Analysis of Losses in 2D Photonic Crystal Waveguides Using the 3D Finite Difference Time Domain (FDTD) Method

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Abstract
The 3D FDTD method is used to obtain loss versus hole depth in a 2D photonic crystal waveguide by simulating 2 different length guides. The transmission results are validated against published measured data.

Introduction

There is much interest in 2D photonic crystal waveguides (2D PC-WGs) which show the potential for low-loss guiding [1] and small radii, low loss bends [2]. One of the key problems for these waveguides is to accurately assess their losses which in terms of both measurement and simulation is quite a challenging task[1,3,4]. In order to correctly model the losses of these structures it is essential to work in full 3D, recently one of the first attempts to achieve this has been published by Hadley [5] where the 3D Helmholtz equation is solved using a finite difference technique. This paper employs the 3D Finite Difference Time Domain (FDTD) method [6] to investigate 2D PC-WG losses and uses measured data including a mini-stop band (MSB) for validation purposes. Transmission results are calculated for guides of lengths 30a and 60a (a=lattice constant) and hole depths of 610nm, 810nm and 1100nm and hence intrinsic loss for the different hole depth guides can be calculated.

Results

The structure to be studied is shown in figure 1. It has been previously characterised experimentally [1] and consists of a 3 layer slab waveguide with a 220nm thick GaAs core, with AlGaAs top and bottom cladding layers of 310nm and 400nm respectively. In [1] transmission results through the guide are presented, showing the presence of a MSB.

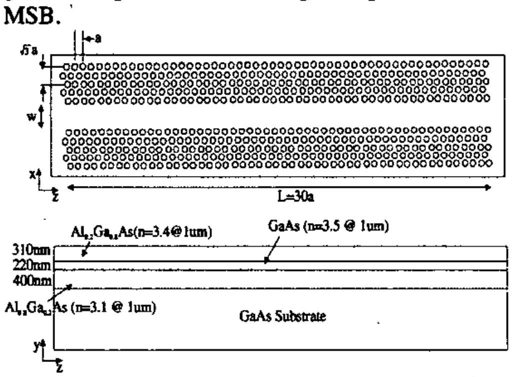

Figure 1 : Fabricated PC WG, filling factor = 38%, r/a=.323, a=280nm, 3 missing rows, propagation in the Γ-K direction, L=30a=8.4um, W=802nm [2].

The 3D FDTD code is a mature in-house code [7] which has a built-in 2D mode solver which is used to launch the fundamental mode of the ridge access waveguide into the PC-WG. Figure 2 shows a top view of the 3D structure.

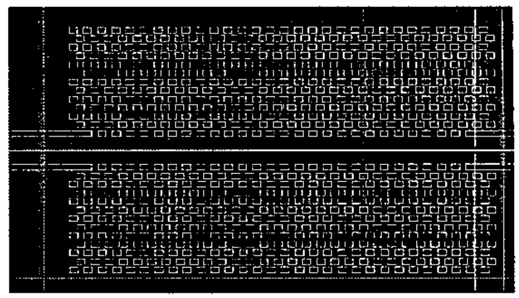

Figure 2 : Simulated PC WG filling factor = 37.6%, r/a=0.322, a=280nm, W=800nm, L=30a=8.4μm

The ridge access guides are included in the simulation to ensure good coupling into the PC guide. The simulation assumes lossless, linear dielectrics. The transmission response is calculated by first performing a reference simulation with no PC section. The incident and transmitted powers are calculated from 49 field probe points which are distributed evenly in the x-y plane at both input and output of the guide. The total incident and transmitted power is calculated from the sum of the z-directed frequency domain Poynting vectors at each probe. Since the waveguide has a symmetry plane at its centre and the structure is being excited by the fundamental TE mode, a perfect electric boundary can be introduced there without altering the results. This allows the simulation size to be halved. First order Mur absorbing boundaries [8] are placed at the ends and at the outside of the waveguide structure to prevent unwanted reflections. The total grid sizes are 200x62x500, 200x62x920 for the 2 different lengths, of 30a and 60a respectively. For the 60a long guide this results in a simulation size of approximately 2100MB of RAM on a Compaq Digital DS20E with a run time for 65000 time steps of 84 hours.

