Waveguiding in photonic crystals consisting of dielectric pillars near 1550nm

Solomon Assefa, P. Rakich, P. Bienstman, S.G. Johnson, J.D. Joannopoulos, G.S. Petrich, L.A. Kolodziejski, E. P. Ippen, H.I. Smith
Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139
solomona@mit.edu

Abstract: An experimental demonstration of bandgap guiding, at wavelengths in the infrared near 1550nm, is presented for photonic crystal waveguides created using dielectric pillars. An adiabatic taper is implemented to increase coupling efficiency.

OCIS codes: (230.7400) Slab waveguides; (250.5300) Photonic integrated circuits; (220.4000) Microstructure fabrication; (130.0250) Optoelectronics

Photonic crystals (PCs) are attractive for high density integrated photonic circuit applications. To utilize photonic crystals, efficient coupling is required between the PC waveguide and the conventional dielectric waveguide. An experimental demonstration of bandgap guiding, at wavelengths in the infrared near 1550nm, is presented for photonic crystal waveguides created using dielectric pillars. Implementation of dielectric pillars contrasts most experimental research that has focused on creating the PC using a triangular lattice of air holes in a dielectric slab. The two-dimensional (2D) photonic crystal investigated here consists of an array of high-index cylindrical pillars residing on a low-index material (Fig. 1), wherein a PC waveguide is created by introducing a row of pillars with a smaller radius. The 2D array of pillars [Fig. 2(a) and (b)] provide a photonic bandgap (PBG) for TM-like modes in the plane of the PC, while the radius of the cylinders in the line defect remains large enough to provide index guiding in the vertical direction [1].

Direct optical coupling between a conventional dielectric waveguide and a PC defect waveguide is not efficient for two main reasons [2]. First, the conventional dielectric waveguide has an entirely forward propagating field component. However, for the PC defect waveguide, the Bloch mode consists of both forward and backward propagating components due to strong scattering. Second, light is guided by total internal reflection in the dielectric waveguide (index guiding). In contrast, for the PC defect waveguide, light is localized in the defect (smaller) pillars that are surrounded by two perfect mirrors formed by the bulk (larger) pillars of the photonic crystal, resulting in bandgap guiding. To provide efficient optical coupling, an adiabatic taper having two coupling stages [3, 4] is required [Fig. 3(a) and (b)]. The first stage converts the forward propagating dielectric optical mode into a mode containing both forward and backward propagating components by adiabatically transitioning from a dielectric waveguide to a coupled-cavity waveguide. In the second stage, the coupled cavity waveguide is transformed into a photonic crystal waveguide by slowly introducing the cladding that is adjacent to the defect waveguide.

The photonic crystal structures are fabricated using an epitaxially-grown GaAs guiding layer (500 nm thick) on AlGaAs, which is converted to a low-index Al_xO_y through a wet oxidation process. To create the bulk photonic crystal, the square lattice of pillars has a period of 500 nm and a rod diameter of 285 nm. The photonic crystal defect waveguide consists of dielectric pillars with a diameter of 235 nm. Light is launched into the GaAs slab using a fiber and input coupler, and the signal from the output is analyzed with a photodiode. The transmission measured through the bulk photonic crystal is shown in Fig. 2(c); the bandgap ranges from 1448 to 1482 nm. Employing the two-stage coupling scheme, transmission versus wavelength for the photonic crystal waveguide is shown in Fig. 3(c). The measured result demonstrates guiding of light inside the bandgap of the surrounding bulk photonic crystal.

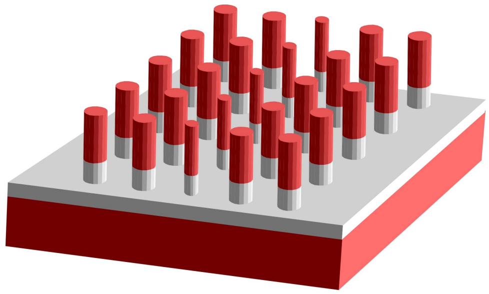
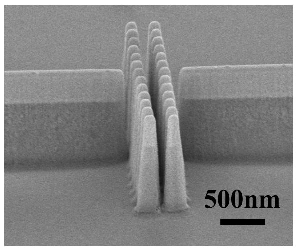
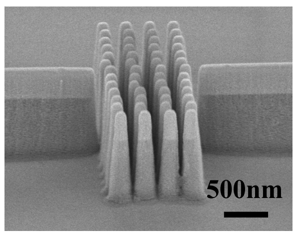


Fig. 1. Schematic representation of a 2D slab photonic crystal waveguide made of cylindrical dielectric pillars.

a)



b)



c)

