COUPLED SILICON-AIR FABRY-PEROT RESONATORS WITH TUNABLE TRIPLET MODES

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SUMMARY

We report on optical properties of Fabry-Pérot (FP) resonator based on Si-air one-dimensional photonic crystal (1D PC) with coupled triple-cavity modes (or defects). These defects obtained by infiltration of the air-cavity with the filler of tunable refractive index. The coupled FP resonators design is CMOS compatible and has potential for application in tuning an individual transmission bands in wave-division multiplexing (WDM) systems.

1. INTRODUCTION

The development of the integrated compact multi-channel filters for different applications, such as, communication systems, multifunctional sensing and microwave antennas has been important and active area of research in the field of photonic integration for the last decade [1]. The required characteristics are the high quality factor (*Q*), high selectivity, high out of band rejection, low power and possibly low insertion. In this regard, multi-resonance based devices, such as coupled microring resonators, coupled travelling-wave resonators and coupled microcavity resonators, are the most promising solutions. One of the successful attempts in realization of wide tuning capability of the coupled resonators was presented in [2,3], where authors demonstrated their solution for an integrated platform using thermo-tuning approach. In our recent work [4] we have demonstrated an electro-tuning approach for multi-channel Si-liquid crystal filter with fine tuning capability of individual channels. The present work is devoted to the detailed analysis of the optical properties of Si-air 1D PC using a combination of possible refractive index variations in three coupled FP cavity channels. The electro-optical effect is demonstrated for triple-cavity device fabricated based on one of the suggested designs.

2. EXPERIMENTAL RESULTS AND DISCUSSIONS

In this work we investigated the optical properties of 1D PC based on Si-air structure with triple optical defects, obtained after infiltration of three central air channels with a nematic liquid crystal (LC) of tunable refractive index *n*. This structure form three coupled FP resonators with corresponding triple-defect modes within the photonic stop bands (SBs) (see Fig. 1a-c). The optical properties of these structures were estimated using a transfer matrix method (TMM).

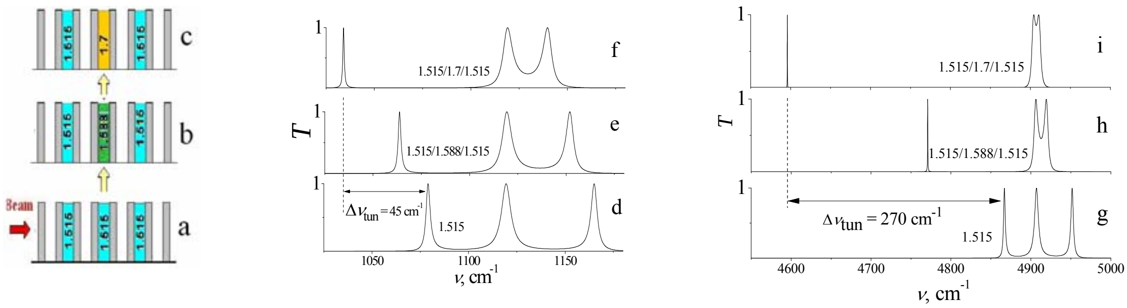


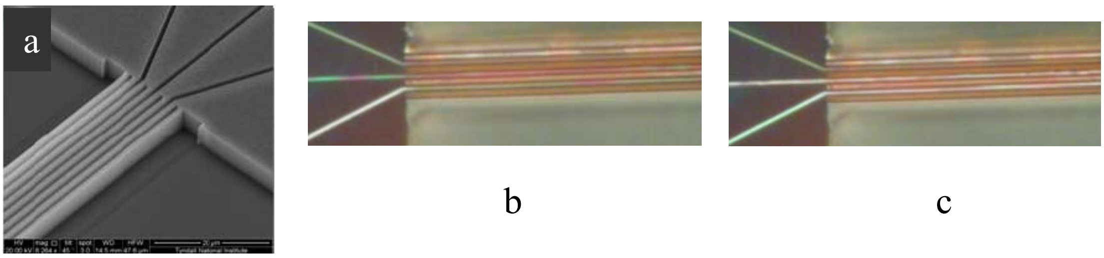
Figure 1. (a-c) Schematic of *n* tuning in one of the triple cavities of FP resonator. The tuning of triple defect modes at variation of *n* of LC from 1.5 to 1.7 in the central cavity demonstrate the effect of triplet splitting into the doublet and a single peak (d-f) in the 1st SB and (g-i) in the 3rd SB. The numbers beside the peaks correspond to *n* of the filler in the resonator cavities.

