Two-Axis Scanning Mirror for Free-Space Optical Communication between UAVs

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Abstract: We have developed a SOI/SOI wafer bonding process to design and fabricate two-axis scanning mirrors with excellent performance. These mirrors are used to steer laser beams in free-space optical communication between UAVs.

Scanning mirrors have been proposed to steer laser beams in free-space optical links between unmanned aerial vehicles [1]. Free-space optical communication offers the advantages of secure links, high transmission rates, low power consumption, small size and simultaneous multi-nodes communication capability. The key enabling device is a two-axis scanning micromirror with millimeter mirror diameter, large DC scan angle (±10° optical), fast switching ability (transition time between positions < 100 μs) and strong shock resistance (hundreds of Gs).

While surface micromachining generally does not offer simultaneously large scan angles and large mirror sizes, MEMS micromirrors based on SOI and DRIE technology provide attractive features, such as excellent mirror flatness and high-aspect-ratio springs, which yield small cross-mode coupling. There have been many efforts to make scanning micromirrors which employ vertical comb drive actuators fabricated on SOI wafers [2-5]. Although vertical comb drive actuators provide high force density, they have difficulty in producing two-axis scanning micromirror with comparable scanning performance on both axes. One way to realize two-axis micromirrors is to utilize the mechanical rotation transformers [6]. Our group introduced the method of utilizing lateral comb drives to create torsional movement of scanning mirrors [7]. As shown in Figure 1, the bi-directional force generated by the lateral comb drive actuator is transformed into an off-axis torque about the torsional springs by the pushing/pulling arms. One benefit of this concept is the separation of the mirror and the actuator that provides more flexibility to the design. A large actuator can be designed without contributing much moment of inertia due to this transforming linkage and therefore the device can have higher resonant frequency, compared to a mirror actuated by the vertical comb drive. This design offers more shock resistance, too. The perpendicular movement of the device is resisted by both the mirror torsional beam and the actuator suspension beam versus the single torsional beam suspension in the case of vertical comb drive.

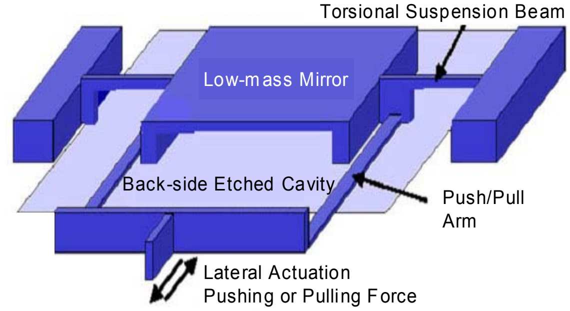

Fig. 1: Torsional movement of the micromirror is realized by the off-axis lateral force generated from comb drive actuators.

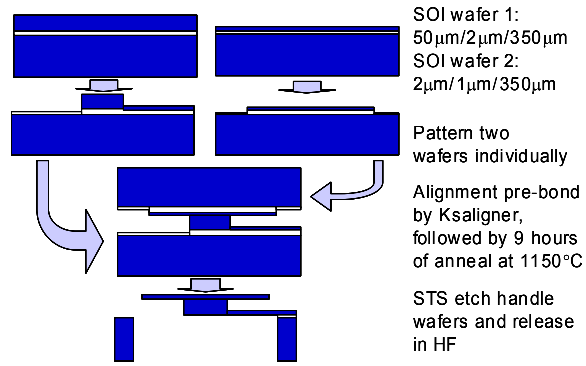

Fig. 2: Process flow of SOI/SOI wafer bonding process

This multilevel design was formerly fabricated using a timed DRIE etch on SOI wafer. However, this timed etch is not uniform across the wafer and needs careful monitoring during etching. Here we propose a new approach, based on a SOI/SOI wafer bonding process, to build these multilevel structures. Besides greater control over the thickness of the critical layer and higher process yield, improvements over the previous method include higher angular displacement at lower actuation voltages and achievement of an operational two-axis scanning mirror. Here we present our preliminary results of the SOI/SOI bonding process.

Figure 2 shows the schematic process flow. It starts with two SOI wafers, one with device layer thickness of 50 μm and the other one of 2 μm. First we pattern the two wafers individually by DRIE etching. In order to achieve the desired 3-level structures, we use a timed etch to obtain a layer which contains non-thickness-critical structures, such as the pushing/pulling arms. A layer of thermal oxide is retained on the backside of the SOI wafer in order to reduce the bow/warpage. After the oxide strip in HF, both SOI wafers are cleaned in

