Novel Fabrication Process of Vertical Spring for Micro Mirror

Tae-Sun Lim, Jong-Woo Shin, Yong-Kweon Kim, and Bumkyoo Choi

Abstract

Novel fabrication process of vertical spring for micro mirror array is proposed. The proposed fabrication process adopts a shadow evaporation process using shielding screen structure on top of the sacrificial layer. The 50×50 micro mirror arrays are fabricated using the proposed process and ceramic packaged. The static and dynamic characteristics of mirror are measured. The mirror plate touches substrate at 16 V and the response time of mirror is about 16.8 μs. The resonant frequency of mirror is 16 kHz. The spring thickness is calculated from static characteristic to be 1075 Å

I. Introduction

Micromirrors are the typical application of overhanging structures using micromachining technology and have many advantages for optical device like projection display[1-3]. There have been various models of micromirrors, for example mirrors with torsional hinge structures and with cantilever structures and so on[3-5]. The torsional hinge mirrors have been improved to hidden hinge model[6]. The hidden hinge model has advantage of lager active area but the fabrication process becomes more complicated than the simple torsional hinge model. A novel micromirror with vertical springs is fabricated which has large active area and simple fabrication steps[7]. Fig. 1 shows micromirror with vertical spring and Fig. 2 shows the process of vertical springs in reference [7]

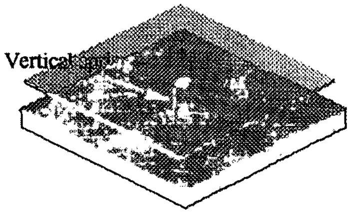

Fig. 1. Micromirror with vertical spring

Trench hole with trapezoidal cross section is made on photoresist sacrificial layer. If the spring metal is evaporated with some incident angle, the metal is deposited only on one side wall of the hole. But in photolithography and etching to define trench hole patterns, the edges of trapezoidal patterns are not easy to be sharp. In this case, the spring metal is deposited on unwanted side wall which disturbs bending of spring.

This paper proposes novel process that improves the uniformity and reliability of vertical spring fabrication by removing this unwanted side-wall aluminum. Using proposed process, 50×50 micro mirror arrays are fabricated, and PFDA film is coated to prevent stiction. After fabrication, micro mirror arrays are packaged using leadless ceramic packaged and experiments to measure the static and dynamic characteristics are followed.

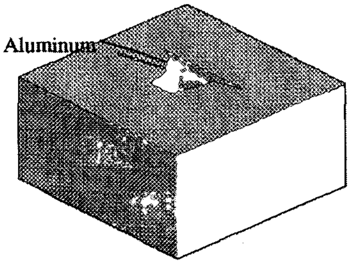

Fig. 2. Fabrication of vertical spring.

II. Spring Fabrication

In the novel process, we try to remove the side wall aluminum using shielding screen structures. Fig. 3 shows the fabrication steps of vertical spring, and Fig. 4 shows shielding

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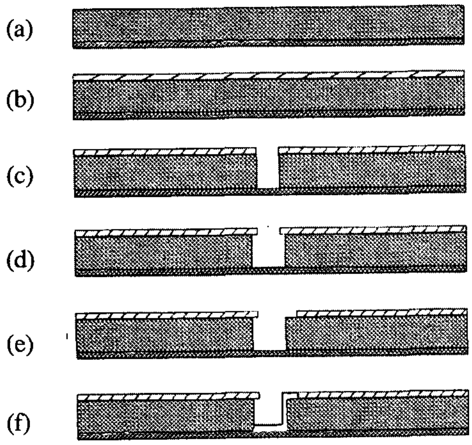
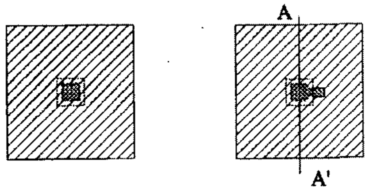
screen structures schematically. Firstly aluminum film is deposited on semicured thick photoresist(Fig. 3-a,b), and rectangular patterns are defined on aluminum film, then we make trench hole by O_2 RIE (reactive ion etching) using aluminum film as a etch mask(Figure. 3-c). If we overetch the sacrificial layer underneath the aluminum etch mask, the overhanging shielding screen structures is fabricated(Figure. 3-d). Next, parts of shielding screen layer over one side-wall of the trench-hole is removed(Figure. 3-e). Lastly we evaporate spring aluminum with some incident angle, then spring aluminum is deposited only on the side-wall over which the screen is removed(Figure. 3-f). The remaining aluminum screen prevents aluminum being deposited on other side walls of hole.



