1.3 m Si-Based MOEMS Optical Tunable Filter with a Tuning Range of 90nm*

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Abstract: Optical filters capable of single control parameter-based wide tuning are implemented and studied. A prototype surface micromachined 1.3μm Si-based MOEMS (micro-opto-electro-mechanical-systems) tunable filter exhibits a continuous and large tuning range of 90nm at 50V tuning voltage. The filter can be integrated with Si-based photodetector in a low-cost component for coarse wavelength division multiplexing systems operating in the 1.3μm band.

Key words: MOEMS; Fabry-Perot; tunable filter; surface micromaching
EEACC: 4140F; 6260M　　**PACC**: 5130; 6140
CLC number: TN713　　**Document code**: A　　**Article ID**: 0253-4177(2003)11-1140-05

1 Introduction

Tunable optical filter with narrow bandwidth and wide tunable range are indispensable components in the predominant developed DWDM (dense-wavelength-division-multiplexing) system. Compared with the traditional thermal tuning and carrier plasma counterparts, MOEMS tunable technology gains worldwide attention for its unique advantage to obtain large tuning range, compactness, and potential low cost[1~8]. Tayebati *et al*. from CoreTek Incorporation[5] demonstrated 1550nm tunable filter with stable half symmetric cavity and 70nm tuning range in 1998. Our group fabricated a 1.55μm Si-based tunable filter with 30nm tuning range last year[6]. Recently, NP Photonics Incorporation demonstrated the 1.55μm MOEMS tunable filter product with tuning range of 110nm, using its proprietary compliant MEMS (CMEMS) technology[7]. A joint research group of Europe reported an InP-based 1.55μm MOEMS filter with the largest tuning range of 142nm at 3.2V in 2003[8], using InP-air-gap DBRs.

In this paper, a 1.3μm silicon-based MOEMS tunable optical filter with a wide tuning range of 90nm using 50V tuning voltage is demonstrated. To the best of our knowledge, it is the largest continuous tuning range of traditional Si-based MOEMS tunable filter ever reported.

2 Principle of tunable filter

The transmittance wavelength of F-P cavity

* Project supported by Major State Basic Research Program (No. G2000036603), National Natural Science Foundation of China (No. 96104003), National High Technology Research and Development Program of China (No. 2002AA312010)

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Received 28 March 2003, revised manuscript received 4 July 2003　

depends on the cavity length, and the wavelength shift changes linearly with the cavity length change:

$$\frac{\Delta\lambda}{\lambda_0} = \gamma\frac{\Delta d}{d_0} \quad (1)$$

where $\Delta\lambda$ is the wavelength shift, Δd is the cavity length change, λ_0 is the initial wavelength, d_0 is the initial cavity length, γ is a constant depended on the optical structure of the filter.

Under the electrostatic force, the maximum deflection of the cavity for a structure consisting of a plane suspended on four identical cantilever beams is[9]

$$\Delta d = \frac{1}{8}\times\frac{\epsilon(2bL^4 + A_pL^3)}{Ebh^3d_0^2}V^2 \quad (2)$$

where b, L, h are the width, length, and thickness of the cantilever, respectively, E is the Young's modulus, A_p is the surface area of the center plane, V is the applied voltage.

Combining the Eqs. (1) and (2), it can be derived that the wavelength shift is quadratic to the applied voltage.

3 Fabrication

A schematic structure of the device is shown in Fig. 1. A resonant Fabry-Perot cavity was formed between the two Si/SiO_2 distributed Bragg reflector (DBR) mirrors with the upper DBR freely suspended about 650nm above the substrate. During wavelength tuning, a DC voltage was applied between the top and bottom electrode, creating an electrostatic force that attracted the suspended membrane toward the substrate surface. Therefore, the effective F-P cavity length was shortened with the applied voltage, resulting in a blue shift in its center wavelength. Both top and bottom DBR are grown by electron beam evaporation with the center wavelength of 1300nm. Cr/Au layer acts as the bottom electrode. A sacrificial layer was deposited on it, followed by Cr/Au top electrode. An AR coating was deposited by PECVD (plasma-enhanced chemical vapor deposition) on the bottom of the substrate. The final structure was released after the removal of the sacrificial layer. The center membrane was a 350μm×350μm diamond supported by four cantilever beams. The optical window was a 150μm × 150μm square. The supporting beams were 30μm wide and 150μm long, which consisted of top DBR and top electrode Cr/Au, with the total thickness of around 4μm. Figure 2 shows a scanning electron microscopy (SEM) photo of the device.

