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Review

Efficient coupling of light wave into slow modes planar photonic crystal slab waveguides

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The generation of the slow modes in a planar photonic crystal waveguide has been highlighted theoretically and experimentally in the two last decade. However, the exploitation of this phenomenon to control the light propagation in the optical integrated circuits faces several obstacles and technological locks. On the one hand, it is almost impossible to excite this type of modes in the slowing light devices because of the group velocity mismatch and even if we are able to overcome this problem, the frequencies of the slow modes are very close to the band edge which causes the optical signal distortion by high value of group velocity dispersion. On the other hand, the slow modes are characterized by a special spatial distribution of the electromagnetic field which extends beyond the defect which serves as a wave guide, this lead to an intense interaction of a part of the guided light with the holes of photonic crystal and cause the appearance of the different type of losses. Several solutions have been proposed to address these various issues and our contribution is in this perspective, and more specifically, it is trying to find the parameters that enable an optimal coupling of the fast modes of our planar photonic crystal waveguide into his slower one. To achieve this goal, we chose to work in two stages. First, we have sought the structural parameters that will help us to generate a slowly mode with zero-dispersion effect. After, we have worked and demonstrated the efficient static coupling of light into the slow modes photonic crystal waveguide.

Key words: Slab waveguide, photonic crystal, slow modes, efficient coupling.

INTRODUCTION

Nowadays, the need for ultra-fast communication has become one of the main challenges in the telecommunications sector. Existing technologies have reached their limit and seriously, we began to explore the new alternatives that increase the speed of communication with a broad bandwidth. In this context, the solutions based on optical circuits are quite promising and they are able to meet the expectations and requirements of modern telecommunications (Baba, 2008). However, the use of light to transmit information from one end to the other, absolutely requires to enhance our current level of control of the processes and phenomena behind the generation, propagation and detection of photons. In addition, the miniaturization of optical devices and photonic components are necessary to achieve compactness and to reduce the manufacturing cost.

The planar photonic crystals are perfectly adapted to these needs, because they allow us, in one hand, to have a pushed control on the light-waves propagation through

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the photonic crystal micro-structure. On the other hand, they offer the possibility to improve by several orders of magnitude the integration density of optical functions in the photonic circuits (John, 1987). The introduction of a linear defect by removing the central row of holes in the ΓK direction, allows us to achieve the guidance function of light-waves in the planar photonic crystal waveguide (PPhCW) if these conditions are fulfilled:

(a) The planar photonic crystal (PPHC) must have a spectral band within which, any propagation of light waves is prohibited, at least for one of the light polarization states and for one of high symmetry directions of PPHC,
(b) The guided modes must have a large part of their photonic band below the light-line otherwise they will couple to the continuum of modes radiation and will cease therefore to propagate in the PPhCW defect,
(c) It is preferable for the PPhCW to present a unimodal behavior to avoid the problem of inter-modal coupling who is accompanied in most cases with a huge degradation of the guidance performance (Settle et al., 2007),

We can distinguish the PPhCW band diagram in two operating regimes:
(i) The fast one for which the dispersion curve is almost similar to that of the fundamental mode of ordinary waveguide.
(ii) The slow light regime, which corresponds to a radical change in the dispersion curve. She begins to gradually flatten as we approach the photonic band edge. Chromatic dispersion becomes very important, so it limits the usefulness of working in this field.

Several studies have proposed to overcome the divergence problem of the group velocity dispersion (GVD) in the vicinity of the band edge (Baba et al., 2009). Some of these studies have suggested the exploiting of the phenomenon of the mini-stop bands induced by the anti-crossing effect that can be observed in the ΓK interval. In the vicinity of the anti-crossing point, the dispersion curve has a tendency to flatten on both sides around this point and thus giving birth to a frequency branch for which the group velocity is largely reduced (Petrov and Eich, 2004).

By contrast, other studies have suggested, to obtain a reduced group velocity, to use the dispersion compensation. In this configuration, the PPhCW is formed by two PPhC portion with opposite chromatic dispersion sign (Baba and Mori, 2005). Once the dispersion engineering of the PPhCW is tailored to the application needs, we will focus on the problem of coupling light to the slow mode regime. The light pulses are routed to the entry of the PPhCW through a regular planar waveguide. To minimize the injection losses, it is necessary to attain a perfect impedance match between the rib waveguide fundamental mode and PPhCW TE-like mode (Baets and Marti, 2004). Then, we must realize the deceleration of the fast mode of the PPhCW until they lead the slow light regime area in the band diagram. To resolve this problem, there must be a transition zone within the PPhCW which enables the implementation of a smooth gradual deceleration of group velocity to the desired value. This is achieved by changing adiabatically one of the PPhCW structural parameters (Vlasov and McNab, 2006).