(a) Sacrificial layer deposition
(b) Aluminum mask deposition
(c) Trench hole etching
(d) Shielding screen structure
(e) Opening one side wall of hole
(f) Spring aluminum evaporation



(a) Top view of Fig. 3-(d) (b) Top view of Fig. 3-(e)

▒ Sacrificial layer
▨ Spring aluminum
☐ Aluminum

Fig. 3. Spring fabrication process

When spring aluminum evaporation, the incident angle (α) varies according to position on wafer. By tilting wafer (β) we can control the incident angle ($\alpha+\beta$) of spring aluminum. The incident angle must be less than critical angle (γ) at which shielding screen does not work. When the thickness of photoresist is 5 μm and the length of screen is 3 μm, the critical angle is about 31 °. Fig. 5 shows the incident angle of spring aluminum in the chamber of evaporator.

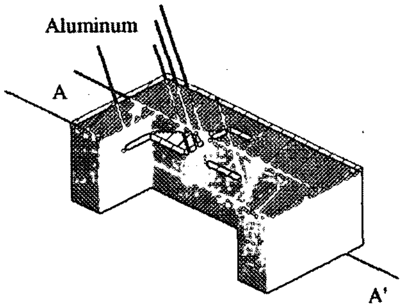


Fig. 4. Spring aluminum evaporation

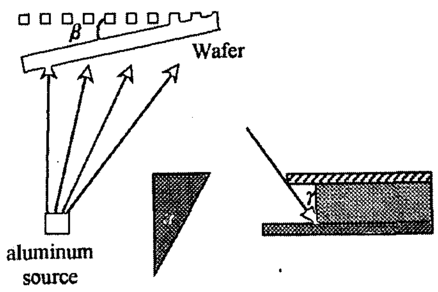


Fig. 5. Incident angle of spring aluminum

Table 1 shows thick photoresist etching condition for screen structure. We use anisotropic etching to make trench-hole and isotropic etching to overetch photoresist. In isotropic etching the etch rate of lateral direction is 0.6 μm /min. This value is important to control the position of spring.

Table 1. Etch condition of photoresist.

	Anisotropic etch	Isotropic etch
RF power	200W	200 W
Pressure	50mTorr	700mTorr
Gas	O_2 50 sccm	O_2 50 sccm

The rectangular pattern on aluminum film is defined by dry etching using Cl_2 gas and is preferred to be as small as possible, because marks of this pattern remains on mirror plates. When we remove aluminum screen over side wall on which spring aluminum is deposited, we first use dry etching and then use wet etching. Otherwise the scattered aluminum during dry etching remains in trench-hole and makes some residue. Fig. 6 shows fabricated springs. There is no side wall to disturb bending of spring.

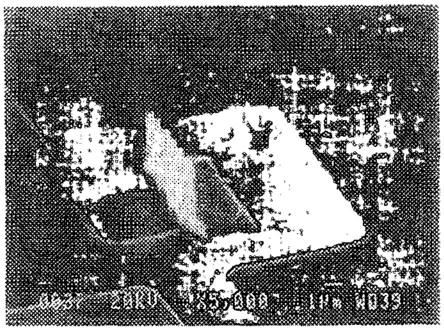


Fig. 6. SEM photograph of fabricated spring

III. Mirror Fabrication

Fig. 7 shows micromirror fabrication process. At first, thermal oxide layer is deposited on silicon substrate for isolation and patterned to form electrical contact via(Figure. 7-a). The aluminum electrode is defined on the oxide layer, and then thick photoresist sacrificial layer is coated to 5 ㎛ thickness, and semicured(Figure. 7-b). Next, aluminum layer is deposited by thermal evaporation to 4000 Å and spring is fabricated as explained above paragraph. The width of spring is 5 or 6 ㎛ and the height is 5 ㎛ being equal to thickness of sacrificial layer. After making spring, the hole is filled with photoresist for planarization(Figure. 7-c,d,e). Then aluminum for mirror plate is deposited by thermal evaporation and patterned(Figure. 7-f). The final step of fabrication is removing the sacrificial layer for release(Figure.7-g). We also use O2 isotropic RIE in this step.

