Realization of FDDI optical bypass switches using surface micromachining technology

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ABSTRACT

We report a novel FDDI (fiber data distribution interface) optical bypass switch using the surface-micromachining technology. In this design, all of the switches' components are made of polysilicon films and are monolithically patterned. The switch consists of four multimode optical fibers and a two-sided mirror sitting vertically on the top of a sliding plate which can be driven by an integrated micro-actuator. The gap between two in-line fibers are minimized to reduce insertion loss without using any lenses. The total insertion loss of the switch has been measured to be 2.8 dB for the CROSS state and 3.1 dB for the BAR state with a LED source operates at 1.3 μm wavelength. The cross-talk between two states is measured to be 26.1 dB. The insertion loss and cross-talk can be improved further using different designs. Using this approach, the size, weight and cost of current FDDI bypass switches can be dramatically reduced. Furthermore, the micromachined FDDI bypass switches are potentially integrable with the optical sources/detectors and controlling electronics.

Keywords: fiber data distribution interface, FDDI, optical switches, micromachining, FDDI optical bypass switches

1. INTRODUCTION

In information processing and multimedia applications, acquiring and distribution of information is one of the most important processes conducted today and networks play an very important role in this process. Ever increasing needs for high-speed communication, multivendor network interoperability, network management, and low-cost high-performance networking to the desktop have promoted data communications to a new information age. Using optics as a means of communication has received a great deal of interest due to its unique properties, such as high-spatial bandwidth, immunity from lightening strikes and resultant current surges, no radio-frequency or electromagnetic interference and more flexible requirements for its operating environment. Fiber optic networks such as fiber distributed data interface (FDDI) is widely accepted and supported in the industry as the next-generation international standard for high-speed, local area networks.

FDDI technology is an American National Standards Institute (ANSI) standard that supports data transfer rates of 100 million bits per second (100 Mbps). FDDI was developed in relation to other LAN technologies and uses common IEEE 802.2 LCC communication services. It uses a timed-token

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protocol to coordinate station access to the network. Figure 1 shows the FDDI dual ring architecture. Each FDDI station is connected to two rings simultaneously: a primary ring and a secondary ring. Information flows on the primary ring in one direction from one station to its downstream neighbor station, while the secondary ring serves as the redundant backup path. It provides a solution to the growing congestion of older LANs brought about by the increased use of high-performance workstations, servers, graphic interfaces, and multimedia applications. There are a number of factors which have contributed to the success of FDDI. It provides a significant increase in data rates compared with other commercially available LANs (local area networks). For example, it provides 10 times larger bandwidth than Ethernet. In addition, high performance VLSI FDDI chip sets have improved FDDI's reliability and lowered its implementation costs. Finally, FDDI's use of fiber optics for the technological benefits and declining costs has also contributed to its success.

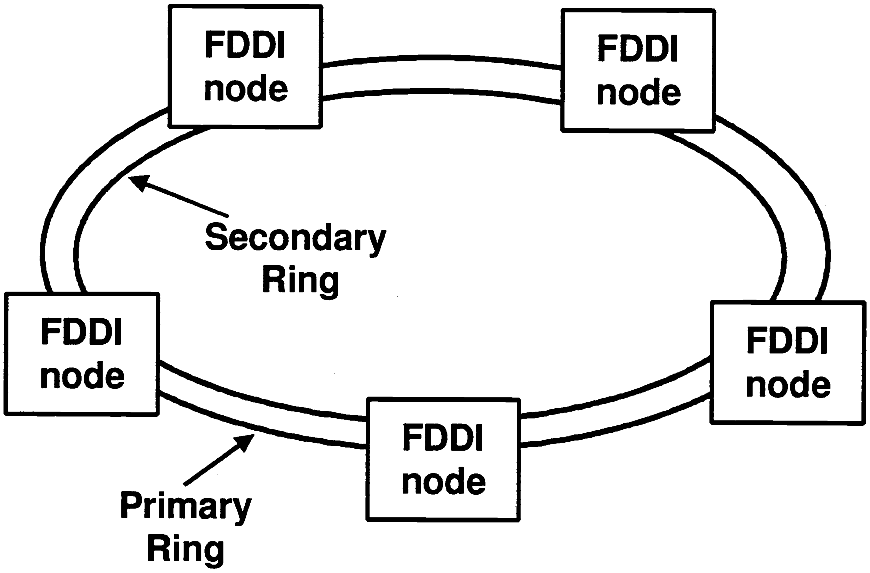

Fig. 1. FDDI dual ring architecture.

