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Micromechanical Tunable Optical Filter*

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Abstract: A micromachined vertical cavity tunable filter with AlGaAs/GaAs distributed Bragg reflector is presented. This filter can be electrostatic tuning over a range of 28nm with an applied voltage of 7V.

Key words: micromachined tunable filter; wavelength division multiplexing; distributed Bragg reflector
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1 Introduction

Wavelength division multiplexing (WDM) has shown great promise for increasing the transmission bandwidth and the routing capability in optical communications. An ideal filter for WDM applications would have a wide and continuous tuning range, low tuning power, low insertion loss, high extinction ratio, low polarization dependence, and simple coupling and simple fabrication to facilitate 2D arrays. Recently, based on a micromechanical tunable Fabry-Perot structure, widely tunable surface-normal filters, detectors, and lasers have been demonstrated[1~6], all with record tuning ranges and possessing many of desirable attributes.

Traditionally, semiconductor Fabry-Perots have provided tuning based on a cavity refractive index change through the Stark and electro-optical effects. The tuning range of these devices has been limited to less than 10nm due to the small index change. However, micro-mechanical Fabry-Perots with tunable air gaps provide much wider tuning ranges than their Stark or electro-optical effect counterparts. Micro-mechanical Fabry-Perots have demonstrated a tuning range as high as 70nm with 5V applied bias.

These micromechanical tunable filters typically have an air-gap cavity sandwiched by dielectric or semiconductor distributed Bragg reflectors (DBR). A semiconductor DBR offers several desirable attributes over its dielectric counterparts, including (1) higher uniformity and reproducibility provided by the precisely epitaxial growth methods, (2) a typically 5~10 times lower tuning voltage, and (3) predictable material and mechanical characteristics.

Wavelength tuning is accomplished by applying a voltage between the p-DBR and n-DBR across the air gap. A reverse bias voltage is used to provide the electrostatic force, which attracts the cantilever downward to the substrate and shortens the

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air gap, thus tuning the mode wavelength toward a shorter wavelength.

The tuning range of a MEMS-filter is governed by the smallest of the following three factors: (1) the minimum free spectral rang (FSP), which is the wavelength separation between two FP modes, (2) DBR bandwidth, and (3) the wavelength difference resulted from maximum deflection of the cantilever. The maximum deflection is determined by the mechanical property of the cantilever as well as the capacitive nature of the attractive force. It has been derived analytically as well as simulated using complete soft.

In this paper, we present a micromachined vertical cavity tunable filter with AlGaAs/GaAs DBR. This filter can be electrostaticly tuned over a range of 28nm with an applied voltage of 7V.

2 Devices fabrication

A F-P cavity composed of 15 pairs of AlAs/$Al_{0.8}Ga_{0.2}As$ DBRs were epitaxially grown on a n^+ doped GaAs substrate by metal organic chemical vapor deposition (MOCVD). The bottom DBR is n doped and the top DBR is p doped. Between the top and bottom DBRs there is an undoped AlAs λ-cavity (sacrificial layer). The mode wavelength of the filter is $1.3\mu m$.

In the fabrication of the tunable micromachined devices, a key step is to produce an air cavity. In order to get a high quality air cavity, etching is the foundational process for surface micromachining. Most devices in Ⅲ-Ⅴ semiconductors based MOEMS involve one or more etching processes[7~9]. In our experiment chemical wet etching was adapted due to its implement ability and controllability both in non-selective and selective etching.

The shape of cantilever is patterned by non-selective etching. Selectivity of reaction solutions is very important[10]. Following objectives should be achieved: (1) same etching rate of different materials of the layer structure, (2) high contrast ratio of etching speed between vertical and lateral etching, (3) photoresist to be preserved during etching, (4) etching speed to be easily controlled and etched surface to be smooth. In our situation, H_3PO_4 : H_2O_2 : H_2O solution was used. The proportion of mixtures, temperature, and reaction time should be controlled carefully.

Figure 1(a) shows the cross section of the wafer after vertical non-selective etching. Obviously the AlAs sacrificial layer is exposed. Then the AlAs sacrificial layer was laterally removed using selective wet etching, and the top DBR was released as shown in Fig. 1(b). The air cavity in the Fig. 1(b) is about $25\mu m$ long, thus the air cavity is formed.

