Efficient coupling to W1 Photonic crystal waveguide on InP membrane through thinly supported access guides

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Abstract : Thinly supported access ridges have been designed in order to improve the coupling efficiency into W1 Photonic crystal –PhC- waveguides on InP membrane. This integration allows to control the termination of the W1 PhC guide. Low propagation losses have been measured for these thinly supported guides.

Introduction

InP-based Photonic Crystal –PhC– membranes are attractive because they can combine the advantage of operating PhC guides (mainly W1) below the air light-line [1], so theoretically in a lossless regime, with the possibility of including emitters such as quantum boxes emitting at 1.55µm. The theoretical lossless regime can be reached in the case of a perfect system. Part of the imperfections comes from e-beam lithography [2] and part comes from holes etching.

We have investigated here an ICP-RIE process leading to very smooth etched surfaces. Previous work had implemented a Cl2/Ar-based processes for deep etching. But, we were not able to suppress some residual roughness [3]. In the case of a membrane, deep etching is no more an issue, since the membrane thickness does not exceed 350-400nm (λ/4) in order to operate in a monomode regime. But the etched surfaces have to be very smooth, because any additional roughness will produce scattering, thus increasing propagation losses. We have developed a process including N2 in the gas mixture, as already proposed by P.Strasser et al [4], and discussed in [5].

Injecting light in a strongly confined PhC guide is still difficult due to the strong modal mismatch. Also, the role of the termination of the W1 guide has been evidenced to play a crucial role [6]. We propose here a new type of access guide, thinly supported access guides that are realized during the same technological steps than the holes. They allow to control the final termination of the PhC guide. relative position of the injected power. We fabricated W1 PhC guides on a 340nm thick InP membrane. A 770nm sacrificial GaInAs layer is selectively etched away to produce the membrane. Different lengths of W1 are fabricated in order to obtain the propagation losses through the Fabry-Perot oscillation method. The PhC triangular matrix has a 420nm period. The air-filling factor is close to 30%. These PhC parameters allow to cross the air light-line in a wavelength domain close to 1500nm. Due to the strong effect of termination [6], the reasonably low propagation losses found here are a first estimate, and have to be confirmed.

PhC technology

PhC holes are defined by e-beam lithography in a PMMA resist layer, and then transferred with a CHF_3-based RIE process in a SiO_2 250nm-thick underlying layer deposited on the semiconductor material. After removing the PMMA resist, this SiO_2 layer is used as a mask for ICP etching. ICP etching is performed in a Sentech SI500 system. We first investigated different Cl_2/N2 ratio , while keeping a low Cl_2 fraction in order to avoid a too large chemical contribution. This two-gas mixture does not allow the obtainment a smooth and simultaneously vertical surface: the surface passivation is always too large, and lead to closed holes as visible on the SEM picture (cross section) of fig.1-a. The non-verticality of the holes is detrimental for propagation because it produces additional losses. In order to keep the advantage of surface passivation through N2, and simultaneously improve the verticality of the etched profile, we have added BCl3 in the Cl2/N2 gas mixture. In the presence of the electronegative N2 molecule, the extremely electron-deficient compound BCl3 is dissociated and then contributes to the chemical part of the etching. BCl3 is also ionized, and the heavier ions (versus those produced through Cl2) contribute to a stronger physical component of the etching process, and as a consequence a more vertical profile. The advantage of BCl3 is clearly visible on Fig 1-B. The ICP source power is set to 1000W, the DC-bias is set to -200V in order to limit the mask etching rate.

A B

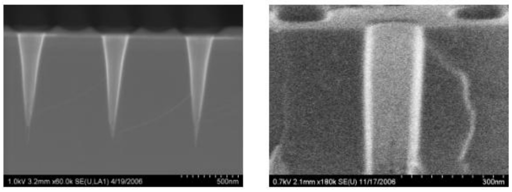

Figure 1. SEM cross section view of etched holes using A-Cl2/N2 process B- Cl2 / N2 / BCl3 process

W1 PhC guides are fabricated on a 340nm thick InP membrane. A 770nm sacrificial GaInAs layer is selectively etched away to produce the membrane (fig.2). Different lengths of W1 are fabricated in order to obtain the propagation losses through the Fabry-Perot oscillation method. The PhC triangular matrix has a 420nm period. The air-filling factor is close to 30%. These PhC parameters allow to cross the air light-line in a wavelength domain close to 1500nm.

