Design and Analysis of Polarization Selective Tunable Photonic Crystal Filters

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***Abstract*—Our goal in this work is to achieve a tunable photonic crystal micro-opto-electro-mechanical system which excites two resonances with opposite polarization. In order to get a polarization selectivity we use two-dimensional photonic crystals with periodically arranged elliptical holes. We investigate the tunability and make statements about parameters that play an important role in optimization of this system. A final design is found for our goal. For the computation we use a three-dimensional finite element solver which solves the inhomogeneous Helmholtz equation.**

I. INTRODUCTION

Fabry-Pérot (FP) filters, designed as a micro-opto-electro-mechanical system (MOEMS) are used in optical communication systems as channel-selective elements in dense-wavelentgh-division-multiplexing (DWDM) systems as well as in the near-infrared (NIR) spectroscopy and vertical cavity lasers [1]. By micro-mechanically actuating the length of the FP cavity (see Fig. 1(a)), the resonance can be tuned with high accuracy [2], [3]. The integration of photonic crystals (PCs) [4] improves the functionality of the filter [5]–[7]. This combination forms a PC-MOEMS (see Fig. 1(a)). By tuning, an extended spectral range is covered and thus the applicability of this system improved.

II. SIMULATION RESULTS

We simulate a quarter of the unit cell, with periodic boundary conditions so that the transmittivity is calculated for an infinite structure. The results are presented in the following.

A. Combining Photonic Crystal Slab (PCS) and Fabry-Pérot (FP) Filter

For the first result of our design we use a periodicity of $a = 1.2\ \mu$m, a target wavelength of $\lambda_{\text{target}} = 1.45\ \mu$m, a refractive index of InP layers $n_{\text{InP}} = \sqrt{10.2}$, a major semi axis of $u = 0.9508a/2$ and a minor semi axis of $v = 0.535a/2$ (see Fig. 1). We calculate the InP layer thicknesses and air gaps via $h_{\text{InP}} = 3\lambda_{\text{target}}/4n_{\text{InP}}$, and $d_{\text{air}} = \lambda_{\text{target}}/4n_{\text{air}}$ ($n_{\text{air}} = 1$) (see Fig. 1(a)) [8]. The results are presented in Fig. 2. The green curve shows the transmittivity spectrum of a FP filter (without PCS). The blue curves show the transmittivity spectra of a PC-MOEMS for two polarizations, and the red curve shows that of another FP filter where the PCS is replaced with a layer without holes (see Fig. 1(a)).

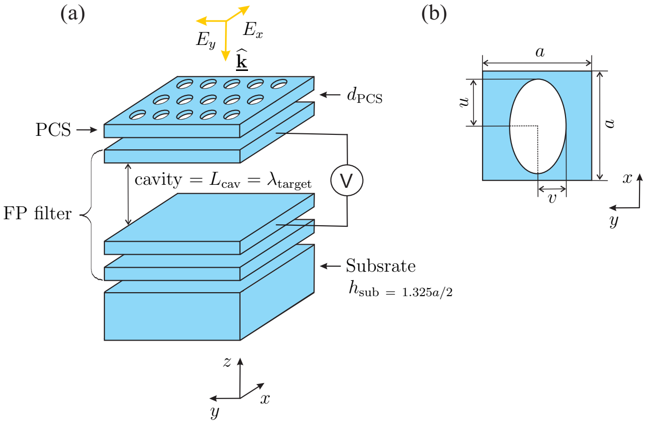

Fig. 1. (a) Geometry of the periodic InP/air based PC-MOEMS (PCS/FP filter), (b) a single elliptical hole (square unit cell).

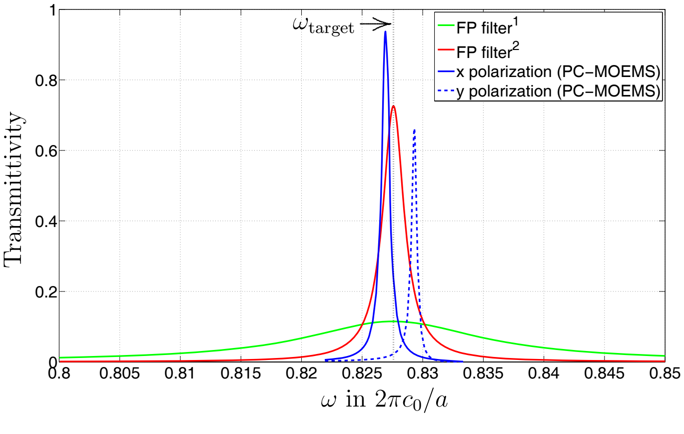

Fig. 2. Transmittivity spectra of different filter structures with substrate; one top layer, cavity, and two bottom layers (FP filter^1), two top layers, cavity, and two bottom layers (FP filter^2), electric field polarization parallel to x axis (major axis of ellipse) (blue solid curve), electric field polarization parallel to y axis (minor axis of ellipse) (blue dashed curve), refractive index of InP $n_{\text{InP}} = \sqrt{10.2}$.

