Micro-Optical Switch With Uni-Directional I/O Fibers

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ABSTRACT

The authors have developed a new 2 x 2 micro-optical switch. The switch features a uni-directional input/output and a drive mechanism with latch functions. The newly developed structure combines two moving mirrors and a fixed V mirror to implement a 2 x 2 micro-optical switch with uni-directional input/output. Furthermore, the moving mirrors have been reduced in size by integrating the drive and latch functions by the use of magnetic shaft mirrors and driving coils. The micro-optical switch has been implemented as a module mounted in a ceramic package. The modular switch is 23.5 x 9.86 x 6.76 mm in size and provides a switching time of 1.3 ms for 15 V (469 mA) and an input pulse width of 1 ms. The reflectivity of the moving mirror is 98.6 % (reflection loss: 0.06 dB) and the connection loss between the fixed mirror surfaces is 5.4 dB.

INTRODUCTION

Communications networks are undergoing a major change. The rapid spread of the Internet has accelerated the shift from traditional telephone-based networks to multi-media-oriented networks. In recently years, active research has been conducted on micro-mechanical optical switches. These optical switches feature wavelength-independent, high levels of channel isolation, small size, and high-speed operation. Micro-optical switches employ either optical fibers or plane optical waveguides as the transmission medium. Switching systems are roughly divided into two groups: one actuates the transmission medium, and the other inserts a reflective object into the transmission medium. Systems which use optical fibers and insert micro-mirrors for switching are the most advantageous in terms of size reduction and response. This system has therefore been selected for the newly developed 2 x 2 micro-optical switch.

Current MEMS optical switches arrange input/output fibers in two or four directions[1],[2],[3]. One problem with these switches is that the mounting space is rather large. To mount the optical switch on the board, the fibers must be fused. To allow for space for this fusion, reels are arranged in the input/output directions (Fig. 1). The newly developed optical-switch features uni-directional I/O fibers to achieve space savings. In addition, the driving and latch functions have been integrated by use of magnetic shaft mirrors and driving coils, reducing the size of the mirrors' moving parts. This article presents the operating principles, configuration, and fabrication process of the new optical switch as well as the characteristics observed in an initial prototype test.

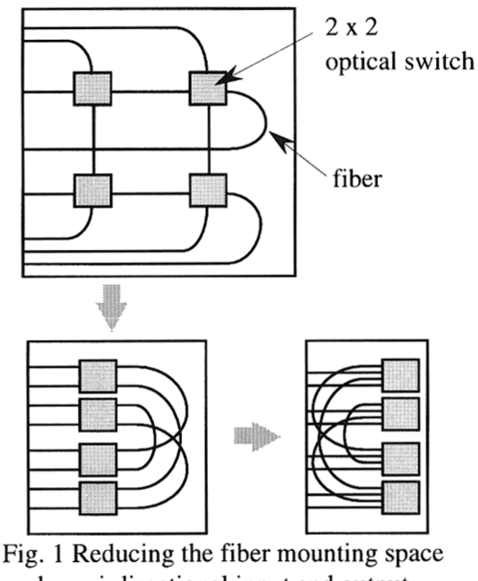
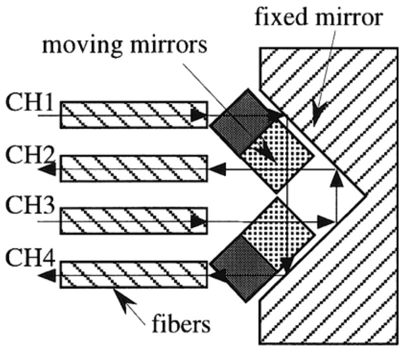


