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An UV linear variable optical filter-based micro-spectrometer

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Abstract

This paper presents the design, fabrication and spectral measurements of an Ultra-Violet (UV) Linear Variable Optical Filter (LVOF)-based micro-spectrometer operating in the 300 nm – 400 nm wavelength range. The UV LVOF has been fabricated in an IC-Compatible process using resist reflow. Characterization by passing monochromatic light through the LVOF, shows high linearity of the profile. It is expected that using signal processing, spectral resolution better than 0.5 nm can be achieved with this UV LVOF. The filter provides the possibility to have a robust high-resolution micro-spectrometer in the UV on a CMOS chip.

Linear Variable Filter, micro-spectrometer, Ultra-Violet, UV, on-chip

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1. Introduction

Low-cost single-chip spectrometers have huge potential in systems for biomolecule identification and chemical analysis by optical absorption, fluorescence and emission line characterization. Such microspectrometers offer significant advantages over existing instruments, including size reduction, small sample size, low cost, fast data-acquisition and high reliability. Many biological molecules are fluorescent. The excitation wavelengths are usually in the UV part of the optical spectrum. MEMS-based microspectrometers operating in the UV spectral range (e.g. 230-280 nm) require either small feature size in grating design or a cavity width less than 140 nm in optical resonator design. Fabrication and electronic modulation of a resonator with such a narrow airgap between the two mirrors is severely hindered by capillary forces inside of the cavity. Also, electrostatic pull-in and subsequent sticking of the two mirrors limits the operating range of the device to one third of the initial air gap [1]. These problems are avoided in solid-state UV optical filters fabricated in post-processing steps after completion of UV photodetector and circuit in a standard IC technology. The LVOF is based on a tapered cavity on top of a linear

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array of photodetectors [2] and enables the transfer of the optical spectrum into a lateral light intensity profile over the array of photodetectors. Figure 1 shows the principle of operation of a LVOF spectrometer. The LVOF is basically a one-dimensional array of many Fabry-Perot (FP)-type of optical resonators. Rather than a huge number of discrete devices, the LVOF has a center layer (the resonator cavity) in the shape of a strip and a thickness that changes over its length. Reflective layers are on either side. The spectral resolution of a Fabry-Perot interferometer is determined by surface flatness, parallelism between the two mirror surfaces and mirror reflectivity. The possibility to have a high number of spectral channels in a LVOF spectrometer theoretically makes it possible to have a spectral resolution better than 0.2 nm over the visible spectrum using signal processing techniques. For a Fabry-Perot type of LVOF, the thickness variation of the cavity layer has to be in order of quarter of the wavelength and very well controlled, which makes fabrication of miniature LVOFs a technological challenge. The theoretical limit for the spectral resolving power of the LVOF-based spectrometer is the spectral bandwidth divided by the number of channels in the detector array. However, this is difficult to achieve when considering the Signal to Noise Ratio. This simple geometric optimum is only approached in case of a high SNR.

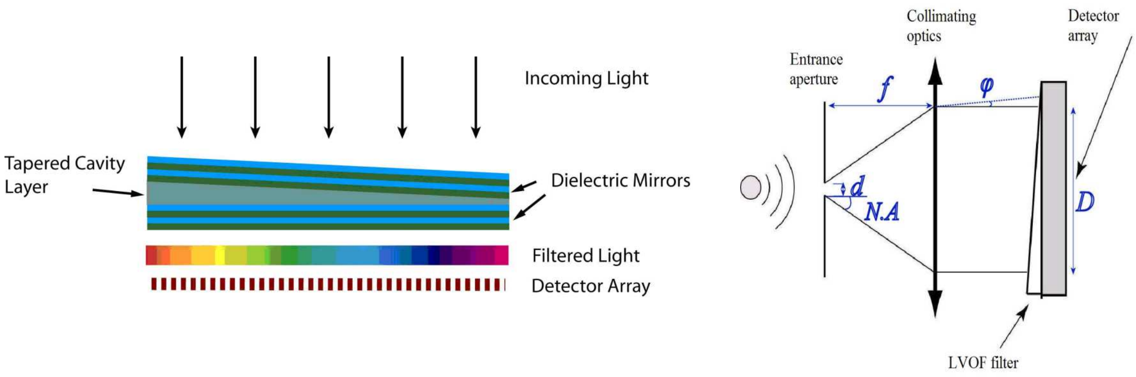

Fig. 1 (a) operation of a LVOF illuminated by collimated light (b) design principle of LVOF-spectrometer collimator

To design the collimator, Fig. 1b results $f = D/2NA$, in which D is size of the LVOF, f is the focal length of the lens and NA is entrance numerical aperture. Smith–Helmholtz invariant theorem results $d \cdot NA = D \cdot \varphi$, that can be rewritten as $d = D \cdot \varphi / NA$ in which d is the diameter of the aperture and φ is maximum acceptable angle of incidence on the LVOF. φ depends on the desired spectral precision [3].

2. Design and fabrication of the LVOF

Table 1 shows the designed thickness of the layers used for the multilayered LVOF. HfO_2 and SiO_2 have been used as high-n and low-n materials. The thickness of the tapered cavity layer changes linearly from 440 nm to 600 nm to cover the spectral range of interest. The spectral response of the filter is simulated using TFCalc® 3.3 and shown in Fig. 2. Fabrication has been done in an IC-Compatible process. Initially layers 1-10 have been sputtered on the substrate. Sputtering of the dielectric layers has been done in a FHR MS 150 tool. It is possible to achieve 2 % optical thickness variation control of the layers with the tool. Photoresist has been spin-coated and patterned by a special pattern optimized to produce a linear slope after reflow [4]. The lithography mask to make such pattern has been designed by a geometrical model and optimized by FEM simulation of the reflow process. The tapered resist pattern has been transferred into SiO_2 cavity layer by a dry-etching process optimized for minimum surface roughness [5]. Figure 2a shows a photograph of fabricated UV LVOFs. The rainbow pattern on the LVOFs structures is the result of their sloped. The IC-compatible process for fabrication of the tapered layers allows the possibility to fabricated different slopes with one lithography step. Fig 2b shows LVOF deposited on glass substrate mounted on a CMOS camera for characterization and spectral measurement.

