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GVD control of low loss slot photonic crystal waveguides for hybrid silicon photonics

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Abstract

Photonic Crystal Waveguides are key components to study diverse phenomena in the linear and nonlinear regimes for integrated circuits and rise as a promising platform to host novel materials. Nevertheless, serious limitations are manifest when slow light is targeted, mainly the propagation losses [1,2]. Even though, photonic crystals are theoretically lossless, the practical implementation is limited by the fabrication accuracy, mainly during the lithographic and etching steps. Interesting studies have been performed in W1-like photonic crystals in order to engineer the losses for given group indices [2]. Further, slot waveguides are known to suffer from larger roughness-induced scattering extrinsic losses than Si wires due to a higher electric field interaction regarding the continuity of the electrical displacement vectors. Then, slot photonic crystal waveguides (SPCW) enhance both sides: hollow core effect and slow light, the light-matter interaction with guest materials, such as polymers or doped compounds.

For optical data transfer and nonlinear applications, the dispersion properties of the waveguides should be carefully addressed. Some interesting approaches for this dispersion engineering in photonic crystals have been theoretically proposed and numerically explored during the last decade. Some of them rely in exotic shapes or asymmetries. This is compelling from a physical point of view but when nanofabrication is considered, the latter approaches are difficult if not impossible to produce. In this work, we have performed rigorous experimental studies under different approaches to determine the best compromise regarding electronic beam lithography, group index, propagation length and losses in slotted structures. As in the lithographic process the average hole position (center) is easier to control than the hole shape, we have experimentally shifted the first two row of holes and vary the radius of the first row to see the effect on the dispersion curves.

Simulations and Experiments

The basic geometry consists in a structure with a lattice constant of a=420 nm, and the hole radius r is 125 nm to ensure a wide TE bandgap. In order to tune the mode and achieve changes in the dispersion curves, the first row of holes was shifted towards the slot by 0.20a and the second row shifted outwards by 0.35a (see Fig. 1). In this study, the radius of the second row of holes was fixed to 125 nm but the radius of the first row was shifted in order to quantify the experimental effects in small changes of only one parameter. The sweeping values are from 95 nm until 125 nm. We have guaranteed the single mode operation and some degree of freedom against possible fabrication imperfections.

In this abstract we only present, as a typical example, the results obtained for the waveguide with r_1=95nm. For instance, we show in Fig.1 a comparison between the two band diagrams of a dispersion engineered waveguide and a SPCW with a fixed radius of 125 nm and no hole shifting. The structures have been filled with a Cargille liquid of refractive index of 1.45 at 1550nm. Some insights about the effect of the indices of the forbidden band and dispersion properties will be detailed during the conference.

