Micromachined Fabry-Perot Optical Filters

M. Bartek, J. H. Correia and R. F. Wolffenbuttel

Delft University of Technology, ITS/Et, Laboratory for Electronic
Instrumentation/DIMES, Mekelweg 4, 2628 CD Delft, The Netherlands
e-mail: M.Bartek@its.tudelft.nl, J.H.Correia@its.tudelft.nl and
R.F.Wolffenbuttel@its.tudelft.nl

The design, fabrication and measured characteristics of micromachined Fabry-Perot (F-P) optical filters for the visible spectral range are presented. Silver films of 40-50 nm thickness, evaporated on a 300 nm thick low-stress silicon nitride membrane, are used as high-quality mirrors. Two parallel mirrors, with a square aperture of up to 2x2 mm^2 *and initial cavity gap of 1.2 µm, form a tunable Fabry-Perot optical filter. One of the mirrors is fixed the other is under tension on a movable Si frame, which is electrostatically deflected to control the mirror spacing and parallelism. Results are compared with non-tunable F-P filters that are composed of an Ag/SiN/Ag or Ag/SiO*$_2$*/Al layer stack. The FWHM of 40 nm (tunable filter) and 16 nm (non-tunable filter) have been achieved.*

1. Introduction

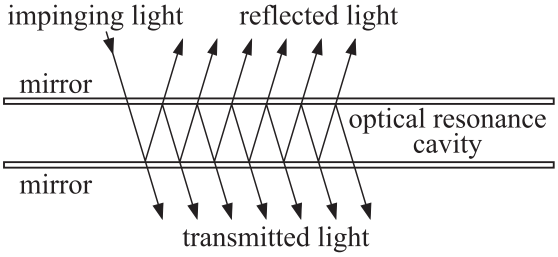

Fig. 1: Fabry-Perot optical resonator.

In recent years much attention has been paid to the development of tunable micromachined optical filters based on a Fabry-Perot (F-P) resonator (Fig. 1) [1, 2, 3]. Research has been primarily focused on the near-infrared region (wavelength of 1.3 and 1.55 µm) because of interest in the multi-mode optical fibre communication. Attempts to fabricate a device in the visible spectral range have also been reported [4], but were less successful. The goal is to develop an integrated spectrometer. In such an application, the requirements are much more demanding (wide optical band operation, the mirror flatness is more critical). This paper presents design, fabrication and characterisation of a miniature F-P interferometer based on silver mirrors for the visible spectral range.

2. Micromachined Fabry-Perot optical filters

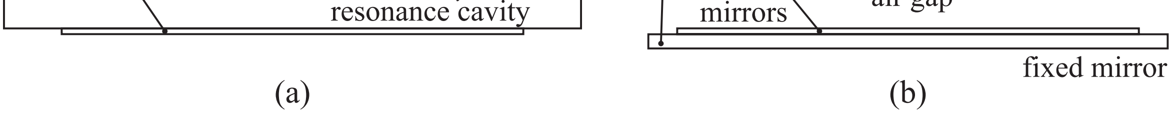

Fig. 2: Non-tunable (a) and tunable (b) F-P optical filters have been investigated.

Two types of F-P filters have been investigated: non-tunable and tunable (see Fig. 2). In the non-tunable filter the mirror spacing is fixed and is equal to the layer thickness deposited during fabrication. In the tunable filter, one of the mirrors is movable, resulting in adjustable mirror spacing.

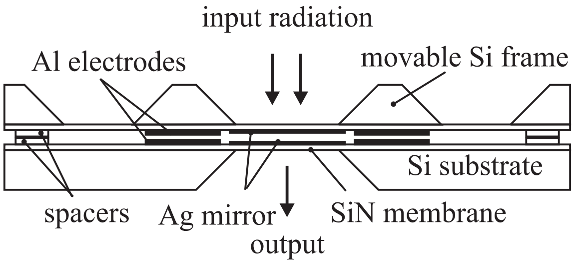

Fig. 3: Cross-section of the proposed micromachined F-P optical filter.

The proposed structure of the tunable filter is shown schematically in cross-section in Fig. 3. The device is formed by two parallel 40 nm thick silver mirrors supported by a 300 nm low-stress silicon nitride membrane. The mirrors have a square aperture of 2x2 mm^2 and an initial cavity gap of 1.2 µm. One of the mirror is fixed, the other is under tension on a movable Si frame, which is electrostatically deflected using several distributed electrodes to control the mirror spacing and parallelism.

