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# Micro-Opto-Mechanical Systems

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## ABSTRACT

Complete pre-assembled micro-opto-mechanical systems (MOMS) on silicon integrated circuits can be realized by combining Micro-Electro-Mechanical Systems (MEMS) and optics to integrate the coordinated motions of basic microactuators with optical components such as mirrors and diffraction gratings. The advantages of building an optical system in the manner of an integrated circuit is that such micro-fabricated MOMS: (i) will not need component alignment; (ii) can be mass produced (i.e., prices on the order of dollars per unit device); (iii) will have high packing density; (iv) can be directly integrated with electronics to produce sophisticated devices; and (v) should be low-power, small, and light weight.

We have identified a set of basic micro-opto-mechanical; components which is compatible with MEMS processing. These components include moveable optical waveguides, graded index lenses, moveable reflectors, beam splitters, and passive and active diffraction gratings and are shown in Figure 1. Specific examples of each type of device will be discussed.

Some of the components shown in Figure 1 such as waveguides and graded index lenses are not unique to MEMS, but when used with other basic micro-opto-mechanical components, can be used to create micro-opto-mechanical systems. A good example of this can be seen with optical waveguides. By themselves, waveguides are a well developed technology; however, when combined with a translational reflector or a deformable beam, can be used to form an optical modulator. The issue is to fabricate the waveguides by a process with is compatible with MEMS processing rather than by high temperature flame hydrolysis. As a consequence, silicon waveguides are of great interest for MOMS applications [1]. Graded index lenses can be used to couple sources such as laser diodes into waveguides or other optical components [2,3]. Cantilever reflectors such as shown in Figure 1(iii) are perhaps among the best known success of MOMS devices. These devices, primarily developed by Texas Instruments, can be formed into large arrays suitable for large screen displays [4]. Anisotropic etching of (110) silicon can be used to produce highly planar optical surfaces for reflectors and beam splitters [5,6]. Nickel plating was used to produce a polygon reflector on an electrostatic micromotor for potential polygon scanner applications [7]. We are not aware of a laterally translated reflector; however, optical etalons have been produced by many researchers for optical modulator applications [8]. The same principle applies to optical lenses for dynamic focusing. Again we are not aware of an actual device that has been fabricated. The integration of optical waveguides with micromechanics is a very important potential application of MOMS. For example, Bezzaoui and Voges describe the fabrication of silicon oxinitride (SiON) optical strip waveguides on microbridges, cantilevers and resonators [9]. Such micromechanically deflected waveguides could be used to form optical switches and modulators. One of the most important applications of MEMS processing techniques to optics is the production of reflective (or transmissive) diffraction gratings. Diffraction gratings with rectangular or sinusoidal profiles can be produced by chemical etching [10]. However, the most important applications of diffraction gratings are achieved by combining a diffraction grating with micromechanical elements. Smith et al describe a diffraction grating on an

