行政院國家科學委員會專題研究計畫　期中進度報告

子計畫八：以微機電技術開發應用於高密度波長多工通訊網路之光切換元件研究(2/3)

計畫類別： 整合型計畫
計畫編號： NSC91-2215-E-009-028-
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計畫主持人： 邱俊誠

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行政院國家科學委員會補助專題研究計畫 □成果報告 ■期中進度報告

（計畫名稱）新穎元件架構實驗型高密度多段波長多工通訊網路系統整合研究 – 子計畫八：以微機電技術開發應用於高密度波長多工通訊網路之光切換元件研究(2/3)

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共同主持人：
計畫參與人員：

成果報告類型(依經費核定清單規定繳交)：■精簡報告　□完整報告

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中文摘要

本計畫完成一背對背式微振鏡系統，該系統結 合一光學全相波導將可用於實現一光通訊所需之 OADM（optical add/drop multiplexer）模組。此模組是將耦合著各種波長的入射光訊號導入解多工器，入射至設計的特殊光路位置。微振鏡陣列則是用於在光學多工器中擷取/置入所需的光通訊訊號。一個整合 Poly-MUMPs 與覆晶封裝技術所設計製作之微振鏡已經完成。在此微振鏡設計中，一個殘餘應力懸臂量被設計於微機電元件後段釋放處理製程中，翻起此微振鏡；而一具有高可靠度的旋轉樑則是用於使此振鏡具有一維旋轉自由度。藉由一後段熱處理方式，有效提昇殘餘應力致動 器的制動力效能；透過覆晶封裝技術，將一微平版黏和於前述微振鏡上特定位置，產生一微振鏡旋轉角度限制器，覆晶封裝中所使用的金球經由適當的製程控制可以調整金球高度至所需的位置，進而控制微振鏡旋轉角度限制器的位置。目前已經完成微振鏡元件的光訊號切換特性量測，此振鏡將可用於前述 OADM 系統中。

關鍵字：微振鏡、解多工器、多工器、Poly-MUMPs、覆晶封裝、熱處理

Abstract

The proposed approach that combined the holographic gratings with the back-to-back micromirror devices had been proposed to realize the optical add/drop multiplexer. The incident lights with different wavelength are coupled into DMUX and diffracted into designed position through localized multiplexing method. Micromirror array is used to drop specific information or add the desired one into MUX. A back-to-back micromirror device had been developed using Poly-MUMPs and flip chip technologies. The pre-stressed beams were used to flip up the micromirror devices after the released process. The torsion flexure design provides a reliable rotation degree of freedom. Thermal heat-treatment method had been applied to enhance actuating force. Through the flip chip packaging technology, a top-plate had been designed and bonded with the micromirror devices as a stopper to control the pop-up angles. Flip chip bonding using gold bumps had been investigated to gain control of the height of the stopper. The switching characteristics of the proposed micromirror devices had been examined preliminarily. Finally, a back-to-back micromirror device for optical add/drop multiplexer applications is obtained.

Keyword: micromirror, DMUX. MUX, Poly-MUMPs, flip chip, heat-treatment

1. Preface

For a Dense Wavelength Division Multiplexing (DWDM) networking system, Optical Add/Drop Modules (OADM), that play important role both in optical core networks and in regional access networks, are often required for optical communication. The OADM selectively removes (drops) a wavelength from a multiplicity of wavelengths in a fiber, and adds in the same direction of data flow the same wavelength, but with different data content. Through the OADM modules, the specific data or information could be extracted from or carried into the DWDM networking system such that information could be received or transmit among each communication nodes [1].

2. Purpose of Research

The main-scope of project is to develop micromirror devices for OADM prototype module based on MEMS technology. This micromirror device is capable of dropping from or adding into specific wavelength from multi-channel fibers. Furthermore, the micromirror device can be integrated with other components so that multi-functions including switching, filtering, modulation, and add/drop multiplexing could be further explored.

3. Designs, Results and Discussions

An OADM configuration that integrated volume holographic gratings with MEMS optical switches had been proposed in figure 1. The volume holographic filter with features of narrow-pass-band, high signal-to-noise (S/N) ratio, high insertion efficiency, and compact structure is used to realize DMUX and MUX. The incident lights with different wavelength will be coupled into DMUX and diffracted into designed position through localized multiplexing method. Micromirror array is used to drop specific information or add the desired one into MUX.

