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Optical MEMS

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Abstract

Micro electromechanical system (MEMS) technology have led to the development of optical devices with a large number of application areas. The reason is the unique MEMS characteristics that are its fabrication, system integration, and operation of micro-optical systems. The precision mechanics of MEMS micro-fabrication techniques, and optical functionality all make possible a wide variety of movable and tunable mirrors, lenses, filters, and other optical structures. The large number of electromagnetic modes that can be accommodated by beam-steering micro-mirrors and diffractive optical MEMS, combined with the precision of these types of elements, is utilized in fiber-optical switches and filters, including dispersion compensators. The potential to integrate optics with electronics and mechanics is a great advantage in biomedical instrumentation. Micro-optical systems also benefit from the addition of nanostructures to the MEMS toolbox. Photonic crystals and micro-cavities, which represent the ultimate in miniaturized optical components, enable further scaling of optical MEMS.
Keywords- Micro-Optics, Tunable Optics, Micro-Mirrors, Photonic Crystals, Micro-Cavities

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I. INTRODUCTION

Optics and photonics have benefited greatly from miniaturization through Micro Electro Mechanical Systems (MEMS). Optical MEMS enables the application of silicon fabrication technology to micro-optical systems. This paper provide research in tunable elements, telecommunications biology and biomedicine sensors, and nanostructures.

II. MEMS AND OPTICS: A CONCISE HISTORY

Much of the early work on optical applications of Micro Electro Mechanical systems (MEMS) was inspired by sensora and actuators developed in suspended thin films. Optical application of this technology in the form of projection displays based on micro machined two-dimensional spatial-light modulators emerged in the early 1970s [1]. These early devices and systems led to the development of the Digital-Mirror-Device (DMD) [2], [3] by Texas Instruments.

III. MEMS TUNABLE OPTICAL ELEMENTS

A. MEMS and Micro-Optics

The early work on MEMS-actuated optics, combined with the long traditions and capabilities of classical optics, has led to the development of a very rich discipline of tunable micro-optics. We discuss a few examples of these MEMS tunable optical elements in this section.

1) Tuning Micro-Optics

A "tunable" optical component is one in which the optical characteristics may be controllably changed; the parameters to be tuned may include focal length, magnification, beam direction, spectral composition, or a host of other factors. In macroscopic optics, this tuning typically requires mechanical motion of one or more elements with respect to others, but in micro-optics entirely new means of optical tuning is possible.

2) The Role of MEMS

The first role is MEMS fabrication technology itself. The swcond role of MEMS in tunable optics is the generation of means to actuate tunable components.

B. Tunable Micro-mirrors

Actuated micro-mirrors are the oldest micro optical devices fabricated using MEMS techniques. They may be considered the "original" tunable micro-optical element.

1) Electrostatic Actuation

As MEMS technology has advanced, the spectrum of mirror concepts has broadened. Whereas the optics of mirror has relatively simple, one area on which considerable research effort has been expended is actuation for achieving angular and translational movement.

2) Magnetic Actuation

Magnetic actuation using silicon and magnetic polymers has led to angular deflections at resonance of $\pm 10°$ for fields of only 0.07mT . magnetically actuated mirrors do not require the high voltages of most electrostatic concepts, and it only require low magnetic fields that can be generated using integrated or ultra-miniaturized coils.

3) Thermal Actuation

Thermal actuators are used in vertically actuated mirrors for adaptive optics with 6 μm stroke.

4) Pneumatic Actuation

Pneumatically actuated optical copnents are used for techniques of microfluidics. Mirror tilt angles of up to 75 μm and purely vertical motion of 80 μm have been demonstrated using on-chip integrated heaters for thermo-pneumatically actuated devices.

