Photonic Crystal Continuous Taper for Efficient Coupling into 2D Photonic Crystal Channel Waveguides

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A new kind of photonic crystal (PhC) taper is presented. A transmission factor of 90 % into a one row (W1) PhC channel waveguide is shown experimentally, over a length of only 5 µm with a width reduction factor of 5.

Keywords: photonic crystals, tapers, waveguides, insertion losses, integrated optics

Introduction

Photonic crystal (PhC) devices could play a key role in photonic integrated circuits, but several problems remain to be solved satisfactorily, such as the achievement of low insertion loss between narrow PhC channel waveguides and the exterior. In-plane techniques can be used to couple light from and to ridge waveguides via tapers [1] while an alternative way is to use out-of-plane coupling [2]. Realising a taper within the PhC environment can produce a large reduction in length compared to the situation for low index contrast waveguides - and lateral losses, which can arise from the sidewall roughness of deep ridge waveguides, are avoided. Several configurations have been presented, e.g. removing holes from parts of the PhC lattice [3, 4] and grading the hole size [5]. Here, we describe a new kind of full PhC taper that shrinks the beam continuously using a distorted PhC lattice.

Structure design

A realisation of the proposed device is shown in Fig. 1a. It consists of a PhC channel waveguide formed by removing one row of holes (W1), preceded by a taper structure where the width of the PhC waveguide varies progressively through the use of two lateral tilted-PhC lattices. Connecting the access ridge waveguide firstly to a wider PhC channel waveguide (~W5) is much less critical than coupling directly to a W1 channel. Given sufficient precision in positioning, access ridge waveguides could also potentially be eliminated completely by placing PhC tapers directly at the facets of the sample, leading directly into a full PhC environment and avoiding an additional source of losses by mismatch. The continuous shape of this taper is expected to provide a better mode-matching approach.

We have used a two-dimensional finite difference time domain (2D FDTD) computational method to simulate the devices. The lattice is triangular, has six-fold rotational symmetry and, with air holes in a semiconductor of effective refractive index $n = 3.4$ (corresponding to the fabricated structure), the period is 215 nm (for operation at $\lambda = 850$ nm). The air filling-factor is 0.35, corresponding to a hole diameter of 134 nm, and the selected polarisation is TE (i.e. with the $\vec{E}$-field in plane). We have analysed the impact of varying several parameters and in particular the taper angle. Areas of high transmission can be found, while pronounced drops in transmission also appear, corresponding to regularly spaced, wavelength-specific, reflections of the taper that are dependent on the taper angle. The simulation curve in Fig. 2 illustrates the situation and is obtained for a combined taper-down to taper-up structure with each PhC taper being 22 periods long and having a half angle of 6°.

A maximum transmission of 96 % is possible with such a double taper, which is 4.6 µm long and shrinks the beam-width by a factor of 5, from 1.21 µm to 0.24 µm.

Fabrication and measurements

The PhC tapers were realised in an AlGaAs/GaAs epitaxial waveguide structure composed of a 150 nm $Al_{0.6}Ga_{0.4}As$ top cladding layer, 320 nm $Al_{0.19}Ga_{0.81}As$ guiding core and 1.8 µm $Al_{0.6}Ga_{0.4}As$ lower cladding layer on a GaAs substrate. The photonic crystal patterns were written directly via electron beam lithography at 50 kV using proximity effect correction on a 200 nm thick polymethyl-methacrylate resist layer. They were then transferred by reactive ion etching into an intermediate SiO_2 mask layer (200 nm) and finally into the AlGaAs/AlGaAs material to a depth of 0.6 µm (Fig. 1) (using $SiCl_4/O_2$ at a flow rate of 15 sccm/0.5 sccm, pressure of 7 mTorr and an r.f. power level of 250 W).

