PLE1 (Invited)
8:00am-8:30am

Surface-Micromachined Photonic Integrated Circuits

Ming C. Wu

University of California, Los Angeles (UCLA)
Electrical Engineering Department, Los Angeles, CA 90095-1594

The ability to integrate micro-optical elements with movable structures and microactuators has opened up many new opportunities for optical and optoelectronic systems[1,2]. It allows us to manipulate optical beams more effectively than conventional methods, and is scalable to large optical systems. Optical MEMS (MicroElectroMechanical Systems) have applications in display[3,4,5], sensing[6], and optical data storage[7,8]. Recently, telecommunications have become the market driver for Optical MEMS. Many different kinds of devices and systems have been reported, including optical switches[9,10], optical crossconnect[11,12], wavelength division add/drop multiplexers[13], tunable filters/lasers/detectors[14], dispersion compensators[15], and polarization dispersion compensators[16].

Surface-micromachining technology offers many advantages for implementing Optical MEMS. It is versatile; many different types of optical MEMS devices can be fabricated by the same process. This enables monolithic integration of an entire free-space optical system onto a single chip. In the past several years, we have shown that refractive and diffractive microlenses, micropositioners with multiple degrees of freedom (e.g., rotary or XYZ stages), and precision microactuators can be fabricated by standard three-layer polysilicon surface-micromachining process (e.g., Cronos' Multi-User MEMS Processes or MUMPs). Post-processing steps are employed to fabricate microlenses and other optical elements. By combining these building blocks, single-chip optical disk pickup head[8] and femtosecond optical autocorrelator[17] have been demonstrated. Another advantage of using standard processes is fast prototyping and commercialization. New devices are based on new designs rather than development of new processes. Establishment of design libraries can further shorten the design cycle.

One of the key challenges for surface-micromachined Optical MEMS is the quality of micromirrors. Surface-micromachined micromirrors often exhibit some curvature due to the residue stress or stress gradient of the deposited thin films. They also suffer from dynamic distortion under high frequency scanning.[18] Bulk micromachining has been shown to produce optically flat single crystalline micromirrors.[19,20] However, it does not have the flexibility and versatility of surface-micromachined structures. Efforts have been reported to increase the mirror flatness of polysilicon micromirrors.[7,18] Recently, we have developed a wafer-scale mirror bonding process to fabricate high performance single-crystalline Si micromirrors on surface-micromachined actuators. This technique combines the advantages of single-crystalline optical elements and the versatility of surface-micromachined structures. 2D optical scanners with optically flat micromirrors have been demonstrated.[21] Honeycomb micromirrors have also been developed to reduce the mass of micromirrors.[22] Detailed performance will be presented at the conference.

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[1] M.C. Wu, "Micromachining for Optical and Optoelectronic Systems," Proc. IEEE, Vol. 85, pp. 1833–1856, 1997.

[2] R.S. Muller and K.Y. Lau, "Surface-micromachined microoptical elements and Systems," Proc. IEEE, Vol. 86, pp.1705-1720, 1998.

0-7803-6257-8/00/$10.00©2000 IEEE

[3] L.J. Hornbeck, "Projection displays and MEMS: Timely convergence for a bright future," Proceedings of SPIE, vol. 2639, pp. 2, 1995.

[4] D.M. Bloom, "The Grating Light Valve: revolutionizing display technology," Proc. SPIE, vol.3013, p.165-71 (Projection Displays III, San Jose, CA) Feb. 1997.

[5] P. M. Hagelin and O. Solgaard, "Optical raster-scanning displays based on surface-micromachined polysilicon mirrors," JSTQE, vol. 5, no.1, pp 67-74.

[6] Pu, C.; Zhu, Z.; Lo, Y.-H. Surface micro-machined optical coherent detection system with ultra-high sensitivity. Sensors and Actuators A (Physical), vol.A78, p.36-40, 1999.

[7] J. Drake and H. Jerman, "A micromachined torsional mirror for track following in magneto-optical disk drives," Proc. Solid-State Sensor and Actuator Workshop, Hilton Head, SC, pp. 10-13, June, 2000.

[8] L. Y. Lin, J. L. Shen, S. S. Lee, and M. C. Wu, "Realization of Novel Monolithic Free-Space Optical Disk Pickup Heads by Surface Micromachining," *Optics Letters*, Vol. 21, No. 2, pp. 155-157, 1996.

