Efficient Waveguiding in Low Index Photonic Crystal Films

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We experimentally investigate a sandwich photonic crystal film made from glass-like amorphous materials. For the first time polarization sensitive waveguiding in such low-index contrast photonic crystal waveguides and waveguide bends has been observed.

Keywords: photonic crystals, periodic structures, characterization methods, low index materials

Introduction

To control light on a micrometer scale many experimental efforts have focused on the investigation of photonic crystals (PCs). In particular waveguides embedded into PCs are predicted to have completely new and exciting properties. Although most of the recent experimental studies have concentrated on 2D-PCs with a high in-plane index contrast [1] the use of amorphous low index materials, like Nb_2O_5 and SiO_2, has also potential advantages. Losses are usually smaller, mature fabrication technologies exist and they fit much better to the well established fiber technology. In this contribution we will report on the realization of sandwich photonic crystal films including defect waveguides and bends in glass-like oxides with a relatively low refractive index of 2.17. We will discuss the advantages and disadvantages of these components regarding propagation and coupling losses, relative size of the band gap and dimensions for single mode waveguiding and bend efficiencies.

Design

Due to the low index contrast a proper design of the in-plane PC structure and of a proper film thickness for single mode guidance is crucial for obtaining a band gap guided defect mode at the desired wavelength of operation of 1.55 µm. The sandwich system (see Fig.1) was designed to be symmetric to minimize mixing between TE and TM modes.

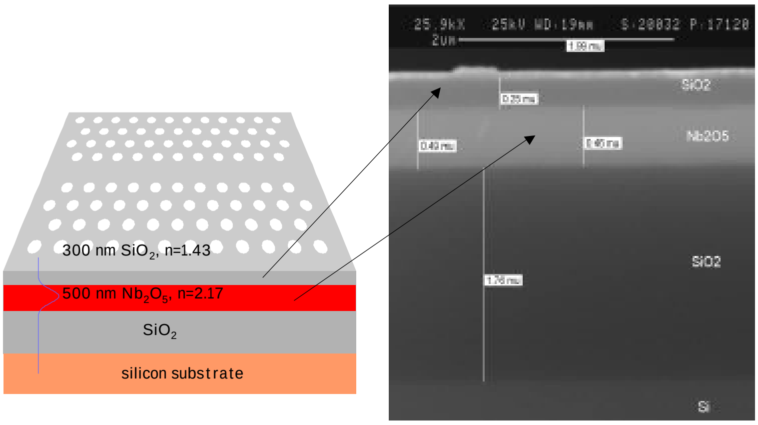

Fig.1: The $SiO_2/Nb_2O_5/SiO_2$ sandwich system

The final structures were designed by means of 3D band structure calculations and show a band gap for TE polarized light. Hexagonal lattices of air holes of diameters ranging from 415nm to 465nm and of 620nm separation with an etching depth of 800nm were analyzed with the help of 3D band structure and finite-difference time-domain (FDTD) calculations and show a maximum band gap around an operation wavelength of 1530-1600nm. W1 defect channels inside these PCs were formed by leaving a row of holes along the ΓK direction of the crystal unstructured. These defect channels can guide light because of the photonic band gap, but since the effective index of the PC is lower than that of the defect channel, waveguiding also occurs by total internal reflection.

Sandwich system

The samples under investigation were made from a layered composite with a waveguiding film consisting of 500nm of Nb_2O_5. A 300nm-cladding layer and a 2000nm buffer layer made from SiO_2 (n=1.43) were used to isolate the guiding region from air and from the silicon substrate, respectively (see Fig.1).

Fabrication

The structures are exposed by e-beam lithography. After exposure the PC pattern is transferred into the sandwich system by means of a three-layers-resist. For etching a combination of reactive ion etching (RIE) and inductive coupled plasma (ICP) etching is used. After the etching process the sample is cleaved to obtain facets for the optical characterization. To couple light into the photonic crystal waveguides ridge waveguides of the same width are used. (see Fig. 2).

