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웨이퍼 레벨 공정이 가능한 2 축 수직 콤 구동 방식 마이크로미러

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Wafer-Level Fabrication of a Two-Axis Micromirror Driven by the Vertical Comb Drive

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Abstract

We present the design and fabrication prcoess of a two-axis tilting micromirror device driven by the electrostatic vertical comb actuator. A high aspect-ratio comb actuator is fabricated by multiple DRIE process in order to achieve large scan angle. The proposed fabrication process enables a mirror to be fabricated on the wafer-scale. By bonding a double-side polished (DSP) wafer and a silicon-on-insulator (SOI) wafer together, all actuators on the wafer are completely hidden under the reflectors. Nickel lines are embedded on a Pyrex wafer for the electrical access to numerous electrodes of mirrors. An anodic bonding step is implemented to contact electrical lines with all electrodes on the wafer at a time. The mechanical angle of a fabricated mirror has been measured to be 1.9 degree and 1.6 degree, respectively, in the two orthogonal axes under driving voltages of 100 V. Also, a 8 X 8 array of micromirrors with high fill-factor of 70 % is fabricated by the same fabrication process.

1. Introduction

Micromirror is one of the various opto-electromechanical systems (MOEMS). The ability of steering and directing the light of a micromirror enables it to be adapted to display systems and free space optical communication systems.

Generally, the performance of a micromirror is evaluated by the scanning angle, fill factor, surface flatness and roughness, resonant frequency, driving power, etc [1]. Various design and fabrication methods of a MEMS mirror have been proposed to improve above respects.

Among many actuation schemes, such as magnetic, piezoelectric, thermal, and others, electrostatic actuation mechanism is usually preferred because of its low power consumption. A traditional design is to employ parallel-plate type actuators. The structure is rather simple, however, due to the pull-in effect, the stable scanning range of a mirror inevitably reduces. Recently, many have reported micromirrors actuated by vertical combs in order to overcome the pull-in effect, utilizing both bulk and surface micromachining skills [2],[3].

Usually electrical contacts with the outer voltage source are formed on the SOI wafer, where actuators are fabricated. In this case, the fabrication of a high-fill factor large mirrorarray is perplexing. A tryout has been reported to solve the problem above by I. W. Jung *et al* [4]. They have bonded the mirror plate to the actuator by fusion bonding to show a possibility of fabricating large mirror arrays of 99 % fill-factor. Flip-chip bonding has been utilized to bond the mirror to the wiring chip, one by one. In this paper, we propose a method to fabricate a two-axis gimbaled mirror with vertical comb actuators on the wafer-level, including the final releasing step.

2. Design

2.1. Overall structure

The overall structure of a micromirror cell is depicted in the Figure 1(a). A SOI wafer was utilized to fabricate the actuator part of a mirror. The upper layer of the SOI actuator is connected forming the ground plane. Four electrodes located at the lower layer of the SOI wafer are electrically isolated from the ground plane by the buried oxide layer.

The gimbal structure is introduced in order to minimize the mechanical crosstalk between two axis. A pair of outer-springs is designed to sustain the gimbal, while an another pair of inner-springs supports the mirror post. Outer-springs are extended from a pair of electrodes, forming connections with inner-combs.

Single crystalline sillicon(SCS) mirror plates are mounted on top of actuators by fusion bonding to enhance the fill-factor. The mirror post exists to prevent the contact of the mirror plate with the ground plane during tilting motions.

Electrical lines are lifted-off on a glass substrate. Ends of all lines are linked to the bottomside of electrodes as shown in Figure 1(a). The other ends are connected to wire bonding pads.

