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Characteristics measurement of fabricated micromirror array with vertical springs

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Abstract - A $50 \times 50\ \mu m^2$ aluminum micromirror array is fabricated using shadow evaporation process. The fabrication process is very simple with use of shadow evaporation process, and the micromirror array has a high fill-factor. The static and dynamic characteristics such as deflection angle vs. applied voltage, step response, and frequency response are measured using a contact free optical measurement technique. The downward threshold voltage was 8 V, step response time was 13.5 ㎲ when 32 V step voltage applied, and a resonance observed at 11kHz. The lifetime of micromirror with anti-stiction coating was tested and micromirror operated successfully over 200 million cycles of touch-down operations.

I. INTRODUCTON

Micromirrors are of great interest for dense light modulator arrays for use in laser printing and projection display systems and various micromirrors have been developed[1~6]. For their use in projection display systems, it is required that the arrayed micromirrors have a high fill-factor(large effective area) for better device performances such as brightness and contrast ratio. For high fill-factors, simple torsional hinge model generated into the hidden-hinge model[7] to hide the mechanical hinge underneath the mirror plate. The fill-factor was improved to be above 90%, but the structure became complicated and the fabrication process also complicated. In comparison, the proposed vertical spring model[8] in fig. 1 also has a high fill-factor, but the fabrication process is very simple with use of shadow evaporation process. This paper describes the experimental results of fabricated micromirror using a non-contact optical measurement system. In the experiments using the optical measurement system, electromechanical characteristics of micromirror such as static, dynamic responses, and life-time of vertical spring were measured.

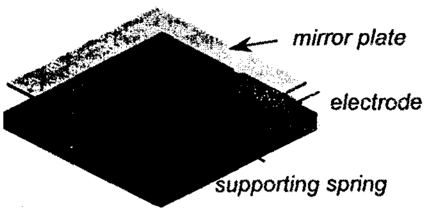

Fig. 1 Schematic view of micromirror with vertical spring

II. MICROMIRROR FABRICATION

The fabrication of vertical spring use shadow evaporation process[8]. The side-walls of trench hole are used as a shadow mask for evaporation process. Because the shadow evaporation process requires no additional photolithography to define spring shape, fabrication process is very simple with fewer number of masks. No considerations of design parameters such as alignment margin are required either.

In Fig. 2, we can see a SEM photograph of micromirror array. The mirror plate is succesfully supported by vertical springs, and the distance between the mirror plate and the substrate is about 4 ㎛. Fig. 3 shows vertical spring array, and the vertical springs were succesfully fabricated to be rectangular plate springs.

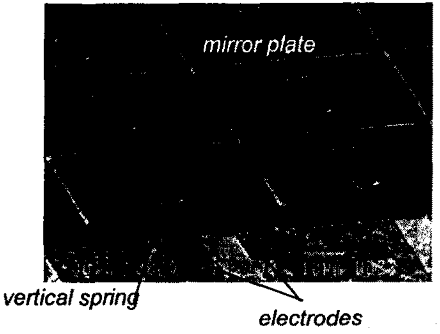

Fig. 2 SEM photograph of square two spring model

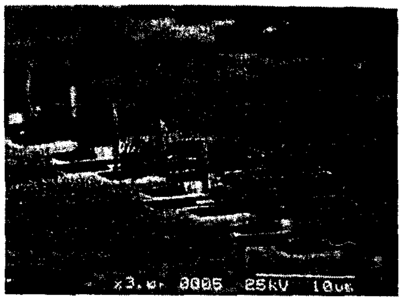

Fig. 3 SEM photograph of vertical springs

III. ELECTROMECHANICAL CHARACTERISTICS OF MICROMIRROR

Static and dynamic characteristics of a fabricated micromirror pixel were measured using a laser-based optical measurement system described in Fig. 4[9, 10]. A He:Ne laser beam(beam diameter 0.48mm, divergence 1.7mrad) is focused on one mirror pixel with an objective lens (f=200mm). The focused spot size is about 30㎛ in diameter. The laser beam is reflected by the micromirror onto a position sensitive PIN photodiode(DL20, UDT sensors, inc.). The PIN photodiode is a linear device over 90% of its whole active area($20 \times 20mm^2$, square shape). By virtue of the linearity of the PIN photodiode, the angular displacement of micromirror could be measured directly by detecting the PIN output signal.

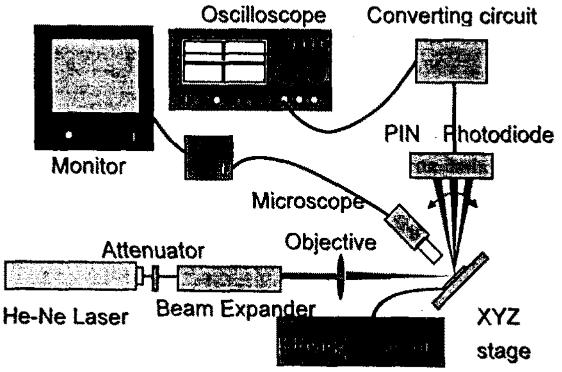

Fig. 4 Contact free optical measurement system

3.1 Static Characteristics

The steady-state angular deflection of a micromirror(diagonal, one-spring model) was measured as a function of applied voltage. We applied a ramp voltage and the deflection of the micromirror was measured by the PIN photodiode at the same time. The applied voltage was 9V(peak-to-peak) and the frequency 0.7Hz. Fig. 5 shows a relationship between the applied voltage and the angular deflection of diagonal one-spring micromirror. A notable aspect of the figure is the hysteresis even in the analog region. This result is in accordance with the experiments of Wetsel et al. over TI's DMD[10]. The theoretical estimation agreed well with the experimental data without introducing a non-linear spring constant[11].

