Study on a MEMS silicon-based non-silicon mirror for an optical switch

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A micro-electro-mechanical system (MEMS) silicon-based non-silicon mirror for a 2D optical switch is designed, fabricated and measured. The result shows that the mirror has good reflective performance. And driven by static electricity, it can rotate more than 10° at voltage less than 15 V. This kind of novel mirror will have good potential applications for MEMS optical switches.

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Optical switch is becoming a core technology for all-optical network. Among several schemes of optical switches, micro-electro-mechanical system (MEMS) is at the competitive edge because of its compactness, high integration level, and cheapness. Micromirror is the key structure for most MEMS optical switches and silicon is commonly used as the material of micromirror[1,2]. In this paper, a novel silicon-based non-silicon material MEMS mirror is designed for an optical switch. Both bulk and surface micromachining processes are used to fabricate the micromirror. Comparing with polysilicon scheme, the fabrication process may be simplified and the yield rate may be higher. Also the deformation of micromirror can be reduced effectively by using anneal process. The testing data presents that the surface topography of the novel micromirror is smoother than that of a silicon-mirror so it has good reflective characteristic. Driven by static electricity, it can rotate more than 10° at voltage less than 15 V.

Figure 1 shows the structure of a micromirror for a 2D optical switch. The angle of rotation θ will be limited by the stopper. When the mirror rotates about θ, the incident ray will rotate 2θ and switch to another light path.

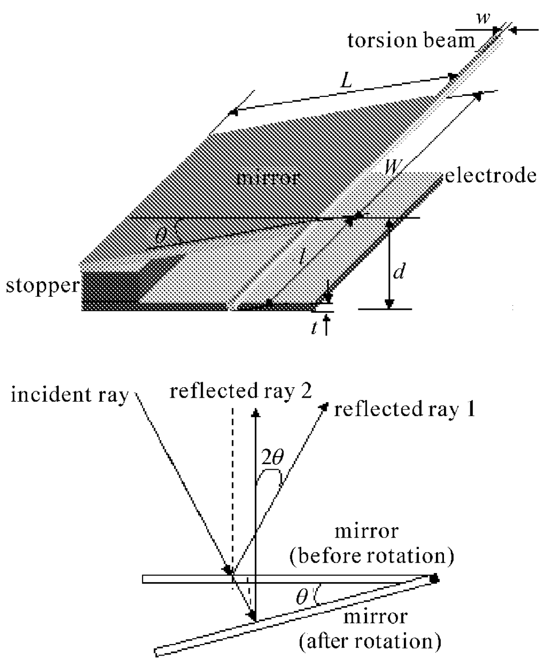

Fig. 1. Schematic of micromirror for optical switch.

The rotation of micromirror is actuated by an electrostatic driver. The relation between the size of micromirror and the voltage can be analyzed by solving the moment equation. The moment of static electricity is expressed as T_e, and the dielectric constant of vacuum is ε. By using electrostatic mechanical theory, the T_e can be obtained as[3]

$$T_e = \frac{\varepsilon}{2}V^2W\int_0^L \frac{x}{\left[\left(\frac{d}{\sin\theta}-x\right)\theta\right]^2}\mathrm{d}x = \frac{\varepsilon V^2 W}{2\theta^2}\left[\frac{L\sin\theta}{d-L\sin\theta}+\log\left(\frac{d-L\sin\theta}{d}\right)\right]. \quad (1)$$

While micro-mirror rotates, the restoring moment T_r of the torsion beam can be shown as

$$T_r = \frac{GJ\theta}{2l}, \quad (2)$$

where $J = \frac{wt^3}{3}\left(1 - 0.630\frac{t}{w} + 0.052\frac{t^5}{w^5}\right)$, G means shear module.

By using Eqs. (1) and (2), the relation between the driving voltage and the size of the micro-mirror can be found as Fig. 2 shows when the micromirror rotates 20° and the included angle between the incident light and the reflected light is 40°. The structural parameter of the mirror is $L = 280$ μm, $W = 600$ μm, $l = 350$ μm. It is very clear that the influence of thickness of beam on the driving voltage shows that even a 0.2 μm change of the beam thickness will make the voltage increase about 20 V or more. So in order to have a low driving voltage, the beam should be designed as thin as possible.

The fabrication of the micromirror for 1 × 2 optical switch needs just 3-layer mask because the non-silicon material has good anti-corrosive properties for KOH solution etching. The main process steps can be shown as Fig. 3. The fabricating process is more simple than that of a polysilicon micromirror[4].

Because of self-weight, the mirror will rotate a small angle after being released. Figure 4 shows a microscope

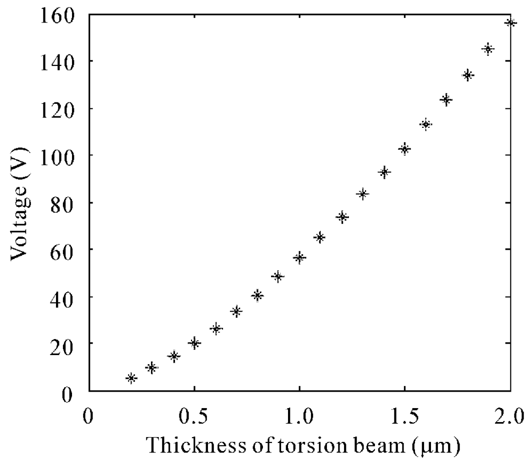

Fig. 2. The relation between mirror thickness and driven voltage.