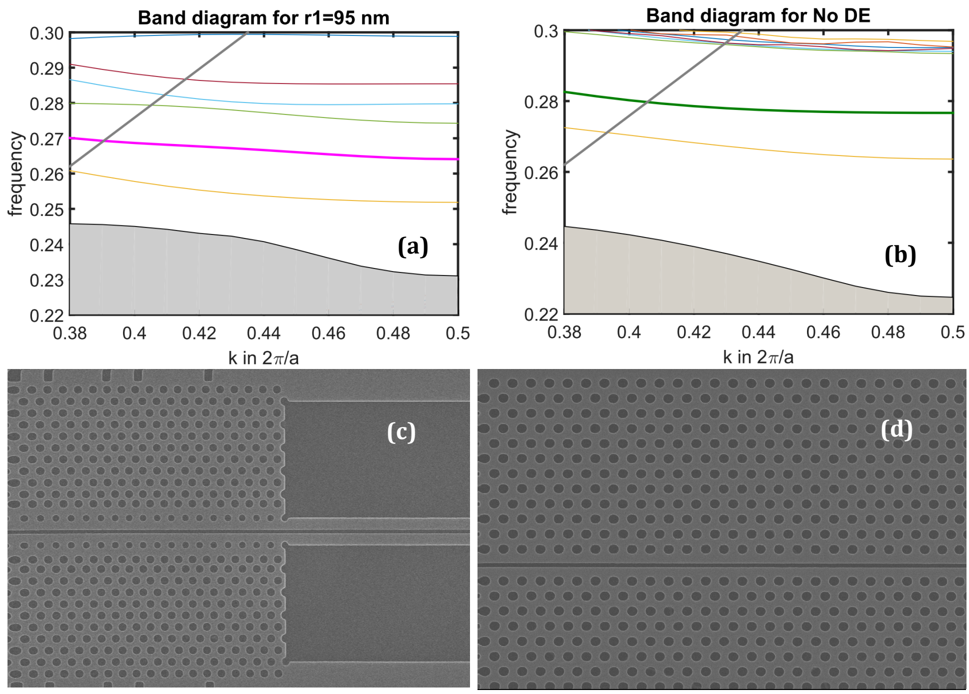

Fig. 21. Band diagram of (a) r_1=95nm radii of the first row of shifted holes and (b) photonic crystal with no DE (r=125nm), (c) and (d) are the respective SEM images of the waveguides. Notice the difference between the first and second row of holes.

It is known that losses dramatically vary with the light group velocity (ng), typically scaling as ng and then ng^2 after a given ng-threshold [1]. This is the reason why any loss estimation in our waveguides should be achieved for a given ng value. The losses in a particular waveguide of 700 µm long could be appreciated from Fig. 2 (a) where a strip waveguide (red) is plotted as reference to compare the on-chip propagation losses. Even though the differences are not noticeable in the scanning electron microscope, there are clear alterations in the optical characterization that we explore with different devices.

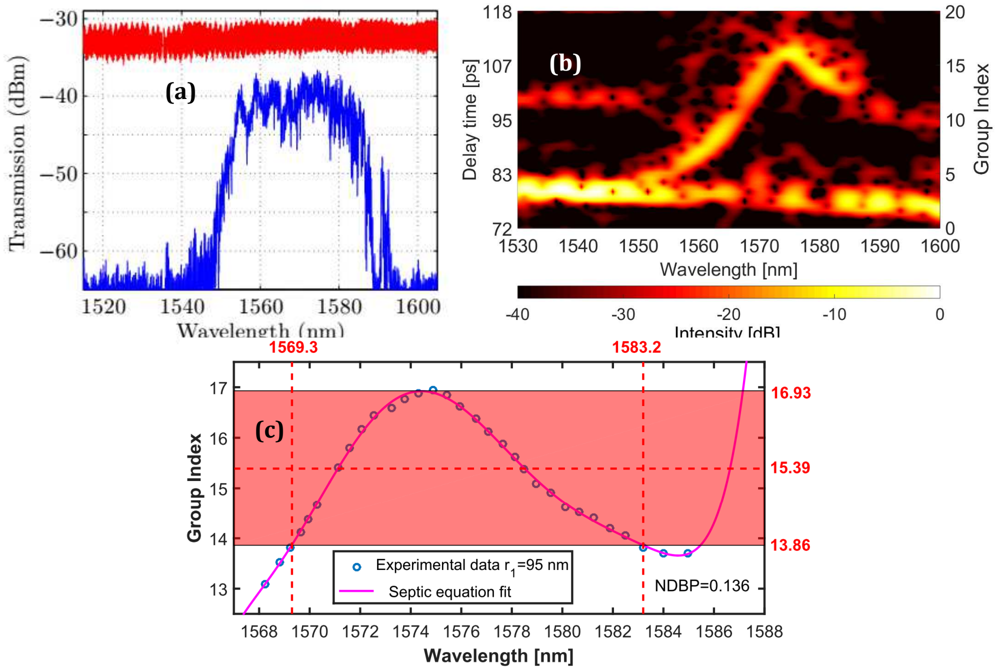

Fig. 2. (a) Optical transmission of a 700 μm SPCW (blue) and a strip waveguide (red). (b) Reflectance map showing the behavior of the photonic delay as a function of the wavelength and (c) Fitting of the dispersion curve with a seventh order polynomial fit (septic equation) with an estimation of a 10% variation of ng.

In Fig. 2 (b) we present the reflectance map of the photonic crystal waveguide [4] where the deflection of the optical delay is clear and the estimation of the average group index is around 15.4 (c). This represents to the best of our knowledge the first experimental demonstration of dispersion engineered SPCW.

Several nonlinear experiments in the slow light regime require the dispersion compensation over a wide bandwidth. For instance, in W1 waveguides, the increase of the confined electric field due to spatial pulse compression have been used to improve the FWM efficiency or the photon generation of correlated photon pairs in the quantum regime. So the engineered hybrid waveguides open a window to novel frontiers in the investigation of new materials and phenomena.

References

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