Mirror Coating and Packaging for a Horizontal MEMS Optical Switch Array

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Abstract

A prototype package for a microelectromechanical system (MEMS) optical ON-OFF switch array has been designed, fabricated and assembled. The package consists of a horizontal surface micromachined 3D PolyMUMPs mirror chip, optical fibers and a micro-bench which acted as a carrier for the MEMS chip and optical fiber assemblies. The packaging alignment was achieved using an auto-alignment system. A multi-layer dielectric optical coating has also been designed and applied to enhance the optical performance of the mirrors. The packaged MEMS optical switch has been characterized.

Introduction

Microelectromechanical system (MEMS) optical switches can fulfill different applications in fiber-optical communication systems including the routing of optical signals, optical protection switching and variable optical attenuation in systems which use optical amplifiers. They can thus be important components in a fiber-optic network. MEMS switches which rely on the reflection of light beams by electrostatically actuated mirrors can provide low optical insertion loss and low crosstalk which are two of the most important requirements [1-5].

However, packaging of these MEMS optical switches is challenging because of the need for precision alignment of collimated beams with optical fibers. In this paper, we describe the development of prototype MEMS optical ON-OFF switch packages. The work described in this paper includes the design and fabrication of horizontal surface-micromachined 3D PolyMUMPs mirror chips, package design for the optical switch, process development for the silicon optical bench (SiOB), alignment and attachment process for the fibers and V-groove fiber blocks, precise alignment between the fiber arrays and MEMS mirrors, dielectric coating on MEMS mirrors, and packaging and characterizing of the MEMS optical switch.

MEMS mirror chips

Horizontal MEMS mirror chips were designed as shown in Figure 1. The chip size was 10 x 5 x 0.5 mm^3. There were 18 mirrors on each die, organized in three rows and six columns.

The MEMS mirror, as shown in Figure 2, was fabricated based on the process of PolyMUMPs by a foundry. The MEMS mirror was 200 x 200 μm^2 in area. Each mirror had 100 etched through holes of 5 x 5 μm^2 in size. The function of these holes was to reduce the mass and allow the structure to be undercut by the etchant, thus ensuring the subsequent release of the polysilicon structure. The mirror was surrounded by two frames for electrical conduction, support and to minimize damping effect. The MEMS mirror array itself consisted of eight self-assembled structures. These structures automatically lifted-up from the substrate and locked themselves onto mechanical spring latches when the devices were spun in a centrifuge. Five gold bonding pads, one pad connected to the frame and other four pads connected to the area below the mirror, were designed to control the motion of the mirror. The movement (both displacement and tilt) of the mirrors can be controlled by applying voltage that generates electrostatic forces on the frame and the mirror.

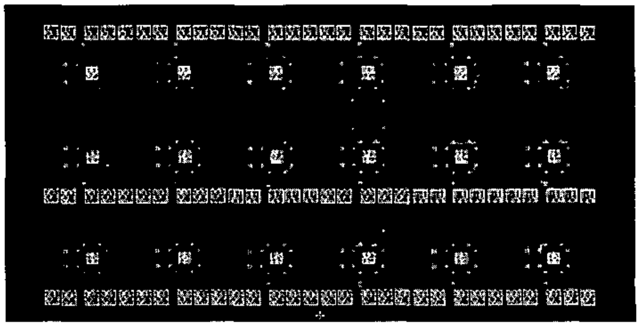


Figure 1 MEMS mirror design

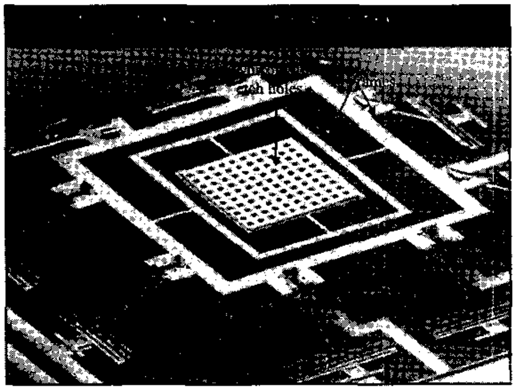


Figure 2 A picture of MEMS mirror

The chips obtained from the foundry only had the polysilicon layers released from the silicon substrates. Assembling the latches to lock the micro-mirror structure in position was carried out using a centrifuge. The non-contact batch micro-assembly by centrifugal force is a patented and published process for self-assembling the microstructure in a fast, low-cost, non-contact and non-destructive manner [6, 7]. The concept is to apply centrifugal force by rotating themselves 90^0 out of substrate plane. The centrifugal force can be adjusted by the spin speed and rotating disc size. The final position of the mirror was decided by the geometry of the pre-designed locking system.