In this work, we have chosen to vary gradually and smoothly the position of the hole centers of the first row along a finite number of periods on both sides of the PPhCW line defect. The idea is to shift smoothly the band diagram from the fast mode regime to the slow one. The transition is adiabatic, which helps to minimize the injection losses caused by the group velocity mismatch between the fast modes and those that operate in the slow regime.

OPTIMAL DESIGN OF PLANAR PHOTONIC CRYSTAL WAVEGUIDE (PPhCW) FOR SLOW LIGHT REGIME

Our PCW is achieved by inserting a triangular lattice of cylindrical holes with radius $r=0.3a$ in a semiconductor slab having an optical index $n=3.45$ and a thickness $h=0.55a$, the period of the triangular lattice is $a=410$ *nm*. h is chosen so as to ensure only the existence of the fundamental mode in the vertical direction. The PPhCW channel guide is formed by omitting the insertion of the middle row of cylindrical holes in the ΓK direction. The determination of the PPhCW band diagram requires the use of a full 3D calculation, but seeking for the simplicity we make this calculus by using the 2D finite element solver. In this situation, we choose the effective index of the fundamental rectangular waveguide mode as optical index of the semiconductor slab. It allowed us to find the dispersion curve of the fundamental mode of the PPhCW and the corresponding group velocity. Both curves show that the regime of slow light is located near the photonic band edge of the guided mode. In this area, the effects of higher-order dispersion is highly intensified and become the principal source of optical signal distortion and broadening (Figure 1).

In general, the high-dispersion behavior encountered in the PPhCW is due to the light resonance with the micro features of the PPhCW. To control the high order dispersion, we must carefully choose the structural parameters in the vicinity of the defect line. In this article and after many simulations, we have found the values given in Figure 2 as an acceptable choice to achieve the goal of moderate low group velocity with extra low chromatic dispersion on a large spectral range. This new design leads to a novel dispersion curve for the PPhCW TE-like mode that exhibits a broadband spectral range for which the value of group velocity is almost constant. This

