Development of Microshutter Arrays for Ground-Based Instruments

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Abstract: We are developing microshutter arrays matched to the ground based instruments, which can be actuated electrostatically. Dimension of a shutter blade is 100μm $\times$ 1000μm. The test models fabricated on 410μm SOI wafers demonstrate that they can be opened by applying $\sim$ 100V DC voltage.

Keywords: Microshutter, MEMS, MOS, Spectroscopy

1. INTRODUCTION

Multi-object spectrographs (MOSs) introduced great power in large surveys of galaxies and stars, and definitely will be the most important instrument for ELTs.

In many cases, multiplicity of the existing MOSs is realized with a slit-mask plate, which should be prepared before the observations using a laser cutting machine. Therefore, observatories should retain the machine and an operator for that. Also, if you would like to use them in the thermal infrared wavelength, they should be cooled down to cryogenic temperature. This is another difficult task, because you have to warm up the slit-exchanging unit, install slit-masks, and cool it down again during the daytime to exchange the slit-masks.

Using fibers is another choice, which requires a complicated robotic system or manpower to place fibers at positions of target objects. In addition, because the fiber system doesn't have a "slit", it will be difficult to subtract residual sky background. Again, to use it in the thermal infrared, (1) there is limited material which transmits that wavelength and (2) all the system are cooled down to cryogenic temperature, so fiber positioner mechanism should be located inside a dewar, which is difficult to maintain.

However, recent development of Micro Electro Mechanical System (MEMS) technology enable us to fabricate more sophisticated focal-plane selector with a very small scale, and several approaches are proposed. One is micromirror arrays, which are large arrays of small ($\sim 100\mu$m) steerable mirrors, and large format arrays have been developed and supplied by Texas Instruments for commercial projection system such as rear-projection TVs or projectors. This device is called "Digital Micromirror Device (DMD)", and several instruments have been developed utilizing it[2, 3]. However, because of the reflective system, their focal plane are skewed. Therefore a complicated optics are necessary to re-skew it, and final image quality is not so promising. Scattered light either at the edge or backside structure of micromirrors will be another problem, and may prevent us from achieving high contrast such as 2000:1 or more.

Microshutter arrays are alternative and straightforward approach free from above problems. This device is an array of small ($\sim 100\mu$m) shutter blades connected to a frame by narrow ($\sim 1\mu$m) torsion bars, and the blades will be opened either electrostatically or electromagnetically, and latched open electrostatically(see Fig.1).

It is first proposed[4] and under development by NASA/GSFC for an application to the near-infrared MOS of James Webb Space Telescope. 128×64 arrays of $100\mu m \times 200\mu m$ shutter blades have already been developed and been tested[1]. Adding light shields, contrast ratio of 7000:1 has been achieved. However, the GSFC devices are actuated electromagnetically; which means that all the shutters are opened eletcromagnetically first, then are closed except the shutters at the target positions. This means that (i) a mechanism to scan the surface of an array with an electromagnet is necessary, and (ii) it takes time to open the specified shutters.

2. ELECTROSTATIC ACTUATED MICROSHUTTER

Therefore, we have been developing microshutter arrays which can be opened electrostatically. Fig.1 shows the schematic of the proposed microshutter, and Fig.2 shows the principle of the electrostatic actuation.

Basic structure is same as that of the GSFC device; a torsion bar supports a shutter blade, and the blade opens/closes by rotating along the torsion bar. To increase the transmission ef-

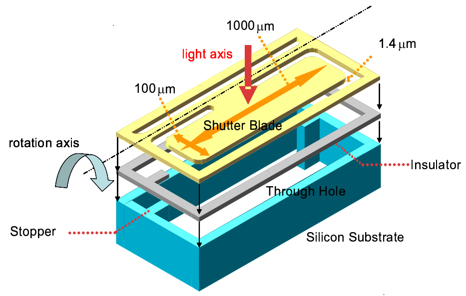

Figure 1. A schematic of a single shutter of the microshutter arrays under development.

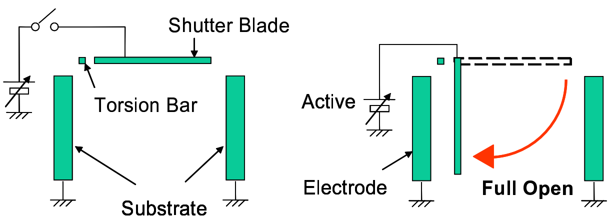

Figure 2. Principle of the electrostatically actuated microshutter.