In a network, switches play an important role. With optical switches, we not only can perform various optical information processes but we also can increase the reliability and stability of the operation of the network. In a FDDI fiber optic network, it allows use of an optional optical bypass facility. The FDDI optical bypass switch performs a bypassing function of a failed node. When the FDDI node is powered on, the bypass switch reroutes the incoming signal from ring into the station, and redirects the transmitted signal from the station to the ring. When the FDDI node is powered off or failed, the optical bypass switch allows the data signals to bypass the node and maintain the ring continuity. Figure 2(a) and (b) show normal operation and bypass state of the FDDI optical bypass switch, respectively.

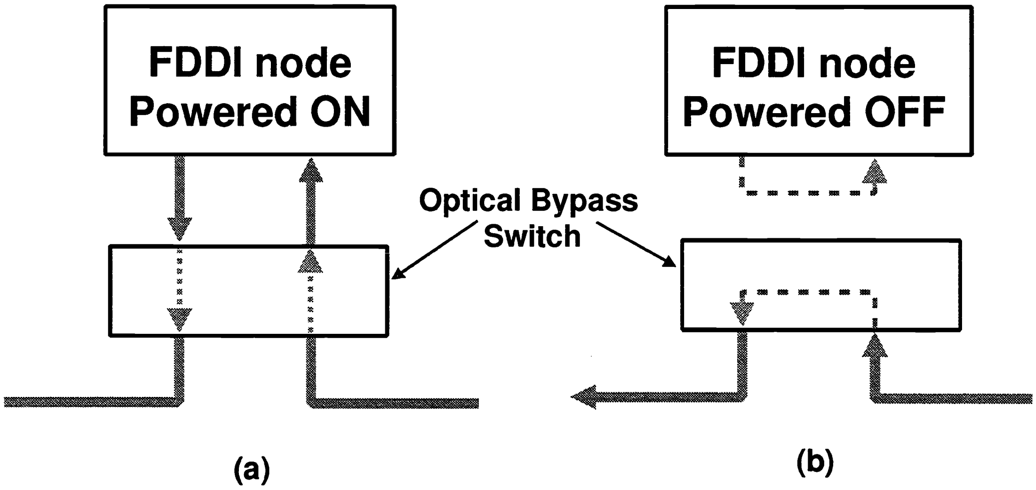

Fig. 2. Schematic diagrams of (a) normal operation and (b) bypass state of the FDDI optical bypass switch.

Since the use of the optical bypass switch introduces an additional optical loss, the FDDI optical bypass switch should be designed to minimize its optical loss. Free-space approach has a number of advantage compare to the conventional waveguide approach. It offers lower coupling loss and smaller cross talk. Currently, fiber optic switches are realized by manually assembled bulk optical elements and they are very expensive. Bulk-micromachining of Si substrate has been applied to free-space optical fiber switches.[1] In this approach, the hybrid-mounting of bulk optical elements and the wafer bonding technique are used, therefore, monolithic integration is difficult and a substantial assembly is required. On the other hand, surface-micromachined micro-optical elements can be optically pre-aligned in the design stage and are monolithically patterned during the microfabrication process. They can be made compact and light weight, and are potentially integrable with the optical sources/detectors and controlling electronics. The fabrication and characterization of various three-dimensional micro-optical elements have been demonstrated.[2,3] Therefore, the surface-micromachining technology is very attractive for implementing the FDDI optical bypass switch.