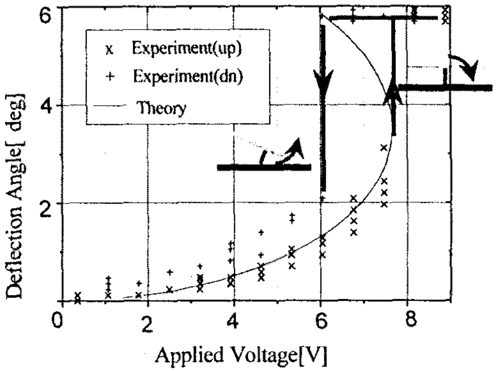

Fig. 5 Experimented static characteristics of micromirror

In comparing the theoretical estimation and the experimental results, to match the downward threshold voltage and up threshold voltage in both cases, the spring thickness was calculated to be 850Å. In evaporation process, we detected the deposited film thickness with a thickness monitor and it was about 1200Å. But, the monitored value represents the thickness of film which is deposited on a substrate with normal incidence. We think that the tilting of substrate(30 degrees) reduced the film thickness to about 70% of that normal incidence.

3.2 Dynamic Characteristics

Dynamic characteristics of the micromirror(the same one as in the static characteristics measurement) were measured with the same measurement system. A step voltage was applied and the motion of the micromirror was measured by PIN photodiode. Fig. 6 shows the motion of micromirror when 32V of step voltage was applied. In this case, the mirror plate touches the substrate, and a rise time of the mirror motion was measured to be about 13.5㎲. When we applied a step voltage less than downward threshold voltage, we observed two cycles of oscillation about the equilibrium position. And a resonance was observed at 11kHz.

To study the mechanical fatigue of the vertical spring, we actuated the micromirror to touchdown the substrate under room temperature(21℃) and humidity(41%) as shown in Fig. 7. The micromirror under life-time test was a diagonal one-spring model with 1200Å spring thickness(also estimated from the experiment). To avoid stiction problem in life-time test, we deposited the PFDA(Perfluoro Decanoic Acid, $F(CF_2)_9COOH$, manufactured by PCR) film by thermal evaporation in a vacuum oven(110℃, 640Torr). For the failure test we applied a square voltage of 22 Volts(peak-to-peak) and 2kHz frequency. Fig. 7(a) is the micromirror response when the failure test just began, and fig. 7(b) is the micromirror response after 30hours(2×10^8 cycles) of full deflection operations. The two wave-forms looked identical and no mechanical fatigue could be found. The vertical spring operated over 200 million cycles without mechanical failure or stiction problem.

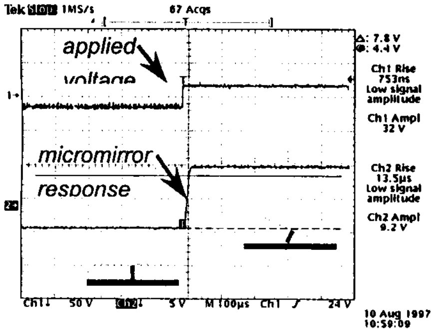

Fig. 6 Step response of micromirror

IV. CONCLUSION

A micromirror array with vertical spring structure is fabricated using shadow evaporation process. Because the mechanical spring is hidden underneath the mirror plate, the array can have large active area. With shadow evaporation process, the micromirror can be fabricated with reduced fabrication steps, and with reduced number of masks. Static and dynamic characteristics of micromirror with vertical spring have been experimented. The mirrors touched the substrate by applying 8 V. And the rise time was about 13 µs when 32 V of step voltage was applied. In lifetime test, no mechanical failure or stiction problem was found until 200 million cycles of touch-down operations.

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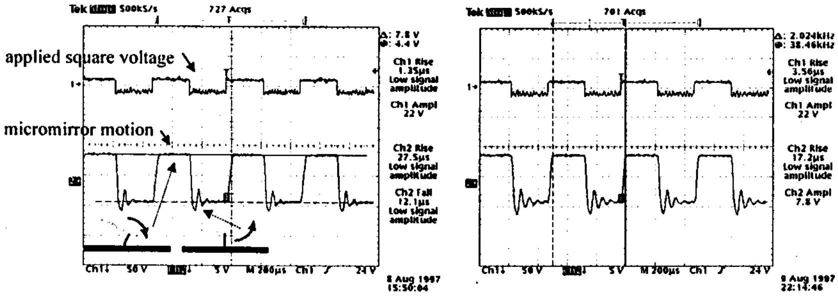

(a) initial state

(b) after 30 hours(200 million cycles)

Fig. 7 Dynamic response of micromirror under life-time test