From the transmittivity spectra we see that the FP filter predefines the target wavelength respectively the target angular frequency ($\omega_{\text{target}} \approx 0.8276$), while the PCS cause a shift in the wavelength, additionally affecting the quality factor.

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We vary the following specifications for our analysis: the lengths of the major and minor semi axes u, v, the distance of the PCS to the next InP layer d_{PCS}, and the length of the cavity L_{cav} (see Fig. 1). They are the most sensitive parameters with respect to performance.

First we vary d_{PCS} and L_{cav} in a full 3-D simulation, and compare the results to the corresponding 1-D calculation with the corresponding effective refractive index of the top layer. We find that both structures show the same behavior; if d_{PCS} or L_{cav} increases/decreases then $\lambda_{\mathrm{target}}$ increases/decreases. Which asserts that the target wavelength depends mainly on the FP filter.

Next we compare our results to those of PCS [9] where we vary the dimensions of the semi axes. In both cases we find the same behavior; if u or v increases/decreases then $\lambda_{\mathrm{target}}$ decreases/increases. This confirms again that the PCs affect both the wavelength of FP resonance and the quality factor.

Fig. 1(a) shows the PC-MOEMS structure, which is a combination of two systems; a PCS (system 1) and a FP filter (system 2), each of which has its own resonance. The resonance of system 1 is caused by lateral mode, which is the result of the coupling between the radiated mode and the waveguide mode [7]. System 2 on the other hand, resonates in the vertical direction [7]. The resonances of the whole system (PC-MOEMS) (see blue curves in Fig. 2) result from the coupling between both systems 1 and 2, where the suitable dimensions of the holes are necessary to get this resonance. In case of resonance in the vicinity of target wavelength, the field distribution of the PC-MOEMS is similar to that of the structure without the holes (FP filter).

The goal is now to optimize the design so that we get two resonances with opposite polarization. One of the resonances should occur at the target wavelength respectively the target angular frequency ($\omega_{\mathrm{target}} \approx 0.8276$).

B. Tunability in PC-MOEMS

For the optimization of the FP resonance, three parameters are required; major semi axis u, minor semi axis v, and PCS distance d_{PCS} (see Fig. 1). With an appropriate selection of these parameters, on the one hand we get a good polarization selectivity at the target wavelength ($\omega_{\mathrm{target}} \approx 0.8276$), and on the other hand we can affect the distance between the two resonances with opposite polarization behavior. Fig. 3 shows an example with $u = 0.9842a/2$, $v = 0.535a/2$, and $d_{\mathrm{PCS}} = 0.58a/2$ (see blue curves).

The resonance wavelength can be selected by tuning the cavity length (see rest of the curves in Fig. 3). This is accomplished by electrostatically changing the length of the cavity (see Fig. 1(a)). We conclude that we can tune the wavelength in a consistent manner, while the shape of the resonances stays approximately constant.

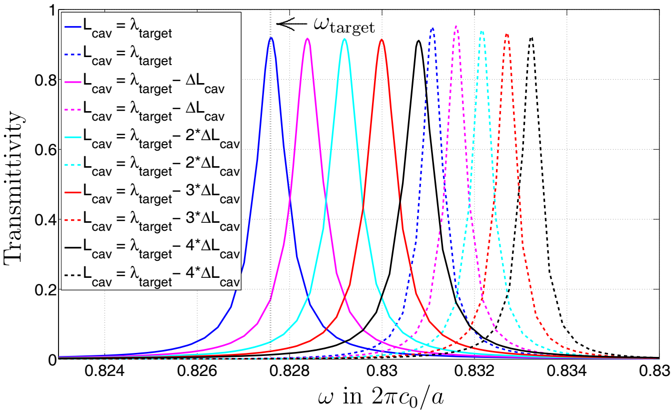

Fig. 3. Tunability spectra of a PC-MOEMS; electric field polarization parallel to x axis (major axis of ellipse) (solid curves), electric field polarization parallel to y axis (minor axis of ellipse) (dashed curves), refractive index of InP $n_{\mathrm{InP}} = \sqrt{10.2}$, $\Delta L_{\mathrm{cav}} = 2.5$ nm.

III. CONCLUSION

In this work we presented a filter design which is tunable for frequency and polarization selectivity. It is observed that the dimension of the holes and PCS distance play an important role in the design. PCs have a great impact on the resonance characteristics of the FP filter. They shift the target wavelength and change the quality factor of the resonance that is predetermined by the FP cavity. Suitable parameters were identified by extensive simulation in order to achieve two resonances with opposite polarization. An experimental implementation of the filters is under way.

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