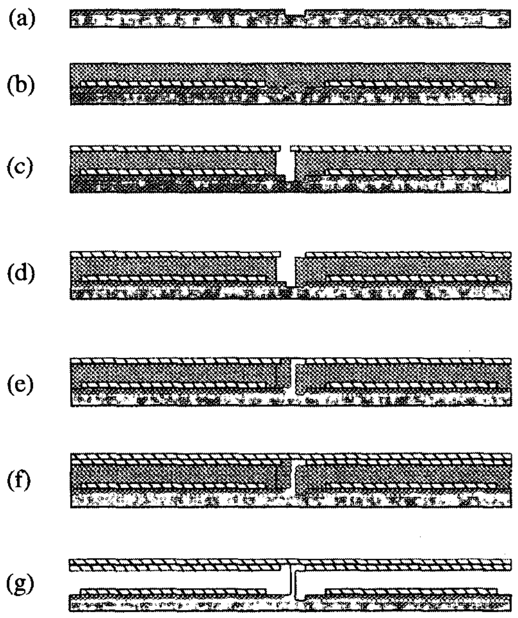


Fig. 7. Mirror fabrication process.

Fig. 8 shows the fabricated micromirror array. The mirror size is 50×50 ㎛2 and the array is composed of 50×50 pixels. There are four different types of mirrors. 1 or 2 springs are on central lines or diagonal lines. The rectangular patterns on aluminum mask layer also varies according to number of springs, that is 4 ×10 or 4×9㎛2. In these case the fill factors of mirror (designed value) are from 87 % to 90%.

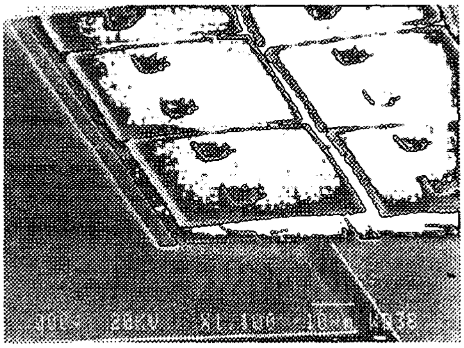


Fig. 8. Fabricated micromirror array

After mirror fabrication, PFDA (Perfluoro Decanoic Acid) film is coated by thermal evaporation. PFDA films prevent mirror plate from sticking to substrate during actuation

Simple packaging using Koyocera 128 leadless ceramic package is followed by PFDA coating, and Fig. 9 shows packaged mirror arrays

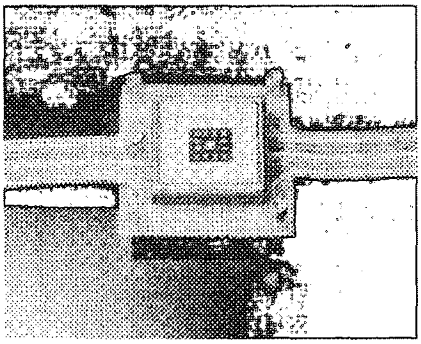


Fig. 9. Ceramic packaged mirror arrays.

IV. Electromechanical Characteristics

Electromechanical characteristics of micro-mirrors are measured by optical measurement system using HeNe laser beam. Fig. 10 shows the optical measurement system. Laser beam is focused on the mirror pixel through the beam expander and optical lens, then is reflected to PIN photodiode. Because the PIN photodiode is linear device detecting the position of beam spot on diode, the angular displacement of mirror pixel can be measured by PIN photodiode output signal[8].

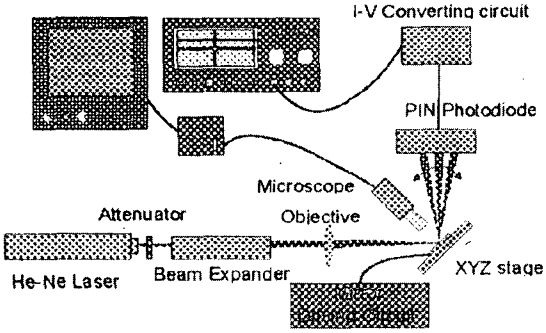


Fig. 10. Optical measurement

Fig. 11 describes the steady state angular deflection as a function of applied voltage. We applied 35 V(pk-pk) to measrue static characterisitic.Maximum angular deflection is about 7° and downward threshold voltage is 16V. Fig. 11 also shows theoretical simulation result expressed as equation 1.