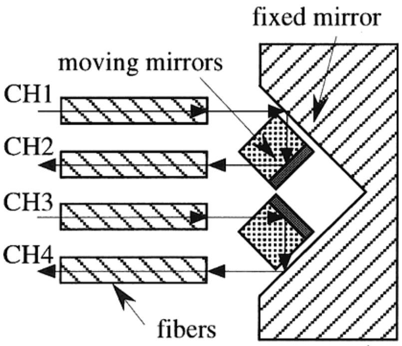
Fig. 1 Reducing the fiber mounting space by uni-directional input and output

CONFIGURATION AND OPERATING PRINCIPLES

The newly developed micro-optical switch consists of two moving mirrors, a fixed V mirror, and array fibers. As shown in Fig. 2, the 2 x 2 mirco-optical switch with uni-directional I/O has been made possible by introducing double mirror reflections. When the moving mirrors are in the horizontal position (Fig. 2a), they form light paths CH1-CH4 and CH3-CH2. When they are in the vertical position (Fig. 2b), the light paths are switched over to CH1-CH2 and CH3-CH4.

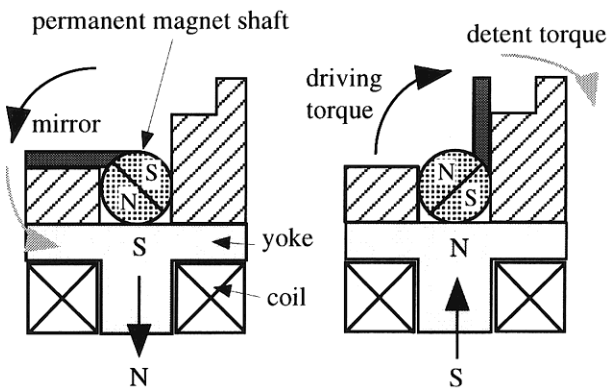


(a) Horizontal position



(b) Vertical position

Fig. 2 Configuration of optical switch



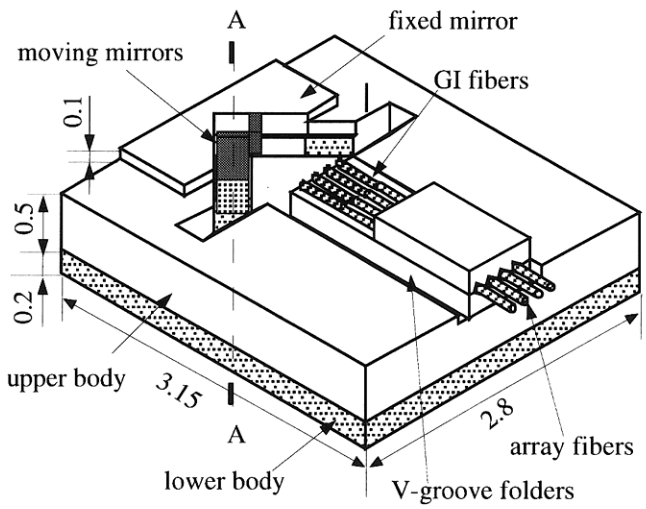
(a) Horizontal position (b) Vertical position

Fig. 3 The operating principle of the moving mirror

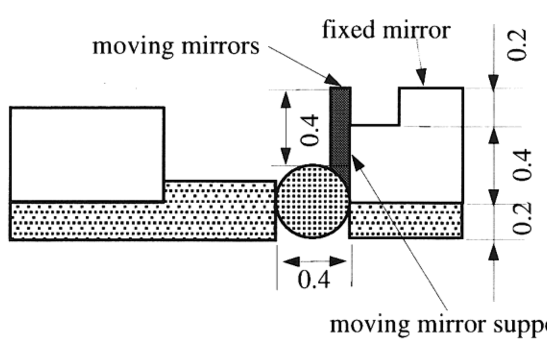
Fig. 3 shows the operating principles of the moving mirror which integrates the drive and latch functions. Even if the device is deactivated when the mirror is in the horizontal position (Fig. 3a), the mirror can be latched because the magnetic shaft is attracted to the yoke and the detent torque acts counterclockwise. By reversing the current in the driving coils, a driving torque can be generated to turn the mirror to the vertical position (Fig. 3b). If the device is deactivated in this state, the mirror can be latched because the magnetic shaft is attracted to the yoke and the detent torque acts clockwise. By reversing the current again, the mirror returns to the horizontal position.