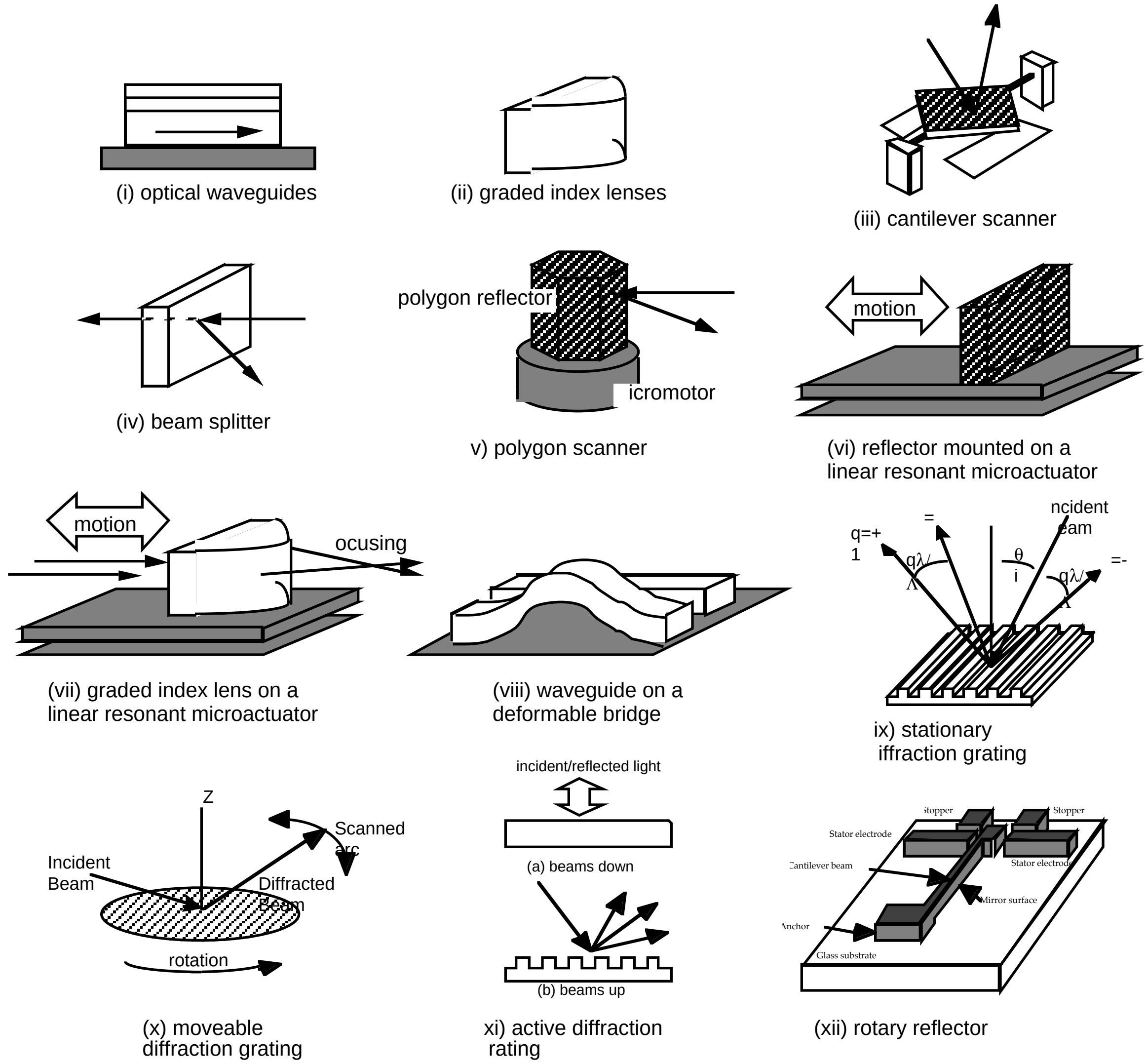


Figure 1 - A set of basic MOM devices.

electrostatic micromotor for scanning and optical switching applications [11]. One of the most important commercial application of micromechanics to optics is the diffraction grating light valve. In this device the diffraction grating is composed of a number of very thin, parallel beams. In the rest position, the elements form a planar optical reflector. The beams can be capacitively deflected to form a diffraction grating. Bloom has demonstrated array versions of this basic device which have the potential to rival the Texas Instruments deformable mirror for bright, high-resolution display systems.

The goal of MOMS is to create complete optical systems on a single integrated circuit. Such devices have been called Application Specific Integrated Micro-instruments (ASIM's). A good example of this potential is the optical spectrometer on a chip produced by Kwa and Wolffenbuttel [14].

**Diffraction Grating Microscanners**

An optical microscanner which consists of a diffraction gratings on the rotor of an electrostatic polysilicon micromotor is shown in Figure 2. The diffraction gratings are produced by chemical etching, then chemical-mechanically polished (CMP) to reduce the average surface roughness, improving the optical efficiency of the gratings.

The process outlined in Figure 3 was used to produce diffraction grating microscanners. These devices require thick (e.g., 5.5 µm) polysilicon rotors to provide sufficient mechanical stiffness

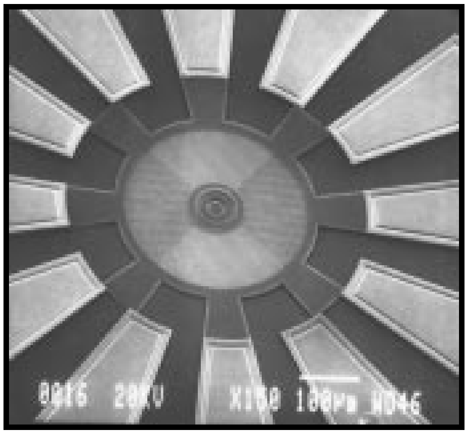

Figure 2. SEM photo of a rotating diffraction grating microscanner. The motor is a 500-µm diameter salient-pole side-drive micromotor with polished rotor/stator polysilicon and pyramidal grating element of 1.8 µm period.