2. FABRICATION

The fabrication of the switch is done using three-layer polysilicon surface-micromachining technology at MEMS Technology Application Center at North Carolina (MCNC) under Advanced Research Projects Agency (ARPA) supported Multi-User MEMS Processes (MUMPs). The schematic structure of the switch is shown in Fig. 3. The switch consists of a three-dimensional movable mirror and four optical fiber guiding rails. The mirror sitting vertically on a sliding plate is positioned at the center of the switch and allowed to move along the x-axis. The mirror is coated with a 500 nm-thick gold layer to increase the reflectivity. The fabrication process of the switch is similar to that of micro-

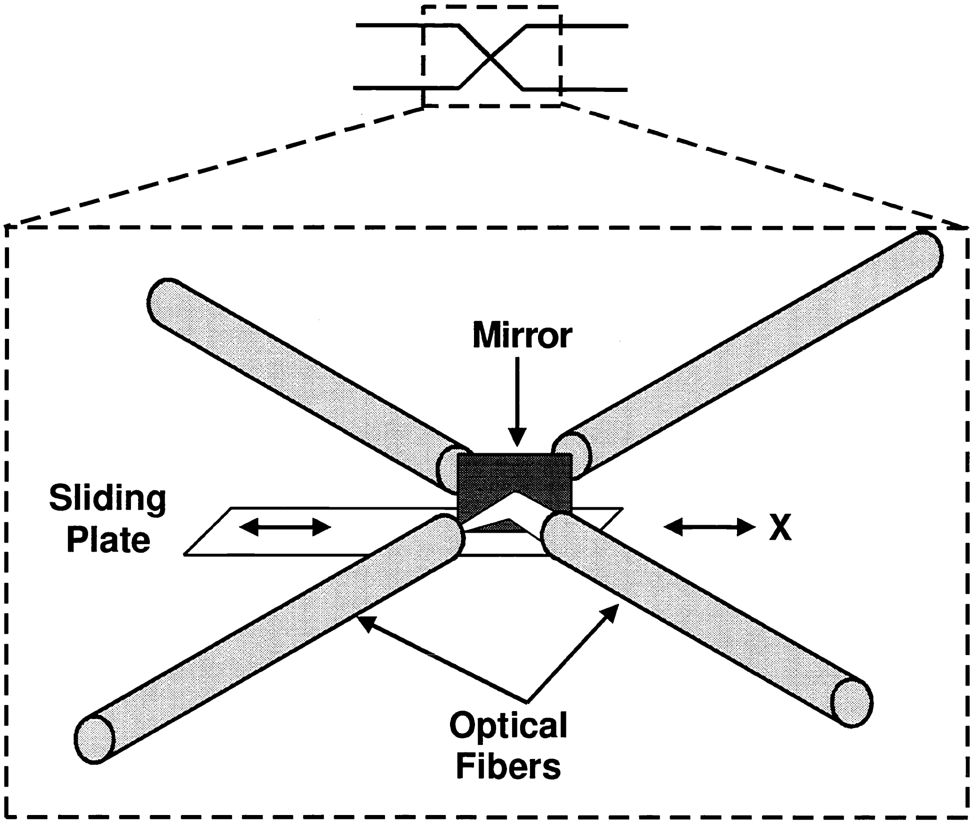

Fig. 3. Schematic diagram of the surface-micromachined FDDI optical bypass switch.

Fresnel lenses[4] and micro-gratings,[5] and it is described in the following: First, a 0.5-μm-thick polysilicon is deposited on the silicon substrate coated with low-stress silicon nitride. This layer of polysilicon serves as a electrical contact where it is needed. Before the deposition of the first structural polysilicon layer (poly1), a 2.0-μm-thick sacrificial phosphosilicate glass (PSG) layer is deposited. The sliding plate and part of the mirror hinge assembly are defined on the poly1. A 0.5-μm-thick PSG layer is then deposited before the deposition of the 1.5-μm-thick second structural polysilicon layer (poly2). The mirror, sliding plate guide rail and part of the mirror hinge assembly are defined on poly2. At the final processing step, a 0.5-μm-thick gold layer is deposited on the surfaces of the mirror to increase the reflectivity.