[9] H. Toshiyoshi and H. Fujita, "Electrostatic micro torsion mirrors for an optical switch matrix," J. Microelectromechanical Systems, vol.5, p.231-7, 1996.

[10] R.T. Chen, H. Nguyen, M.C. Wu, "A high-speed low-voltage stress-induced micromachined 2x2 optical switch," IEEE Photonics Technol. Lett., Vol. 11, pp.1396-8, 1999.

[11] L.Y. Lin, E.L. Goldstein, and R.W. Tkach, "Free-space micromachined optical switches for optical networking," IEEE J. Selected Topics in Quantum Electronics, vol.5, p.4-9, 1999.

[12] D.T. Neilson, V.A. Aksyuk, S. Arney, N.R. Basavanhally, K.S. Bhalla, D.J. Bishop, B.A. Boie, C.A. Bolle, J.V. Gates, A.M. Gottlieb, J.P. Hickey, N.A. Jackman, P.R. Kolodner, S.K. Korotky, B. Mikklesen, F. Pardo, G. Raybon, R. Fuel, R.E. Scotti, T.W. Van Blarcum, L. Zhang, and C. R. Giles, "Fully provisioned 112x112 micro-mechanical optical crossconnect with 35.8 Tb/s demonstrated capacity," Optical Fiber Communications Conference (OFC 2000), Postdeadline paper PD-12, 2000.

[13] J.E. Ford, V.A. Aksyuk, D.J. Bishop, and J.A. Walker, "Wavelength add-drop switching using tilting micromirrors," J. Lightwave Technology, vol.17, p.904-11, 1999.

[14] Y.M. Li, W. Yuen, G.S. Li, and C.J. Chang-Hasnain, "Top-emitting micromechanical VCSEL with a 31.6-nm tuning range," IEEE Photonics Technology Letters, vol.10, p.18-20, 1998.

[15] C.K. Madsen, J.A. Walker, J.E. Ford, K.W. Goossen, G. Lenz, "A tunable dispersion compensating MARS all-pass filter," 25th European Conf. Optical Communication (ECOC), 1999. p.20-1, vol.2.

[16] L.Y. Lin, E.L. Goldstein, N.J. Frigo, and R.W. Tkach, "Micromachined polarization-state controller and its application to polarization-mode dispersion compensation," Proc. Optical Fiber Communications (OFC) Conf., paper ThQ-3, 2000.

[17] G. D. Su, L. Y. Lin, and M. C. Wu, "Single-Chip Femtosecond Autocorrelator Realized by Surface-Micromachined Integrated Optics," 1997 *Conference of Lasers and Electro-Optics (CLEO),* Paper CWL2, Baltimore, Maryland, 1997.

[18] J.T. Nee, R.A. Conant, M.R. Hart, R.S. Muller, K.Y. Lau, "Stretched-film micromirrors for improved optical flatness," Proc. MEMS 2000, Miyazaki, Japan, 2000, pp. 704-9.

[19] R.A. Conant, J.T. Nee, K.Y. Lau, and R.S. Muller, "A flat high-frequency scanning micromirror," Proc. Solid-State Sensor and Actuator Workshop, Hilton Head, SC, pp. 6-9, June, 2000.

[20] A.S. Dewa, J.W. Orcutt, M. Hudson, D. Krozier, A. Richards, and H. Laor, "Development of a silicon two-axis micromirror for an optical cross-connect," Proc. Solid-State Sensor and Actuator Workshop, Hilton Head, SC, pp. 93-96, June, 2000.

[21] G.-D. J. Su, H. Nguyen, P. Paterson, H. Toshiyoshi, and M.C. Wu, "Surface-micromachined 2D optical scanners with high-performance single-crystalline silicon micromirrors," Proc. 2000 CLEO, Postdeadline paper CPD-21, May 2000.

[22] P.R. Patterson, G.-D. J. Su, H. Toshiyoshi, and M.C. Wu, "A MEMS 2-D Scanner with Bonded Single-Crystalline Honeycomb Micromirror," Proc. Solid-State Sensor and Actuator Workshop, Hilton Head, SC, June 2000, pp. 17-18 (Late News paper).