12th Optoelectronics and Communications Conference/16th International Conference on Integrated Optics and Optical Fiber Communication (OECC/IOOC2007)
Technical Digest, July 2007, Pacifico Yokohama

13E2-1 (Invited)

MEMS Devices and Technologies for Photonic Network

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Abstract

We present recent research activities on microelectromechanical systems (MEMS) and devices in the field of fiber optic applications such as variable attenuators, tunable wavelength filters, and modulators integrated with silicon light wave circuits.

Introduction

Microelectromechanical solutions have found a wide range of application in the field of micro-optics thanks to the larger optical effect generated by the mechanical motions than most solid-state solution could provide. For instance, angle change of mirror can make a large offset of reflected light, which could be used in optical crossconnects and variable attenuators. Micromechanical motion in the wavelength scale can also be used for wavelength filtering when it is combined with tunable interferometers. Figure 1 illustrates typical optomechanical modulations that could be combined with MEMS, which implies a plenty of potential of MEMS approach in micro optics and photonics. Amongst the recent research activities in this field, we give three points of view: (1) MEMS approach towards small components rather than large systems, (2) hybrid assembly technique for better optomechanical performance, and (3) a challenge towards the silicon photonics.

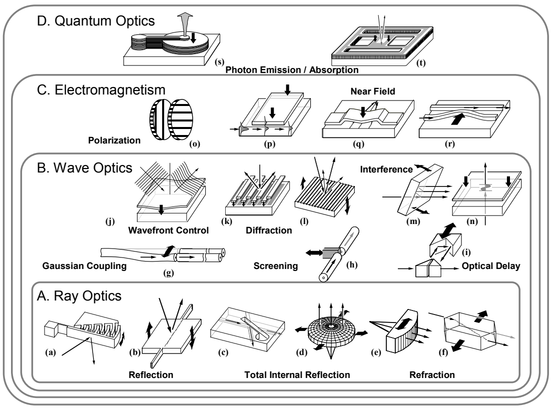
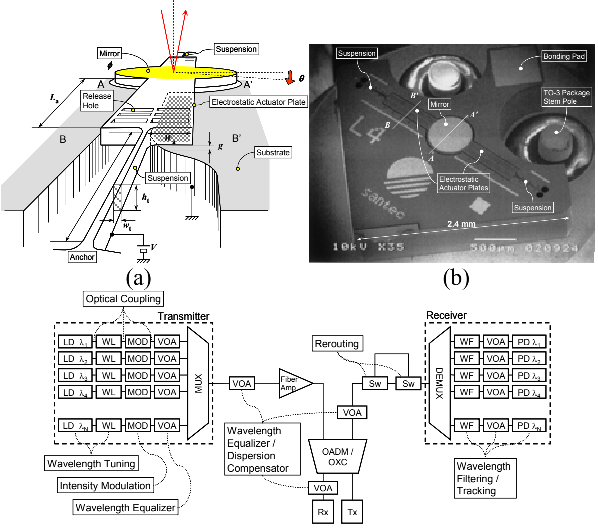


Figure 1 MEMS versions of optical modulation

Towards Small Components

Large scale optical crossconnect was the main target of the optical MEMS devices in late 1990s but it has been shifted towards smaller components for their large number of sales shipping. For instance, we have developed a VOA using an electrostatically controllable tilt mirror [1], as shown in Figure 2 (a) and (b). Starting material was a bonded silicon wafer (SOI, silicon on insulator) processed by high aspect-ratio silicon dry etching. A micro mirror of 0.6 mm in diameter and 0.03 mm in thickness was electrostatically controlled with dc voltages of lower than 5 V. Reliability has been the most critical pass of MEMS devices for commercialization; the VOA has cleared its low-voltage operation (5 V for 50 dB attenuation or higher), electrostatic drift issue, temperature dependent fluctuation, and mechanical shock tolerance [2]. Compared to large scale optical crossconnects used in the trunk line of optical fibers, small components such as VOA are used in quantity everywhere in the fiber systems.



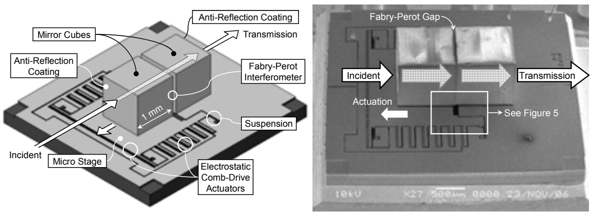
(a) (b)

(c)

Figure 2 Bulk-micromachined electrostatic mirror for fiber optic variable attenuator: (a) Electrostatic mechanism, (b) SEM image of the device on a stem, and (c) VOAs used in optical fiber systems [1, 2].