Figure 3 shows the three different hole depths relative to the slab waveguide. It can be seen that the 610nm holes just enter the bottom cladding layer, the 810nm holes, are close to the bottom of

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the cladding layer and the 1100nm deep holes are below the bottom cladding layer.

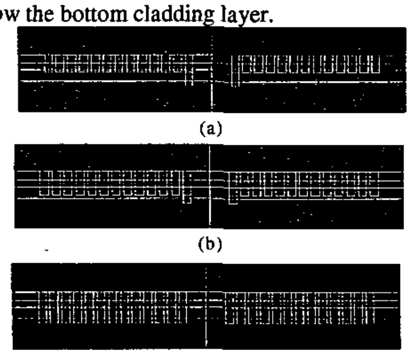

Figure 3 : Simulated structure showing the 3 different hole depths (a)610nm, (b)810nm, (c)1100nm

Figure 4 shows the measured transmission response for L=30a which has been estimated from published data compared with the simulated responses for the three different hole depths.

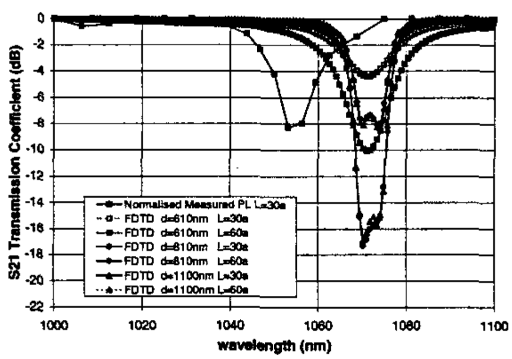

Figure 4 : Comparison between measured and simulated transmission coefficient for 2 different length guides with 3 different hole depths.

The wavelength and depth of the MSB are in good agreement (<1.9% difference in wavelength) for a hole depth of 810nm which is close to the typical hole depth obtained in the structure. The intrinsic losses of the waveguides are extracted from the different length guide transmission results. Figure 5 shows the extracted loss results. It can be seen that the 610nm deep holes exhibit the highest loss as might be expected since they give the least confinement to the ridge guide mode. The 810nm holes show the lowest loss with a best case of 29.4dB/cm at 1002nm. It is also seen that as the holes penetrate into the bottom substrate layer, the loss increases. This is most likely due to increased coupling to substrate modes. This figure is much lower than the 200dB/cm given in [1], however, lossless dielectrics are being used here to give a lower bound. The FDTD code allows the inclusion of material loss and work is on-going in this direction.

Conclusions

This paper has used the 3D FDTD method to characterise the losses of a photonic crystal waveguide. Good agreement between measured and simulated data is obtained for a mini-stop band of the PC WG. Intrinsic loss has been extracted from

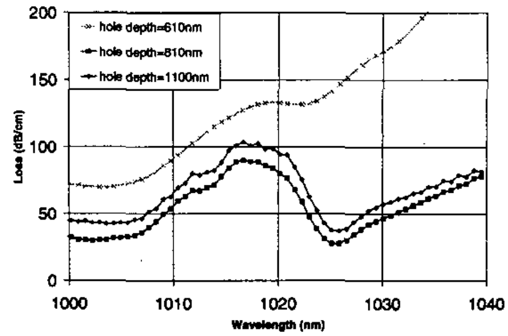

Figure 5 : Simulated losses of 2D photonic crystal waveguides with 3 different hole depths

different length guides and an estimate of the lower bound of waveguide loss has been made. Using 3D FDTD it is possible to investigate all radiative loss mechanisms including those recently proposed in [5] and through the control of these further reduce intrinsic losses in the structures.

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