A thin film optics software package (TFCalc 3.2.5) was used to perform optimisation of the mirror layer thickness, composition and order (optical data [5, 6]). The silver layers must be inside the resonance cavity to avoid excessive absorption losses in the silicon nitride layer during multiple reflections. The Ag layer thickness is a trade off between achievable FWHM (Full-Width-Half-Maximum) and absorption loss. Silver was selected as the mirror material because of its high reflectivity (>90%) over the entire visible spectral range and fabrication simplicity [7]. The poor long-term stability [8] of silver-based reflective coatings in macroscopic applications can be avoided in microsystems, as the dimensions allow protection by sealing.

Geometrical form, bending distances, deflection, stress, fatigue and flatness of the diaphragm based on a low stress silicon nitride membrane/Si frame were simulated in order to study the mechanical behaviour of a movable mirror. The results of FEM simulations predict excellent flatness of the movable mirror in the whole range of required deflections (0-460 nm for control voltages of 0-21 V) and have been published previously [9].

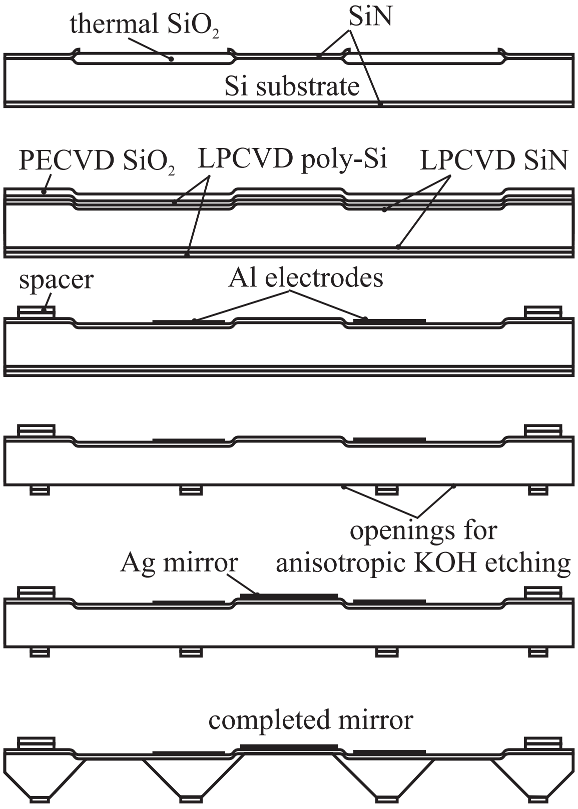

Fig. 4: Schematic fabrication sequence.

3. Fabrication

On the same wafer (100 mm, double-side polished), upper and bottom dies have been fabricated using a 5-mask process (see Fig. 4). Firstly, 400 nm recesses are formed using LOCOS. Subsequently, a 300 nm low-stress (<0.15 GPa) LPCVD silicon nitride layer is deposited and protected by a 300 nm LPCVD poly-Si layer. Then, PECVD oxide (0.3-1 µm) is deposited on a wafer front-side with thickness corresponding to the required initial resonance cavity gap. The PECVD-oxide/poly-Si stack is patterned to form spacers between upper and bottom dies for later die attachment. The 300 nm Al interconnect and control/sensing electrodes (deposited by sputtering) are 'buried' in 400 nm recesses to increase the initial spacing of the electrodes and avoid sticking during operation. The wafer backside is patterned to prepare windows for anisotropic KOH etching. Silver mirror layers are evaporated and patterned using lift-off on the wafer front side. The anisotropic KOH etching (33 wt.% KOH solution at 85°C) is performed in a holder to protect the Ag mirrors. To facilitate the wafer dicing into the individual dies, deep V-shaped trenches are formed during KOH etching. After the bottom die is mounted on a PCB, the upper die is attached using glue. Fig. 5 shows a photograph of the fabricated device.

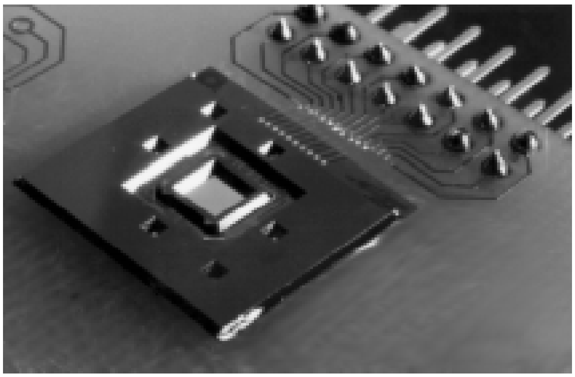

Fig. 5: A photograph of the fabricated miniature tunable F-P optical filter.