Hybrid Assembly with MEMS

MEMS is an enabling technology for integrating an optical component with its motion control actuators by batch processing. However, optical components in MEMS devices sometimes suffer from poor optical performance such as temperature-sensitive mirror flatness and process-dependent surface smoothness, when compared with mirrors and lenses of macro scale. To overcome this problem, we have developed an optical platform for mounting an optical component (glass cube of high-reflection and anti-reflection coating) to compose a wavelength-tunable Fabry-Perot interferometer [3], as shown in Figure 3. Bonding of mirror cubes is currently done manually under microscope observation, but it could be replaced with automatic assembly using die bonders. Special care was paid for the blue material to fix the micro optics on the silicon platform. DC voltage around 70 V was used to control the gap between the mirror cubes and to tune the peak wavelength of transmission in a range from 1479 nm to 1579 nm with bandwidth of 2.6 nm to 2.9 nm, as shown in Figure 3.



(a) (b)

Figure 3 Fabry-Perot interferometer with a pair of HR-mirror cubes mounted on a bulk micromachined translation stage for wavelength filter application [3].

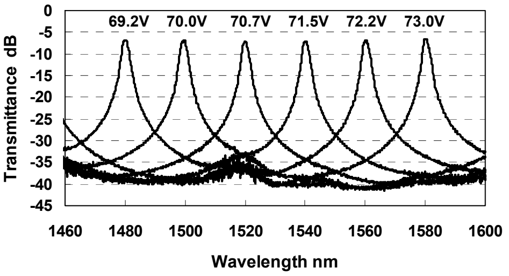
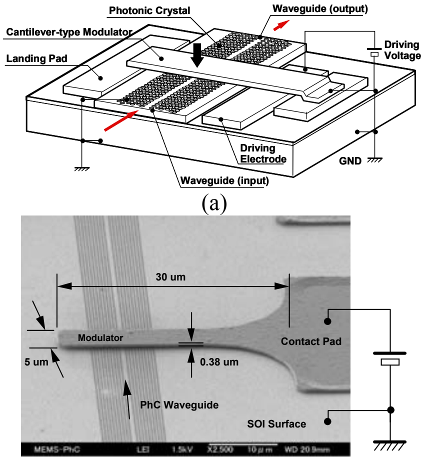


Figure 3 Demonstration of wavelength tunable filter controlled by the electrostatic actuation mechanism [3].

Integration with Silicon Photonics

Lightwave traveling in a high-refractive index material (silicon) can be modulated by mechanically inducing disturbance in the evanescent field of the waveguide. For instance, micro disk resonators combined with micromechanical motion have been reported by Lee et al. for integrated wavelength-selective switch application. In our group, we have developed a process for making a silicon surface micromachined structure on a silicon photonic waveguide such as photonic crystal (PhC) waveguide and silicon nanowire waveguide. Figure 4 shows the schematic illustration and an SEM image of the optical modulator made of polysilicon (0.38 micron thick) deposited on a pre-fabricated photonic PhC waveguide. Electrostatic force of applied voltage brought the cantilever in the close vicinity (100 nm or less) over the PhC waveguide to induce modulation in both intensity and phase. Thanks to the high refractive index of silicon, the effective length of modulator was only 5 microns long. Further reduction of device size is under development by using a single layer of silicon rather than using additional deposited layer of polysilicon.



(a)

(b)

Figure 4 Surface micromachined polysilicon structure for optical modulator integrated with silicon PhC waveguide [5].

Conclusions

There still remain various types of optical MEMS principles unexplored, and their effects become more significant when device is made to be as small as the waveguide of interest, which is now possible by the fast-evolving micro and nano fabrication technologies.

Acknowledgements

The author would like to thank the co-workers in his research group. The MEMS VOA is by the joint work with Keiji Isamoto et al with Santec Co. The tunable Fabry-Perot filter was developed by Toshiro Yamanoi et al with Koshin-Kogaku Co. The MEMS PhC modulate was co-developed with Prof. Satoshi Iwamoto and Prof. Yasuhiko Arakawa with RCAST, the Univ. of Tokyo, and also by Dr. Akio Higo.

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