Ultra-sharp edge filtering in nanotethered photonic wire

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Abstract : An InP-based photonic wire including periodically spaced nanotethers can demonstrate a complex resonant behaviour leading to an ultra-sharp filter edge. This coupled resonant mechanism is investigated mainly experimentally but also with first theoretical views.

Keywords: Optical waveguide filters, coupled resonators, photonic wires, suspended membrane

I- INTRODUCTION

Optical filtering is a key function in all-optical networks. Simultaneously to a large –at least 20dB– rejection, the highest sharpness is desired for a very selective spectral response. Additionally, such a reflector can be used in optical modulation or switches. Ring resonators based filters have been extensively investigated, and in such an environment, filters can be custom-designed implementing a large number of coupled ring resonators [1,2]. A very sharp edge filter has also been proposed in a photonic crystal –PhC-environment, including phase-shift elements aside the PhC waveguide [3].

We propose here and demonstrate, both theoretically and experimentally, that a photonic wire including regularly spaced nanotethers can behave as a reflector exhibiting a very sharp band-edge.

II- SIMULATION

A photonic waveguide including a periodic perturbation exhibits a transmission stop-band – forbidden frequency range – due to the in-phase feedback contribution coming from all the grating elements, the well-known Distributed Bragg Reflector (DBR) effect.

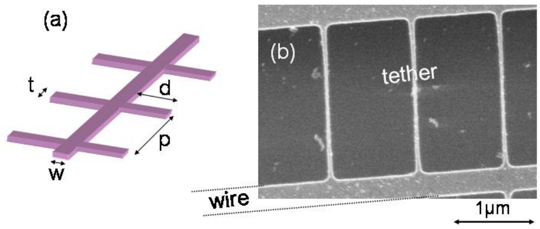

Fig.1: (a) schematic of the tethered wire
(b) SEM picture of a suspended wire (period p=1 µm, tether length d=2µm, wire width w=0.3 µm)

The stop-band width is determined by the feedback strength, and the stop-band edge sharpness is determined by the overall grating shape. On this basis, addition of dissipative elements damps the filter shape while, on the contrary, reactive elements sharpen it.

In our case, the photonic wire is suspended in air through regularly spaced nanotethers (fig.1-a). These nanotethers operate as a Bragg reflector. Furthermore, for a specific wavelength, each tether operates as a weak reactive element that can be viewed as a resonator or a stub : the tethers are transverse waveguides with a sizable reflection at their ends (Fig.1b). The photonic wire is coupled to the series of all these stubs.

We have simulated the spectral response generalizing the archetypal model proposed by S. Fan for the increased sharpness of a side-coupled waveguide-cavity system arising when including a partially reflecting element in the waveguide [4].
In our case, the reflecting element is the cross section between the tether and the wire, and the resonant cavity is the tether itself.

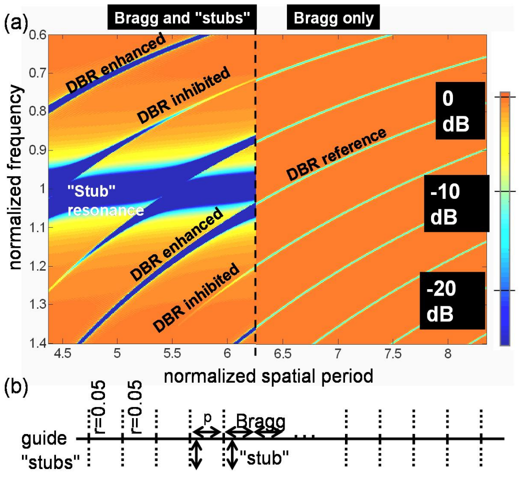

Fig.2 : (a) Calculated transmission (colour scale) versus frequency and tether period p. Each reflector features r=0.05. See text. (b) Sketch of the multiple cavity+stub arrangement.

We have extended the calculation including 36 cavities and as many coupled elements (Fig.2b). We have plotted on Fig.2 the calculated transmission (colour scale) versus the frequency and spatial period which is the distance between tethers. The usual frequency gaps due to the Bragg effect alone are plotted on Fig.2-a right. The abscissa is equivalent to period *p*.

We see on Fig.2-a left the transmission when both the DBR effect due to the periodic reflectors and the resonance in each stub take place: a large frequency gap is visible additionally to the narrow gaps due to the low reflectivity of the crossing sections set to r=0.05. Additionally, as for the single cavity case [4], the depth of the DBR dip is much enhanced even far from the stub resonance, and its edge is also sharper (detail not shown). For this simulation, every other Bragg resonance is "enhanced", and the other one is "inhibited", likely for symmetry reasons.

III- EXPERIMENTS

Suspended tethered wires have been fabricated on a 260 nm thin suspended InP membrane. An established process based on ICP etching of the nanopatterns followed by a selective etching of the sacrificial layer and a super critical drying is used [5], see Fig.1-b. Investigated parameters are the following: wire width *w*= 0.3, 0.4 and 0.6 µm, tethers spacing *p*=1 or 2 µm, tethers length *d*= 1 to 2 µm, tethers width *t*= 40 to 100 nm. Closely spaced tethers have been chosen for a single transmission dip in the measured 1410-1620 nm wavelength domain. Measurement of 680-µm-long photonic wires are performed on an end-fire fibre set-up including a polarisation-maintaining tuneable source in TM-like polarisation (E vertical), and plotted in Fig.3 for two selected cases. Transmission in case (a), when p = 1µm is smaller than the one in case (b) where p = 2µm, because the number of tethers is twice larger, thus leading also to higher propagation losses.

The spectral dip shape is qualitatively in agreement with the trends of S.Fan work [4] (Fig.2), but more firm connections have to be established as the stub resonance is not evidenced in the limited experimental spectral range. Reducing the wire width gives rise to a dip with a larger spectral width and a sharper edge, because the overlap of the swollen field profile with the tether is larger. Inversely, going to wider wires w>0.4 µm was found to lead to the disappearance of the coupled resonant effect.

Additional structures are currently investigated.

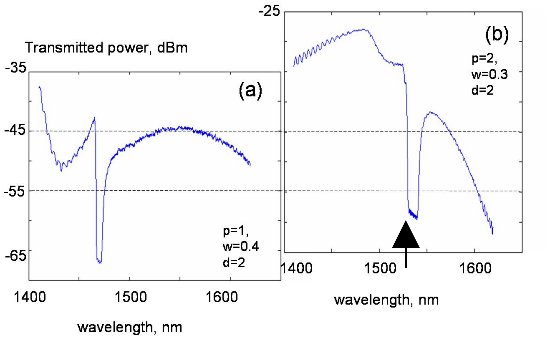

Fig.3 : Measured transmission for tethered wires ;
(a) in the case of p=1µm, w=0.4µm, d=2µm and t=70nm
(b) in the case of p=2µm, w=0.3µm, d=2µm and t=70nm. The falling edge (arrow) drops by 14 dB in a 1 nm span at 1529 nm.

CONCLUSION

We have experimentally evidenced that a photonic wire including regularly spaced nanotethers on both sides exhibit sharp edges in its transmission spectrum that we attribute to a complex coupled–resonator behaviour, reminiscent of both "all-pass" and "coupled-optical-resonator waveguide" behaviours. We propose that the resonance takes place in each tether much like in a stub, and all resonators are coupled through the waveguide wire. We will report more in detail on the parametric range, notably the wire widths and the tethers cross sections, for which this effect is best observed.

References

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