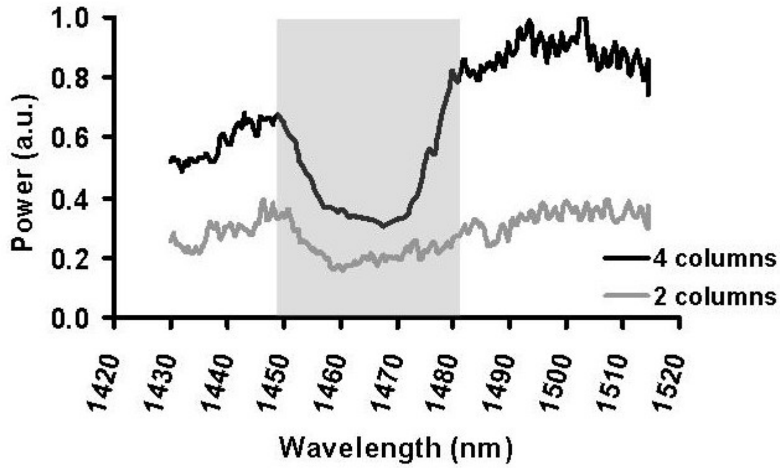
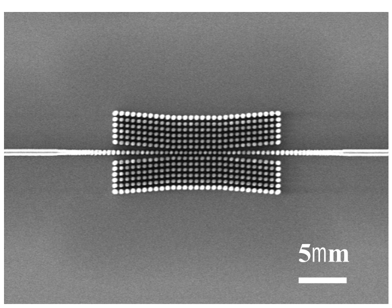
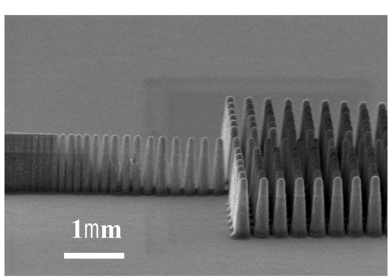


Fig. 2. (a) Scanning Electron Microscope (SEM) image of photonic crystal with 2 columns of dielectric pillars (b) SEM of a photonic crystal with 4 columns of dielectric pillars (c) transmission measurement through the structures in (a) and (b).

a)



b)



c)

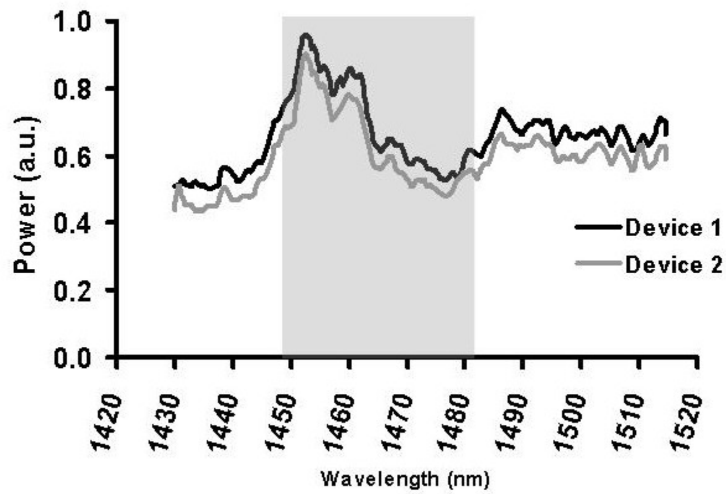


Fig. 3. (a) Top-down SEM image of tapered photonic crystal waveguide (b) Side view SEM of tapered photonic crystal waveguide (c) transmission measurement through the structures in (a) and (b). Two PC waveguides fabricated on the same chip demonstrated similar transmission.

1. S.G. Johnson, P.R. Villeneuve, S.H. Fan, J.D. Joannopoulos, "Guided modes in photonic crystal slabs," Phys. Rev. B **12**, 8212 (2000).
2. S.G. Johnson, P. Bienstman, M.A. Skorobogatiy, M. Ibanescu, E. Likoridis, J.D. Joannopoulos, "The adiabatic theorem and a continuous coupled-mode theory for efficient taper transition in photonic crystals," Phys. Rev. E **66,** 066608 (2002).
3. Solomon Assefa, P. Bienstman, P. Rakich, S.J. Johnson, J.D. Joannopoulos, G.S. Petrich, L.A. Kolodziejski, E. P. Ippen, "Coupling into Photonic Crystal Slab Waveguides," presented at CLEO 2003.
4. Peter Bienstman, Solomon Assefa, S.G. Johnson, J.D. Joannopoulos, G.S. Petrich, L.A. Kolodziejski, "Taper Structures for Coupling into Photonic Crystal Waveguides", J. Opt. Soc. Am. B **20**, 1817 (2003).