STRUCTURE OF THE OPTICAL SWITCH

Fig. 4a shows the body structure of the 2 x 2 micro optical switch. The body consists of an opening for the moving mirrors, a fixed mirror, and array fibers. The moving mirrors, array fibers and driving coils are mounted on this body to form the micro-switch. Cross



(a) Upper and lower bodies



(b) Cross section A-A units : mm

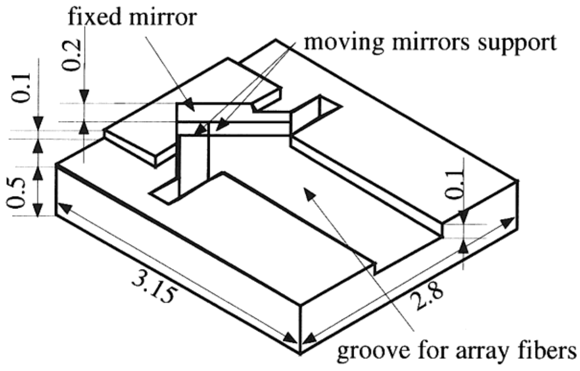
Fig. 4 Schematic view of the micro-optical switch section A-A is shown in Fig. 4b.

The parts which require high positioning accuracy, including the groove for fixing array fibers, moving mirror support, and fixed mirror positioning, are formed on a wafer (upper body)(Fig. 5a). The groove for inserting the moving mirrors is formed on a separate wafer (lower body)(Fig. 5b). The two wafers are then joined. This joined structure was developed to simplify the fabrication process. The upper and lower body use wafers 600 μm and 300 μm in thickness, respectively.

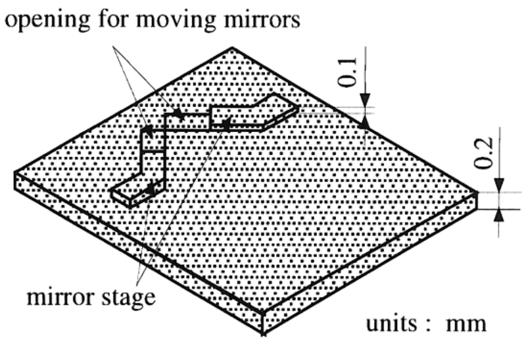
Fig. 6 shows the structure of the magnetic shaft. The mirror is made from a glass plate ground to a thickness of 90 μm and then sliced to a size of 0.6 x 0.24 mm using a dicing saw. To increase reflectivity, a Cr/Au (400/3500 Å) film is formed on the mirror surface by evaporation. Using an electric discharge machine a magnetic shaft 0.4 mm in diameter and 0.24 mm in length is processed from permanent magnetic material. This magnetic shaft is joined to the mirror to form a magnetic shaft mirror.

Fig. 7 shows the structure of the driving coils. A silicon steel sheet 0.35 mm in thickness is processed using an electric discharge machine to form a core with a 0.1 mm gap. Then 40 μm-diameter copper wire is wound through 650 turns to form a driving coil. The wire has a resistance of 32.0 ohms.

As shown in Fig. 4a, the array fibers consist of four single-mode optical fibers 125 μm in diameter, arranged 250 μm apart and sandwiched between V groove holders. A cross section of the array fibers is shown in Fig. 8. A GI (graded index) fiber, fused at the end of each optical fiber, collimates the light traveling from the array fibers to the mirror surfaces. By operating the mirrors, the length of the light path in the optical switch is switched between 1.5 mm (CH1-CH2) and 2.0 mm (CH1-CH4). The length of the GI fibers has been optimized to minimize the connection loss in either light path.