Table 1: Layers thicknesses of multilayered UV Linear Variable Filter.

Material	Thickness (nm)
HfO2	43.5
HfO2/ SiO2	43.5/59
HfO2/ SiO2	43.5/59
HfO2/ SiO2	43.5/59
HfO2/ SiO2	43.5/59
SiO2	440 - 600
HfO2/ SiO2	43.5/59
HfO2/ SiO2	43.5/59
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HfO2/ SiO2	43.5/59
HfO2/ SiO2	43.5/59
HfO2	43.5

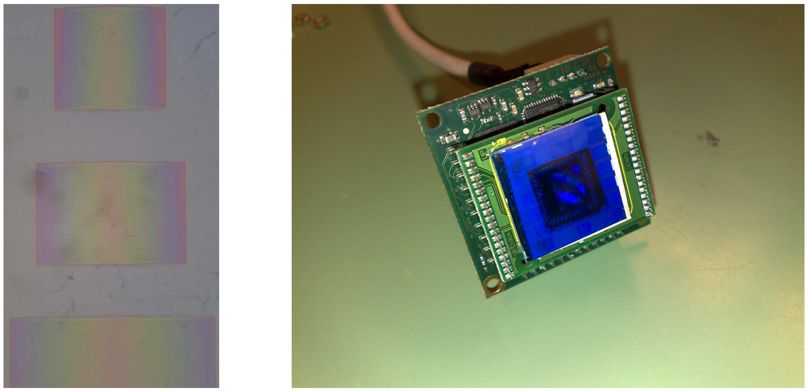

Fig. 2 (a) photograph of LVOFs (b) LVOFs mounted on a CMOS camera

3. Characterization and spectral measurements

Monochromatic light has been projected on the LVOF mounted on a CMOS camera. The responsivity of the CMOS camera has been measured independently and taken into account when the LVOF is characterized. Figure 3a shows the image recorded by the CMOS camera at different wavelengths. Figures 3b shows the intensity profile of the CMOS camera pixels at different wavelengths. Figure 3b shows a 4 pixels shift at each 1 nm wavelength shift, which is equivalent to a 0.5 nm spectral resolution. Spectral measurement using the LVOF, involves the design of collimator optics based on the equations mentioned earlier, capturing the raw data of pixels on the CMOS camera and using a signal processing algorithm to extract the spectrum of the light [6]. The spectrum of a Mercury lamp is to be measured with the current LVOF and is the subject of future work.

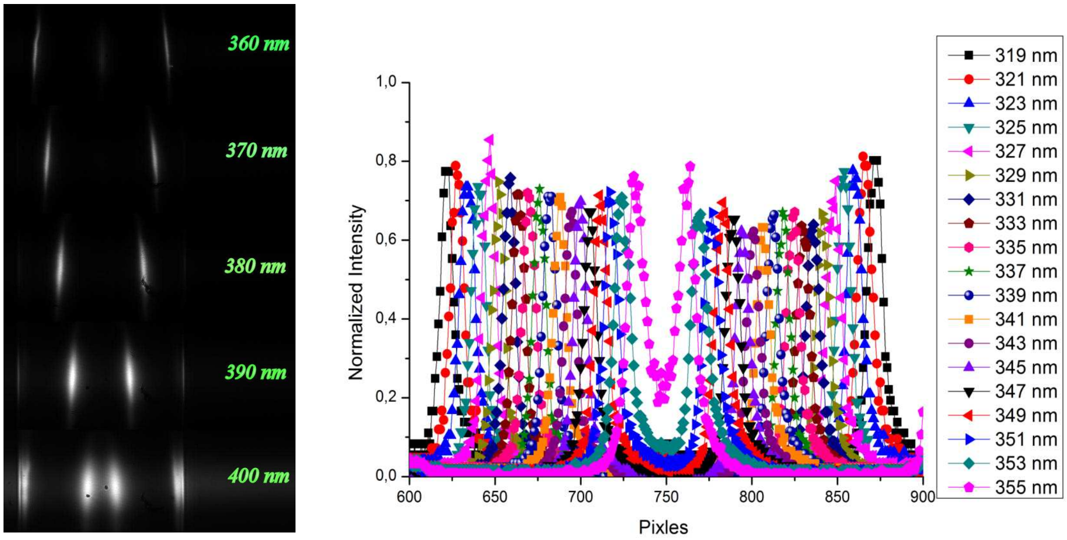

Fig. 3 (a) Recorded image at several wavelength (b) intensity profile of the pixels of CMOS camera at different wavelengths

4. Conclusions

IC-compatible fabrication technique has been used to fabricate a Linear Variable Optical Filter in the Ultra-Violet spectral range of 300 nm – 400 nm. The thickness of the cavity layer of the tapered Fabry-Perot filter has a slope of 160 nm over the length of the LVOF structure which can be flexibly changed from 1 mm to 10 mm. The LVOFs shows very good linearity. For each 1 nm spectral shift the peak of the illuminated region of the LVOF changed 4 pixels on the CMOS camera which is equivalent to 0.5 nm spectral resolution. The IC-compatible fabrication process brings the possibility to directly deposit the LVOFs on a UV detector array to result in a robust micro-spectrometer.

Acknowledgements

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