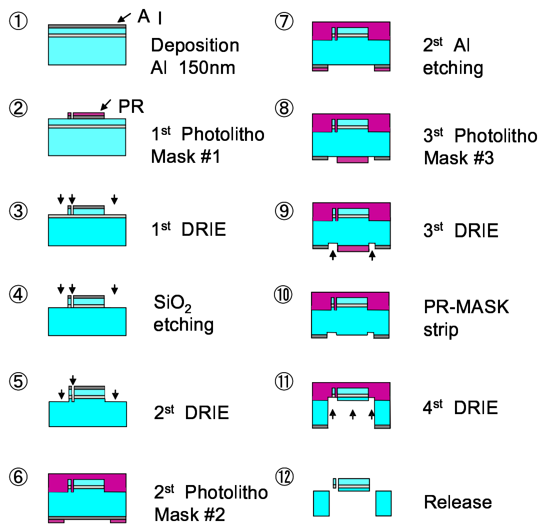

Figure 3. Process flow of a microshutter.

Table 1. Specification goal of electrostatically actuated microshutter arrays.

Items	Specifications
Shutter size	$1000\mu m \times 100\mu m \times 2\mu m$
Array dimension	20×200
Device size	$20mm \times 20mm \times 0.2mm$
Contrast ration	> 2000
Filling factor	$> 80\%$
Drive voltage	$< 200V$
Operation lifetime	$> 100,000$
Oparating Temperature	100K

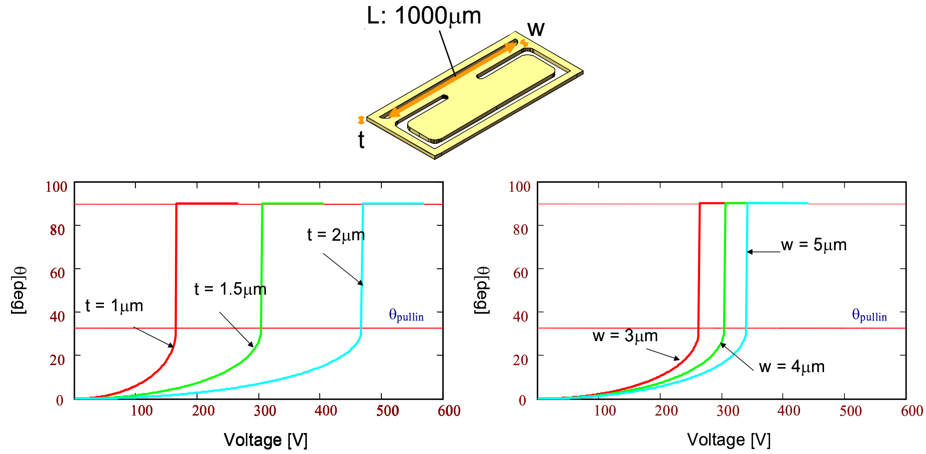

Figure 4. Simulated relation of opening angle θ (open : $\theta = 90$) and voltage (V) between a shutter blade and substrate. **[Upper]** Schematic of the simulated model. Varied parameters are width w and thickness t of the torsion bar. Length and width of the shutter blade are assumed to be 1000μm and 100μm, respectively. **[Lower-left]** t dependence of $\theta - V$ relation. $w = 4\mu$m is assumed. **[Lower-right]** w dependence of $\theta - V$ relation. $t = 1.5\mu$m is assumed.

ficiency of the shutter, dimension of the shutter blade is elongated to 100μm $\times$ 1000μm, that will be a spatial direction when it is on a spectrograph. Fig.3 shows the process flow of the microshutter. It is fabricated on a silicon over insulator (SOI) wafer by deep reactive ion etching (DRIE). The shutters are opened by applying voltage between the shutter blades and the substrate, while they are isolated by the insulation layer.

Table 1 shows the specification goal of the electrostatically actuated microshutter arrays.

2.1. Simulation of Actuation Voltage

To assess required voltage to open shutters electrostatically, we first carried out simulations to obtain voltage-displacement relation. Fig.4 shows the result. It is found that selecting appropriate width w and thickness t of the torsion bar, the shutter can be opened with reasonable voltage of $< 200V$.

2.2. Fabricated Microshutter Arrays

Following the simulations, we have decided to use 410μm SOI wafers with 1μm insulation layer and 2μm silicon layer. Fig.5 shows SEM and microscopic images of the fabricated shutters with $w = 1\mu$m, and Fig.6 shows the $\theta - V$ relation. It can be seen that we have successfully opened the shutter electrostatically. Using $w = 1\mu$m torsion bar, shutters can be opened by $\sim 100V$ voltage.

