

Nanoimprint lithography for multiple cavity height Fabry-Perrot filter array from two-level master

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Summary:

We demonstrate the design, fabrication and testing of a Fabry-Perrot filter array that can be adapted as an optical element in front of a sensor array. The technique uses nanoimprint lithography with a simple two-level master. The thickness of resin needed for each cavity is designed to match the resonant wavelength. Leveraging the local resin volume conservation, a modulation of the residual layer thickness is obtained by fill-factor engineering. The device is validated by transmission spectroscopy across the visible range.

Keywords: Optical filter array, Fabry-Perrot, Nanoimprint lithography, Fill-factor engineering

Introduction

Optical spectroscopy is widely used for sensing various species of interest whose spectral fingerprints are well known. Besides FTIR, that uses one single detector, common spectroscopy separates light into bins and uses a sensor array (CMOS or else) to record the intensity in each. The use of gratings is precise but requires space. Depending on the application, the most convenient, lightest and most compact solution is to directly insert a filter array right in front of the detector, ideally performed at wafer level [1]. Tuning a different filter for each pixel can be challenging. RGB filter arrays traditionally make use of one material per band, but it does not provide solutions for many narrow bands. Fabry Perrot (FP) filters, instead, can make use of one material to obtain narrow band filters that are tuned by the height of the cavity. Traditional additive manufacturing requires many alignment procedures and depositions to achieve the right height for each pixel. The present article shows a convenient solution making use of the properties of nanoimprint lithography (NIL).

Description of the New Method

The FP filters have been designed using an optical transfer matrix approach. The resin that was used for NIL spans a refractive index of 1.46 to 1.52 in the visible range, with sub 10^{-5} extinction coefficient, both extracted from spectroscopic ellipsometry. The mirrors that were considered are 60 nm silver layers deposited with the EVATEC BPME. The optical constants of silver used for

simulation were taken from the literature [3]. The starting master design was a checkerboard of 800 by 800 pixels of size 20 μm where the black squares were etched by 418 nm (step value). This design was modified in such a way that the fill-factor was modulated from .125 to .875 along the diagonal direction of the array. Applying the conservation of volume during NIL imprint [2] and assuming no flow in the mm range, it was predicted that the residual layer thickness RLT (i.e. the low level after imprint) would be the base line – i.e. the average level - minus the local fill factor times the step, and the high level a step above that. This horizontal modulation of the fill factor therefore translates into a cavity thickness tuning in the NIL imprint across the array. The master mold was fabricated accordingly, and the NIL imprint was made using an EVG 7200 with a resin thickness matching the height of the silicon master. This imprint was performed on a 60-nm-thick Ag film deposited on a borosilicate wafer, followed by the deposition of an additional 60-nm-thick Ag mirror that was then deposited on top, creating the FP cavity array. The resulting wafer is shown in Fig. 2c.

The fabricated device was characterized by using a spectroscopic ellipsometer Semilab SE-2000 in transmission mode, with the FP filter placed at the focal spot of the focusing lenses. The spot is 300 μm wide and captures a weighted sum of the high-level and low-level cavities, with a small range of fill-factors broadening the peaks.

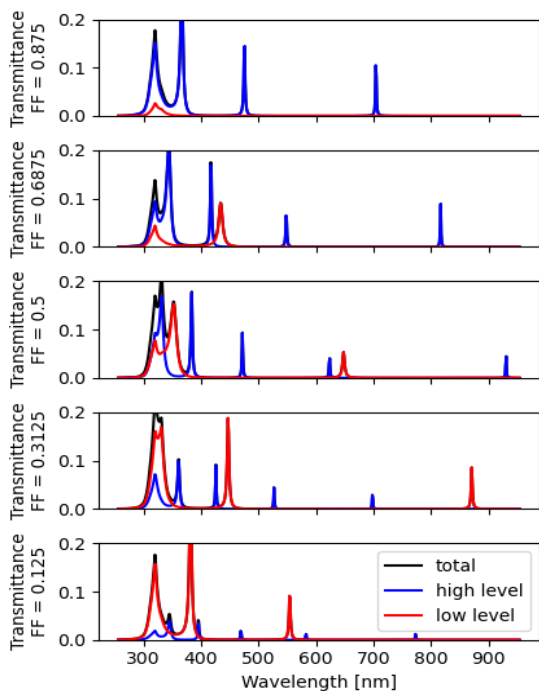


Fig. 1: Simulated response for variable fill-factors

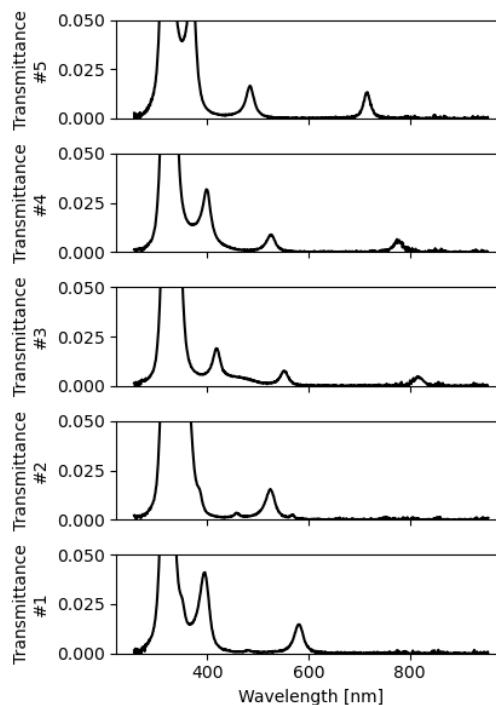
Results

Fig. 1 shows the result of the optical simulation for five fill-factor values, where the contributions of high and low level are separated. With increasing fill-factors the peaks shift to lower wavelengths, as the cavities shrink. The decrease of the low-level peaks intensity as fill factor increases is due to their loss of weight in the signal to the profit of high-level peaks. The peaks at the UV side are due to the low extinction coefficient of Silver near its inter-band transition edge (~ 3.8 eV) [3], leading to near-zero permittivity.

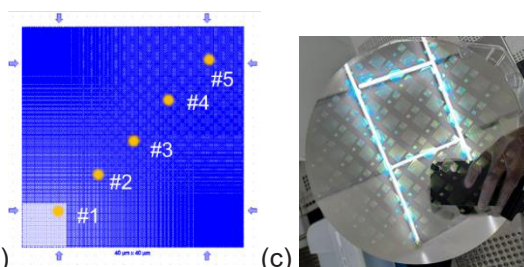
The corresponding experimental values are shown in Fig. 2a where the positions of the spot and its area are shown as an overlay on the structure mask layout. Arrows show the shifts with fill-factor. The peaks are broader in the range of 10 nm, but part of this can be attributed to the spot size integrating a range of fill-factors together. The results show similar trends as the simulation, although not all peaks are matching, probably due to deviation between the expected and obtained RLT due to the flow of the resin. Additional modelling needs to be done to compensate for these effects.

Conclusions

Using NIL, we have demonstrated the fabrication of a Fabry Perrot filter array from a simple 2-level master by pre-tuning the fill-factor across the array. The process will further be developed to combine multilevel master with the presented technique so the fill-factor needed range can be limited to around 10% for fine tuning, and the peak intensity variation be less affected.



(a)



(b)

(c)

Fig. 2. (a) Measured response at (b) measurement sites, (c) wafer with filter arrays

References

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