(a) Upper body



(b) Lower body

Fig. 5 Schematic view of upper and lower bodies

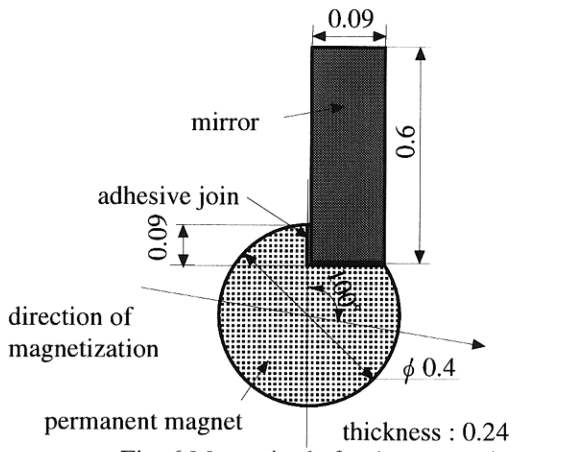


Fig. 6 Magnetic shaft mirror units : mm

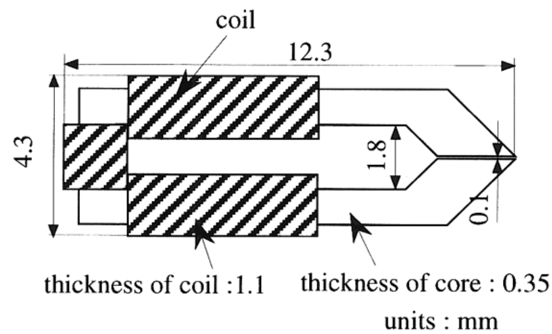


Fig. 7 Driving coils (silicon steel)

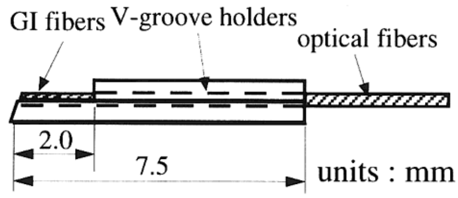


Fig. 8 Cross section of array fibers

FABRICATION PROCESS

To fabricate the upper body, three steps (for the fixed mirror, the groove for the array fibers, and the moving mirrors support)(Fig. 5a) must be formed on a silicon wafer. The wafer is therefore etched three times by deep RIE using ICP. The ICP process is carried out twice from the surface and once from the reverse side. To form two steps from the surface, a double mask is formed using resist and SiO_2. The fabrication process is shown in Fig. 9. The cross section is the same as cross section A-A shown in Fig. 4b. In Fig. 9a to Fig. 9c a SiO_2 film is formed. After photolithography, the SiO_2 mask is formed by RIE. In Fig. 9d the mask for