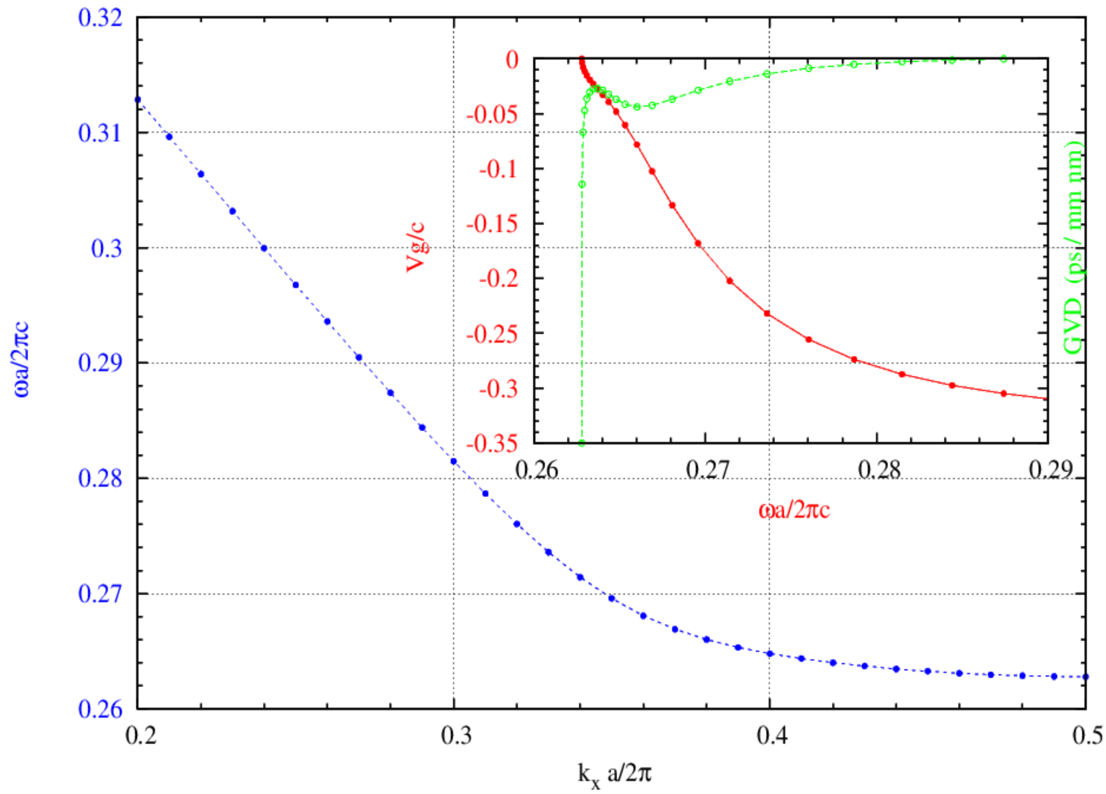

Figure 1. Photonic band diagram, Group velocity and Group velocity dispersion for PPhCW TE-like mode.

W_1	W_2	W_3	r_1	r_2	r_3
0.95	0.9	0.85	0.25[a]	0.27[a]	0.29[a]

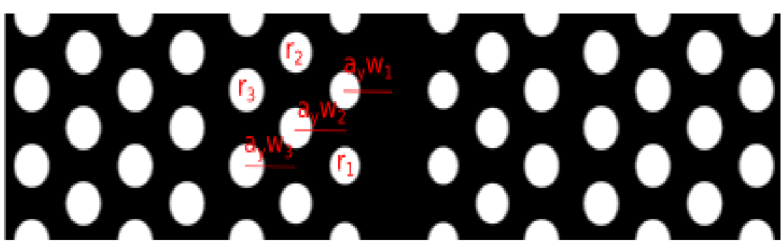

Figure 2. Modified planar photonic crystal waveguide, $a_y = 0.5\sqrt{3}a$.

implies that the chromatic dispersion reaches its lowest value (Figure 3).

It is clear that the optimized PPhCW exhibits a dispersion curve possessing a straight portion over a wide spectral band. This corresponds to a low and constant group velocity and hence a very low level of GVD. The almost zero-dispersion area is now located a little further from the edge of the PPhCW band and has a spectral width of 200 GHz for a value of the group index of about 28 ± 10%.