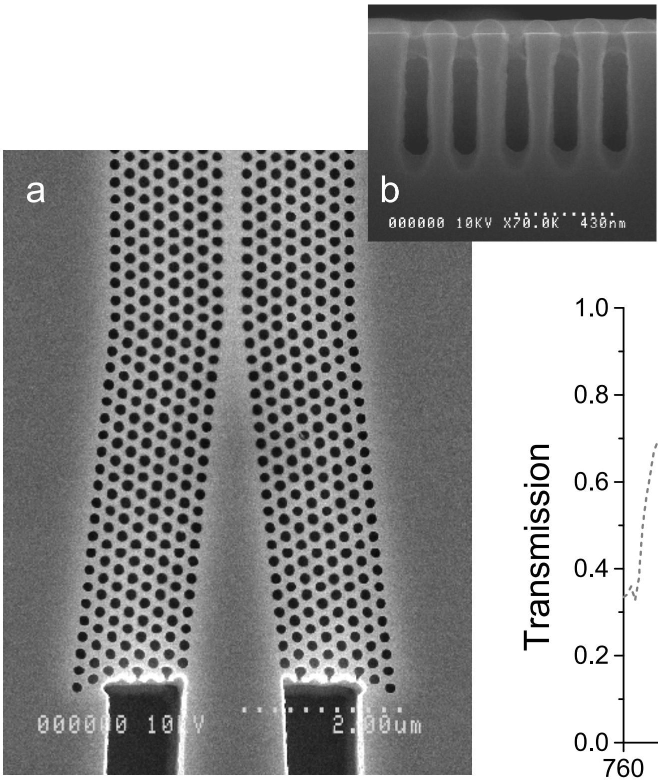

Fig. 1: Top view of a PhC continuous taper accessed by a ridge waveguide (a) and etch profile of the holes (b).

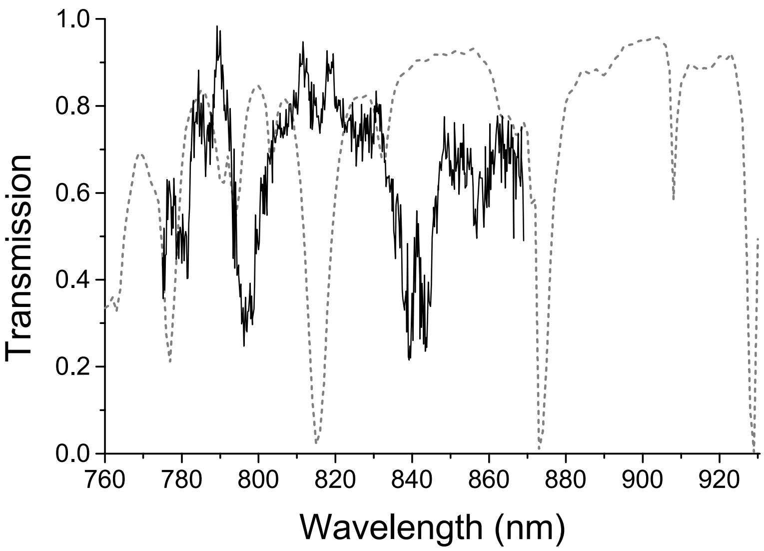

Fig. 2: Simulated (- - - -) and experimental (———) results of transmission of PhC taper to PhC taper.

We have realised the device simulated above (PhC taper to PhC taper), with deeply etched ridge access waveguides of width 2 µm, tapered down to 1.21 µm at the entry of the PhC taper. We have characterised the structures with a tunable Ti-sapphire laser coupled to the ridge waveguides with objective lenses. The experimental results are also shown in Fig. 2 over a range limited by the laser tuning capability. The estimated transmission is obtained by normalising with respect to a 2 µm ridge waveguide having the same overall length. Clear drops in the transmission are observed experimentally at particular points in the wavelength spectrum, as expected, but a full identification between simulation and experiment is not possible. However a shift of the experimental trace somewhat to the right gives a close alignment of the major features. Errors in fabrication are the most likely origin of the shift in the drop features. Our simulations show that a difference of only 10 nm in the hole diameter corresponds to a shift of 18 nm in wavelength for the major drop features. Nevertheless, a transmission as high as 90 % is obtained for some wavelengths, which is in good agreement with the simulation. Furthermore, the experimental losses (10 %) include the possible losses in the ridge tapers and the coupling losses between the ridge guide sections and the PhC tapers. Concerning bandwidth, more than 65 % transmission is demonstrated over 3.6 % of the spectrum, which would be sufficient to cover the C- or L-bands used in wavelength division multiplexing, for an appropriately re-scaled device. Experimental errors that occur when re-aligning and re-measuring a particular device, or between identical devices realised at different locations on the sample, can also be on the order of 5 to 10 %.

Conclusions

We have designed a novel and efficient kind of PhC taper for coupling guided light into planar (2D) PhC channel waveguides. High transmission factors have been validated experimentally and fuller results will be given in the conference presentation. The tapers also show potentially useful spectral selection properties and structures of this type could be important in augmenting the implementation possibilities for PhC-based integrated circuits.

Acknowledgements

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