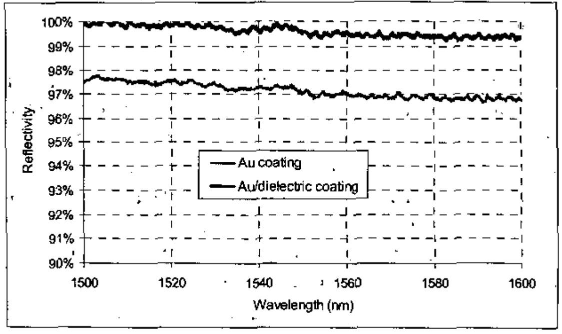
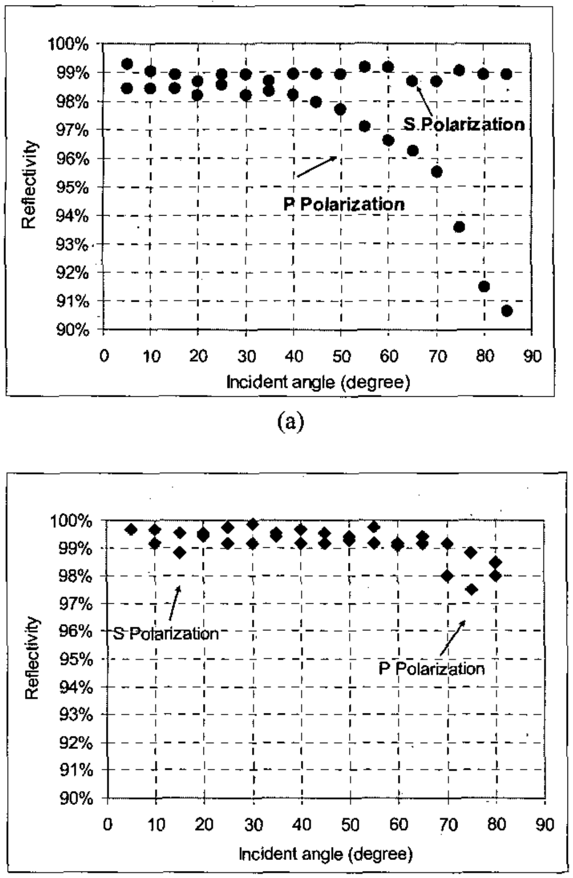


Figure 3 Reflection Measurement for both dielectric coated and uncoated samples



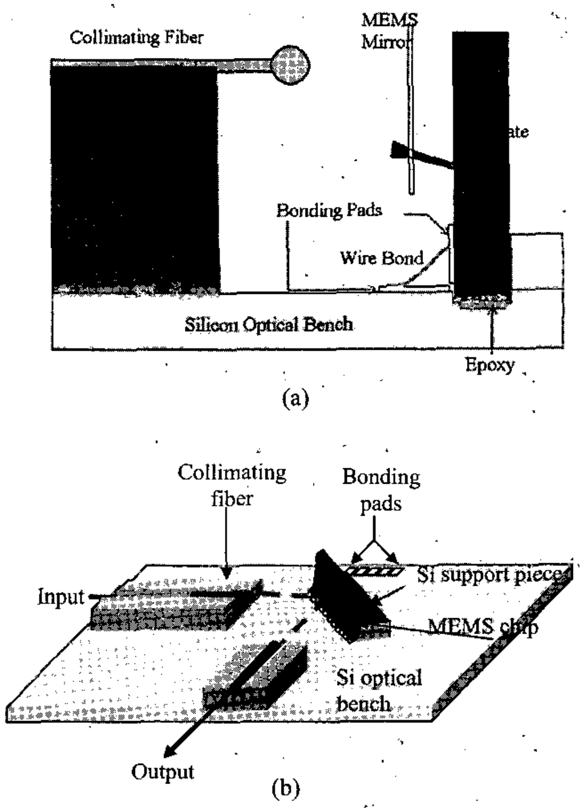
(a)

