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Programmable 2-Dimensional Microshutter Arrays

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Abstract.
We are developing a two-dimensional array of microshutters which can be used as a high efficiency, high contrast field selection device for a multi-object spectrometer. The device is a close-packed array of shutters, with a typical size of 100 microns square and area filling factor of up to 80%. Each shutter, made of single crystal silicon with an appropriate optical coating, pivots on a torsion flexure along one edge. Each of the shutters is individually selectable. An original double-shutter mechanism is employed for actuation. Since the device works in transmission, there is no loss of contrast due to diffraction from the edges of unactuated pixels. When working in reflection, the device can also be used as a micromirror array.

1. Background

There are different approaches to the problem (Garcia et al., 1999, MacKenty 1999, Moseley et al. 1998) aiming at building large format arrays (typical 1000 by 1000 elements) of very close packed individually controlled active elements, mirrors or shutters. The task is extremely challenging and devices developed so far remain complex and expensive to manufacture. The Next Generation Space Telescope (NGST) gave a strong boost to these studies. Primary wavelength region of NGST operation is the near-infrared and devices have to be cooled to cryogenic temperatures, which makes the technological problems yet even more complex.

With the advent of the micro electro mechanical systems (MEMS) era, the development of micromechanical array devices, that allow to redirect light by individually controllable tiny mirrors, has been progressing at a fast pace. Practically all research and development programs in this area are concentrated on micromirrors. So far there has been no large array of transmissive microshutters developed, e.g. arrays of shutters, that are being developed and built by CSEM Co., Switzerland, have a low area filling factor and have small number of shutters (`http://www.csem.ch/microsystems/`). These devices employ a resonant excitation technique of the shutters and designed for operation at room temperature.

In our project we are pursuing the goal of creating large fully addressable microshutter arrays of small elements (100μm typical dimension) with high ef-

ficiency (80% or better for the ratio of shutter area to total area). The device is being developed as a low temperature mask for the infrared spectrometer on the NGST, but it can also be used at optical wavelengths on the ground-based telescopes.

2. Microshutter design and tests

Shutter blade and shutter suspension are machined as a single piece out of a 1 μm thick membrane. The suspension is a torsion beam, which allows for blade deflection up to 180 degrees (Fig.1a). The membrane can be single crystal silicon, silicon-nitride or any other material with sufficient strength. Experiments with both silicon and silicon nitride showed good mechanical performance of the shutter. The membrane sits on a frame, a structured wafer, which allows transmission through the shutters. To select and engage the shutters, the voltage is applied using an addressing microcircuit, which is implemented on the frame and the shutters themselves.

The most important issues in the microshutters development are

- the design of the single shutter,
- the actuation scheme: double-shutter with shutters selection and engagement by electronic microcircuit.

2.1. Single shutter

Asymmetric suspension of the microshutters on a torsion bar attached to the shutter only in the middle, allows to have longer torsion bar and therefore reduce the stresses. Sample tests and mechanical analysis proved that this design allows full deflection of the microblade out of the light path (Fig. 1). The blade can be rotated all the way up to 180°. The crucial difference of our device compared to any existing light beam manipulating devices: large angles of deflection on a compact packaging.

Shutters were made with FEI (focused ion beam machine) at the Lab for Ion Beam Research and Application (LIBRA) of the University of Maryland (UMd). Single crystal Silicon wafers were prepared and thinned down to about 1 μm by Christine Allen of the GSFC Detector Systems Branch. Usage of the ion beam milling allowed very quick turnaround and provided very fast progress from the idea inception to the implementation, test, refinement and development of the design. Within few months we were able to progress from scratch to have a fully operational single element microshutter (Fig. 1c).

Mechanical tests of the shutters strength and rigidity have also been carried out at the LIBRA, UMd. Resonant frequency measurements allowed us to measure the stresses in the shutters. Finite element analysis results agreed well with the measurements of the resonant frequencies and demonstrated uniform distribution of the internal stresses. Although all tests have been carried out at room temperature, there are no factors that would prevent these shutters to operate at cryogenic temperatures.

3. Double-shutter actuation design

Crucial part of the design is the actuation scheme. After examining various proposed designs, we selected an actuation scheme which we call "double-shutter" (Fig. 1b).

An embedded electronic circuit on the surface of the microshutter membrane will perform addressing. Double-shutter actuation allows to translate macro-motion of a large structure, the membrane itself, into micromotion of the shutters (Fig. 1b,c). To implement this, two identical microshutter arrays are rotated 180 degrees with respect to each other and brought in close physical contact. Addressing and selecting is performed electronically by applying a voltage between a shutter blade and its counterpart on the actuation membrane. Once blades are selected and engaged the whole actuation membrane is moved with actuators outside of the active area and all selected shutters open. De-selection will cause an open shutter to return back into the closed position (Fig. 1c, last frame).