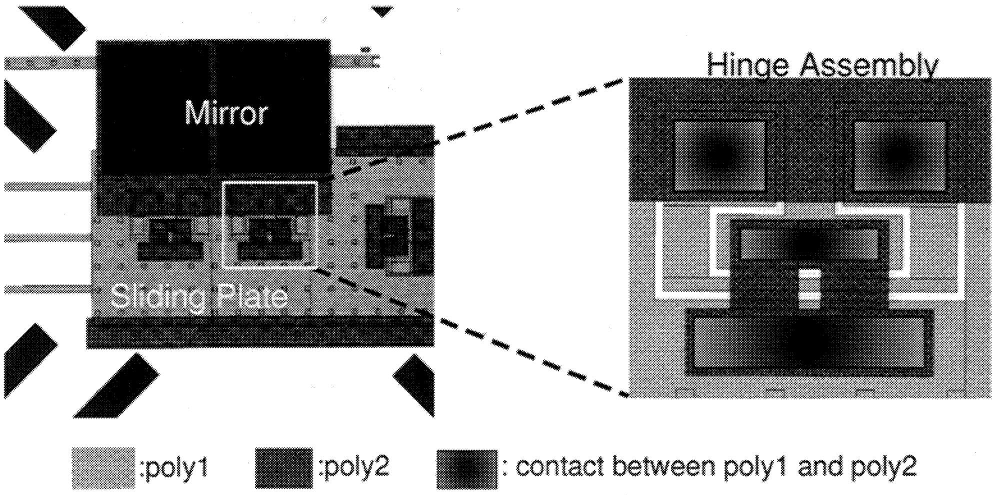

Fig. 4. Top layout view of the mirror hinge assembly.

The schematic diagram of the top view of the mirror hinge assembly is shown in Fig. 4. The detailed description of the mirror hinge assembly is the following: after the deposition of poly 1 layer, the first part of the hinge assembly is patterned (Fig. 5-1, U-shape in the figure). A 0.5-μm-thick PSG layer is deposited in order to isolate poly1 structures from poly2 structures. The contact hole between poly1 and poly2 is then patterned on the PSG layer. The mirror and the hinge lock is defined on poly2 layer (Fig. 5-2). After the final release, the U-shaped poly1 is attached to the poly2 mirror and form the hinge of the mirror, it is locked to the sliding plate by the hinge lock and free to rotate out from the substrate plane.