3. SUMMARY AND FUTURE PLAN

We have demonstrated that an elongated shutter blade with a torsion bar of $w = 1\mu$m and $t = 2\mu$m can be opened by applying voltage of $\sim 100V$ DC. The next step is to develop more practical shutters, and the following are the issues to be solved ;

1. A "light shade" to block the gap between the shutter blade and the substrate are necessary to achive high contrast.

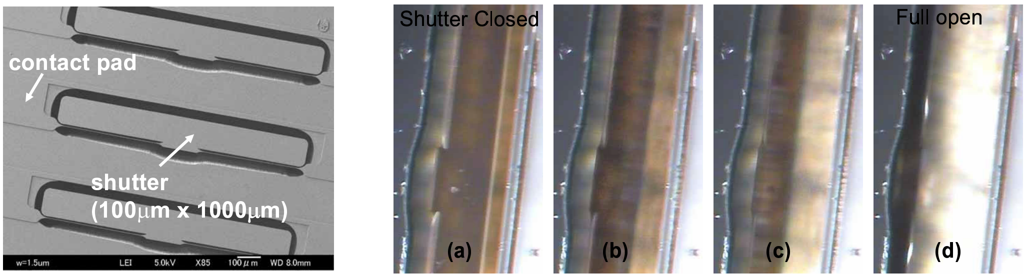

Figure 5. **[Left]** SEM image of fabricated microshutters. **[Right]** Microscopic images of operation of the shutter from closed position(a) to full-open(d).

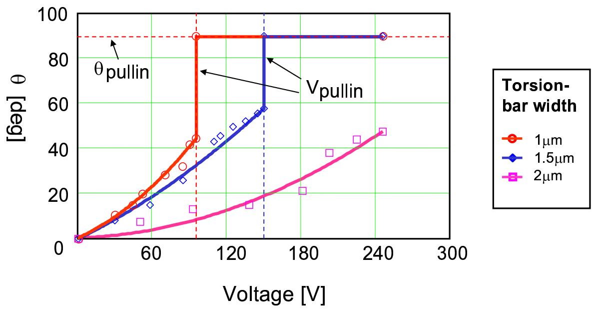

Figure 6. $\theta - V$ relation of the fabricated microshutter with 1000μm $\times$ 100μm.

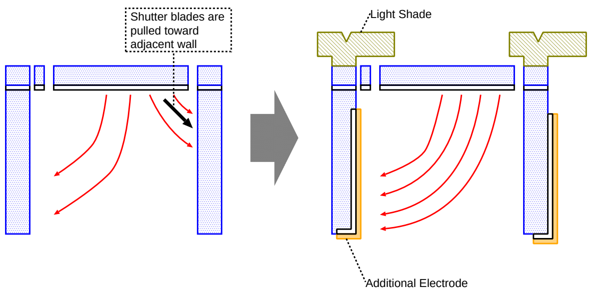

Figure 7. Proposed modification in the next process. Light shades and additional electrodes will be installed.

2. Current thickness of the substrate is 410μm. However, to transmit more than 90% of the F/10 beam, it should be thinner than 200μm.

3. Current shutters are actuated by applying voltage between the shutter-blade and the substrate. However, this creates the electric field to pull the shutter blade toward the adjacent wall, which cause the jamming of the shutter blades. We therefore need to add another electrode to form more stable electric field (Fig.7)

4. Current spacing between the shutters is more than 100μm. This size is larget than the width of the shutter blade, and to obtain usable microshutters, this should be reduced to less than 10μm.

The light shades and the additional electrodes are planned to be appended in the next process run, cryogenic test at $77K$ is scheduled for them.

REFERENCES

1. Li, M. J., Acuna, N., Amatucci, E., Beamesderfer, M., Boucarut, R. A., Babu, S., Bajikar, S., Ewin, A. J., Fettig, R., Franz, D. E., Hess, L., Hu, R., Jhabvala, M. D., Kelly, D., King, T. T., Kletetschka, G., Kotechi, C. A., Kutyrev, A., Loughlin, J. P., Lynch, B. A., Moseley, H., Mott, B., Newell, B., Oh, L., Rapchun, D. A., Ray, C., Sappington, C., Schulte, E., Schwinger, S., Smith, W., Snodgrass, S., Sparr, L. M., Steptoe-Jackson, R., Wang, L. L., Zheng, Y., & Zincke, C. A., *Smart Structures, Devices, and Systems II. Edited by Al-Sarawi, Said F. Proceedings of the SPIE* 5650, 9-16 (2005)
2. MacKenty, J. W., Greenhouse, M. A., Green, R. F., Sparr, L., Ohl, R. G., & Winsor, R. S., *Instrument Design and Performance for Optical/Infrared Ground-based Telescopes. Edited by Iye, Masanori; Moorwood, Alan F. M. Proceedings of the SPIE* 4841, 953-961 (2003)
3. Meyer, R. D., Kearney, K. J., Ninkov, Z., Cotton, C. T., Hammond, P., & Statt, B. D., *Ground-based Instrumentation for Astronomy. Edited by Alan F. M. Moorwood and Iye Masanori. Proceedings of the SPIE* 5492, 200-219 (2004)
4. Moseley, S. H., Fettig, R. K., Kutyrev, A. S., Bowers, C. W., Kimble, R. A., Orloff, J., Woodgate, B. E., *ASP Conf. Ser. 195: Imaging the Universe in Three Dimensions,* 195, 449-452 (1998)