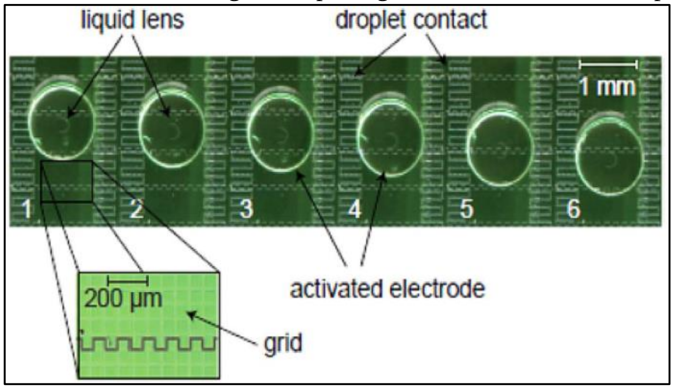

Fig. 1: An electrowetting-actuated repositionable liquid micro lens moving in the vertical direction; when in position, its focal length can subsequently be tuned

C. Tunable Fluidic Optics

Fluidics has become increasingly important for advanced micro-optics. The combination of MEMS fabrication techniques, controlled-liquid configurations and optics has led to the concept of optofluidics, a broad spectrum of technologies, in which fluids and photons play a dominant role in micro-optofluidic systems.

Optofluidics has attracted considerable attention due to its utility in realizing new types of displays but has also seen interesting applications in tunable lateral lensing structures, tunable photonic crystals, and fluidic lasers.

1) Liquid Lenses

Liquid droplets on a surface make excellent spherical lenses. The curvature and focal length of these lenses can be controlled using electrowetting, an electrically induced change in the liquid contact angle.

Also possible with electrowetting actuation atunable lenses with reconfigurable position. As is seen in the example of Figure 5, a liquid microlens is accurately positioned on a structured substrate; once in the correct position its focal length may then also be tuned. In the structures shown, a positioning accuracy of 70μm and a focal length tuning range of 580 μm to 1,240μm was demonstrated.

2) Pneumatic Membrane Lenses

This is an alternative to purely liquid lenses, in which surface tension defines the curvature. Pneumatic tuning allows the generation of convex, planar and concave profiles in the same lens, and yields a large tuning range. These structures combine classical Micromachining with silicone, rather than silicone materials.

3) Fluidic Apertures

These devices employ opaque and transparent liquids, which are switched using electrowetting and other microfluidic techniques. The optofluidic shutter of Figure 2 uses a highly absorbing ink, which is alternately switched into and out of the circular aperture. This completely integrated device, demonstrate switchable attenuation of 47 dB with switching times below 100 ms; the only moving parts were the two liquids, one absorbing and the other transparent.

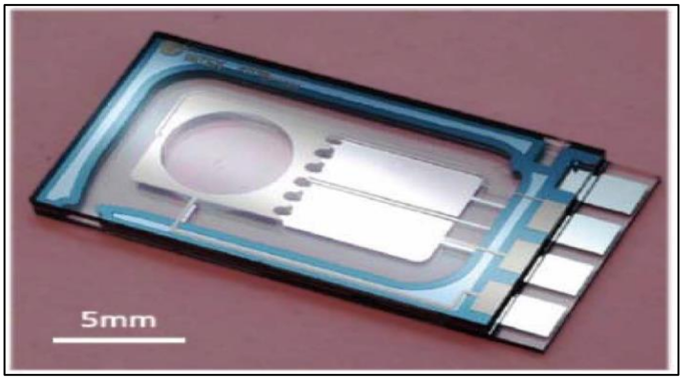

Fig. 2: An optofluidic shutter after chip dicing and prior to liquid filling; an opaque liquid is pumped into and out of the circular aperture using electrowetting

The attenuation concept can be refine further through the realization of a tunable iris, shown in Figure 3, which allows variable attenuation of an optical beam, again using only moving opaque and transparent liquids.

D. Tunable Systems

A further advantage is that microsystems fabrication processes may also be applied to construct tunable systems of considerable mechanical and optical complexity. Such systems may consists of large scale two dimensional arrays of tunable lenses, each independently actuated, where micro fabrication techniques assure good uniformity, high fill factors, and compact dimensions not achievable with classical optics manufacturing approaches.