(b)

Figure 4 Reflectivity measurement at different incident angles for (a) Au coated, and (b) Au/dielectric coated samples

Dielectric coating

The MEMS mirror structure of Au on Si typically reflects the s-polarized light more strongly than the p-polarized light, resulting polarization dependent loss (PDL) in the optical switch. In order to reduce PDL, a multilayer dielectric coating overlaying the gold mirrors was designed. The optical coating consisted of 4 pairs of SiO_2/Ta_2O_5 thin film layers with a total designed thickness of 2037nm. The coating was deposited by an ion-beam assisted e-beam deposition system, which controlled the precise thickness of each dielectric layer by in-situ monitoring of the optical interference on a monitor glass. The measurement of the deposited coating reflection as a function of wavelength at incident angle of 5° was shown in Figure 3. The reflectivity was improved by over 1% after dielectric coating. Figure 4 shows the coating reflectivity measured at different incident angles comparing with uncoated sample. It is clear that dielectric coating was successful in reducing the polarization dependent loss (PDL) of the mirror.



(a)

(b)

Figure 5 Schematic Diagrams of 1 by 1 MEMS optical switch design (a) side-view, (b) all view

Package design

The packaging approach for MEMS optical switch involves passive and active optical alignment based on a Silicon Optical Bench (SiOB) which acted as a carrier for the MEMS array and the optical fiber assemblies. The design of the MEMS optical switch is depicted in Figure 5. The chip was vertically inserted into the trench of SiOB, which was etched to run at 45° angle with respect to the polished edges of the rectangular SiOB. The position was fixed by using epoxy adhesives. Wire bonding was used for electrical connection between the metal pads on the SiOB and the bonding pads on the mirror chip.

Single mode collimating fiber assemblies were designed and fabricated by attaching an array of collimating fiber lenses onto an array of V-shaped quartz grooves. The fiber array could thus be actively aligned in both the horizontal and vertical directions with respect to the mirror array attached on the micro-bench.

Packaging for MEMS optical switch

Processing for fiber array and Si optical bench

Collimating lensed fibers from Corning were used to collimate the light from the input fibers and receive the light in the output fibers. Initial optical performance characterization shows that the optimum fiber to fiber separation was 5mm (Figure 6). Lensed fibers were aligned with V-shaped quartz grooves using a Newport auto-alignment system. A UV-cured epoxy was used for fiber to fiber block attachment.

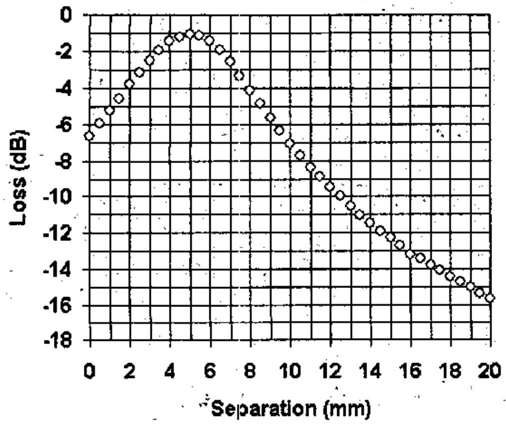


Figure 6 Optical loss versus separation between two collimating lensed fibers

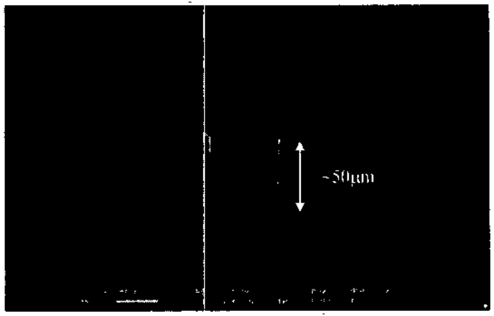
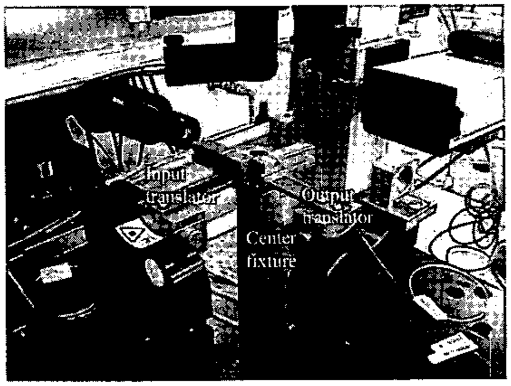