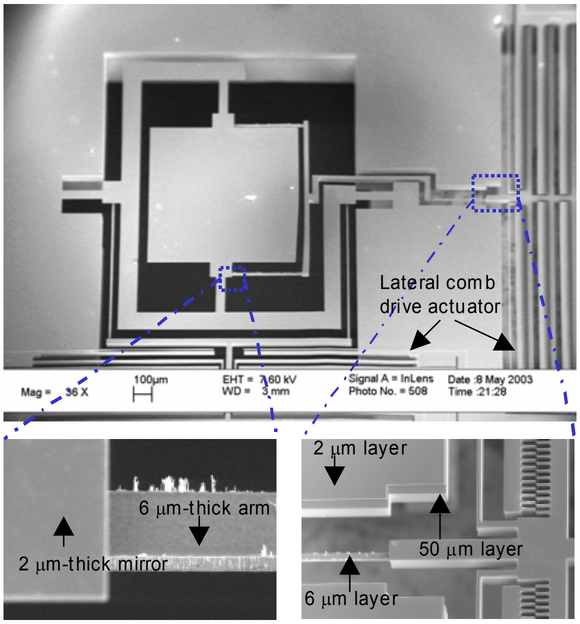

Fig. 3: Two-axis scanner by SOI/SOI bonding process.

Piranha, modified RCA1, RCA2 with a de-ionized water rinse in between. Then two patterned SOI wafers are aligned and pre-bonded at room temperature, after which they are annealed at 1150°C. An inspection under the infrared illumination shows a fully bonded wafer pair. Finally, handle wafers are DRIE etched and the device is released in HF.

A fabricated two-axis scanning mirror is shown in Figure 3. The 2 μm-thick mirror is suspended by two inner torsion beams and therefore rests over a rigid surrounding frame which is supported by two outer torsion beams.

Figure 4(a) shows the angle displacement of a one-axis scanning mirror under DC actuation. A scan angle of 11° is achieved at 55 V, compared with the previous result of 6° at 56 V [7]. The comb drive actuator pulls in afterwards, due to the limited travel distance of comb fingers. A much larger DC actuation range can be achieved simply by increasing the length of comb fingers. Figure 4(b) shows that this device has a resonant frequency of 3.9 kHz. The second mode at 7.2 kHz is due to the vertical bounce mode of the torsional beam. Experimental and ANSYS simulation results agree within 10%. Figure 5 shows a laser beam reflected by a two-axis scanner under DC and AC actuation. There is a slight cross-axis coupling between the roll and pitch axes of the micromirror due to vertical bending of the outer-axis torsion beams. It will be improved by better designs of the torsional beam.

In conclusion, one-axis and two-axis scanning micromirrors have been fabricated in an SOI/SOI wafer bonding process, which shows great promise in meeting the specifications required for secure and reliable free-space optical communication.

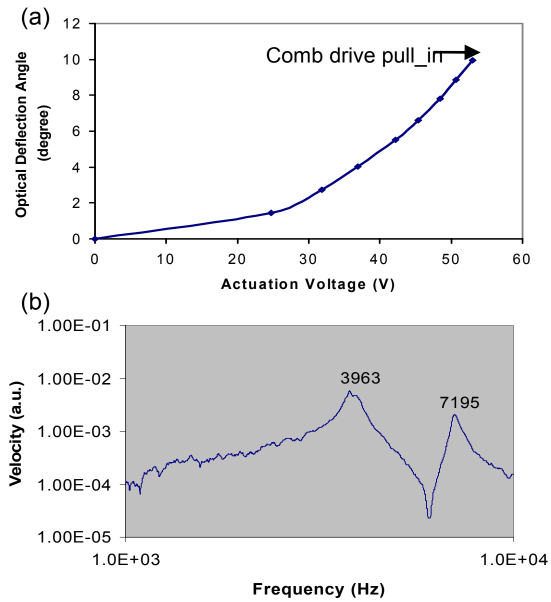

Fig. 4: (a) DC actuation of one-axis pulling scanner. (b) Frequency response of one-axis pulling scanner.

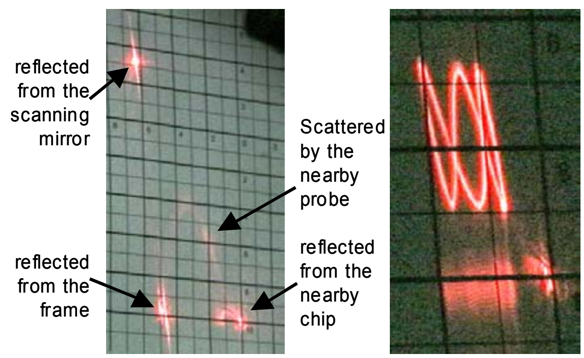

Fig. 5: DC and AC actuation of two-axis scanner (Each grid represents 1° of optical deflection).
Left: $V_{vert.} = 60.2$ V, $V_{horz.} = 79.9$ V; Right: $V_{vert.} = 45.1+10\times\sin(2\times\pi 300\times t)$, $V_{horz.} = 45.4+10\times\sin(2\times\pi 100\times t)$

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