4. Summary

The device being developed in this project will be a large format mask for astronomical multi-object spectroscopy. Major achievement from the technological point of view is the solution of the large deflection angles problem an a close-packed array of elements. Combination of the double shutter actuation scheme with electronic addressing allows random shutter access. Since our device works in transmission, it achieves minimal scattered light and maximum possible contrast of the spectra. Our further plans include developing small and then larger shutter arrays with testing these devices on the telescopes.

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References

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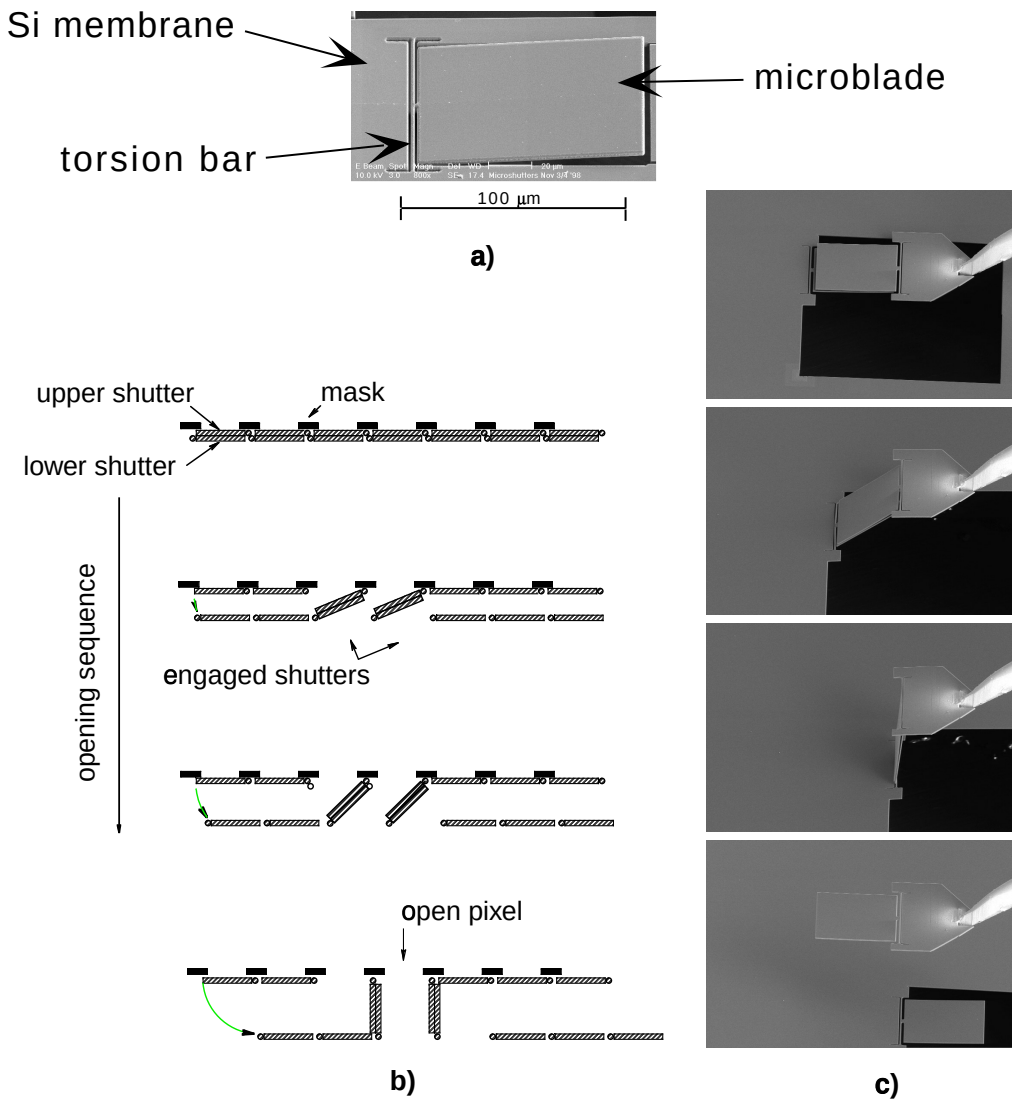

Figure 1. a) SEM image of a single shutter blade, b)Sequence of the microshutter opening (sideview). Microshutter blades are represented by the shaded rectangles. Shaded circles are torsion bars. Two blades are engaged to have one pixel open, c) Opening sequence of the single shutter model. Shutters first are brought to close contact, and a voltage is applied to engage the shutters. The lower shutter is attached to the bulk of a membrane, the upper shutter is welded to a needle-manipulator. The upper shutter is moved along the arc formed by the radius-vector connecting their torsion bars. Frame three shows the shutter blades at 90° to the membrane (full open position). After the voltage is reset, shutters return to initial position (frame four).