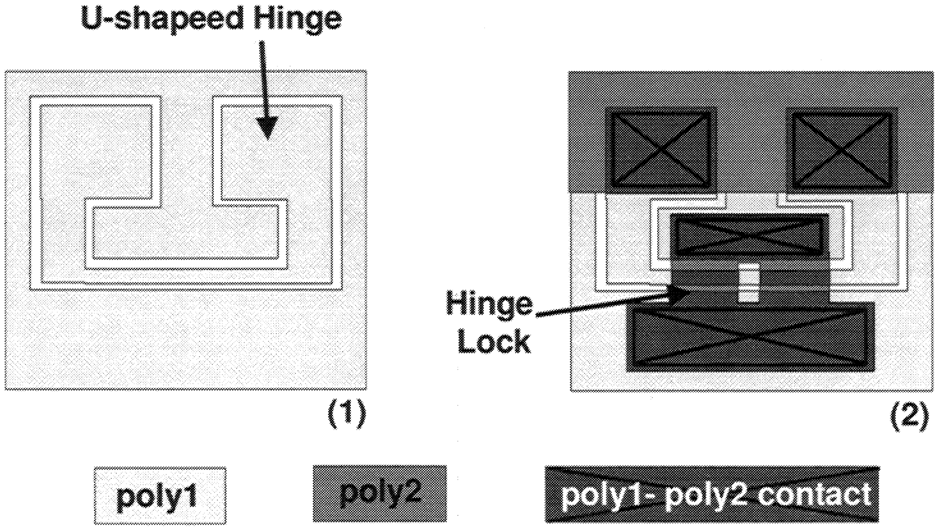

Fig. 5. Schematic of the mirror hinge assembly

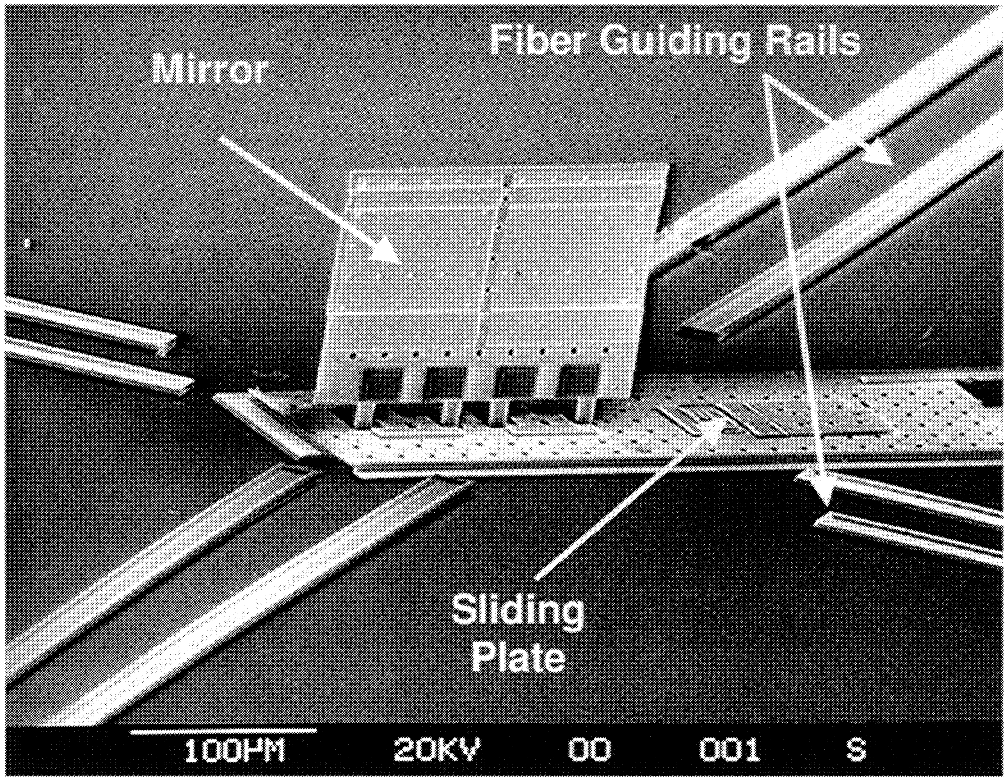

Fig. 6. The SEM of the three-dimensional mirror sitting on a sliding plate.

3. EXPERIMENT AND RESULTS

Figure 6 shows the scanning electron micrograph (SEM) of the mirror with the sliding plate. Four multimode fibers come from four diagonal directions along the guiding rails to the center of the switch and form a "cross" shape. The facets of two fibers along the same diagonal direction are separated by less than 125 μm. The switch has two operating states: CROSS and BAR states. When the mirror/sliding-plate is moved away from the fibers (the center), the fibers along the same diagonal directions are allowed to communicate with each other. This is defined as CROSS state. In the BAR state, the mirror/sliding-plate is slid into the center and the light signal is redirected into the orthogonal fiber. The top-view photographs of the switch with four multimode fibers in CROSS and BAR states are shown in Fig. 7(a) and (b), respectively.

