3-5μm F-P Tunable Filter Array based on MEMS technology

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Abstract. In this paper the design, fabrication and test of a MEMS F-P tunable filter operating in 3-5μm range is presented. The initial design of micro-bridge structure was achieved through COMSOL simulation software. In the simulation, the micro-bridge could achieve a displacement of 0.6μm under very low applied voltage of 30V, while still preserving good mirror parallelism. By using surface micromachining techniques, a 200 × 200 array of F-P tunable micro-bridge was fabricated. SEM photographs of the fabricated device and method of optical performance test are also introduced. This MEMS F-P tunable filter can be a potential application in spectroscopic sensing and optical communication system.

1. Introduction
As an important multiple-beam interference structure, Micro Fabry-Perot cavity tunable filters are widely used in the area of hyper spectral imaging and DWDM (Dense Wavelength Division Multiplexing) optical communication system [1-2]. In recent years, a large effort has been directed towards development of miniaturized and hence cost-effective, portable micro-spectrometers systems. By depositing metal membrane on silicon chip based on MEMS surface process, a new micro F-P cavity has been achieved by us, which can be actuated by electrostatic force and realize the function of optical filter.

2. Design of micro-bridge structure
Micro F-P cavity is driven by static electricity to change the cavity length and achieve wavelength selective. The mechanical and electrical properties simulation is performed by finite element method (using software COMSOL) to establish and optimize the basic micro-bridge design.

The structure proposed by us is shown below in figure 1: the center membrane is a 90μm × 90μm
square supported by four cantilever beams (15μm wide and 115μm long); and the optical window is a circular with 50μm diameter.

**Figure 1.** Schematic diagram of micro-bridge.

**Figure 2.** Voltage-displacement curve of micro-bridge.

This bridge could achieve a displacement of 0.6μm under very low applied voltage of 30V (figure 2) and be in good parallelism in the event of displacement. If the displacement of the bridge is d, and the transverse distance between two different places is Δx (figure 3), we can get the included angle between the top and bottom plane is:

\[
\theta \approx \tan \theta \approx \frac{d_{\text{max}} - d_{\text{min}}}{\Delta x}
\]  

(1)

**Figure 3.** The included angle between two planes.

When applied tunable voltage U=29V,

\[
\theta \approx \frac{(531.4 - 529.96) \times 10^{-9}}{3.5 \times 10^{-3}} = 4.11 \times 10^{-5} \text{ rad} = 0.00235^\circ
\]

(2)

The calculation shows that the value of θ is quite small, which demonstrates the micro bridge has a good parallelism performance in the tuning range.

3. Micro fabrication process
The tunable F-P filter is fabricated by using surface micro-processing technology. The specific microfabrication process is shown in figure 4. A resonant F-P cavity is designed to be formed between two Ge/Al₂O₃/Ge distributed Bragg reflector (DBR) mirrors with the top DBR freely suspended about 2μm above the bottom plane.

![Flowchart of process](image)

**Figure 4.** Flowchart of process.

Initially, the bottom DBR mirrors, which contain Ge/Al₂O₃/Ge (250nm/629nm/250nm), were deposited on a bare, 500μm thick silicon substrate. Next, a bottom electrode (Ni-Cr/200nm) and metal support (Ni-Cr/2μm) were respectively formed on the bottom DBR mirrors, which is shown in figure 4 (b) and (c) above. Subsequently, polyimide was spun onto the required thickness of 2μm and defined the separation between the two DBR mirrors of the F-P cavity. The polyimide was formed as a sacrificial layer and baked at 250°C for 2 hours to reduce the shrinkage effect and enhance its chemical stability to undergo the further fabrication process.

Then deposit a 200nm thick (Ni-Cr) bridge with the graphic structure already given before, shown in figure 4(e) above. The top DBR mirror consisting Ge/Al₂O₃/Ge with a shape of circle (diameter 60μm) was deposited again by thermal evaporation. Finally, coat an antireflective film at the bottom, and release the polyimide sacrificial layer to suspend the micro-filter by using an O₂ plasma etching machine under high pressure.

In order to fabricate a suspended micro-bridge structure, the sacrifice layer between the bottom electrode and the top micro-bridge must meet the several following requirements: 1) the thickness of the layer can reach 2μm, and just a little lower than the metal support; 2) great surface flatness; 3) good chemistry stability and compatible with the following process.

A reactive ion etching (RIE) was applied to improve the quality of polyimide layer surface(figure 5). Firstly, a 2μm polyimide layer was spun on the bottom electrode. However, this process would
produce a 1–1.5μm peak. Spin another photoresist (ENPI) and follow with a reactive ion etching (RIE) to smooth the surface of polyimide layer. By using an acetone dissolution process, the flatness of the etched surface could be increased rapidly (figure 6). This is because baked polyimide is unsolvable in acetone.

![Figure 5. RIE etching process.](image)

![Figure 6. The thickness of etched polyimide.](image)
3. Results and test

The scanning electron microscopy (SEM) photographs of fabricated micro-bridge were shown in figure 7 and 8. It can be found in the cross-section image (figure 7) that a suspended structure has already been fabricated with no obvious ruptures and defects.

![Figure 7. Cross-section SEM photograph of fabricated micro-bridge.](image1)

![Figure 8. SEM photograph of fabricated micro-bridge.](image2)

Two main aspects of the optical performance would be characterized after the two DBR mirrors are added: static response and dynamic response. The static response was characterized by applying stable voltage between the top and bottom electrode to observe the tuning range and transmitted spectrum shifting with voltage. Next, the dynamic response was tested by using an optical method (figure 9) to measure the response time.

![Figure 9. Set-up for dynamic response characterization.](image3)

Factual optical performance test will be discussed in another paper. And the simulated transmittance of the film is shown in figure 10. Peak transmission of the tunable filter has risen from 46.44% to 89.14% after depositing the anti-reflection film of Al$_2$O$_3$ (629nm) on both bottom and top of the device. And the FWHM (Full Wave at Half Maximum) is measured to be nearly 130nm.
Figure 10. The device transmission before and after depositing anti-reflection film coating.

4. Conclusion
A novel structure F-P tunable micro-bridge operating in 3-5μm has been fabricated by surface micro-processing technology. The surface quality of polyimide sacrificial layer could be improved greatly to meet the further process requirement by applying reactive ion etching (RIE) and acetone dissolution. SEM photographs of the suspended structure and fabricated micro-bridge are given. And the tunable filter is designed to have a 89.14% peak transmission and 130nm linewidths after adding DBR mirrors.

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