Figure 7 SEM picture of a 50 μm etch trench

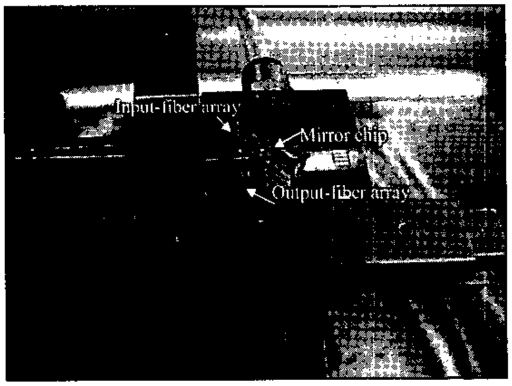
The 30 x 30 x 0.5 mm^3 Si optical bench was deeply dry etched to obtain a trench orientated at 45° from the edge for a 90° configuration of input and output light (Figure 7). Ti-W/Au thin film metallization was deposited as electrical circuits and wire bonding pads. The bond pads on the SiOB were then extended to the area away from the optical alignment region so that electrical wires could be connected to the PCB substrate and eventually to the connector plug in the metal case to supply electrical voltage. Alignment marks were also registered on the positions where the input and output fiber arrays placed to keep a total traveling distance of 5mm.

Alignment between fibers and mirror chip

The input and output fiber arrays were actively aligned in both horizontal and vertical directions with respect to the mirror using a Newport auto-alignment system. Since the machine is normally operated to align components in a same axis, redesign and reconfiguration of jigs were needed in order to align the fibers perpendicularly. Two translators, where input and output fiber arrays were placed, were rearranged into an L shape and a center fixture with vacuum holes was designed and fabricated to facility the MEMS chip. A photograph of the machine setup is shown in Figure 8a. Precise alignment can be achieved by adjusting translators in 6 axes of each translator to achieve maximum output power (Figure 8b).



(a)



(b)

Figure 8 Machine set up for fiber-mirror alignment

Packaging steps

The MEMS chip was inserted into the trench of the SiOB. An external force was vertically applied to push down the MEMS mirror chip using a die bonding tool. A 0.5 mm thick Si piece with polished edge was attached at the back of the chip (Figure 5 b). The chip and the supporting Si piece were glued in place using a UV cured epoxy with a low Tg of 145°C. After releasing the external force, the chip was further fixed using thermal conductive and electrical insulating epoxy which has a high Tg (over 350°C). The sample was cured at 180°C for 1 hour in the oven. Wire bonding was performed to form the electrical connection. The input- fiber array to MEMS mirror and to output fiber array actively aligned using the Auto-alignment system. The fiber arrays were attached to the Si optical bench using UV cured epoxy. Fiber arrays attached SiOB was fixed on a PCB board, and then to a metal case. Wire bonding between the SiOB and the PCB board was performed to make the electrical connection. The packaged MEMS optical switch is shown in Figure 9.