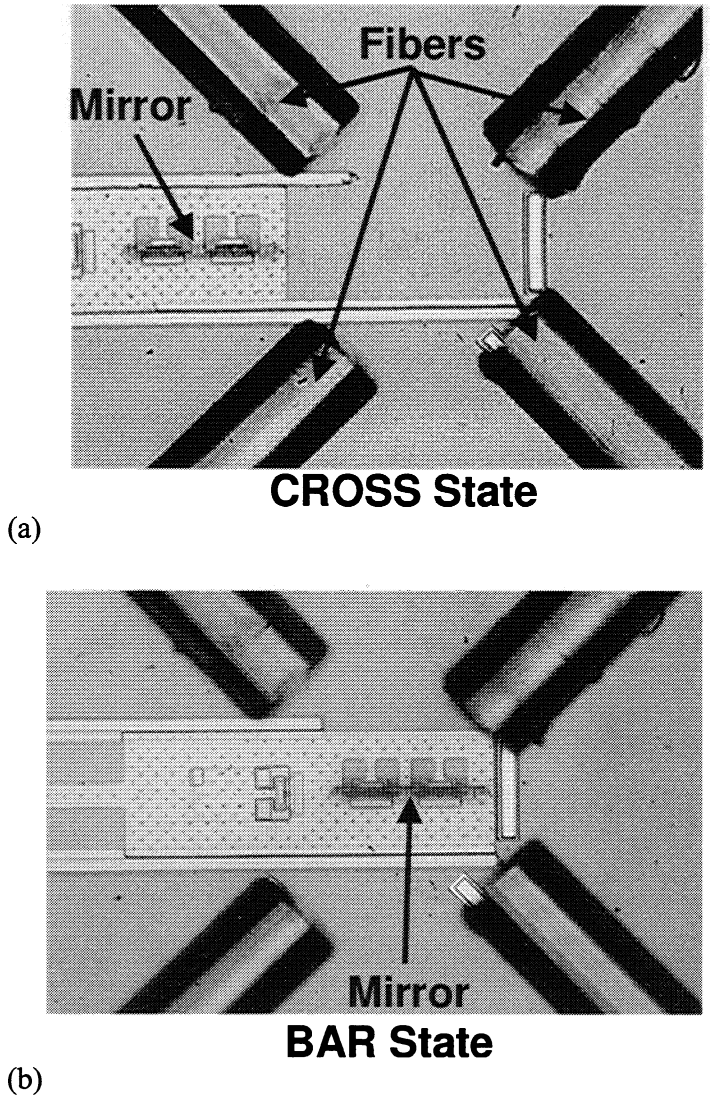

Fig. 7. The top-view photographs of the switch in (a) CROSS state and (b) BAR state.

Low insertion loss and cross-talk are important criteria for fiber optic switches. The insertion loss which includes fiber coupling loss and diffraction loss can be reduced by employing collimating and focusing lenses as in Ref. [1]. However, bulk optical elements are difficult to integrate monolithically. Micromachined integrable lenses[2] can be used by optimizing their efficiency. For optical switches with multimode fibers, the insertion loss can be lowered by reducing the fiber-to-fiber spacing. It has been shown theoretically that the coupling loss between multimode fibers could be as low as 1 dB for fiber-to-fiber spacing of 125 μm, and 0.45 dB for fiber-to-fiber spacing of 50 μm.[6] The insertion loss of the switch for both operating states has been measured with a LED source operating at 1.3 μm wavelength. The total insertion loss of the switch has been measured to be 2.8 dB for the CROSS state and 3.1 dB for the BAR state. From these two measurements, the reflectivity of the mirror is estimated to be 93%. The cross-talk between two states is measured to be 26.1 dB. The insertion loss and the cross-talk can be further improved with smoother gold coating on the mirror, anti-reflection coating on fiber facets, smaller spacing between fibers, and lensed fiber tips.

4. CONCLUSION

In summary, the FDDI optical bypass switch has been demonstrated using the surface-micromachining technology for the first time. With its monolithic microfabrication capability and three-dimensional characteristics, the size, weight and cost of current FDDI bypass switches can be dramatically reduced. Surface-micromachined switches are potentially integrable with other micro-optical elements and controlling electronics, as well as microactuators, and are attractive in low-cost high-performance fiber optic networks as well as for FDDI LANs.

5. ACKNOWLEDGMENT

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