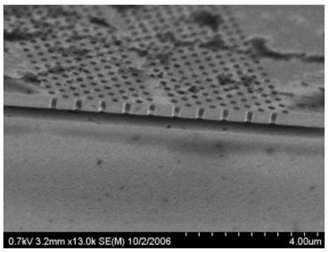

Figure 2. InP membrane after selective etching

W1 PhC guide on InP membrane

The spectrally resolved transmission of a 450µm long W1 measured using the end-fire method is plotted in Fig.3, also with the related dispersion curve: we can follow the even mode crossing the air light line (point A), then the transmission is reduced due to the high losses experienced by the odd mode, especially close to its cut-off (point B or/and B'), then the transmission is ensured by the even mode alone down to its cut-off (point C). Coupling to the odd mode is possible because the position of the external fiber cannot be perfectly centered on the W1 axis. An access guide would prevent this from happening. Losses measured using the Fabry-Perot resonance technique in the reduced frequency window centered at λ=1490nm [7] reach 35dB/cm. This value represents the overall losses, including the perturbation due to the odd mode. Also, additional uncertainty comes from the different termination for all the different guides measured. The very large dispersion at longer wavelength (λ=1540nm) prevents the loss calculation using the same method.

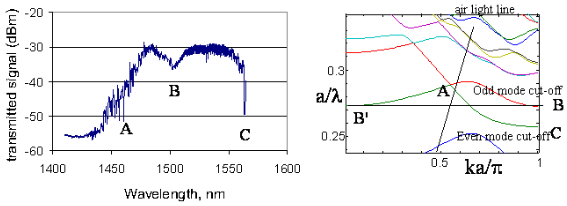

Fig 3. Spectrally resolved transmission of a 450µm long W1 and the related dispersion curve

Thinly supported guides

Thinly supported access guides have been designed in order to produce a perfectly centered optical injection in the W1, and also to control the termination of W1. These guides are written during the same e-beam lithography, thus ensuring a perfect alignment of the axis guide with the W1 axis, and also etched during the same step. Fig.4-a shows a perspective SEM view of a thinly supported guides, with 10µm long sections and 0.15µm wide supporting fins. These fins do not affect the transmission of the guide: fig.4-b displays a detail of the transmission spectrum measured on a 210nm wavelength span (1410nm-1620nm) for 461µm long guide, demonstrating a 4dB contrast fringe contrast, the propagation losses of these guides are 16dB/cm. The Fourier transform spectra on 12 windows (fig.4-c) show no dispersion on this very large spectral range.

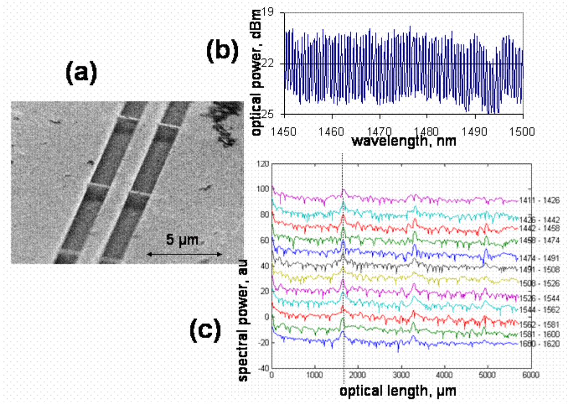

Fig.4 (a) SEM view of a thinly supported guide
(b)Detail of the spectrally resolved transmission
(c)Fourier transformed spectra of this transmission

W1 PhC guides with thinly supported access guides

W1 PhC have been fabricated in between these access guides. Three different lengths have been fabricated : 210µm, 420µm and 630µm, to allow the loss measurement through the Fabry-Perot method. A resolved spectrum of a 420µm long W1 is plotted on Fig.5 : the dip due to the coupling to the even mode is still visible. We can then conclude that, in spite of an on-axis optical injection from the access guide the odd mode is excited. Fabrication imperfection, mainly e-beam lithography are responsible for this optical power transfer from the even mode to the odd mode. We also see that in the spectral region of the single even mode, the transmission is larger than the one in the case of the W1 alone by a few dB (-27.5 instead of -30 dB in Fig. 4, a trend systematically observed) : the thinly supported guides improve the transmission.

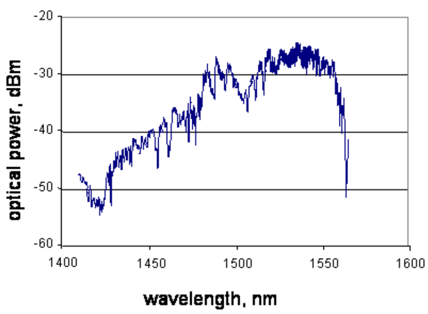

Fig.5 : Spectrally resolved transmission of a 420µm long in between access guides

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These very first results have to be comforted by additional characterization in progress.

Conclusion

Propagation losses have been measured on W1 Photonic Crystal waveguides etched using an N2-based ICP process on InP membranes and operating below the light line. The W1 PhC guide has been designed to support one even and also one odd mode in the spectral domain investigated. The cut-off of the odd mode is in this case a clear signature of the even/odd coupling produced, either by an imperfect injection, or by an imperfect fabrication, or by both. We have proposed the new design of a thinly supported access guide to produce a correctly centered injection. The still observed cut-off of the odd mode in the case of a W1 with these access guides indicates that fabrication imperfections are still present. The design is however validated by an observed better coupling.

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