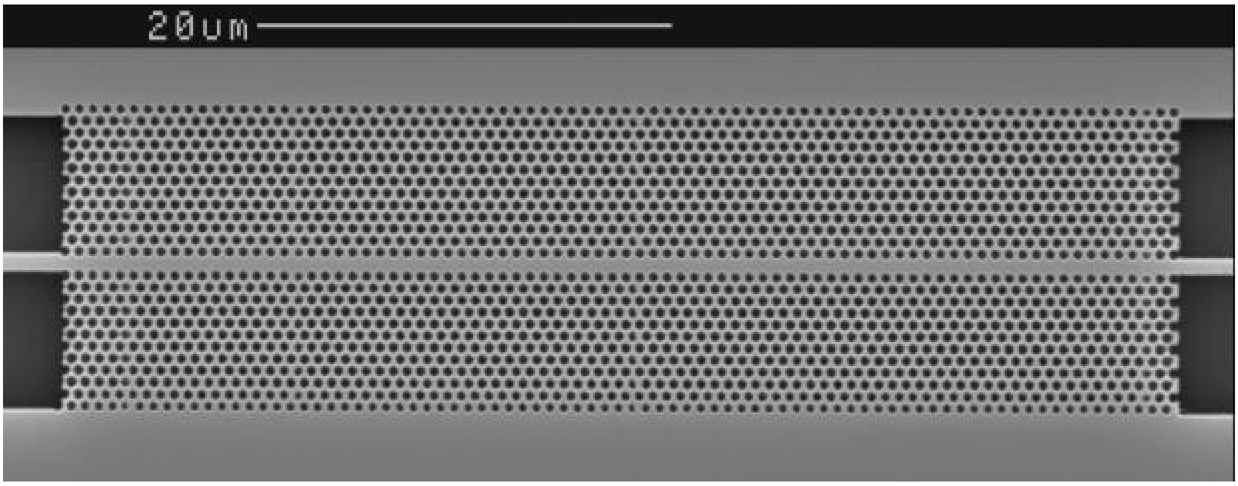

Fig.2: W1-photonic crystal waveguide

Characterization

The optical response of the waveguides was analyzed to determine what kind of waveguiding mechanism dominates. For TE polarization in the spectral range of the photonic band gap a 2 to 4 times higher transmission could be detected (see Fig.3).

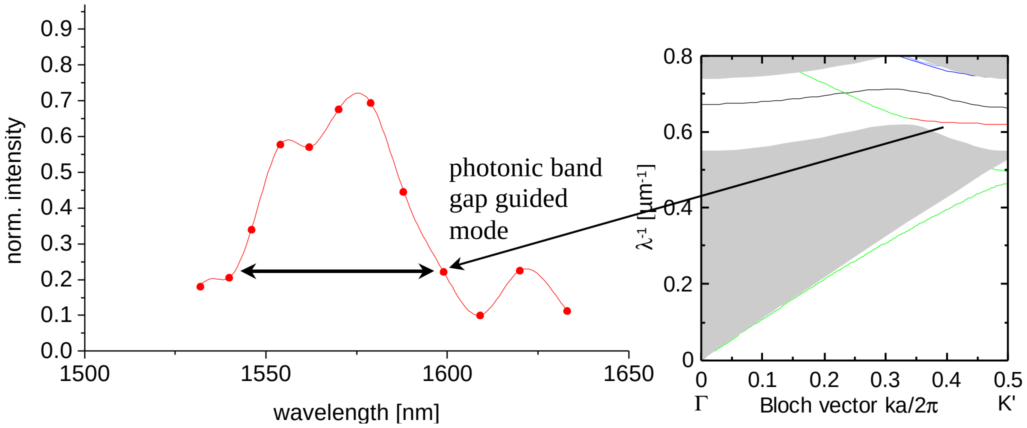

Fig.3: Optical response of W1-PC-waveguide with a period of 620nm and different diameters.

After having experimentally established that the photonic band gap enforces the waveguiding mechanism we realized a W5-PC waveguide double bend (2x 60°) by omitting five rows of holes (diameter ~260 nm, period 595 nm; see Fig.4). This structure shows very efficient single mode waveguiding with a transmission of app. 50% per bend for TE polarization) at 1677 nm (see Fig.5).

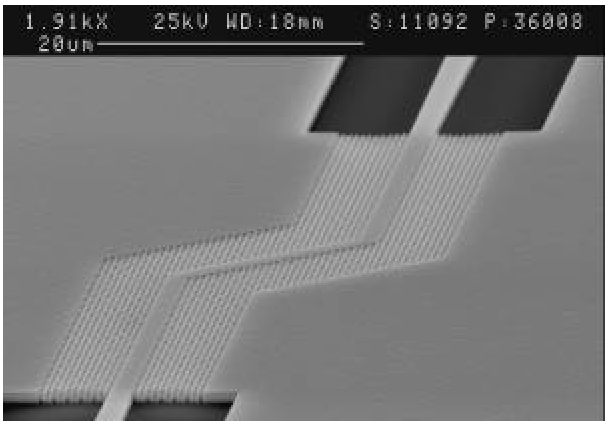

Fig.4: SEM image of the fabricated PC-structure with a W5 double bend.

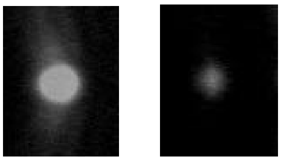

Fig.5: Near-field distribution of 1677 nm radiation (TE polarized (left) and TM polarized) for a W5-pc-waveguide bend.

Conclusion

We observed good agreement between 3D finite-difference time-domain propagation calculations of PC waveguides and bends with the experimentally obtained results.

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[1] E. Chow, S. Y. Lin, J. R. Wendt, S. G. Johnson and J. D. Joannopoulos, “Quantitative analysis of bending efficiency in photonic-crystal waveguide bends at λ=1.55 µm wavelengths,” *Opt. Lett.* **26**, 286-288 (2001).