Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 530-531

E-7-2 (Invited)

MEMS and Optical Applications

Hiroyuki Fujita and Hiroshi Toshiyoshi
Center for International Research on MicroMechatronics
Institute of Industrial Science, The University of Tokyo
7-22-1 Roppongi, Minato-ku, Tokyo 106-8558 Japan
Phone:+81-3-3402-6231 Fax:+81-3-3402-5078 e-mail:h.fujita@ieee.org

1. INTRODUCTION

The research and development of a microelectromechanical system, MEMS, have made remarkable progress since 1988 when an electrostatic micromotor of the size of a human hair was operated successfully. We can build three dimensional microstructures on a silicon substrate and operate micromotors/actuators without particular difficulty[1]. Commercial products such as inkjet printers and projection displays using micromirrors are successful in the market. Other promising applications of MEMS for the near future will be in optics[2,3], data storage devices, fluidics, printers, displays, bio technologies and scanning probe microscopes. These applications have a common feature in that only very light objects such as mirrors, heads, valves, cells and microprobes are manipulated and that little physical interaction with the external environment is necessary.

All the mechanical work can be completed within a microsystem for optical applications and its consequences can be exerted to the external world without contact. In addition, most of the optical components such as lasers, photodetectors, mirrors and optical waveguides are fabricated by semiconductor process which are compatible with micromachining processes in many cases. Therefore, MEMS has profound potential in optical applications.

2. CONCEPT OF OPTICAL MEMS

Integrated optics with semiconductor lasers, optical waveguides, mirrors and lenses have developed quite substantially. Solidstate optical devices based on material properties are capable of deflecting and modulating optical beams without moving parts. Optomechanical devices are advantageous, however, to have large scanning angles and good contrast between on and off states. Microactuators can be utilized in such devices since only small forces are required to move mirrors and shutters. One can obtain optical MEMS by combining microactuators/structures and integrated optics. It is expected to apply optical MEMS to switches in optical communication networks, scanners in optical sensors and focusing in CD and optical disc storage.

The optical MEMS dates back to 1970's. Petersen, et al.[3] demonstrated reflecting light beams by small cantilevers driven by electrostatic force in 1977. A 16-element light modulator array composed of micro cantilevers was used in a small display system. A line of He-Ne laser light was reflected by cantilevers, apertured, focused and scanned by a galvanometer. Thanks to recent technological development, semiconductor lasers, lenses, electronic circuits and movable structures are all integrated in the system which has following advantages: (1) Miniaturization of the total system, (2) high performance based on parallel processing, and (3) elimination of alignment. As an excellent example of such a system, an array of addressable mirrors has been commercilized[1] for a projection display. The small size (17 μm square) leads to a quick response of 10 μs. Underlaying video-RAM circuits conrol the deflection of millions of micromirrors independently. The position and the deflection angle of each mirror are defined precisely by photolithography. Table 1 summarizes the optical applications of MEMS. Some optical MEMS are used to control optical beams and signals, and others are for optical sensing. The most promising applications with large impact are devices for optical communication networks such as micromechanical switches, fiber aligners and connectors, wavelength tunable lasers and filters. In addition, applications in information apparatus, namely displays, optical date storage and scanners for printers and sensors, are also of high prospect.

3. MICROMACHINED MTRIX SWITCH

After successful development of micromachined 2 × 2 bypass switches[4,5] the research target is now shifted to matrix switches. The transmission speed in WDM networks becomes twice as fast in every 8 months. In order to keep up with the speed and to build the network cost-effectively, inexpensive optical matrix switches are highly required. The required matrix size for cross connection is 100 × 100 in a local area network and 10000 × 10000 in a large node of main networks. It will be also used for WDM add-drop with which an arbitrary channel carried by a particular wavelength is chosen and added/dropped to/from the transmission line. Micromachine switches based on free-space optics seem to be promising.