IV. TELECOMMUNICATIONS

Optical MEMS has made a huge impact in the field of Optical Networking in the last 15-20 years, particularly in Telecommunication networks. With the increasing demand for more internet data and higher access speeds, Optical Networks play a crucial role in the backbone of the Global Communications Infrastructure. Optical Network providers find themselves constantly in need of cutting-edge technology and innovation that can grow bandwidth at lower cost.

Optical MEMS is a key part of this technology, which allows more dynamic functionality in the physical optical layer and enables a new class of Dynamic Components. Dynamic Components constitute a new breed of device that complements traditional active components (lasers, detectors, modulators) and passive components (multiplexers, isolators, circulators, couplers). First-generation dynamic components have historically included motor-controllable variable optical attenuators (VOAs) and bulk mechanical.

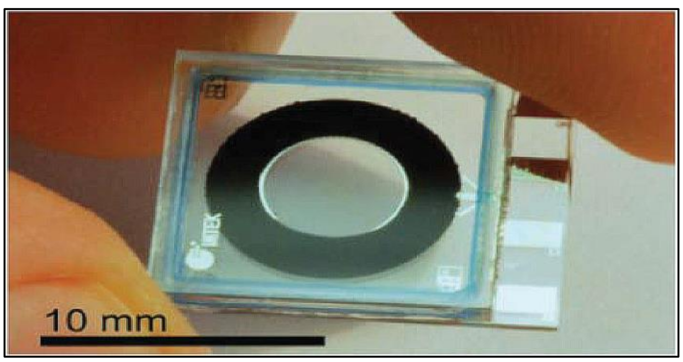

Fig. 3: A fully integrated prototype optofluidic micro-iris in its fully open setting; when actuated, the black opaque liquid moves inward in four discrete steps [5, Fig. 8].

Switches: These early dynamic components did not meet the requirements for integration and compactness. However, dynamic components using Optical MEMS now include optical cross connects, wavelength selective switches, space switches, VOAs, gain equalizers, channel equalizers, tunable filters and lasers, dynamic dispersion control, and programmable optical add/drop multiplexers.

V. BIOLOGY AND BIOMEDICINE

The initiation of optical MEMS for biomedical applications was accomplished by Dickensheets and Kino. In this work, they demonstrated a miniature scanning confocal microscope that utilizes an off-axis grating as the focusing objective lens and micro machined torsional scanning mirrors to realize real-time confocal imaging with a working distance of 1 mm and an effective N.A. of 0.24.

As shown in Figure 4, Kwon et established an isolation method for SOI MEMS technologies and demonstrated vertical comb-drive-based two-dimensional gimballed MEMS scanners with large static rotation. These two-axis optical MEMS mirrors are useful in biomedical imaging, raster scanning and image projection. This method of backside island isolation provides electrical isolation as well as mechanical coupling of SOI structures without additional dielectric backfill and planarization. It allows a gimbal structure with electrical isolation, enabling two-axis rotation of MEMS scanners for biomedical imaging applications.

These optical MEMS components enable biomedical applications such as optogenetic sansnon in vasiveendoscopic screening for disease, etc

VI. SENSORS

Optics provide new functionality to MEMS sensors, and MEMS technology enables scalimng of optical sensors. The results are sensors that combine the precision, low noise and electromagnetic interference (EMI) immunity of optical measurements with the compactness and flexibility of MEMS to enable a wide range of sensor applications.