4. Results

To test the concept of silver-based mirrors, a 40 nm Ag layer was deposited on a SiN membranes from both sides resulting in a non-tunable F-P filter. The interference measurements (projected interference fringes) have shown an excellent mirror flatness. The LPCVD silicon nitride membrane, which is under tension after the release using anisotropic KOH etching, improves the initial flatness of the silver mirror.

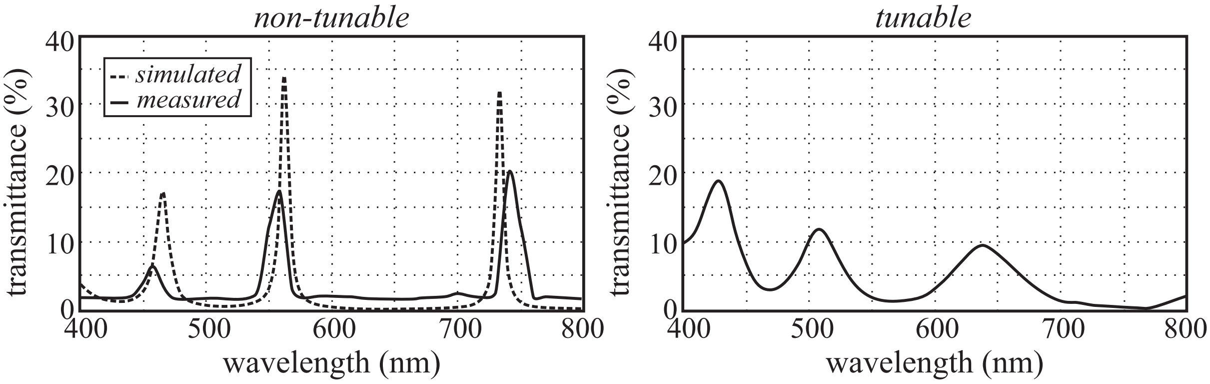

Fig. 6: Transmittance vs. wavelength for a 40nm-Ag/450nm-SiN/40nm-Ag fixed layer stack (at the left); and a 300nm-SiN/40nm-Ag/1000nm-air/40nm-Ag/300nm-SiN tunable layer stack (at the right).

The spectral characteristics in transmittance have been measured between 400 nm to 800 nm using Oriel 77250 monochromator. Fig. 6 compares the results achieved for both non-tunable and tunable F-P filters. At the left, the simulated and measured transmittance for a 40nm-Ag/450nm-SiN/40nm-Ag non-tunable F-P filter is shown. The FWHM of 20 nm is in good agreement with simulations. The tunable filter (Fig. 6, at the right) shows the FWHM of 40 nm which is much more less than the predicted value (8 nm for air gap of ~500 nm). This is caused probably due to mirror non-parallelism. It was found that it is difficult to achieve acceptable mirror parallelism by manual adjustment of the voltages applied on the control electrodes.

The best results have been achieved for an F-P filter composed of a 45nm-Ag/300nm-SiO_2/20nm-Al layer stack (see Fig. 7). A single peak with the FWHM of 16 nm over the entire visible spectral range was achieved. This type of filter is suitable for an array-type micro-spectrometer.

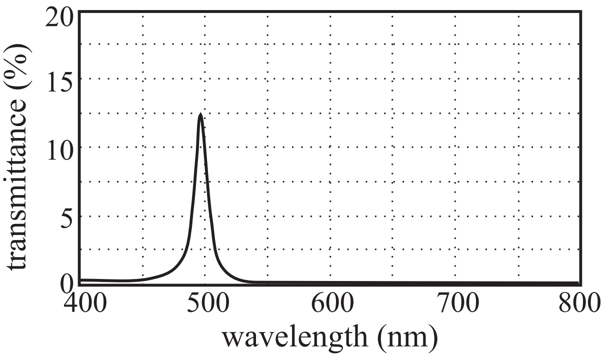

Fig. 7: Measured transmittance vs. wavelength for a 45nm-Ag/300nm-SiO_2/20nm-Al filter.

5. Conclusions

The design, fabrication and measured characteristics of micromachined Fabry-Perot optical filters for the visible spectral range are presented. Silver films of 40-50 nm thickness, evaporated on a 300 nm thick low-stress silicon nitride membrane, are used as high-quality mirrors. Two parallel mirrors, with a square aperture of up to 2x2 mm^2 and initial cavity gap of 1.2 µm, form a tunable Fabry-Perot optical filter. One of the mirrors is fixed the other is under tension on a movable Si frame, which is electrostatically deflected to control the mirror spacing and parallelism. Results are compared with non-tunable F-P filters that are composed of an Ag/SiN/Ag or Ag/SiO_2/Al layer stack. The FWHM of 40 nm (tunable filter) and 16 nm (non-tunable filter) have been achieved.

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