

Experimental Results and 3D Analysis of a High Efficiency Coupling Technique for Planar Photonic Crystals

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Abstract Experimental results of a high efficiency coupling technique for planar photonic crystals are reported. A 3D analysis is carried out to analyze the influence of out-of-plane losses and the discrepancies with 2D simulation results.

Introduction

Planar photonic crystals (PhC) have been proposed for an easier fabrication by using the current planar processing technologies developed by the microelectronic industry. However, several issues need to be addressed when designing the structure. Among them, the minimization of coupling losses and propagation losses are crucial for an efficient implementation of advanced functionalities.

An efficient coupling technique based on setting a number of localized defects within a PhC taper was recently demonstrated [1]. However, only two-dimensional (2D) simulation results were provided. In this paper, three-dimensional (3D) results are obtained and compared to experimental and 2D simulation results. In addition, different filling ratios have been considered for a better 3D analysis of out-of-plane losses.

Fabricated structures

PhC structures were fabricated on a Silicon-on-insulator (SOI) substrate of a 220 nm-thick silicon layer placed on top of a 1 μm -thick silica layer. 248-nm deep UV lithography was used for the fabrication process [2]. The PhC is formed by a two-dimensional triangular array of air holes etched in the silicon layer and with a lattice constant of $a=435\text{nm}$. The illumination conditions were varied for each die to obtain repetitions of the same designs with different hole radius. The transmission as a function of wavelength was measured using an end-fire technique [1].

The structure considered is formed by a line-defect PhC waveguide of a length of $13a$ coupled to a $3\mu\text{m}$ -wide dielectric waveguide. Single mode transmission was ensured by using a line-defect PhC waveguide of a reduced width of $0.6W$, being W the width of the single-line missing-hole defect waveguide [3]. A PhC taper with an especially efficient coupling into and out of the line-defect PhC waveguide [1]. Fig. 1 shows a scanning electronic image (SEM) of the fabricated structure.

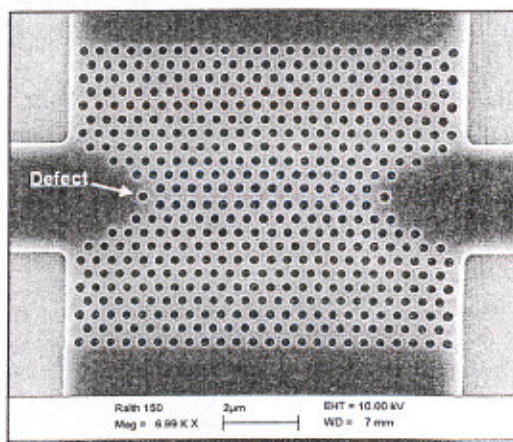


Fig. 1.- Scanning electronic microscope (SEM) image of the PhC taper with defect structure.

Experimental and simulation results

Experimental results have been compared to 2D and 3D finite-difference time-domain (FDTD) simulation results. The effective index method ($n_{\text{eff}}=2.8$) have been used for the calculation of 2D results. Figs. 2 and 3 show the results for the PhC taper structure with and without defect considering a hole radius of 130nm ($R=0.3a$) and of 115nm ($R=0.264a$) respectively. The transmission efficiency is lower when the filling ratio is larger. However, in both cases it can be seen that the transmission efficiency is significantly improved when the defect is placed within the PhC taper.

A good agreement is achieved between experimental and 3D simulation results. However, although similar transmission behaviour is achieved for 2D and 3D simulation results, there are important discrepancies between them such as a smaller bandwidth shifted to lower wavelengths as well as a lower transmission for the 3D results. The latter is mainly originated because out-of-plane losses are not modelled by the effective index method.

The grey area shown in Figs. 3 and 4 correspond to the wavelength range in which the guided mode is below the light line. This wavelength range was

obtained from the calculus of the 3D band diagram of the PhC waveguide by means of the plane wave method. In this region, the discrepancies of the transmission efficiency between 2D and 3D simulation results are directly those determined by the coupling efficiency between the dielectric waveguide and the PhC waveguide since there are no out-of-plane losses in the waveguide.

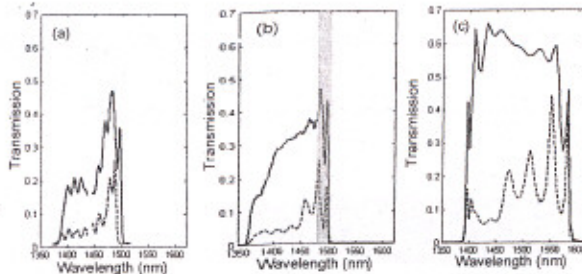


Fig. 2.- (a) Experimental, (b) 3D FDTD simulated and (c) 2D FDTD simulated transmission spectra for the PhC taper structure with defect (solid line) and without defect structure (dashed line). The grey area shown in (b) corresponds to the wavelength range in which the guided mode is below the light line. The hole radius is $R=130\text{nm}$ ($R=0.3a$).