For calculations we use various combinations of *n* in FP-resonator cavities with parallel and cross-tuning in the range 1.5 – 1.7. For parallel refractive index tuning, where *n* varies equally in all three cavities of FP resonators, we observe a simultaneous shift of four triple-modes without their intersection for the 1st SB and up to nine triple-modes for the 3rd SB. The total range of modes tuning (for *n* variation up to 0.01*n*) is $\Delta\nu_{tun}/0.01n = 4.1\ cm^{-1}/0.01n$

for the 1st SB and 16.7 $cm^{-1}/0.01n$ for the 2nd SB. For the cross tuning of *n* (where *n* varies in opposite directions in different cavities of FP resonator) we obtained the following options: 1) stable central mode and tunable side-modes in transmission, 2) stable side modes and tunable central mode, 3) stable central mode and suppression of the amplitude of the side-modes to the minimum transmission for the 1st SB (or their total disappearance for the 3rd SB). In addition to that, at certain conditions, we observed a splitting of triple-mode into a doublet and a single peak (see Fig. 1d-i) with a very high *Q* (up to ~ 22000 in the 3rd SB).

It is worth mentioning that all aforementioned options of mode variations can be realized on the same structure with specific filler, and a certain type of tuning can be achieved by a particular set of the refractive index changes in each of three coupled FP resonators. The use of the FP resonances and SBs of the high order allows extending the range of functionality of the fabricated structure. For example, the tuning of triplet in the 1st SB allows to obtain up to 12 transmission bands at different frequencies, while for the 3rd SB up to 27 transmission bands.

To experimentally demonstrate the proposed idea, the triple-channel resonator device was fabricated on <100> *p*-type SOI wafer with silicon device layer thickness of 4.5 µm, and a 1 µm thick buried oxide layer (Fig. 2a). The design parameters of the 1D PhC structures were selected from the calculations using TMM and gap map approach (see [5] for details) for one of the selected type of tuning discussed above. Electron-Beam Lithography followed by the plasma etching was used to fabricate the nano-scale structures with the lattice constant *A* up to 1000 nm based on the first and second order PBGs operating in the telecommunication wavelength range. The electrical-isolation of the 2nd, 4th and 6th grooves of 1D PC is achieved by dry-etching of the micro-channels across the chip. A cone-shape cavity is designed for the easy infiltration of these grooves with LC E7. A 500 nm layer of Aluminum is deposited by sputtering. By independent application of the voltage to the Aluminum contact pads different orientations of the LC molecules can be achieved in the individual grooves, allowing a variety of manipulations of the transmission channels. This was demonstrated by electro-optical effect observed using polarized optical microscopy (POM) and shown in Fig. 2b,c as an example for the case of application of electric field of 0 V and 10 V to two of the three channels.



b c

Figure 2. (a) SEM image of the fabricated defect-free 1D PC with three-channels connected to 2nd, 4th, and 6th grooves. POM images showing a top view on the channels (b) without applied electric field (0 V) and (c) under applied electric field of 10 V to the bottom and central channels.

3. CONCLUSIONS

Different options for position control of individual transmission channels in a triple-cavity resonator device are discussed. The resonator design is based on Si-air 1D PC. By filling of the particular air grooves in this structure with nematic LC, an efficient coupled Fabry-Pérot resonator can be realized in which a wide stop band is used for broad frequency channel separation. By random tuning of the refractive index in all coupled cavities, a continuous individual tuning of the central channel (or edge channels) up to 25% of the total channel spacing is demonstrated. Based on the proposed design, a prototype triple-channel filter was fabricated on SOI platform and electro-tuning effect was demonstrated.

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