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Ellipse-ring-shaped-hole photonic crystal waveguide

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ABSTRACT

This work proposes a new photonic crystal waveguide called ellipse-ring-shaped-hole (ERPCW) for optical buffering applications. The conventional circle-shaped holes of PCWs are substituted with ellipse-shaped rings in ERPCW. Fifteen structural parameters are identified for designing the proposed PCW. In order to design this structure, SoMIR framework is employed. The calculation results prove that the proposed ERPCW is able to show 42% and 12% improved $\Delta\lambda$ and NDBP compared to the best structure in the literature. The finite difference time domain (FDTD) method is eventually employed to confirm the performance of ERPCW.

1. Introduction

Optical data storages are the essential components of optical CPUs. This is due to the high speed of such CPU and the needs for temporarily storing the optical packets and retrieving them in the proper time. In addition, optical CPU's timing would not be adjusted without optical data storages. Generally speaking, optical data storage mainly slows down light's group velocity in order to provide buffering capabilities. There is another ineffective method of buffering optical data, in which transmission lines are extended in order to buffer optical packets. Due to the space limitations, however, this method is not applicable for nano-scale devices. The term "slow light" refers to the process of degrading the group velocity of a light wave. The literature shows that photonic crystal waveguides (PCW) are the most popular devices in this field. Indeed, PCWs have several applications in other branches of optics: non-linear optics and miniaturization of optical devices [1].

Generally speaking, a significant number works in the literature modify the position and the facet of holes in PCW for attaining high normalized delay bandwidth product (NDBP). For instance, Baba and Frandsen et al. modified the radius of holes next to center of waveguide [2,3]. Other researchers shifted the first and second rows holes next to the center of waveguide for designing high-NDBP PCW [4–6], period in the first row or two rows adjacent to the waveguide changed [7]. Other similar works can be found in [8–12].

The authors recently proposed a framework for designing PCWs called SoMIR [27]. It has been proved that this framework is able to effectively design any kind of PCW with high NDBP. In this work, the SoMIR framework is employed to propose a new structure called ellipse-ring-shaped PCW (ERPCW). As its name implies, the proposed ERPCW are designed with ellipse-shaped rings in order to provide a more flexible structure to achieve high NDBP. The rest of the paper is organized as follows.

Section 2 discusses the preliminaries and definitions of ERPCW structure design. Results and discussion is provided in Section 3. A time domain simulation of ERPCW is provided in Section 4 to confirm the performance of proposed ERPCW. Finally, Section 5 concludes the work and suggests some guidelines for future works.

2. Ellipse-ring-shaped-hole PCW (ERPCW) structure and related definition

Generally, the main foundation of PCW consists of a line defect in triangular photonic crystal slab. The proposed structure of this work is illustrated in Fig. 1(a). As shown in this figure, ellipse-shaped ring holes are utilized instead of circle-shaped holes. Needless to say, ellipse-shaped rings provide more flexibility in terms of designing new structures compared to circle-shaped holes. Yet, it has more structural parameters and higher complexity in finding the best structure. As can be seen in Fig. 1(b), the proposed ellipse-shape rings provide 3 degree freedom for designing each row of hole. These parameters are semi major and minor axis of external ellipse (R_a, R_b) and the ratio of external to internal ellipse (r). Therefore, there are 15 structural parameters for ERPCW.

After defining the parameters, the performance of PCW is evaluated by a 2D plane wave expansion (PWE) with slab equivalent index method as discussed in [9]. The background refractive index

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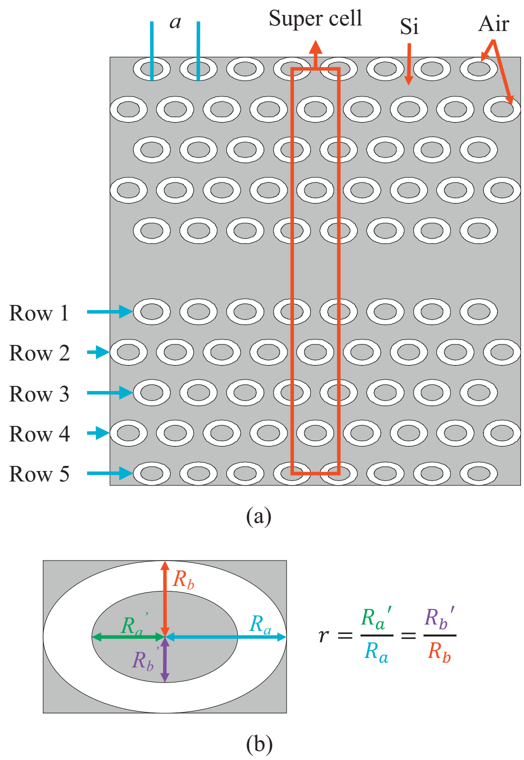