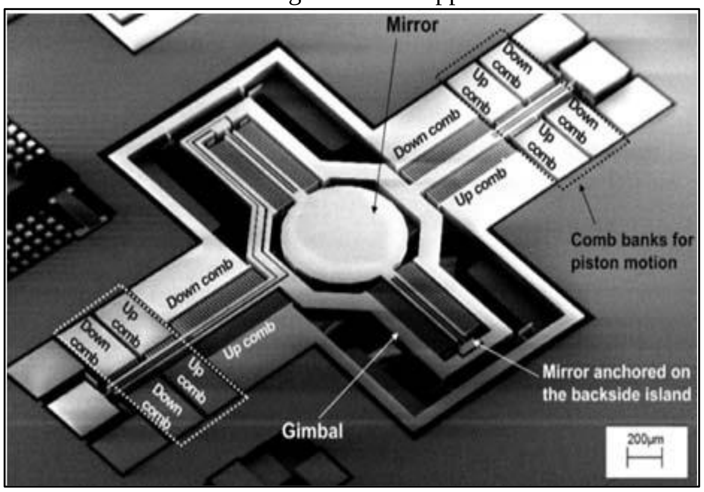

Fig. 4: SEM of 2D MEMS scanner for biomedical imaging applications

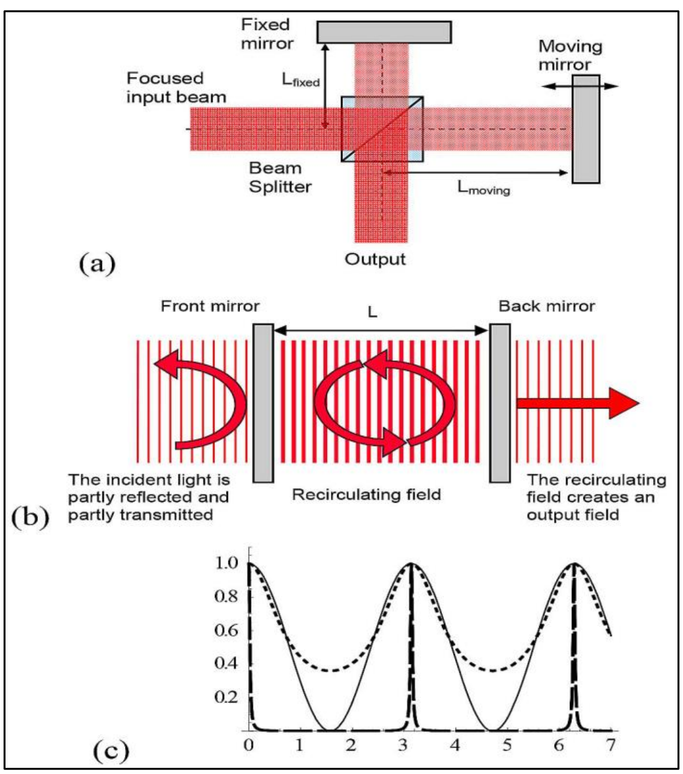

Fig. 5: (a) Michelson interferometer, (b) Fabry-Perot interferometer, (c) Transmission as a function of mirror separation in two beam and recirculating interferometers

Most optical MEMS sensors are based on some type of optical interferometer. Interferometers can be classified in to two groups: multiple-beam interferometers with finite time response and recirculating interferometers with infinite time response.

VII. CONCLUSION

Micromachining allows the tools of the integrated circuit industry, lithography and parallel processing to be applied to optical devices and systems. The payoff is integration of mechanics, fluidics, magnetics and optics into highly functional microsystems with numerous advantages in terms of functionality, flexibility, stability, sensitivity, size and, ultimately, cost. The application areas for these types of Optical MEMS include tunable optics, spatial light modulators, fiber optical communication devices and systems, optofluidic systems for biological and chemical analysis, and interferometric sensors. The augmentation of Optical MEMS by nanostructures has led to the development of Optical Nanosystems based on photonic crystals and ultra-compact optical resonators that are applicable to a wide range of systems across all the sub disciplines of optics.

ACKNOWLEDGMENTS

The field of optical MEMS has seen tremendous developments over the last two decades, and it is not possible to include all relevant references to all the subjects that are discussed. To give a coherent coverage to such a broad field, the authors have discussed and referenced work they are most familiar with in greater detail. The author acknowledge and apologize for the many omissions that necessarily have resulted.

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