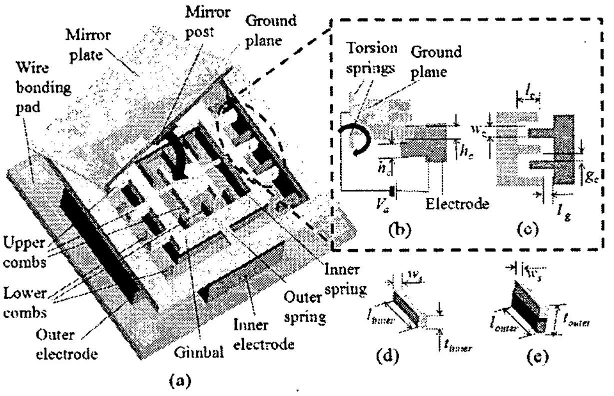


Figure 1. (a) Schematic of a micromirror cell. (b) Simple view of the vertical comb actuation. (c) Top view of vertical combs. (d) Schematic of an inner spring. (e) Schematic of an outer spring.

2.2. Simulation results

The static tilting angle of a mirror is determined when the electrical torque and the mechanical restoring torque of torsion springs are balanced.

The electrical torque is closely related to the variation of the capacitance between combs when a mirror actuates. The gap between vertical combs (g_c), gap between a comb tip and a electrode (l_g), length of combs (l_c) and number of total combs are critical terms which determine the electrical torque. On the other side, the restoring torque is proportional to the stiffness of a torsion spring. It is defined by spring dimensions, such as width (w_s), length (l_{inner}, l_{outer}), and thickness(t_{inner}, t_{outer}). The designed thickness of inner and outer springs are 7 μm and 3 μm respectively. g_c, w_c, and w_s are designed to be 3 μm.

CoventorWare simulations have been done to predict the static tilting angle of our design. More than ±6 degrees of biaxial rotational angles are achieved by the simulation. Resonant frequencies of inner and outer rotation are simulated also. They are 11.8 kHz and 9.8 kHz respectively, according to the simulation.

3. Fabrication process

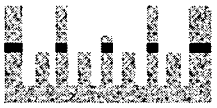
The detailed fabrication process of the device is shown in the Figure 3 below. Total ten masks are needed to fabricate the proposed vertical comb micromirror.

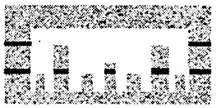

(a) Three etch mask patterning

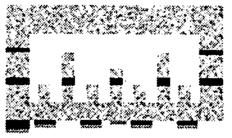

(b) 1st DRIE

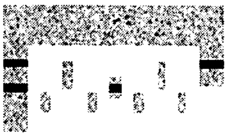

(c) PR ashing and 2nd DRIE

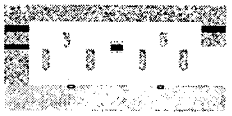

(d) Partial oxide etching

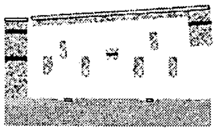

(f) 3rd DRIE


(g) Fusion bonding & chemical-mechanical polishing(CMP)


(f) Three mask patterning


(g) 4th ~ 6th DRIE


(h) Anodic bonding & CMP


(i) Al patterning & releasing

■ Oxide ▨ Glass
▨ Silicon ☐ Nickel
▨ PR ☐ Aluminum

Figure 3. Fabrication process.

Firstly, two TEOS masks are patterned on the device layer of a SOI wafer. After forming additional 2.4 μm thick photoresist(PR) patterns, we define the comb width, and the gap between combs by etching two TEOS masks(Figure 3(a)). Oxide etching was done by reactive ion etching(RIE) process. Three DRIE steps are followed, then. After every single DRIE step, we remove etch masks one by one, to newly define the surface to be etched(Figure 3(b)~(f)). The plasma ashing is required to remove PR mask. The device layer of half of combs are completely etched after multiple DRIE steps. The height of upper and lower combs are determined by this step. TEOS mask deposited at the beginning, is completely removed by 6 : 1 buffered oxide etchant.

A DSP wafer, which is thermally oxidized to 1 μm, is patterned by the PR. Thermal oxide layer is selectively etched, and a DRIE step is followed. This step defines the height of the mirror post taller than 20 μm.

Nextly, a RCA cleaning step is introduced to remove particles on two wafers. Patterned surfaces are bonded together by the fusion bonding technique. Then, the device layer of the SOI wafer is chemically-mechanically polished(CMP)(Figure 3(f)). The SOI handling layer fabrication steps are analogous to those of the device layer. On the polished surface, two layers of TEOS masks and a photoresist mask are patterned. Three DRIE steps are followed again to complete characterizing critical dimensions of the actuator including the thickness of springs and combs(Figure 3(g)). A cavity is created by the third backside etching step, so that the large movement of the mirror is possible. The height of the cavity needs to be at least over 20 μm. Remaining TEOS mask is removed by BOE solution.