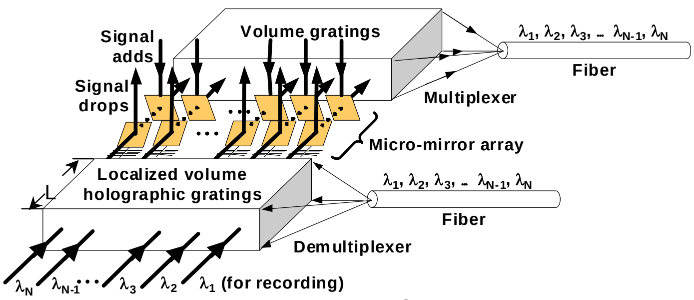


Fig. 1: OADM configuration

To accomplish the task of add/drop function in proposed OADM configuration, a back-to-back micromirror device had been developed using surface-micromachining and flip chip technologies was designed and developed. The pre-stressed beams were used to flip up the micromirror devices after the release process. Electrodes under pre-stressed beams were designed to actuate the micromirror devices. The micromirror devices could be actuated to block or bypass the light signals to extract specific information or add the desired one into MUX. The torsion flexure design will provide a reliable rotation degree of freedom. Thermal heat-treatment method is applied to enhance actuating force. Through the flip chip packaging technology, a U-shape stopper is designed and bonded on the top of the micromirror devices to be the constrain of popped-up angle control. Flip chip bonding with gold bumps had been investigated to gain control of the height of the bonding gap. The accuracy of popped-up angle control and the switching characteristic of the micromirror devices had been measured.

3.1 The Design and Fabrication of Micromirror Devices

Fig. 2 shows the SEM pictures of the released back-to-back micromirror devices. An optical switch consists of a micromirror (300μm in diameter), four pre-stressed beams (350μm in length, 70μm in width), and torsion flexure design to provide rotation degree of freedom. The devices were fabricated through PolyMUMPs process provided by Cronos Integrated Microsystems [2]. The 0.75um oxide layer (PSG2) was trapped between two polysilicon layers (Poly1 and Poly2) to minimize warpage of the mirror surface. The metal layer (Gold) is deposited on the center of mirror to obtain high reflect efficiency. Four pre-stressed beams connected in parallel are designed to provide more actuating force to flip up the micromirror devices. After the HF release process, the back-to-back micromirror devices will be flipped out of plane to have an initial popped-up angle. Electrode (substrate) under the pre-stressed beams is designed to apply electrostatic force to actuate the micromirror devices. However, the initial popped-up angle of the micromirror devices could not meet the requirements of proposed OADM configuration. The light signal output from DMUX could not be dropped completely since the popped-up angle is smaller than 45 degree. Also, the micromirror could not accomplish to add selected signal into MUX.

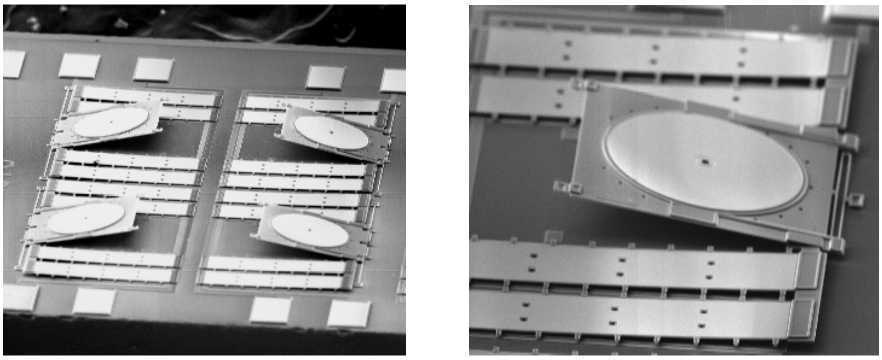


Fig. 2: SEM pictures of released back-to-back micromirror devices without thermal heat-treatment

To enlarge the popped-up angle of the micromirror devices, the actuating force of the pre-stressed beams must be improved. Here, we introduce the thermal heat-treatment method [3] to accomplish this task. After the release process, the mirror chips were put on the hot plate that will be heated to about 140°C for required heat treatment. After the thermal heat-treatment of the pre-stressed beams, the micromirror devices will be flipped up to have larger popped-up angle than the initial one. Fig. 3 demonstrated the results after the thermal heat-treatment process. It is clearly to show that the popped-up angle of micromirror devices had been improved.