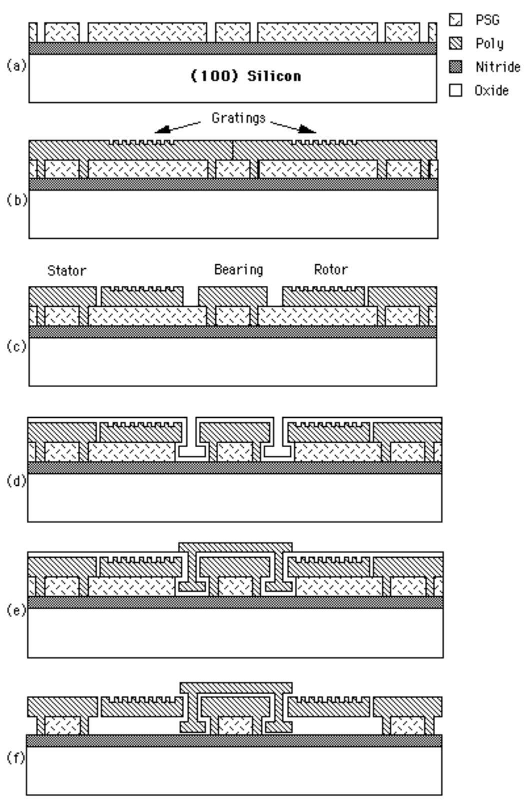


Figure 3: Microscanner fabrication process: (a) anchor definition and patterning; (b) grating definition and patterning; (c) rotor/stator definition and patterning; (d) bearing clearance oxidation; (e) bearing definition and patterning; and (f) released device.

and to prevent out-of-plane warping of large area rotors.

### Laser Diode Tuner

A silicon micromachined micromirror similar to Figure 1(xii) and a laser diode have been successfully integrated. The micromirror beam forms an external cavity resonator for the laser diode and was fabricated by anisotropic etching of (110) silicon in conjunction with silicon-to-glass bonding. The electrodes located on either side of the beam provide the electrostatic force that deflects the beam; the (111) sidewall of the cantilever beam functions as the external mirror of an optical cavity. Mechanical limit the lateral deflection of the beam, preventing electrical shorting to the electrodes. Figure 4 is an SEM image of the final device. The beam is about 1.7 mm long, 8 µm wide, and 130 µm high. The external cavity length, (the gap between the beam sidewall and the laser diode facet) is about 10 µm. The laser diode is a gain guide type with planar stripe; the active layer is an AlGaAs multiquantum well structure. The cavity length of the laser diode is about 340 µm.


Figure 4. SEM image of the integrated laser diode and micromirror.

The fabrication process for the laser diode tuner is shown in Fig. 5. Shallow etching is performed, thereby separating the moving parts from the glass substrate in the final device. LPCVD silicon nitride is then deposited and patterned, defining the high-aspect-ratio features to be etched. KOH anisotropic etching is performed to the desired depth. The (110) silicon wafer is then electrostatically bonded to a Pyrex glass substrate. The silicon wafer is polished from the back side until the structures are free to move. Finally the laser diode chip is bonded onto the substrate.

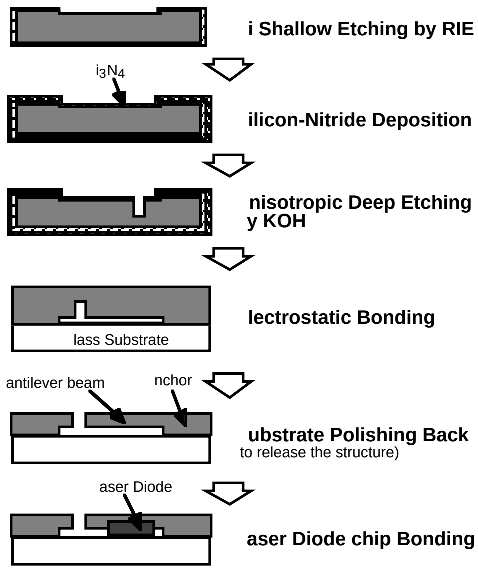


Figure 4. The fabrication process for the integrated laser diode and micromirror.

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