to design photonic crystals using silicon carbide [2] and investigate the variation of width of photonic band gaps in SiC photonic crystals with change in temperature and a comparison with Silicon (Si) photonic crystals [3,4]. Further, analysis of the SiC photonic crystal cavity defect modes using plane wave expansion (PWE) method and finite difference time domain (FDTD) method has been done. However the most widely used materials to design photonic crystal devices are silicon and gallium arsenide because of the available and mature technology of fabrication and optimum refractive index contrast offered by these materials for the existence of the photonic band gaps. We here propose to design photonic crystals using silicon carbide which is one of the hardest materials known and further the creation of photonic crystal cavity in SiC photonic crystal. The reason for using silicon carbide is its high mechanical strength, large thermal conductivity and small thermo optic coefficient.

In this paper, a 2D SiC PhC composed of square lattice of SiC rods in air is realized and the PhC structures are optimized by varying different parameters like radius of the nanopillars, period of the lattice etc. for telecommunication applications [5]. Further, defect cavities have been created in the optimized PhC structures and analysis of the cavity defect modes using plane wave expansion (PWE) method and finite difference time domain (FDTD) method has been done. The defect A1 cavity has been created in the periodic lattice of photonic crystal by removing one central dielectric rod completely from the unperturbed lattice structure that result in localization of light in the specified defect space in the frequency range lying within the PBG of the optimized PhC [6]. The localized defect modes of these A1 defect cavity structures have been extracted and the dispersion relations plotted to investigate the temperature resilient property of the localized defect modes of these structures. Also Quality factor (Q) for both these structures have been calculated using finite difference time domain (FDTD) method for different temperatures ranging from 25 to 200 °C

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* Corresponding author. Tel.: +91 11 27871017; fax: +91 11 27871023.
E-mail addresses: jitenboruah1@rediffmail.com (J. Boruah), dryogitakalra@gmail.com (Y. Kalra), dr_rk_sinha@yahoo.com (R.K. Sinha).

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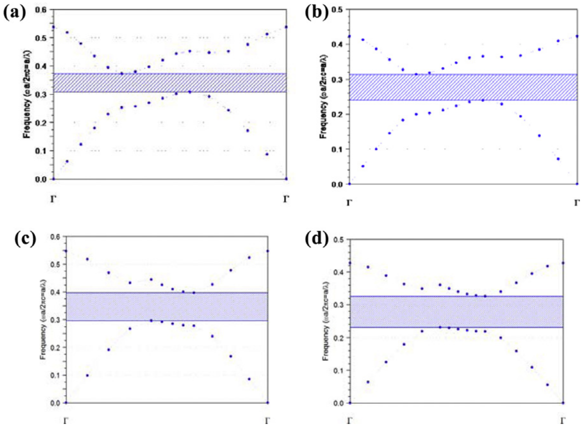


Fig. 1. (a) TE band gap of square lattice of SiC rods in air. (b) TE band gap of square lattice of Si rods in air. (c) TE band gap of hexagonal lattice of SiC rods in air. (d). TE band gap of hexagonal lattice of Si rods in air.

