Optical Materials 75 (2018) 150–165

Contents lists available at ScienceDirect

Optical Materials

journal homepage: www.elsevier.com/locate/optmat

Limitation of optical properties through porous silicon photonic crystals influenced by porosity and lattice dynamic

Kossi Aniya Amedome Min-Dianey [a], Hao-Chun Zhang [a, *], Noé Landry Privace M'Bouana [a], Komi Kougblenou [b], Xinlin Xia [a]

[a] School of Energy Science and Engineering, Harbin Institute of Technology, Harbin 150001, China
[b] Département de Physique et d'Astronomie, Université de Moncton, Moncton, NB E1A 3E9, Canada

ARTICLE INFO

Article history:
Received 27 September 2017
Accepted 14 October 2017

Keywords:
Porous silicon
Photonic crystals
Lattice dynamic effect
Limit in optical properties

ABSTRACT

Finite differential time domain (FDTD) tools were applied to simulate the optical properties characteristics' through square and triangular lattices of porous silicon (pSi) photonic crystals (PhCs); which consisted of periodical patterns of circular air holes built into the pSi material. This was used to investigate the influence of porosity and lattice dynamic on the reflection, transmission and absorption characteristics through unit cell pSi PhC in the visible wavelength domain ($400\ nm - 700\ nm$). The numerical simulation was achieved using FDTD Lumerical solutions with periodic boundary conditions (PBC) and perfectly matched layers (PML) as the appropriate boundary conditions. The results revealed that the limitation of optical properties is dependent on porosity and the lattice dynamic in pSi PhC. This was presented by the trend; the higher the reflection the higher the porosity and a decrease in porosity led to an increase in absorption in both lattice considerations. It was discovered that attaining optimum properties for triangular lattice will entail considering porosities less than 50% and hole radius r to the lattice constant a ratio (r/a) above 0.3 for the absorption characteristic and below 0.3 for the transmission characteristic. Triangular lattice can be adapted to improve the optical pattern through the PhC. In addition, the optimisation of these properties through pSi PhCs was achieved by controlling porosity and the ratio r/a.

1. Introduction

In recent years, prodigious attention has been focused on photonic crystals (PhCs) by the scientific community due to their ability to manipulate light for use in optical and thermal systems. Similarly, porous silicon (pSi) has increasingly become of great interest most especially in silicon technology expansion which has been introduced into various scientific and engineering fields including photonics and energy technologies [1–9]. Interestingly, pSi is a noteworthy material which has been linked to numerous applications in thermal radiation from photonic crystals (PhCs) has recently attracted the attention of several researchers due to its ability to control light propagation within its structure, also, copious applications relating to pSi-based 2D and 3D PhCs have been proposed [10–15]. Astrova et al. developed a novel technological and experimental procedure to pattern macroporous silicon in formation of PhC stripes suitable for spectral characterisation [16]. In addition, Theiβ, numerically analysed the optical properties of pSi in terms of a wide spectral range from infrared to ultraviolet [17]. The author adjusted the parameters of dielectric function models to fit experimentally obtained reflectance spectra. The effect of thermal oxidation and oxide etching on silicon PhCs of triangular lattice has also been studied [18]. Solli and Hickmann exhibited a diversity of unexpected trends in the band gap study of several two-dimensional PhC lattices over the air-filling fraction parameter space for different refractive index contrasts [19]. Furthermore, a basis for manipulating the thermal emission and absorption of radiation in complex photonic structures and the design of novel solar cell devices was investigated by Florescu et al. [20]. These authors revealed that controlling the thermal emission and absorption of radiation in a PhCs enables the realization of high-efficiency solar cells. In another study, Florescu and other scientists analysed the origin of thermal radiation enhancement and suppression inside PhCs as a prerequisite for understanding the thermal radiation

---

* Corresponding author.
E-mail address: zhc5@vip.163.com (H.-C. Zhang).

https://doi.org/10.1016/j.optmat.2017.10.023
0925-3467/

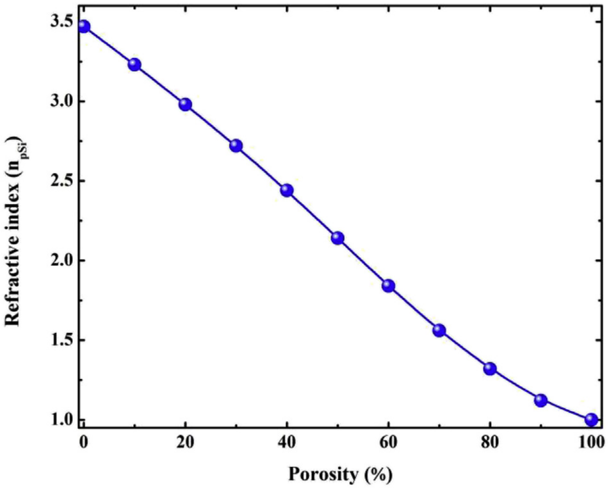

Fig. 1. Refractive index of pSi as function of porosity in Bruggeman model.