Table 1: Various types of Optical MEMS

Applications	Features
(1) MOEMSto control optical signals	
Wavelength Filters	For WDM application; Fabry-Perot type, waveguide type
Wavelength-Tunable Lasers	For WDM application; edge emitting laser, VCSEL
Modulators	Fabry-Perot type with 10 MHz speed
Displays	Arrays of movable micromirrors or gratings
Micromechanical Switches	High contrast, independent of wavelength or polarization, self latching, low cost
Scanners	For optical sensors, readers, printers or displays
Choppers and Shutters	For pyroelectric sensors and beam control
Optical Alignment and Packaging	V-grooves and LIGA-processed structures
Spectrometers	Micromachined gratings for chemical analysis
Microlenses	Made by reflow of photoresist or gray-tone lithography
Dynamic Focusing Mirrors and Lenses	Driven by microactuators
(2) MOEMSfor optical sensing	
Near-Field Optical Microscopes	Micromachined probes
Optical Encoders and Displacement Sensors	Integration of lasers, lenses, waveguides and detectors
(Optical) Storages	For tracking and focusing
Sensors on Waveguides	Physical or chemical sensors using integrated interferometers
Fiber Optic Sensors	Physical or chemical sensors

Lin, et al.[6] with AT&T Lab. developed 8 × 8 matrix switch using arrays of movable mirrors in a 1cm × 1cm chip. They used scratch-drive actuators (SDA) to raise the hinged micromirror from the substrate surface to the vertical position. Square voltage of ± 100V at 500kHz was applied to SDAs that positioned the mirror within 0.1 degree accuracy in 0.5ms. They used single-mode fibers with Grin collimator lenses and obtained the insertion loss as low as 3.1-3.5dB. Active alignment was conducted.

4. PIG-TAILED TUNABLE FILTER

Tixier, et al.[7] fabricated a pigtailed silicon platform for incorporating optical fibers and micromachined devices, 8 WDM tunable filters in this case, based on a new 3D packaging technology. Four silicon pieces were released out of a silicon wafer by using ICP-RIE as a very accurate dicing tool. One edge of the piece containing the filters was patterned into pin-shapes to be vertically inserted into receptacle holes on a silicon motherboard chip with electrical connections. A V-groove board for accommodating the optical fibers was mechanically aligned in the motherboard. This technology enables precise assembly of active optical devices with ribbon fibers, electrical connections to 3-dimensional micro mechanical subsystems and reconfiguring the system in the module level.

REFERENCES

[1] Proc. IEEE vol.86, No.8: special issue on "Integrated Sensors, Microactuators, and Microsystems (MEMS)" (1998).

[2] H. Fujita and H. Toshiyoshi: "Micro-optical devices", SPIE handbook of Microlithography, Micromachining and Microfabrication, vol.2, ed. P. Rai-Choudhury (SPIE, Washington, USA, 1997)

[3] K. E. Petersen, "Micromechanical light modulator array fabricated on silicon", Appl. Phys. Let. 31, 8, (1977) p.521

[4] H. Toshiyoshi, D. Miyauchi, H. Fujita, "Electromagnetic Torsion Mirrors for Self-Aligned Fiber Optic Cross-connectors by Silicon Micromachining," IEEE Journal of Selected Topics in Quantum Electronics, Special issue on Optical MEMS, Jan/Feb.1999., pp.10-17

[5] C. Marxer, N. de Rooij, "Micro-Opto-Mechanical 2 × 2 Switch for Single-Mode Fibers Based on Plasma-Etched Silicon Mirror and Electrostatic Actuation," IEEE Journal of Lightwave Tech., Special issue on Optical MEMS, Jan. 1999. p. 2

[6] L. Y. Lin, E. L. Goldstein, R. W. Tkach, "Free-Space Micromachined Optical Switches for Optical Networking," IEEE J. Selected Topics in Quantum Electronics 5, 4 (1999).

[7] A. Tixier, Y. Mita, S. Oshima, J.-P. Gouy, H. Fujita "3D-Microsystem Packaging for Interconnecting Electrical, Optical, and Mechanical Microdevices to the External World" IEEE MEMS 2000, Jan. 23-27, 2000, Miyazaki, Japan pp.698-703