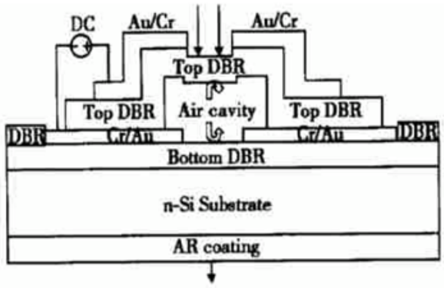

Fig. 1　Schematic structure of the cross-section of the tunable MOEMS filter

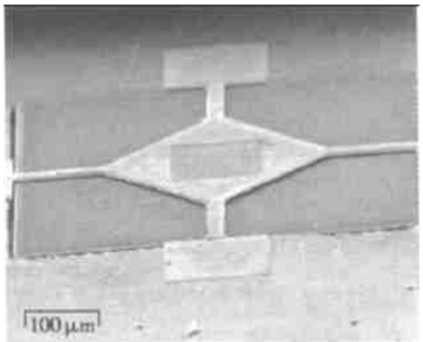

Fig. 2　SEM micrograph of the device structure

4 Results and discussion

The transmission characteristics of the devices were measured using a multimode fiber for input light coupling and InGaAs detector for output light coupling. A tungsten lamp light covering a spectral range of 0.8～1.8μm was used to provide the input light. The light that passed through the tunable filter was coupled into InGaAs detector and amplified by an optical measuring system.

Figure 3 shows the transmittance spectra of the tunable filter under the applied voltage from 0 to 50V. The center wavelength was continuously tuned from 1320nm at 0V to 1230nm at 50V. The intensity of the peak changes little in the tuning range of 0V to 40V (peak in the range of 1260~1320nm), while increases slightly at 50V (peak at 1230nm). We attribute it to the limited reflection band of the DBRs. The reflection band with high reflectivity is limited to the range of 1240 ~ 1600nm. The reflectivities decrease at 1230nm and the transmittance gets relatively higher than the longer wavelength, thus the intensity of the corresponding transmittance peak becomes larger.

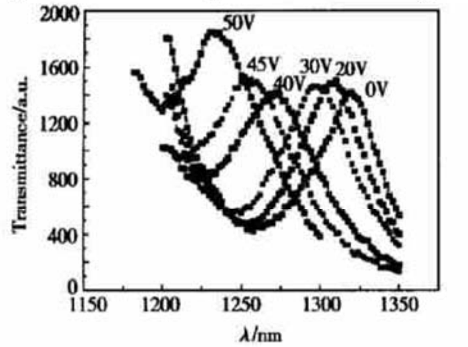

Fig. 3 Transmittance spectra of the tunable filter versus applied voltage

The FWHM of the transmittance spectrum at 0V is about 32nm. The broad FWHM is mainly due to the low mirror reflectivity. FWHM of the transmittance spectrum of a Fabry-Perot filter can be approximately expressed as[4]

$$\mathrm{FWHM} = \frac{\lambda_0^2(1-\sqrt{R_1R_2})}{2\pi n d_0(R_1R_2)^{\frac{1}{4}}} \qquad (3)$$

where R_1, R_2 denote the reflectivity of the top and bottom mirror, λ_0 is the center wavelength, d_0 is initial cavity length, and n is the refractive index of the cavity.

It is estimated that R_1 and R_2 are about 90% and 95%, respectively, when L_0 is 650nm, the center wavelength λ_0 is 1300nm, the corresponding FWHM from Eq. (3) is 32.4nm. The undulation of the sacrificial layer and imperfection of mirror growth contribute to the decrease of mirror reflectivity. The FWHM can be narrowed to 2.07nm, if the quality of the sacrificial layer is improved and the reflectivities of top and bottom mirror increase to 99.5%. Increasing the cavity length properly will also help to decrease the FWHM.

There exhibits an obvious FWHM broadening phenomenon during tuning. The FWHM is 32nm at 0V, 42nm at 30V. When the voltage is larger than 40V, the asymmetric left part of the transmittance peaks is mainly influenced by the limited reflection band, making the calculation of their FWHM different from those under the voltage less than 40V. Here only the FWHM of the spectra under the voltage less than 40V are discussed. The broadening of the FWHM is mainly caused by the rapid decrease of the reflectivities of the mirrors at shorter wavelength. It is estimated that when the FWHM is 54.6nm, R_1 and R_2 decrease to about 88%. According to Eq. (3), it is true that the decrease of cavity length can contribute to the broadening of the FWHM. However, as the decrease of cavity length is so small (about 50nm), the effect of cavity length change can be ignored. The FWHM broadening can be avoided as long as the unchanged reflectivities of the mirrors are guaranteed in the tuning range.