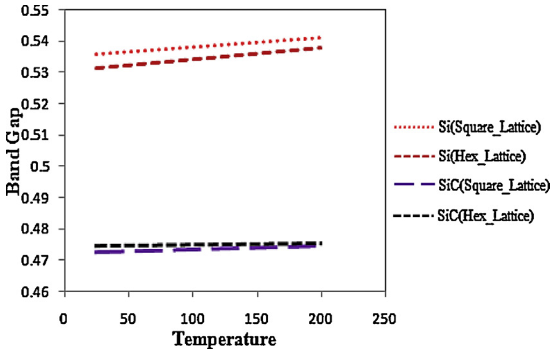
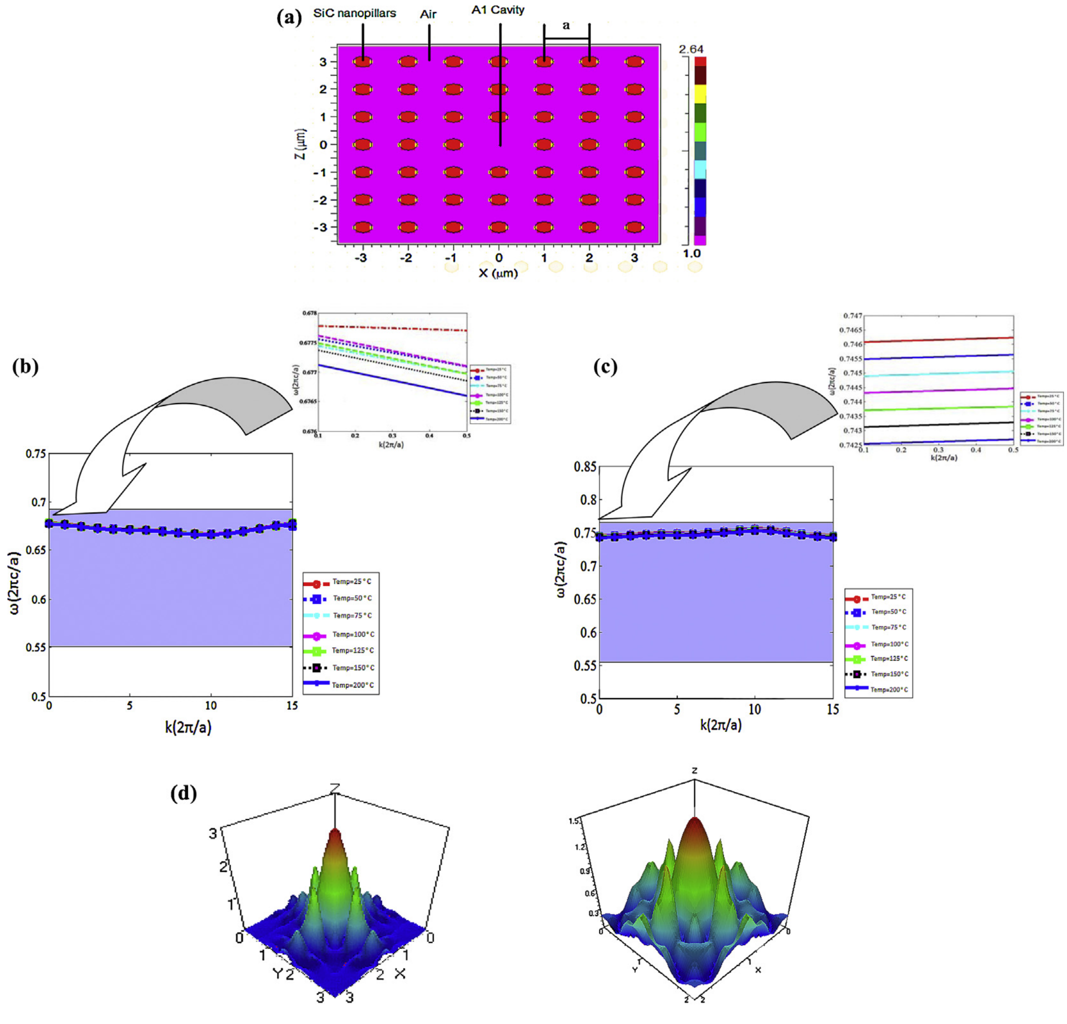


Fig. 2. Variation of band gap width with temperature in square and hexagonal lattice SiC and Si PhC.

and studied resonant wavelength peak shift for the temperature range.

2. Design of SiC photonic crystals

A 2D PhC composed of square lattice of SiC rods ($n = 2.64$) in air with radius of dielectric nanopillars, $r = 0.16\,\mu$m and lattice



(i)

(ii)

Fig. 3. (a) Schematic diagram of SiC PhC A1 cavity having lattice constant, $a = 0.55\,\mu$m. (b) Dispersion graph of localized defect mode of SiC PhC A1 cavity at different temperatures: the blue line is the dispersion curve. Inset: shift in the resonant wavelength of the A1 SiC rods in air PhC micro cavity structures for different temperatures. (c) Dispersion graph of localized defect mode of Si PhC A1 cavity at different temperatures: the blue line is the dispersion curve. Inset: Shift in the resonant wavelength of the A1 Si rods in air PhC micro cavity structures for different temperatures. (d)(i and ii). Localized defect modes of a square lattice of SiC and Si dielectric cylinders in air PhC A1 cavity: Y – component of electric field (E) amplitude. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)