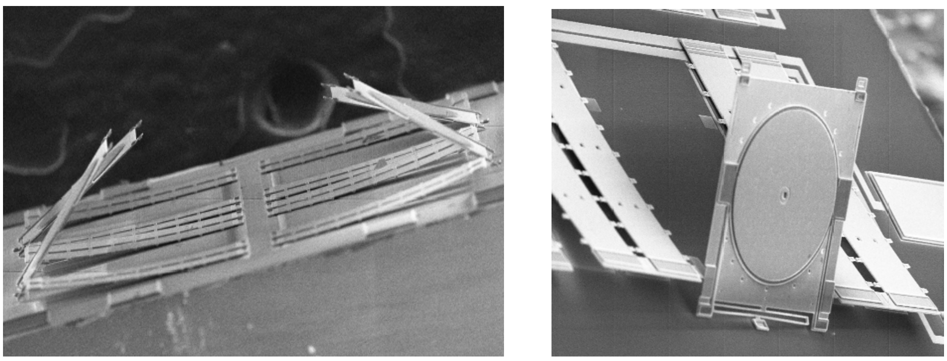


Fig. 3 SEM pictures of released back-to-back micromirror devices with thermal heat-treatment

Thermal cycling response of layered gold/polysilicon microstructures had been investigated [3], however, stress induced during heating process is difficult to control since it depends on the manufacturing process directly. It indicated that actuating forces of the pre-stressed beams might be different and unpredictable for each fabricated micromirror devices. As a result, the popped-up micromirror devices will not reach identical angle, which also brings a problem to integrate the fabricated micromirror devices with volume holographic gratings. To overcome this, an approach to fabricate mechanical stopper to constrain the popped-up micromirror to have desired angle is proposed here. The flip chip packaging is applied to realize this concept..

3.2 Flip Chip Packaging

Flip-chip packaging had been developed to many MEMS designs in the last decade [4-5]. It is frequently used to transfer MEMS structures to other substrates that provided MEMS designers a new capability to integrate different structures and substrates. In this paper, the flip-chip packaging process is applied to obtain precise angle-control of the popped-up micromirror devices to overcome above-mentioned problems. Firstly, a mechanical stopper is bonded on the top of micromirror devices. After the release and thermal heat-treatment processes, pre-stressed beams are able to have enough actuating force to flip up micromirror devices to reach the mechanical stopper. The stopper will constrain the micromirror devices at the desired popped-up angle. Therefore, the popped-up of the micromirror devices could be controlled precisely.

3.2.1 The Design of Mechanical Stopper

The conceptual design of mechanical stopper is illustrated in figure 4. Pre-stressed beams flipped up the micromirror device after the release and thermal heat-treatment processes. However, the mechanical stopper bonded on the top constrains the micromirror device at designed deflecting angle. The well-controlled bonding gap provides the precise deflecting angle of the popped-up micromirror device. The relation is given by

$$\theta = \sin^{-1}\frac{h}{l} \qquad (1)$$

where h is the bonding gap, θ is controlled angle, and l is the length of the micromirror device.

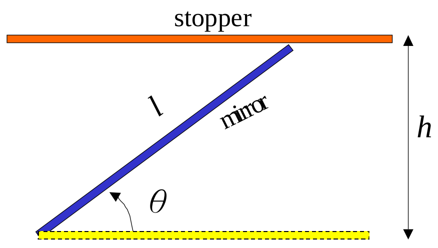


Fig. 4 Conceptual design of mechanical stopper

A top-plate with U-shape stopper fabricated through MUMPs was developed to bond with the micromirror devices for realizing this conceptual design. The design of U-shape stopper is used to prevent blocking of the light signals. Consider the configuration in Fig. 4, if a non-transparent substrate is bonded on the top of the micromirror device as the stopper, the light signal output from DMUX could not pass through the top-plate as well as the selected light signals that should be added into MUX shown in Fig. 1.The bonding was performed using flip chip bonder developed by CAMPmode, University of Colorado at Boulder [6]. Fig. 5 shows the SEM pictures of fabricated back-to-back micromirror devices with mechanical stopper. It is clearly to see that the micromirror device had reached the desired angle since it touches the mechanical stoppers.

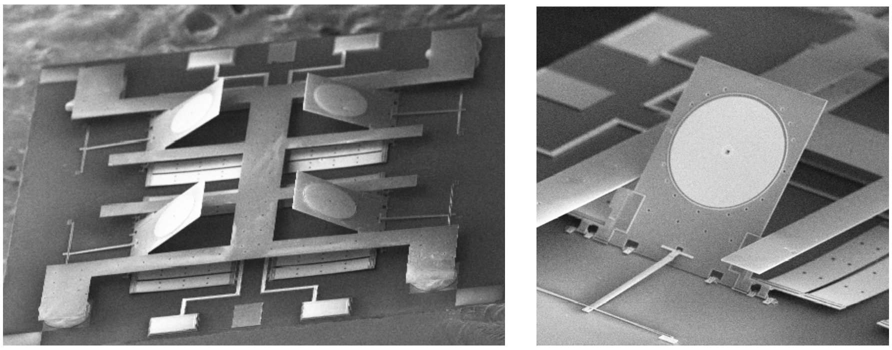


Fig. 5: SEM pictures of fabricated back-to-back micromirror devices with mechanical stopper