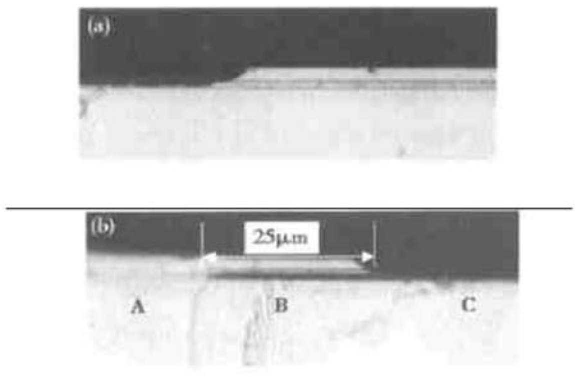

Fig. 1 (a) Wafer cross section after vertical non-selective etching; (b) Wafer cross section after lateral selective etching

The filter was designed to operate at a center wavelength of $1.3\mu m$. The epitaxial structure of filter is composed of a 15 period GaAs/AlGaAs DBRS. Cr/Au electrode was deposited and patterned using standard lift-off techniques. The cantilevers were defined using an isotropic wet etching and released using selective wet etching. The diameter of top DBR is $50\mu m$ and the length and width of cantilever is $100\mu m$ and $16\mu m$, respectively. An SEM photograph of the finished device is shown in Fig. 2.

3 Results and discussion

The filter tuning spectra is illustrated in

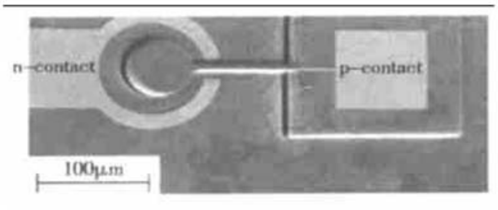

Fig. 2 SEM photograph of tunable filter

Fig. 3. Wavelength tuning is observed over a range of 28nm. The value of extinction ratio is lower than the calculated value. The low extinction ratio is mainly due to DBRs mismatch, which could be easily corrected with a better-calibrated growth or fabricated process.

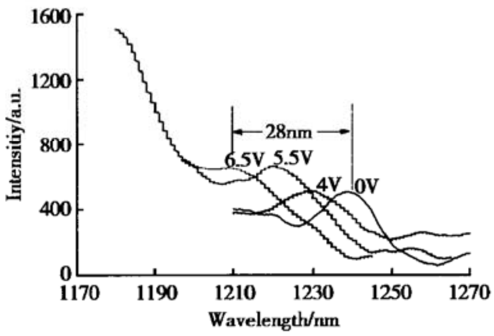

Fig. 3 Transmission spectra for various tuning voltage

The measured linewidth of 11nm (at zero bias) is broader than the calculated value. The key reasons for broadening are the angular optical coupling into the filter and DBRs eptaxial growth error that reduce the reflectivity of DBRs. The broadening can be minimized by optimizing the growth condition and using a fiber lens to minimize the fiber-coupling related broadening.

The performances of filter degrade seriously at tuning voltage of 5~ 6V, because the mode wavelength of the filter is placed in the edge of high reflective bandwidth of DBR. At the edge of high reflective bandwidth, the reflective coefficient is reduced greatly and the performance of the filter including linewidth and extinction ratio is also degraded greatly. This can be circumvented by optimizing the epitaxial growth condition to take fully advantage of reflective bandwidth of GaAs/AlGaAs DBR.

Figure 4 shows the peak wavelength against tuning voltage. The peak wavelength blue shifts monotonously with increasing the tuning voltage. This shows the filter enable continuous wavelength tuning without mode-hopping in a large tuning range.

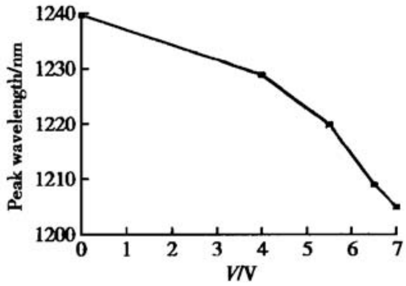

Fig. 4 Transmission peak wavelength against tuning voltage

4 Conclusion

We have demonstrated the successful fabrication and operation of a novel tunable optical filter using GaAs/AlGaAs DBR on a movable mechanical cantilever. We achieved 28nm tuning with 7V tuning voltage. The tuning range is limited by our reflected bandwidth of DBR which can be circumvented by stricter control of the epitaxial growth. This device can be readily adapted to tunable vertical cavity lasers and detectors, and open a wide window of opportunities for wavelength translation.

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微机械可调谐滤波器的研制*

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摘要: 利用 GaAs/AlGaAs 分布反馈 Bragg 反射镜在 GaAs 衬底上制作了一个微机械的调谐滤波器. 该器件在 7V 调谐电压下调谐范围达 28nm.

关键词: 微机械可调谐滤波器; 波分复用; 分布反馈 Bragg 反射镜

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