Fabricating a glass substrate with embedded electrical lines starts from depositing 300 nm of amorphous silicon on a Pyrex glass wafer by LPCVD. After amorphous layer is patterned by DRIE process, the glass surface of the wafer is exposed. The wafer is soaked into the HF solution for 10 seconds. Inside the engraved grooves, 100 nm thick nickel electrical lines are patterned by a lift-off process. A thermal evaporation process is necessary to deposit the nickel layer. Only tips of lines are protruded out of grooves after the fabrication to be sat on one of the silicon electrodes. This becomes a merit when mirrors are designed to be a form of array. Complicated electrical lines, linked to individual electrodes can be reached to corresponding contact pads without making any undesirable connection with other electrodes. It is possible to apply voltages to numerous mirrors without the significant loss of the fill-factor.

After finishing anodic bonding to integrate the fabricated glass substrate into the SOI actuators. the CMP process on the top side of DSP wafer is performed(Figure 3(h)). It determines the mirror plate thickness. Thermally deposited 100 nm aluminum layer is patterned by a lift-off process. After the wafer is partially diced, all devices on the wafer are released at a time by the final DRIE step(Figure (i)).

4. Fabrication results and discussions

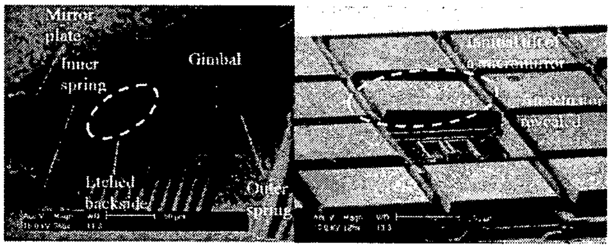


Figure 4. Scanning electron microscopy(SEM) picture. (a) a micromirror. (b) a micromirror array.

The Figure 4(a) is a SEM picture of a mirror which is taken before the releasing step. Since the fusion bonding process is sensitive to the surface quality of a wafer, voids are likely to be generated. After the CMP process voids prohibit the uniform PR coating on the surface. Therefore the bonding area for the anodic bonding process reduces due to DRIE steps followed. Because of the weak bonding stress, mirror plate thinning have not done properly. Thus, the fabricated mirror plate thickness is about 70 μm. Additionally, due to the 6th DRIE step, the underside of mirror plate is partially etched. It can be also confirmed in the Figure 4(a).

As shown in the Figure 4(b), a 8 X 8 micromirror array of fill-factor above 70 % has also been fabricated. The mirror plate size of a mirror is 340 μm X 340 μm.

The static deflection of a mirror cell has been measured by the laser profiler. 1.9 degree and 1.6 degree is achieved for the outer-axis and inner-axis rotation angle, respectively when 100 V is applied. However, the rotational movements were almost unidirectional. It is probably because of the initial tilt shown in the Figure 4(b) which forces combs to be engaged to one direction even the voltage is not applied to. Similar results have been reported in the paper [4]. They have found the reason of the initial-tilting of a mirror from the bulit-in stress of the buried oxide layer composing torsion springs.

Tilting angle of the mirror is an one-third compared to the simulation results. From SEM pictures, we have been able to figure out that vertical combs have been fabricated narrower compared to the designed value of 3 μm. The reason may be the significant side etching of the photoresist mask during the multi-step dry etching shown in the Figure 3(b).

5. Conclusion

A gimbaled two-axis vertical comb micromirror is fabricated by utilizing bulk micromachining techniques such as the wafer-level bonding techniques and DRIE process. The fabrication result shows that the proposed process is appliable to fabricate a high-fill factor micromirror array on the wafer-level.

Two-axis rotational motion of a mirror has been measured. The static angle of two orthogonal axes are 1.9 degree and 1.6 degree, respectively at a hundred volts.

References

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