Efficient Injectors for Slow light Photonic Crystal waveguides

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Abstract. *Efficient coupling in the slow light regime of photonic crystal waveguides is a key prerequisite for many designs. In this paper, we describe an easily implanted injector that promises high coupling efficiency for values of n_g up to 100 and show experimental results demonstrating the usefulness of this technique.*

Introduction

The realization of devices that may control the group velocity of light propagating in photonic waveguides has a number of important applications and is receiving considerable interest among researchers. By reducing the group velocity, the light-matter interaction may be considerably enhanced enabling the creation of devices that perform useful functionalities with lower powers and smaller devices than otherwise possible. Linear interactions, including gain and the electro-optic effect, scale with the slowdown factor (the ratio between the group and phase velocities). Nonlinear interactions then scale with the square of the slowdown, as there is both a phase and an intensity enhancement [1].

Slow light photonic crystal devices promise to be very advantageous for the Silicon on Insulator (SOI) system. Very high quality passive silicon photonic crystals have been reported in the literature [2, 3], however, the absence or weaknesses of many non linearities in silicon have hampered the development of active devices. By using the slow light enhancement, more useful devices may be created, thereby capitalizing on the many advantages of the CMOS compatible SOI system.

There have been a number of promising results on slow light photonic crystals both passive [4] and active [5], but a recurring issue is the low coupling into the slow light regime of the photonic crystal from a photonic wire. Vlasov *et al.* have shown that the termination between the wire and crystal strongly affects the efficiency, with small fabrication errors in this area, having a considerable effect [6]. Recently, Hugonin *et al.* [7] and Marris-Moroni *et al.* [8] have theoretically investigated adding an intermediate photonic crystal region between the slow light photonic crystal and the photonic wire. The principle of this technique is to couple light from the wire into the fast mode of the photonic crystal (in the coupler region) and then from this fast mode into the target slow mode of the main photonic crystal.

In this paper, we fabricate photonic crystal W1 waveguides with intermediate photonic crystal coupling regions (referred to as W') and test the improvement in coupling efficiency using transmission measurements.

Theory and Design

The coupling between a photonic wire and the fast mode of a W1 has been shown to be very good- over 90% [6]- as the modal size and group index are reasonably well matched. This suggests the addition of an intermediate region, W', (with a larger lattice constant and, thus, a faster mode for a given wavelength) as a solution to coupling to slow W1 modes.

We have considered a number of possible configurations for this region, such as slowly chirping the lattice into the main crystal, rapidly chirping and an abrupt change. Somewhat surprisingly the abrupt termination proved the most successful. Numerical simulations then showed that in spite of the abrupt change, the field actually experiences a transient zone, allowing the light to smoothly build up in intensity (while slowing down), see figure 1a.

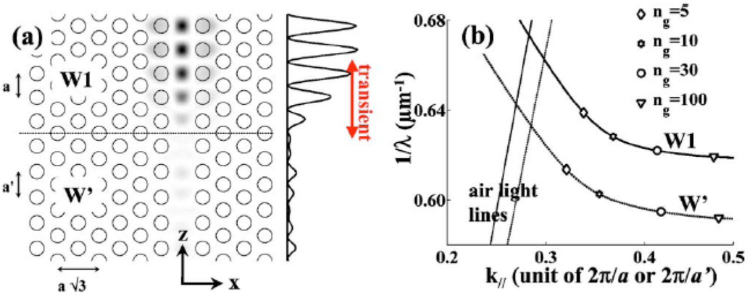

Figure 1: Simulations performed using a Bloch mode Fourier modal method, showing the smooth transition between the injector region and the main crystal (a). Dispersion relations for the W1 and W1 regions are shown on the right (b) [7].

Efficiencies as high as 80% for the coupling into the slow mode at n_g=100 have been predicted with this technique [7].

As this is quite a simple technique, the experimental implementation is straightforward and easily applied in practice. Figure 2 shows how we chose to realize the injector region. For the 10 rows immediately next to the interface with the photonic wire, the hole spacing along the direction of the defect is increased, thus, enlarging the lattice constant and pushing the mode to longer wavelengths, creating the W' region as in figure 1b.

