Turning an SOI into MEMS Devices for Optics and RF

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Silicon has been known as an excellent material for MEMS (microelectromechanical systems) [1] and various applications including sensors and actuators have been developed since the early stage of MEMS. The use of silicon in this field has escalated particularly due to the combination of DRIE (deep reactive ion etching) and BESOI (bonded-and-etched-back silicon-on-insulator). The top active layer of SOI lying on an electrical insulator provides us with the readiness to a use of electrical actuator once it has been DRIE-patterned and released after the sacrificial etching of the BOX (buried oxide). Despite the simplicity of the layer structure of SOI, electromechanical structures of various topologies can be designed as illustrated in **Figure 1**; mechanical suspensions and electrodes for electrostatic actuation can be assigned to either the SOI active layer or the handle layer. Those parts can be either electrically isolated or connected by the via-connection through the BOX [2]. In this talk, we pick up bulk micromachined SOI MEMS actuators designed for optical and RF (radio frequency) applications from our R&D activity in the last ten years.

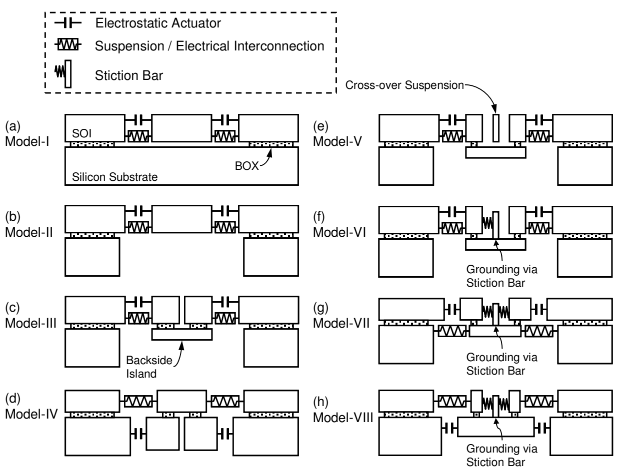


Figure 1 SOI MEMS structures of various topologies

Thanks to the CMP (chemical mechanical polished) – finished surface, the active layer of SOI can be used as a mirror for optical application when coated with Cr/Au layers. **Figure 2** shows the SEM (scanning electron microscope) image of a MEMS VOA (variable optical attenuator) [3]. The SOI layer has been shaped into a torsion mirror structure that could be tilted by the electrostatic attractive torque between the actuator plates (with etch-release slots) and the substrate. The mirror is used as an intensity tuner for the infrared light traveling in the optical fiber network.

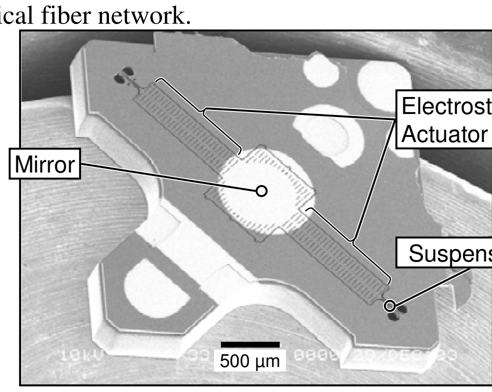


Figure 2 Electrostatic MEMS mirror for fiber optic tuner.

Highly resistive silicon can also be used as a mechanical body of small dielectric loss for passive microwave devices operating at frequencies over 10 GHz. **Figure 3** shows a MEMS phase shifter that could tune the phase by electromechanically switching the suspended coplanar waveguides to either the longer or shorter delay lines. The electrostatic actuation mechanisms are integrated in the other side of the SOI substrate. The phase shifters of different shift values can also be cascaded to develop a multi-bit monolithic phase shifter [4].

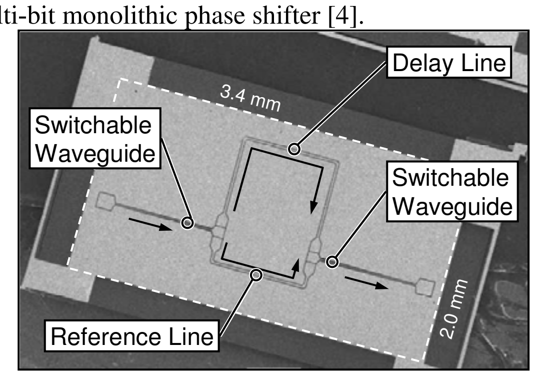


Figure 3 Integrated switchable phase-shifter.

Even more complex structure can be produced by the SOI bulk micromachining. **Figure 4** shows an XYZ-stage with the electrostatic comb drive actuators [2]. A triple-gimbal structure is used to integrate the most outer vertical comb drive mechanism for the Z-motion of the inner XY-stage of double-gimbal structure with lateral comb drives. For such a complex structure, the electrical interconnection conflicts with the design of mechanical suspensions due to the limited number of layers. We used a slender bar of SOI that was brought into surface stiction contact to the substrate to make a jump-wire interconnection, by which the design conflict was avoided.

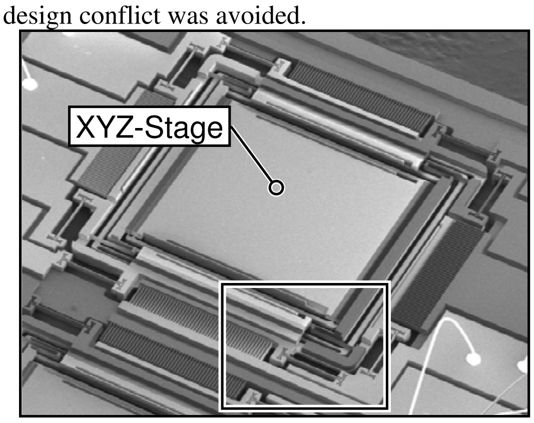


Figure 4 Micro XYZ-stage by SOI bulk micromachining

The presentation will include the design and fabrication techniques of the SOI bulk micromachined MEMS devices as well as its applications in the optical and RF fields.

[1] K. E. Petersen, "Silicon as a mechanical material," Proc. IEEE, 70 (5) 1982, p. 420.
[2] K. Takahashi, Makoto et al., "Switched-Layer Design for SOI Bulk Micromachined XYZ Stage Using Stiction Bar for Interlayer Electrical Connection," *IEEE J. Microelectromech. Syst.*, 18 (4) 2009, p. 818.
[3] K. Isamoto et al., "A 5-volt operated MEMS variable optical attenuator by SOI bulk micromachining," *IEEE J. Selected Topics in Quantum Elec.*, 10 (3) 2004, p. 570.
[4] D. Yamane, et al., "A Ku-band Dual-SPDT RF-MEMS Switch by Double-side SOI Bulk-micromachining," *IEEE J. Microelectromech. Syst.*, 20 (5) 2011, p. 1211.