3.3 Experimental Results

With the fabricated micromirror device, the characteristics of the device need to be investigated. The accuracy of the popped-up angle of the micromirror during the ON/OFF stage of the applied electrostatic force is measured. Fig. 7 illustrates the optical configuration to measure the popped-up angle of the fabricated micromirror devices. The laser is manually aligned to the popped-up micromirror until the path of incident light reflected from the rotation mirror and reflected light from the micromirror is the identical one. This implies that the popped-up angle of the micromirror (θ) is equal to the tilting angle of the rotation mirror (ϕ). Table 2 lists the measurement results of three fabricated micromirror devices. In comparison to the proposed 45-degree popped-up angle for the OADM configuration; the relative error is within 1.6%, which shows the capability of the present assembly method in controlling the angle of the micromirror.

Finally, Fig. 8 shows the results of dynamic characteristics of the fabricated micromirror devices. The ON/OFF states of the optical switch were tested. The switching speed had been demonstrated to reach 100Hz. The electrostatic pull-down voltage of the pre-stressed beams is about 100V.

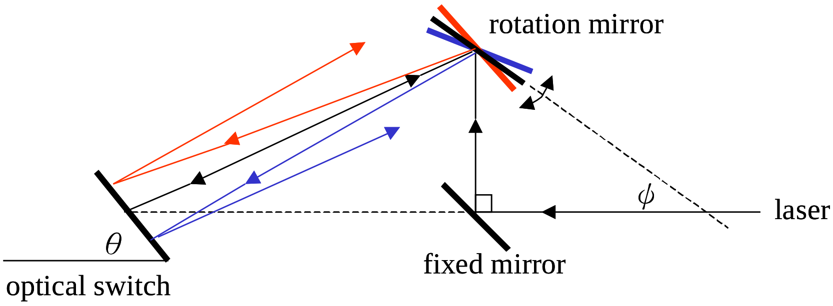
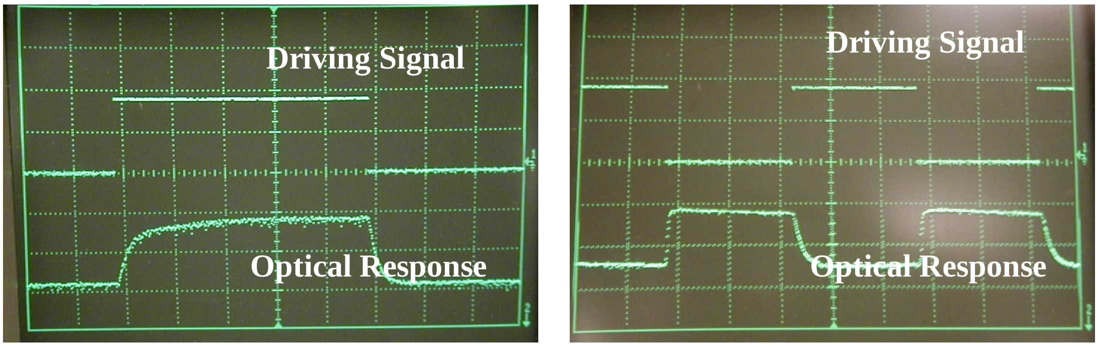


Fig. 7 Optical configuration to measure the popped-up angle of micromirror devices

Popped-up angle measurements			
Device 1	Device 2	Device 3	Device 4
44.6°	45.2°	45.3°	44.3°

Table 2 Popped-up angle measurement results of fabricated micromirror devices



(a) On state (Micromirror is pulled down)   (b) Off state (Micromirror is popped up)

Fig. 8 Dynamic characteristic of the fabricated micromirror devices

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計畫成果自評

A novel back-to-back micromirror device was developed using PolyMUMPs, flip chip bonding technology and heat treatment. By using standard PolyMUMPs process, we are able to fabricatereliable optical MEMS components with ease. With the flip chip bonding technology, the air gap between two bonding substrates can be controlled accurately. Upon applying heat treatment to the assembled device, the flip-up angle of the fabricated micromirror devices is remained within 1.6% of error. Experimental tests indicated that the present device is capable of performing add/drop function that is required in the OADM. With the present research accomplishment, we are able to contribute our design concept and assembly process to other sub-projects so that a novel OADM device for optical communication can be obtained.