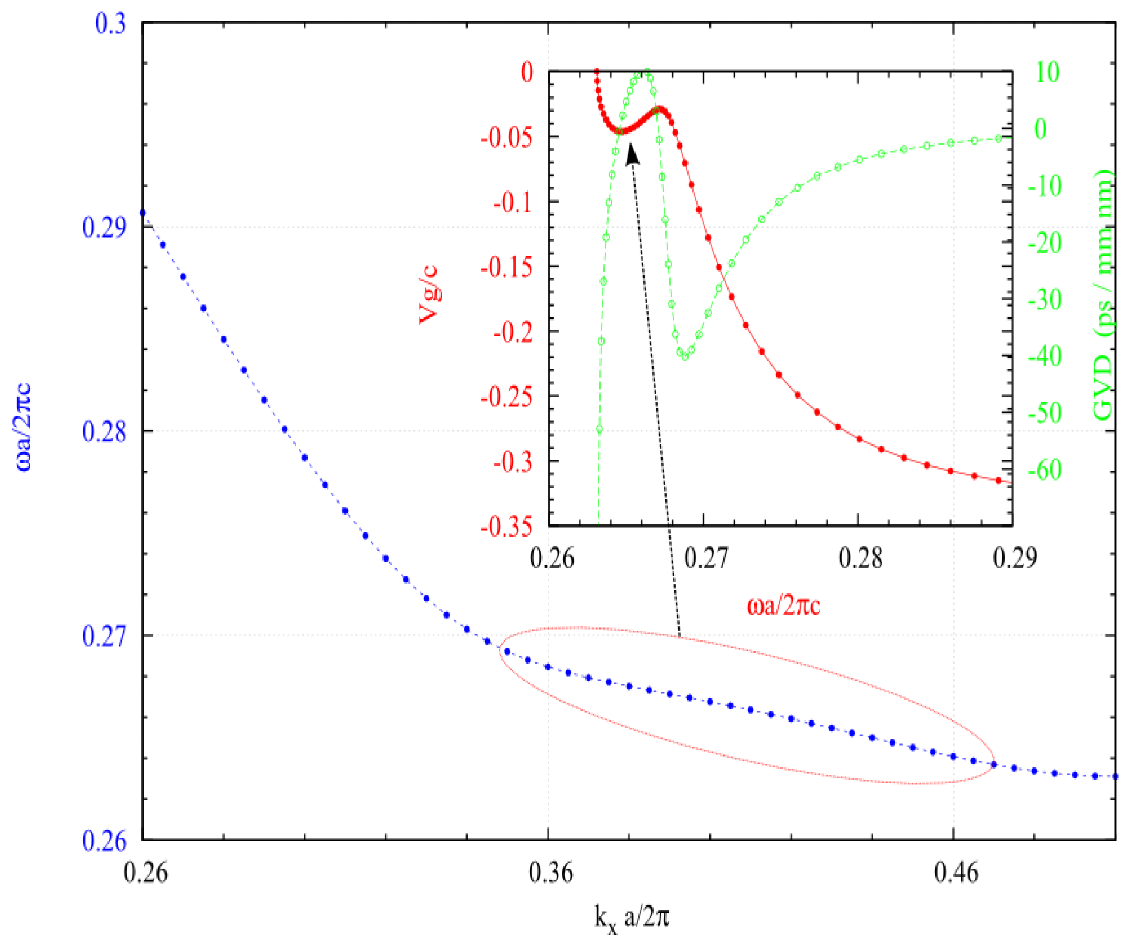

Figure 3. Photonic band diagram, Group velocity and GVD of optimized PPhCW TE-like mode.

LIGHT COUPLING TO SLOW PPhCW MODE

To couple an optical pulse from an optical fiber to the linear defect of the PPhCW, we must proceed in three steps: First, we must couple the fiber mode to that of an ordinary waveguide. Then we have to couple the latter to the TE-like mode of PPhCW in his fast regime and finally slow down it gradually until they reaches the regime of slow modes. For the first two stages, effective solutions have been developed but the solutions proposed for the third stage are still experimental. They are divided into two main categories: butt-coupling and taper-coupling technique. In this study, we chose to mix the two techniques to improve the coupling of the fundamental mode of the conventional waveguide with that of PPhCW in his slower regime. Our approach is to use the advantages of the butt-coupling technique to minimize the insertion loss induced by the coupling process of the fundamental mode of the rectangular waveguide to the fast one of the PPhCW. Then, we change the position of holes center progressively on a few periods for the first row of holes neighboring the defect line in order to shift adiabatically the PPhCW mode from the fast regime to the slower one (Figure 4).

It is clear that if we excite a PPhCW fast mode at the normalized frequency f_r=*0.2665*, it will propagate in the defect line of the PPhCW and gradually it will feel the progressive variation of the w_1 channel width. Then it start slowing down his group velocity until it reach the target value as it is showed in the diagram of transmission / reflexion (Figure 5).

CONCLUSION

In this work we have showed the critical importance of PPhCW in the optical circuits operating in the slow light regime. We have discussed the factors to be taken into account to generate slow light guided modes which propagate in PPhCW defect line without distortion of optical pulses carrying the signal. We have showed that is possible to engineer a specific dispersion profile by

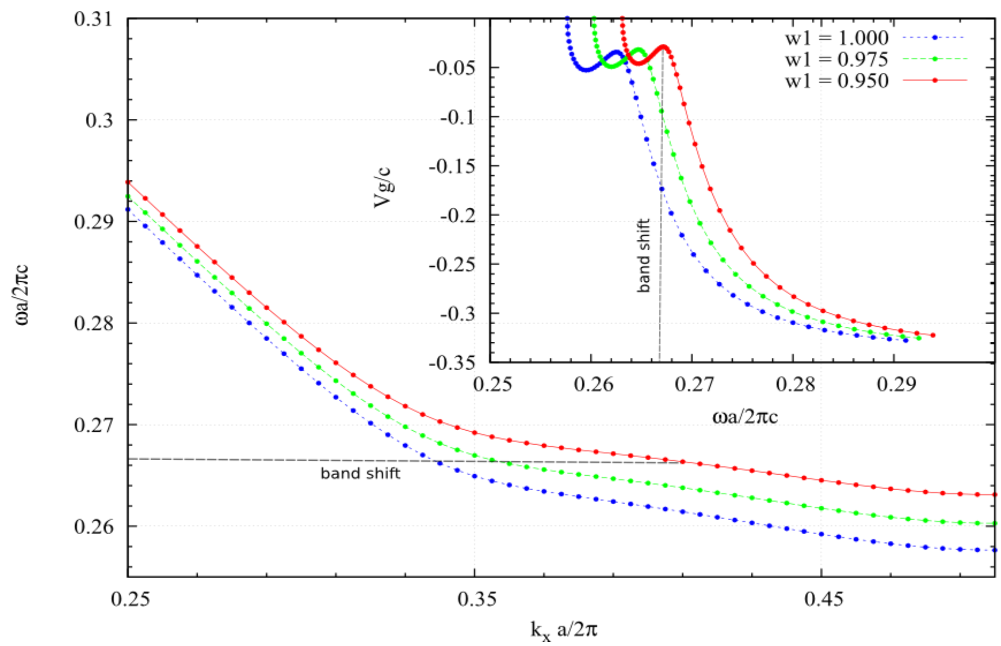

Figure 4. Dispersion curve shift for the PPhCW TE-like mode when w_1 is modified.