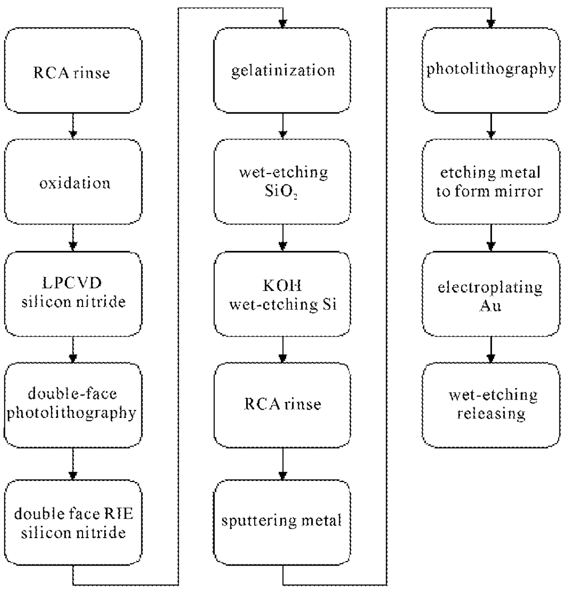

Fig. 3. Main processing steps of mirror fabricating.

photo of a released mirror. From the reflection situation of the mirror, the inward rotation can be observed clearly.

The initial angle will not effect on the location of the mirror because the angle of rotation will be limited by the stopper. But it may effect on the couple efficiency of the first location if the initial angle is variation with time. The initial angle can be decreased by using a balance mirror structure.

Another very important advantage of this non-silicon micromirror is that the deformation of mirror can be reduced effectively by annealing. This processing is more simple than using boss-structure to make polysilicon mirror flatten[4].

The surface topography of the micromirror is also measured by scanning tunneling microscope of Chongqing University. Figure 5 shows the test result. From Fig. 5, it can be found that the roughness of the micromirror surface is about 10 nm. It is more smooth than that of a polysilicon micromirror (~ 55 nm)[5].

By using a reflectivity measuring instrument, a curve

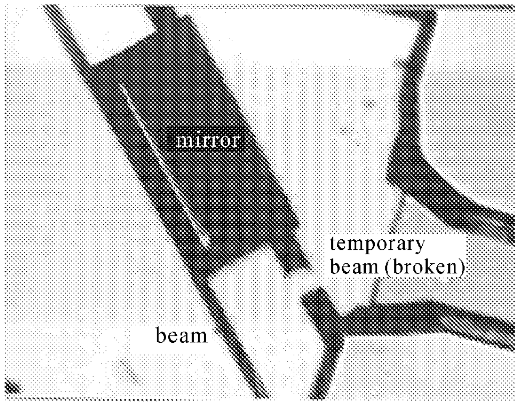

Fig. 4. A released micromirror.

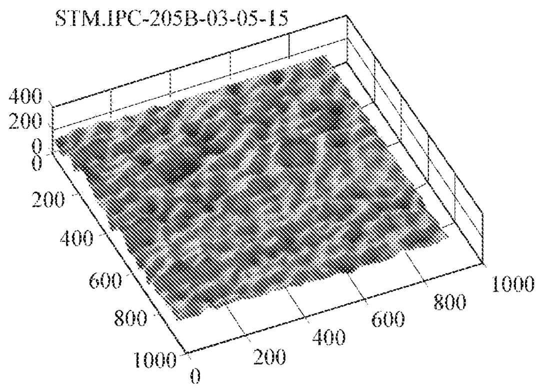

Fig. 5. Surface topography of the micromirror.

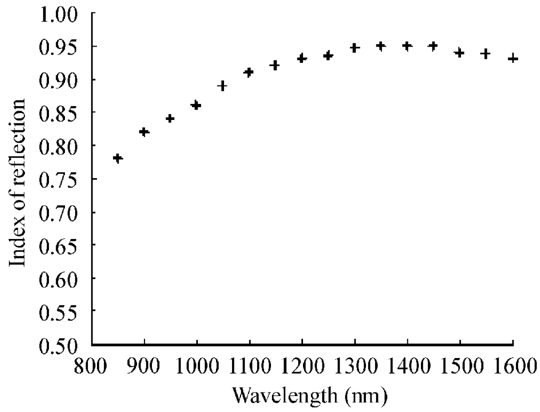

Fig. 6. Reflectivity of micromirror.

of spectrum is shown in Fig. 6. Results show that the reflectivity of the micromirror is relatively flat. And the reflectivity is about 95% at wavelength of 1.55 and 1.31 μm. It means that the insert loss produced by the micromirror is about 0.22 dB without considering other factors such as the separation of the two fibers, the angle misalignment and so on. If more accurate coupling structure of fibers and fiber collimator are used, the insert loss of the optical switch may be reduced to about 0.4 dB.

When adding voltage on the mirror, it will rotate obviously, and the angle can be measured by using digital image processing. The driving voltage is about $8-15$ V by testing several sets of optical switch units while the rotate angle is about 20°, which agrees on the theoretical calculation.

By using a signal generator as the driving source, the micromirror can work about several hundred times continuously without any failure.

The novel micromirror has just the elementary switching function. More experiments will be down to study the characteristics of this kind of novel micromirror.

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