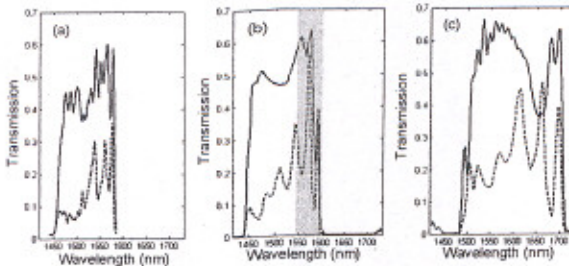


Fig. 3.- (a) Experimental, (b) 3D FDTD simulated and (c) 2D FDTD simulated transmission spectra for the PhC taper structure with defect (solid line) and without defect structure (dashed line). The hole radius is $R=115\text{nm}$ ($R=0.264a$).

The wavelength range in which the PhC waveguide operates below the light line is broader when the filling ratio is smaller. However, in both cases the waveguide still mainly operates above the light line, as it can be observed in Figs. 3 and 4. In this region, radiation modes can be excited in the vertical direction giving rise to out-of-plane losses. Therefore, discrepancies between 2D and 3D simulation results are mainly attributed due to out-of-plane losses and not due to higher coupling losses between the dielectric waveguide and the PhC waveguide. On the other hand, discrepancies between experimental and 3D simulation results are due to the existence of fabrication imperfections such as sidewall roughness that increase propagation losses in the former. In order to better analyze out-of-plane losses, the transmission spectrum for the PhC with taper structure has been calculated by considering different

lengths of the PhC waveguide. Fig. 4 shows the 3D simulated transmission spectrum considering (a) $R=130\text{nm}$ and (b) $R=115\text{nm}$. It can be seen that below the light line, the transmission efficiency is not worsened as the PhC waveguide increases. However, the transmission efficiency decreases for wavelengths above the light line due to out-of-plane losses.

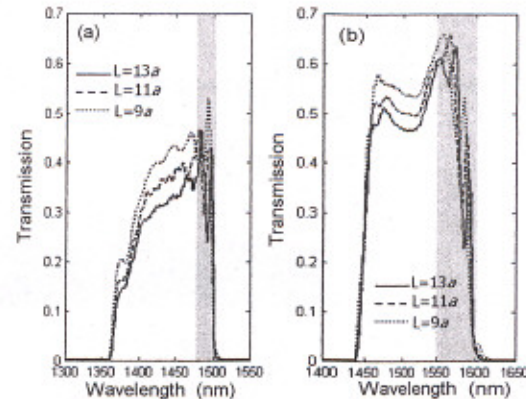


Fig. 4.- 3D FDTD simulated transmission efficiency as a function of the wavelength for the photonic crystal taper with defect structure for (a) $R=130\text{nm}$ ($R=0.3a$) and (b) $R=115\text{nm}$ ($R=0.264a$) by considering three different lengths, L , of the PhC waveguide.

Propagation losses have been estimated by using the so-called cut-back method. For both cases shown in Fig. 4, almost constant propagation losses were obtained for a broad wavelength range located above the light line. The estimated propagation losses were $0.6\text{dB}/\mu\text{m}$ for $R=130\text{nm}$ and $0.35\text{dB}/\mu\text{m}$ for $R=115\text{nm}$. The larger propagation losses in the former confirm that out-of-plane losses are higher as the filling ratio increases. Therefore, the lower transmission efficiency shown in Fig. 2 is due to out-of-plane losses in the PhC waveguide and not due to larger coupling losses. In fact, coupling efficiencies up to 75% are obtained for the PhC taper with defect structure in both cases shown in Figs. 2 and 3 when out-of-plane losses are removed from the results.

Conclusions

High coupling efficiencies into a line defect PhC waveguide have been demonstrated. However, out-of-plane losses in the PhC waveguide may seriously degrade the transmission performance when the wavelength of operation is above the light line.

References

- 1 P. Sanchis, *et al.*, IEEE Photon. Techn. Lett., 16 (2004), page 2272.
- 2 W. Bogaerts, *et al.*, IEEE J. of Light. Techn., 23 (2005), page 401.
- 3 M. Notomi, *et al.*, Electron. Lett., 37 (2001), page 293

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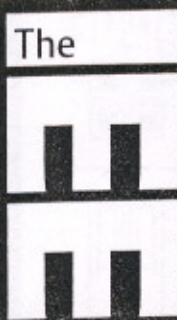
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