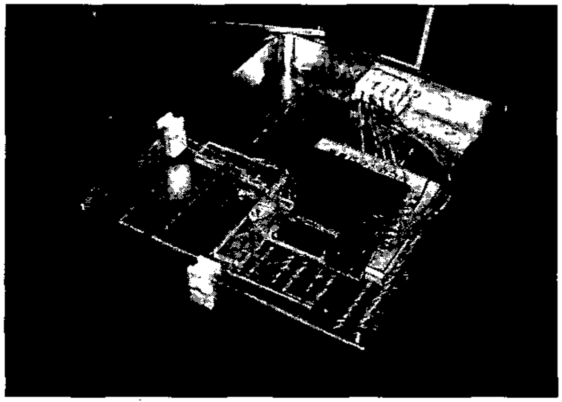
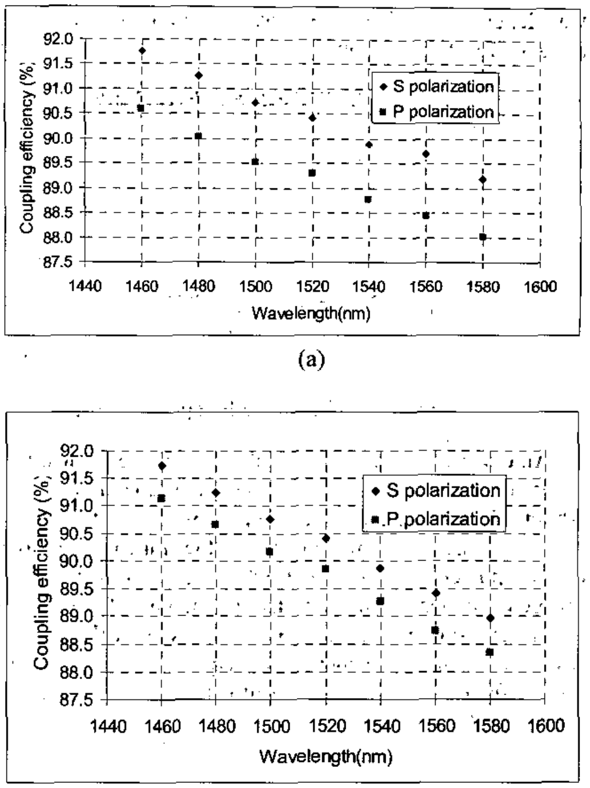


Figure 9 A packaged MEMS optical switch

Package Performance

The excess loss of the package was measured to be 0.5dB. This was in addition to the intrinsic loss of the MEMS mirrors which had a high loss (about 16dB) because their reflecting surface had an array of etched holes. The etched holes gave rise to diffraction and also reduced the effective area of reflection of the mirror. Improved design of the MEMS itself is clearly an area requiring further development. In order to destiguish between intrincic optical loss (from the etch holes in the mirror) and the external package loss, Si samples coated with Au or with Au/dielectric coating were used to replace the mirror chip. Using the same packaging procedures were carried out. It was found that less than 0.5 dB insertion loss from fiber-mirror-fiber configuration was achieved for both Au-coated and Au/dielectric coated samples. Figure 10 shows the coupling efficiency measured at different wavelength for both Au coated and Au/dielectric coated samples. It is clear that dielectric coating applied Au has reduced the PDL from 1.2% to 0.6%.



(a)

(b)

Figure 10 Coupling efficiency for (a) Au coated, and (b) Au/dielectric coated samples

A Packaged 1 x 1 MEMS optical switch was characterized by measuring static optical properties (polarization dependence) and dynamic performance (extinction ration and switching speed).

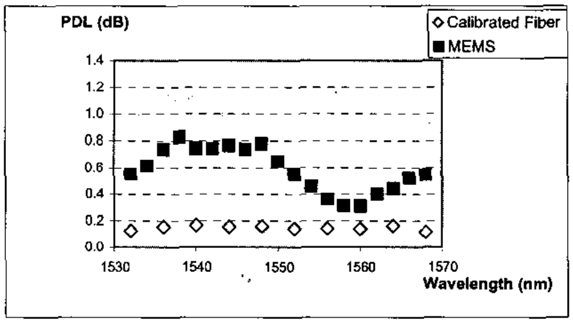


Figure 11 Polarization dependence loss at different wavelength for MEMS package

The polarization dependence loss (PDL) measured at different wavelengths in the range of 1530 to 1570 nm is shown in Figure 11. The PDL values measured for the MEMS mirror varied in the range of 0.3 to 0.8 dB. Compared with Figure 10, a possible cause for the higher PDL is polarization dependent diffraction from the periodic etched holes in the MEMS mirror. Normalized wavelength dependent loss is shown in Figure 12, which indicates that only 1 dB excess wavelength dependent loss was present in the wavelength range of 1530 to 1570 nm.