The transmittance spectra are asymmetric, which have a long tail on the short wavelength side. We observed the similar phenomenon in Ref. [6]. It is probably induced by the curvature of the released top mirror. Other evidence shows the cavity length gradually reduces from the edge to the center of the mirror due to the mirror bending. Local heat treatment of the mirror or using smaller mirror may partly relieve the stress-induced mirror curvature.

The wavelength shift dependence on the applied voltage for the tunable filter is shown in Fig. 4. The wavelength shifts from initial 1320nm to 1310nm at 20V, 1290nm at 30V, and 1230nm at 50V. The wavelength shifts as a function of square of the applied voltage are shown in Fig. 5. It is obvious that they have good linear relationship. The tuning coefficient is calculated to be 0.0346nm/V^2. The result is roughly three times larger than that of the 1.55μm MOEMS tunable optical filter we fabricated before, which was 0.01287nm/V^2[6]. The major difference between the two designs is the increase in membrane size from 250μm to 350μm and the decrease of the dielectric Si/SiO_2 pairs between the two electrodes from 8.5 pairs to 3.5 pairs. The use of the dielectric top mirror allows a wide tuning range compared to the devices in which both top and bottom DBRs are semiconductor based, however it also decreases the tuning coefficient to some extent. There should be trade-off between the tuning range and tuning coefficient. As shown in Eq. (2), the tuning coefficient can be further increased by using thin, long, and narrow beams.

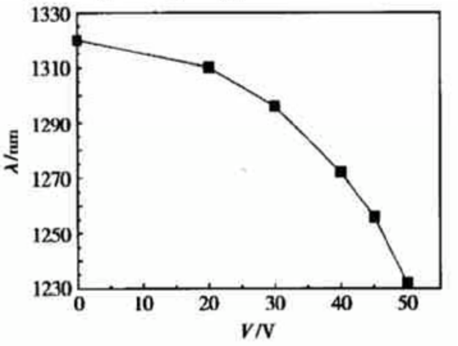

Fig. 4 Wavelength shift dependence on applied voltage for the tunable filter

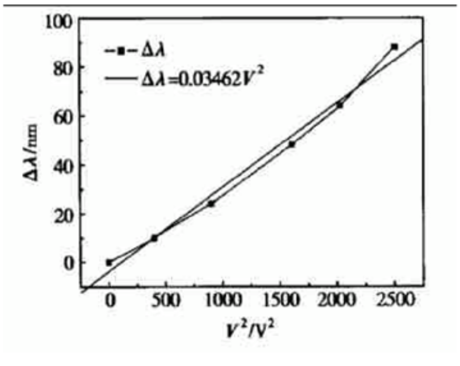

Fig. 5 Wavelength shift dependence on square of applied voltage

5 Conclusion

A Si-based 1.3μm MOEMS tunable optical filter with a continuous tuning range of 90nm has been demonstrated. It is so far the largest tuning range of traditional Si-based MOEMS tunable filter ever reported in the literature. The technology has wide applications in DWDM system in the long run, especially when integrated with vertical cavity devices to achieve active tunable devices.

Acknowledgements The authors would like to thank Professor Wu Ronghan, Dr Yang Xiaohong and Mr. Tang Jun of Institute of Semiconductors, CAS, for their valuable discussion and great help in optical testing.

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具有 90nm 调谐范围的 1.3 m Si 基 MOEMS 可调谐光滤波器*

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摘要: 利用表面微机械技术, 成功制作了 1.3μm Si 基 MOEMS 可调谐光滤波器. 原型器件在 50V 的调谐电压下, 调谐范围为 90nm. 该技术可以用于制作 1.3μm Si 基可调谐光探测器.

关键词: MOEMS; 可调谐滤波器; Fabry-Perot; 表面微机械技术

EEACC: 4140F; 6260M **PACC**: 5130, 6140

中图分类号: TN713 **文献标识码**: A **文章编号**: 0253-4177(2003) 11-1140-05

* 国家重点基础研究发展规划(No. G2000036603), 国家自然科学基金(批准号: 96104003), 国家高技术研究发展计划(No. 2002AA312010) 资助项目

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2003-03-28 收到, 2003-07-04 定稿