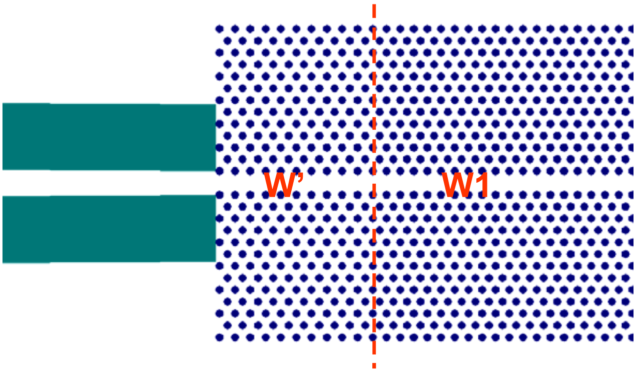

Figure 2: An example of a W1 photonic crystal waveguide with a coupling region (W') between the slow light region (W1) and the access photonic wire. The lattice constant along the direction of the defect is enlarged in the coupler region. For illustrative purposes the enlargement shown here is 50 nm.

Fabrication

The devices were fabricated on a SOITEC Silicon on Insulator wafer comprising a 220 nm thick Silicon layer on 2 µm of silica. The pattern was exposed in ZEP520A electron

beam resist using a hybrid ZEISS GEMINI 1530/RAITH ELPHY electron beam writer at 30 keV with a pixel size of 2 nm and a writing field of 100 µm. The resist was developed using xylene with ultrasonic agitation. Pattern transfer was carried out using Reactive Ion Etching with CHF_3 and SF_6 gases. The silica beneath the photonic crystal was removed using Hydrofluoric acid (the rest of the pattern was protected with photoresist).
The fabrication of these devices was carried out in the framework of the ePIXnet Nanostructuring Platform for Photonic Integration [9] and was very similar to that used in [2]. A propagation loss of 12 db/cm was measured for benchmark W1 waveguides.

Transmission Measurements

The devices were characterized using an endfire setup with a broadband LED source source. Figure 3 shows a comparison between W1s with and without the W' injector region. As the mode cutoff is approached (at a wavelength of approx. 1545nm) and the group velocity of the mode reduces, the improvement due to the injector region becomes very apparent- for example, at a wavelength of 1540nm, the transmission of the W1 with the injector is twice that of the normal W1.

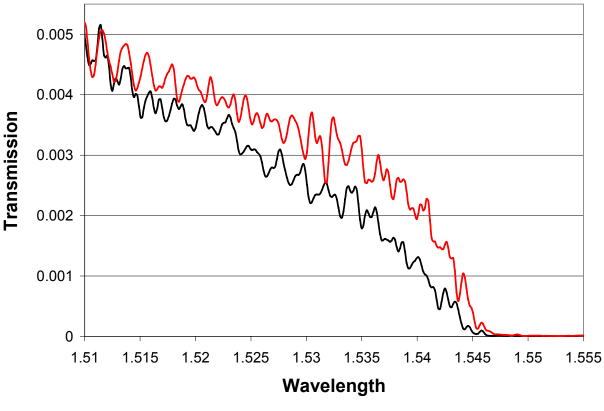

Figure 3: Transmission spectra for a normal W1 (black) and a W1 with 10 period injector regions with a 20 nm period enlargement (red). The nominal lattice constant was 420 nm and the W1 length was 200 µm. The shape of the transmission curves is also influenced by the propagation loss, which is higher in the slow light regime.

The injector region is also expected to improve the tolerances for the fabrication of the interface between the photonic wire and photonic crystal. Normally, nanometer scale imperfections may have significant effects on the transmission but as this region now only affects the coupling from the wire into the fast mode, its significance is much reduced.

Conclusion

An injector region has been implemented that significantly improves the coupling to the slow regime of W1 photonics crystals. This technique may be expected to add to the performance of many slow light photonic crystal designs. Further work will involve the investigation of the more advanced injector proposed in [7], which is predicted to have superior performance in the n_g>100 region.

Acknowledgments

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