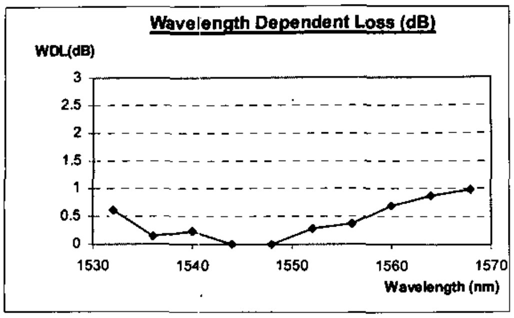
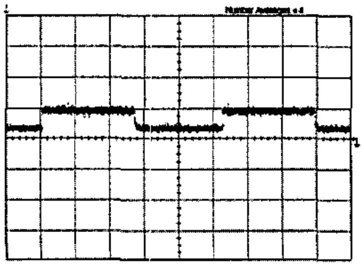
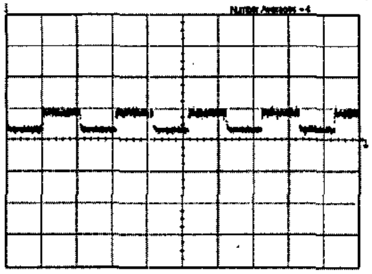


Figure 12 Wavelength dependent loss

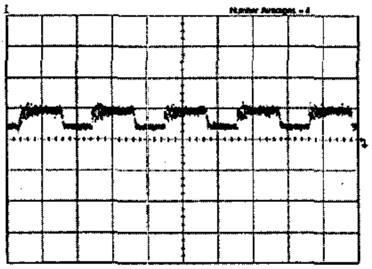
An electrical voltage was applied to MEMS optical switch to produce electrostatic forces on the frame of the mirror. About 25 V was needed in order to overcome the frictional force and generate movement of the mirror. The output optical power was recorded when 25 V square wave at different frequencies was applied, as shown in Figure 13. The results are summarized in Figure 14 as optical modulation response against frequency. The frequency response was flat up to 100 Hz and showed a roll-off in frequency response beyond 100 Hz.



1 Hz, 200ms/div



10Hz, 50ms/div



100Hz, 5ms/div

Figure 13 Optical signals at different frequencies

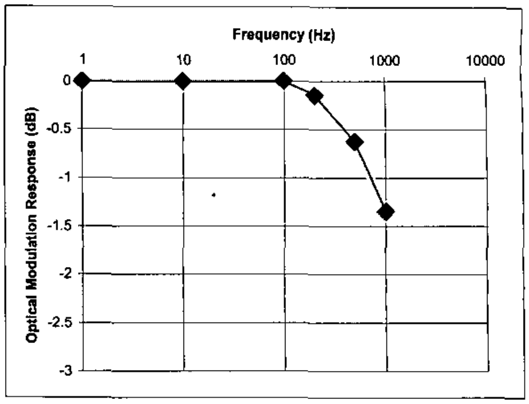


Figure 14 Optical modulation response against frequency

Conclusions

A prototype package for a microelectromechanical system (MEMS) optical ON-OFF switch array was designed, fabricated, assembled and characterized. The packaging approach involves passive and active optical alignment based on a micro-bench which acted as a carrier for the MEMS array and the optical fiber assemblies. Single mode collimating fiber assemblies were formed by attaching an array of collimating fiber lenses onto an array of Quartz V grooves. The fiber array could thus be actively aligned in both the horizontal and vertical directions with respect to the mirror array attached on the micro-bench. Active alignment of the input and output fiber blocks with respect to each other and the mirrors on the optical bench was achieved by a commercial auto-alignment system.

The package design had an excess loss of 0.5dB. The MEMS mirror itself had a loss of about 16dB, a 9dB on-off ratio, a switching speed of ~100Hz and a PDL of 0.8 dB. The poor perfomance of the MEMS switch was mainly caused by the array of etched holes which acted as a 2D diffraction grating. Further development is needed to elimate the etch holes in the mirror. Nevertheless this paper demonstrated the viability of the proposed packaging assembly for low excess loss (0.5 dB) coupling of light with a reflective mirror array. The packaging approach can be used to package 2D array of fibers and may be further extended to a 3D volume using two stacked collimating fiber arrays.

Acknowledgments

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