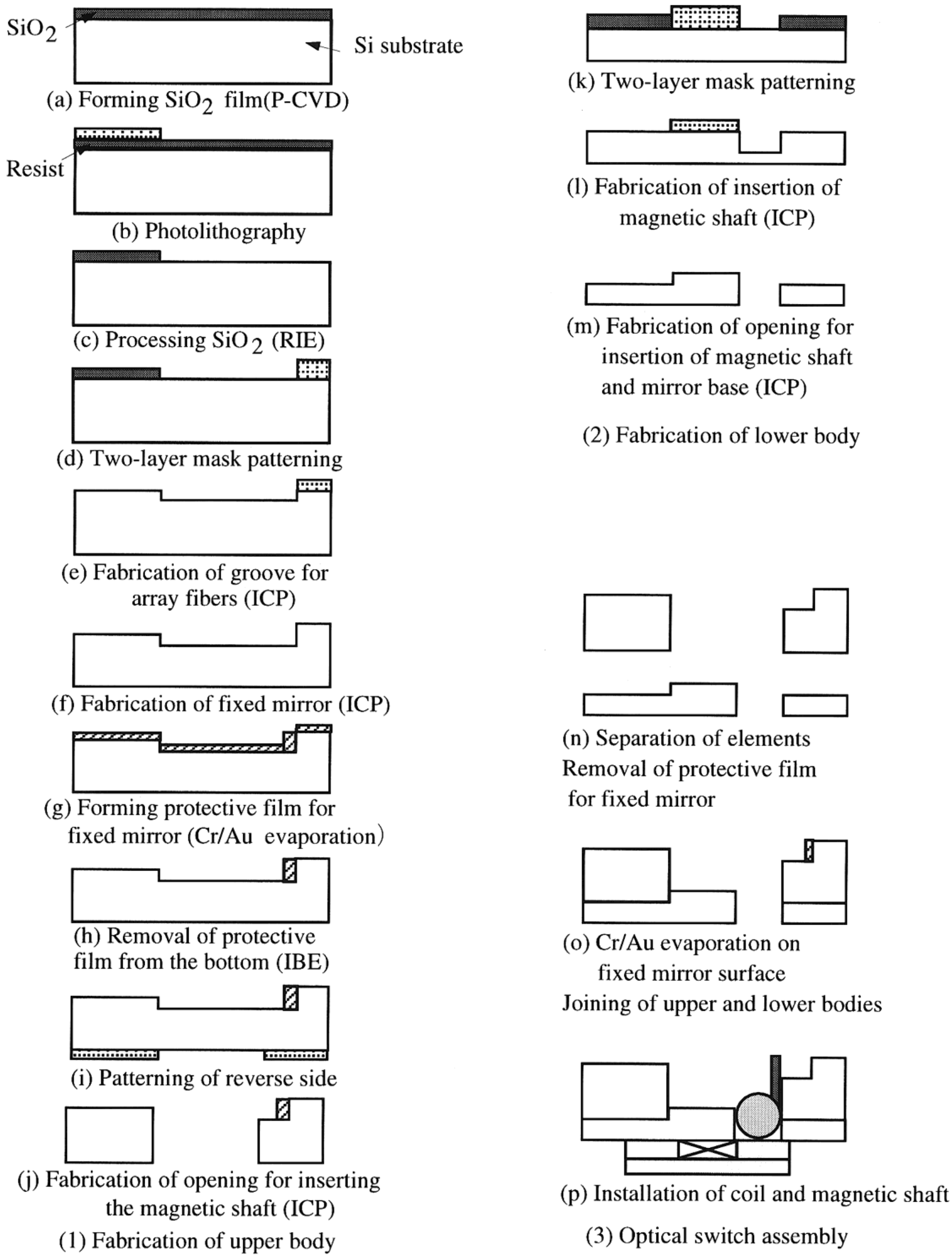


Fig. 9 Fabrication process for micro-optical switches

the fixed mirror is formed. This area has no SiO_2 mask because if it has a double mask of resist and SiO_2, there would be a step in the fixed mirror area. In Fig. 9e by using the SiO_2 and resist as a mask, the wafer is etched to a depth of 100 μm to form the first step for the groove for the array fibers. In Fig. 9f by using the resist alone as a mask, the wafer is etched by another 100 μm to form the fixed mirror. In Fig. 9g a Cr/Au (400/3500 Å) film is formed by evaporation to protect the fixed mirror surfaces during fabrication. In Fig. 9h the protective film on the bottom is removed by IBE. In Fig. 9i by using a double-sided aligner, the reverse side is patterned. In Fig. 9j the wafer is etched to a depth of 400 μm to form the through-hole for the moving mirrors.

The lower body has two steps: a mirror stage for holding the moving mirrors in the horizontal position and an opening for the moving mirrors(Fig. 5b). The wafer must therefore be etched twice by ICP. Except for the difference in the mask patterns, the process is carried out in the same manner as for the surface of the upper body: in Fig. 9k a double mask for the mirror support and opening for moving mirrors is formed. In Fig. 9l by using the SiO_2 and resist as a mask, the wafer is etched to a depth of 200 μm to form part of the step for the opening for moving mirrors. In Fig. 9m by using the resist alone as a mask, the wafer is etched to form the mirror support and the through-hole for the moving mirrors (100 μm).