Eq.1. describes the equilibrium condition between electrically generated torque and mechanically generated torque by spring. We can know from figure that experiment result matches the theoretical simulation well[9-10].

$$\tau_e - \tau_m = \frac{1}{2}\,\frac{\varepsilon_0 V^2 L^3}{4Z_0^2}\left\{\frac{\frac{\alpha\beta}{1-\alpha\beta}+1n(1-\alpha\beta)}{\alpha^2}\right\} - \frac{E\alpha\beta^3}{12l}\,\frac{2Z_0}{L}\,\alpha = 0 \quad \textbf{(1)}$$

whrere

$$\alpha = \frac{Z_t}{Z_0} \qquad \beta = \frac{L'}{L}$$

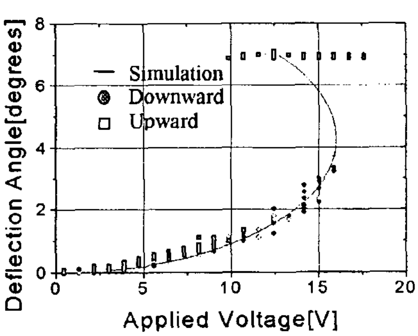


Fig. 11. Static characteristics of micromirror.

We can expect that real thickness of spring varies from the value of thickness monitor by sin function of incident angle ($\alpha+\beta$) approximately.

So we can change the thickness of spring roughly by tilting wafer. In case of 10° (β) tilting the incident angle of spring aluminum ($\alpha+\beta$) is about 27°, and the thickness of deposited aluminum (in thickness monitor of evaporator) is about 3300 Å. The thickness of spring can be calculated by comparing the experiment result and simulation, and the calculated thickness is about 1075 Å. To measure dynamic characteristics, step voltage is applied to mirror pixel. Fig. 12 shows a step response of mirror pixel to measure the response time of mirror. The response time of mirror pixel is about 16.8 μs when 24.8 V step voltage is applied. In this case, the mirror plate touches the substrate. If we apply voltage less than threshold voltage and remove voltage, mirror plate oscillates freely without touching the substrate(Fig.13). We can see that mirror oscillates with some damping factor, and resonant frequency is calculated by measuring the period of free oscillation. Resonant frequency can be also measured, if we observe output voltage with applying A.C voltage to mirror with changing frequency. Resonant frequency measured by this method is about 17 kHz. The calculated theoretical resonant frequency is 16 kHz.

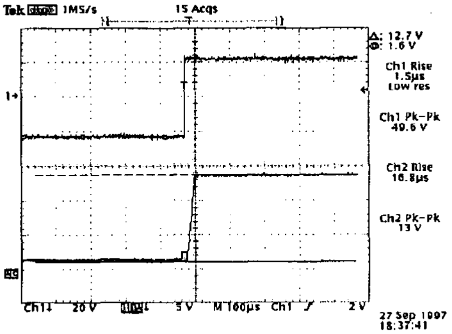


Fig. 12. Step response of micromirror.

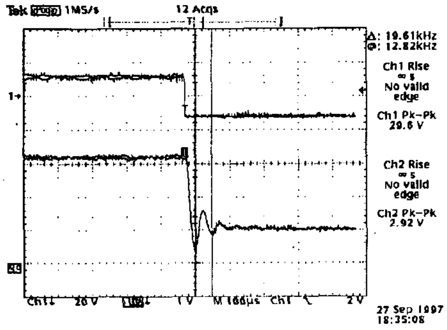


Fig. 13. Oscillation of micromirror.

V. Conclusion

Novel fabrication process of vertical spring for micromirror is proposed. The novel process reduces unwanted side-wall aluminum of vertical spring using shielding screen structure. The thickness of vertical spring is calculated to be about 1075 Å. 50×50 micromirror arrays are fabricated using proposed process and PFDA film coated for anti stiction. After simple ceramic packaging, electromechanical characteristics of mirror pixel are measured by laser optical measurement system.

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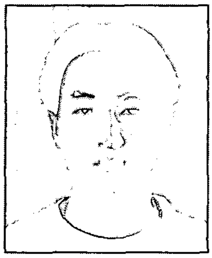

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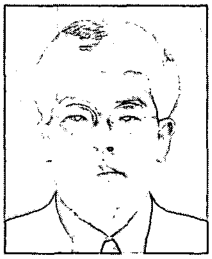

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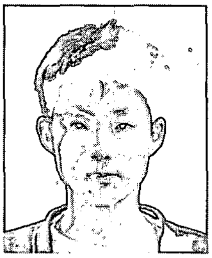

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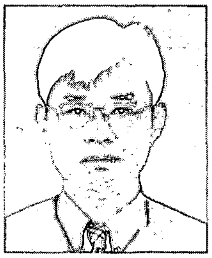

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