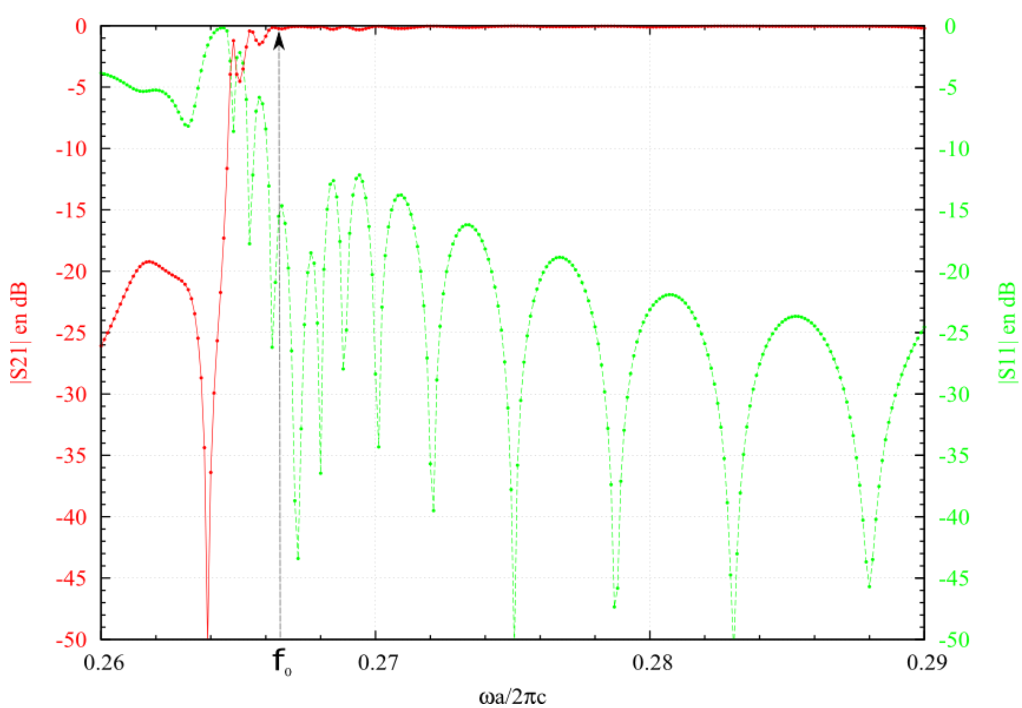

Figure 5. Diagram of transmission and reflexion of the modified PPhCW for TE-like mode.

modifying the structural parameters of PPhCW in the vicinity of channel waveguide, in order to control the effect of chromatic dispersion. We have also addressed the problem of mode coupling between ordinary waveguide modes and planar photonic crystal waveguide modes operating in slow light regime and we have demonstrated numerically the coupling efficiency of our design.

REFERENCES

Baba T (2008). Slow light in photonic crystals. Nat. Photonics 2:465-473.
Baba T, Adachi J, Ishikura N, Hamachi Y, Sasaki H, Kawasaki T, Mori D (2009). Dispersion-controlled slow light in photonic crystal waveguides. Proc. Jpn. Acad. Ser. B 85:443-453.
Baba T, Mori D (2005). Wideband and low dispersion slow light by chirped photonic crystal waveguide. Opt. Express 13(23):9398.
Baets R, Marti J (2004). Analysis of butt coupling in photonic crystals. IEEE J. Quantum Electron. 10(5):541.
John S (1987). Strong localization of photons in certain disordered dielectric lattices Phys. Rev. Lett. 58:2486-2489.
Petrov AY, Eich M (2004). Zero dispersion at small group velocities in photonic crystal waveguides. App. 85(21):4866.
Settle MD, Engelen RJP, Salib M, Michaeli A, Kuipers L, Krauss TF (2007). Flatband slow light in photonic crystals featuring spatial pulse compression and terahertz bandwidth. Opt. Express 15:219-226.
Vlasov YA, McNab SJ (2006). Coupling into the slow light mode in slab-type photonic crystal waveguides. Opt. Lett. 31(1):50.