The completed upper and lower bodies, driving coils, and magnetic shaft mirrors are then assembled as shown in Fig. 9(3). In Fig. 9n the elements of the upper and lower bodies are separated using a dicing saw. The protective film for the fixed mirror on the upper body is removed by wet etching. In Fig. 9o a Cr/Au (400/3500 Å) film is formed on the surface of the fixed mirror by evaporation. The upper and lower bodies are then assembled. In Fig. 9p the driving coils are attached and the magnetic shaft is installed. Finally, the array fibers are installed, and the switch is mounted in a ceramic package to form a module.

RESULTS

Fig. 10 shows an SEM view of the fixed mirror section after fabrication of the upper body. The surface roughness of the fixed mirror was Ra = 417 Å. The photograph of a cross section of the upper body in Fig.11 reveals that the fixed mirror has an angle of approximately 1.4 degrees.

Fig. 12 shows the micro-optical switch fitted with the

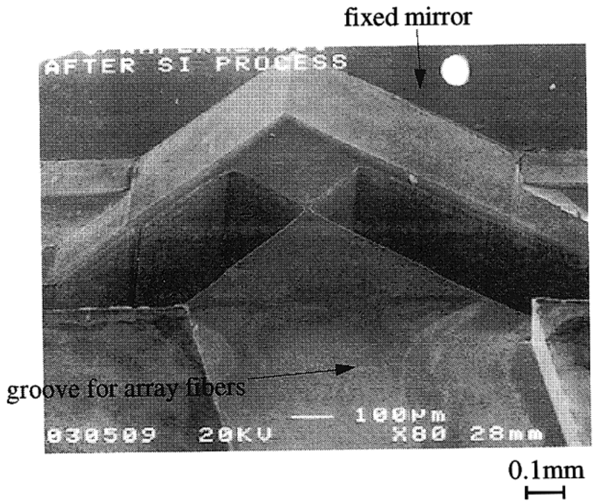


Fig. 10 SEM photograph of the micro-optical switch

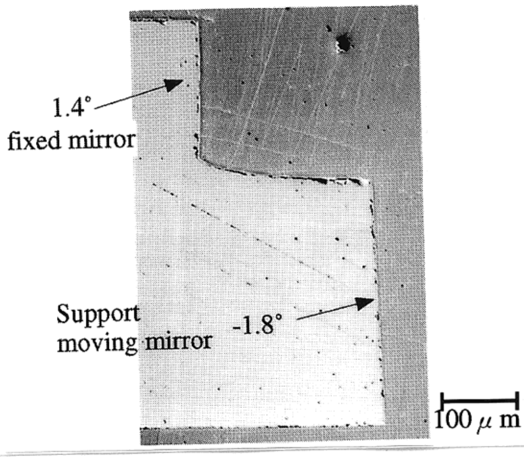


Fig. 11 Cross section of upper body of optical switch

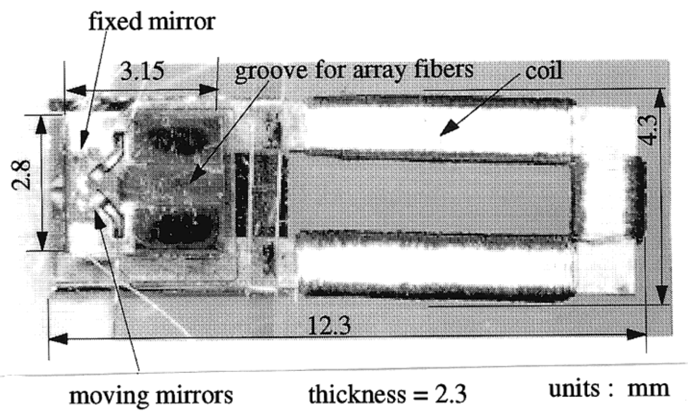
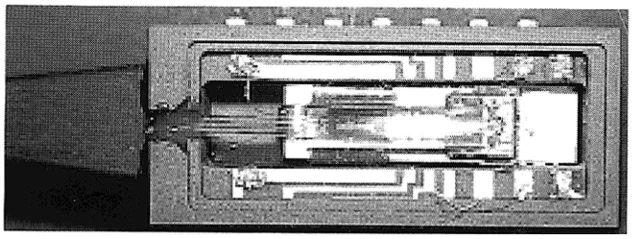