Fig. 1. (a) ERPCW with super cell which is used for PWE method. (b) Ellipse shape ring with three identifier parameters (R_a, R_b, and r).

is the effective refractive index of the guided transverse electric (TE) polarized mode in silicon-on-insulator (SOI) slab. There are two guided modes in photonic band gap as shown in Fig. 2. The modes, which lie below the SiO_2 light line, are intrinsically lossless in the vertical direction [8]. Both of these two modes are located below the light line of SiO_2. The even mode is selected as the main PCW propagation mode since it has linear behavior than odd mode in wide range of wave vectors [28–30]. Note that a slab equivalent index is 3.18 for 400 nm thick silicon dioxide slab in SOI is considered in this structure [10].

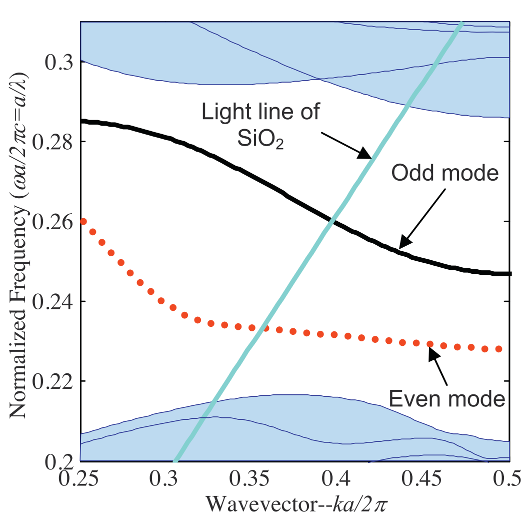

Fig. 2. Photonic band structure of ERPCW related to the super cell which is shown in Fig. 1.

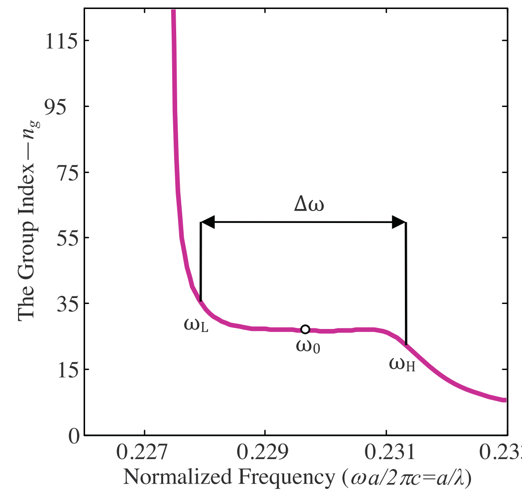

Fig. 3. Group index (n_g) diagram of even mode and the bandwidth region considering 10% fluctuation for n_g.

The group index which indicates the group velocity of light wave is defined as follows:

$$n_g = \frac{C}{V_g} = C\frac{dk}{d\omega}, \quad (1)$$

where ω is the dispersion, k indicates the wave vector, C is the velocity of light in the free space, and n_g shows the group index. Since n_g is changing in the bandwidth range, it should be averaged as follows [15]:

$$\overline{n_g} = \int_{\omega_L}^{\omega_H} \frac{n_{g(\omega)d\omega}}{\Delta\omega}. \quad (2)$$

The bandwidth of a PCW is the section of the n_g curve that n_g has a constant value with maximum fluctuation rage of ±10% as shown in Fig. 3 [17].

Group velocity dispersion (GVD) is further issue that slow light in PCW is faced. High GVD shows that optical pulses will distort while propagating along PCW. The GVD parameter is calculated as follows [15]:

$$\beta_2 = \frac{d^2k}{d\omega^2} = \frac{dn_g}{d\omega} \times \frac{1}{C}, \quad (3)$$

where ω is the dispersion, k indicates the wave vector, C is the velocity of light in the free space, and n_g shows group index. The safe interval for β_2 is $\beta_2 < 10^6(a/2\pi C^2)$ which must not be violated by the final optimized PCW structure [2,15,18].

Finally, the main performance metric for the proposed structure is as follows [8]:

$$\text{NDBP} = \frac{\overline{n_g}\Delta\omega}{\omega_o}, \quad (4)$$

where n_g is the average of group index, $\Delta\omega$ is the normalized bandwidth, and ω_0 is the normalized central frequency of light wave.

After defining the performance metrics, we are going to identify the parameters and constraints. In other words, we formulate the problem for a systematic designing method which we proposed previously in [27]. The NDBP in Eq. (4) is chosen as the O module of SoMIR framework. The P module and C module which include