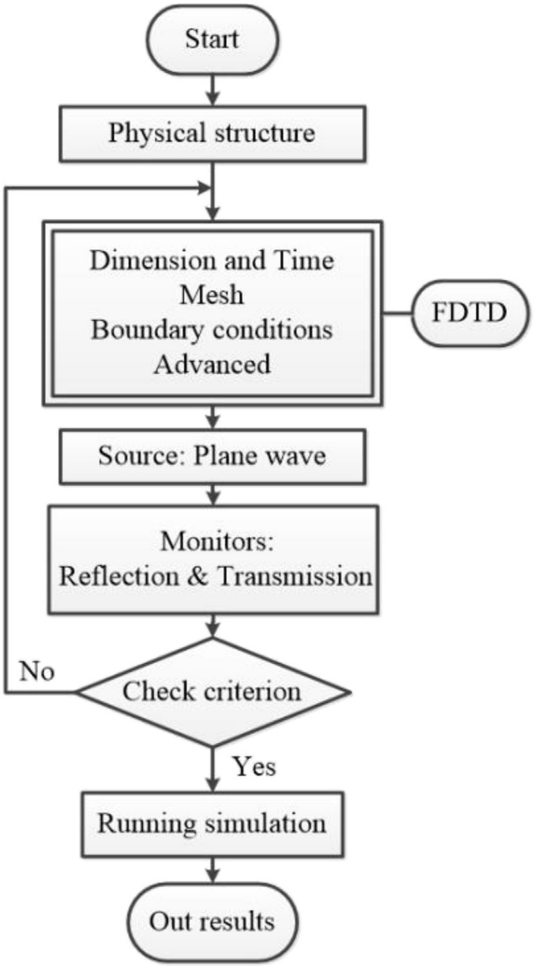

Fig. 3. The simplified flowchart involved in the FDTD simulation process.

properties of finite PhCs [21]. A theoretical investigation on the spectrally selective absorption properties in 2D PhCs cavities based on 3D finite differential time domain (FDTD) technique was developed by Chen et al. [22]. They discovered a significant enhancement in the absorption at defect level, which was obtained at surface normal direction in a single defect PhC cavity for both in-plane and vertical sources. A gradual decrease in the averaged energy of 2D PhCs based on bulk and pSi materials was revealed by Szabo et al. who applied FDTD method in calculating wave propagation [23]. Mohammad, investigated 1D planar PhCs structure for s-polarization state and was revealed that the larger the difference between the two indices the wider the band gaps become [24]. The efficiency analysis of parallel 2D FDTD method was suitably proved and applied by Yang et al. to calculate and analyse the transmission properties as well as the regulation of band gap in the PhC that adjust the gradual increasing of the side length of the square medium cylinder [25]. Ma and Ogusu applied the compact FDTD algorithm in 2D triangular-lattice PhCs with arbitrary-shape inclusions based on unit cell boundaries transforming technique for calculating photonic band diagrams where the case of hexagonal air-holes was presented [26]. Theoretical modeling for nonlinear FDTD applied to the dispersion and transmission characteristics of the PhC waveguide was extensively presented by Saito et al. which described the behavior of a second harmonic generation in THz regime by considering both linear and nonlinear optical susceptibility [27]. Recently, several investigations have reported to have assisted the optimal absorption of light through silicon nanostructures such as PhCs for thin film solar cells as well as for photovoltaic

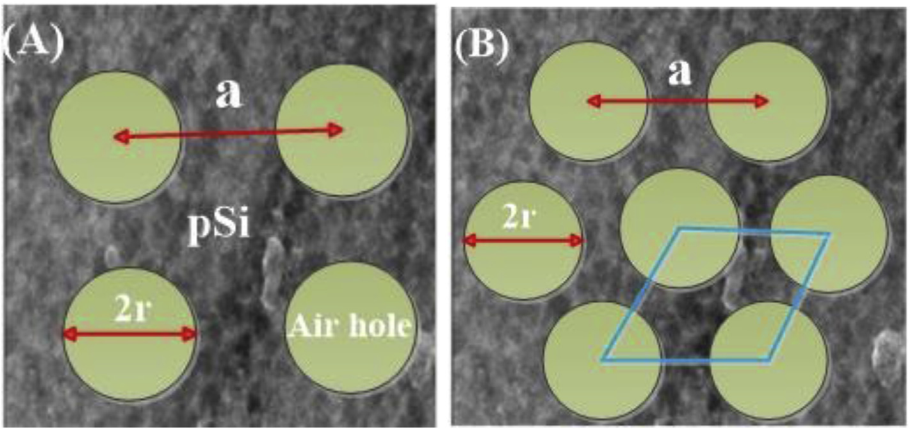

Fig. 2. Illustration of unit cell of pSi PhC with circular air holes: square lattice (A), triangular lattice (B).