Fig. 12 Photograph of the micro-optical switch with driving coils

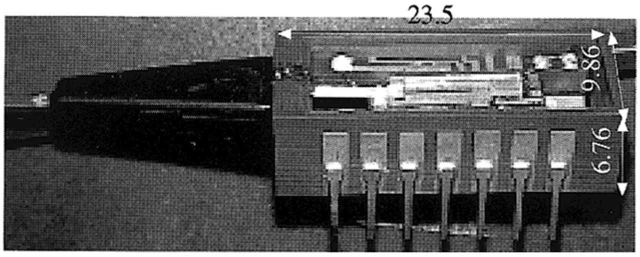
driving coils. In this state, the switching time of the moving mirrors was measured using a high-speed video camera. The mirrors were switched while applying rectangular waves of voltage to the coils for a certain period. It was found that the switching time was 1.3 ms for 15 V (469 mA) and an input pulse width of 1 ms.

After forming a Cr/Au (400/3500 Å) film by evaporation, the reflectivity of the moving mirrors' glass surface achieved a favorable level of 98.6 % (reflection loss: 0.06 dB). When measured using the fixed mirror surfaces alone, the connection loss is 5.4 dB between CH1 and CH4 and 6.7 dB between CH2 and CH3.

After mounting in a ceramic package, the array fibers were adjusted and assembled with the moving mirrors in the horizontal position. Fig. 13 shows enlarged photos of the optical switch module. Fig. 14 shows an enlarged view of the moving and fixed mirrors. The feasibility of the new optical switch system has been established.



(a) Front view



(b) Angled view units : mm

Fig. 13 Photograph of the micro-optical switch module

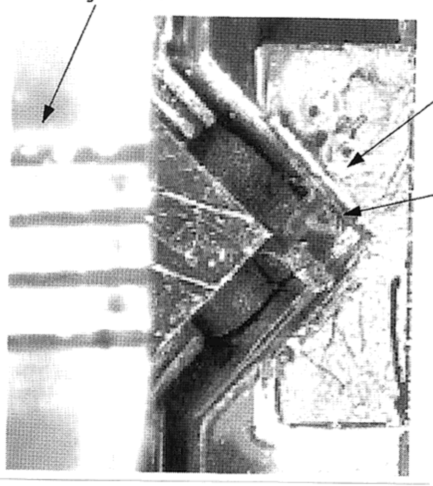


Fig. 14 Enlarged photograph of the micro-optical Switch

CONCLUSION

The following conclusions have been obtained regarding the new 2 x 2 micro-optical switch featuring uni-directional input/output and a drive mechanism with latch functions to allow for size reduction.

(1) The driving principles of a moving mirror which integrate the drive and latch functions was developed.
(2) Using this moving mirror, a 2 x 2 optical switch with uni-directional input/output was designed to reduce the size of the mounting space for array fibers. This switch was fabricated using an ICP process.
(3) The optical switch provides a switching time of 1.3 ms for 15 V (469 mA) and an input pulse width of 1 ms.
(4) The connection loss on the fixed mirror surfaces is 5.4 dB for CH1-CH4 and 6.7 dB for CH2-CH3.
(5) The feasibility of the new optical switch system has been established.

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