SURFACE MICROMACHINED RECONFIGURABLE MULTI-SLIT MASK

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TABLE OF CONTENTS

ABSTRACT

The concept of an electromechanically reconfigurable multi-slit mask has been proposed using a 3-poly surface micromachining technology. The fabricated prototype device consists of a 300μm by 1.2mm shutter along with a thermal actuator based stepper motor. The stepper motor has a 10μm stroke and consumes 300mW per cycle of operation. A flange-type guide rail design has been incorporated in the shutter to permit linear translation in only one axis.

INTRODUCTION

The general principle of the reconfigurable slit mask is illustrated in Figure 1. Each slit unit consists of a physical opening (slit) along with a sliding plate (shutter). An actuation mechanism (linear stepper motor) moves the plate such that the opening can be covered or uncovered electromechanically.

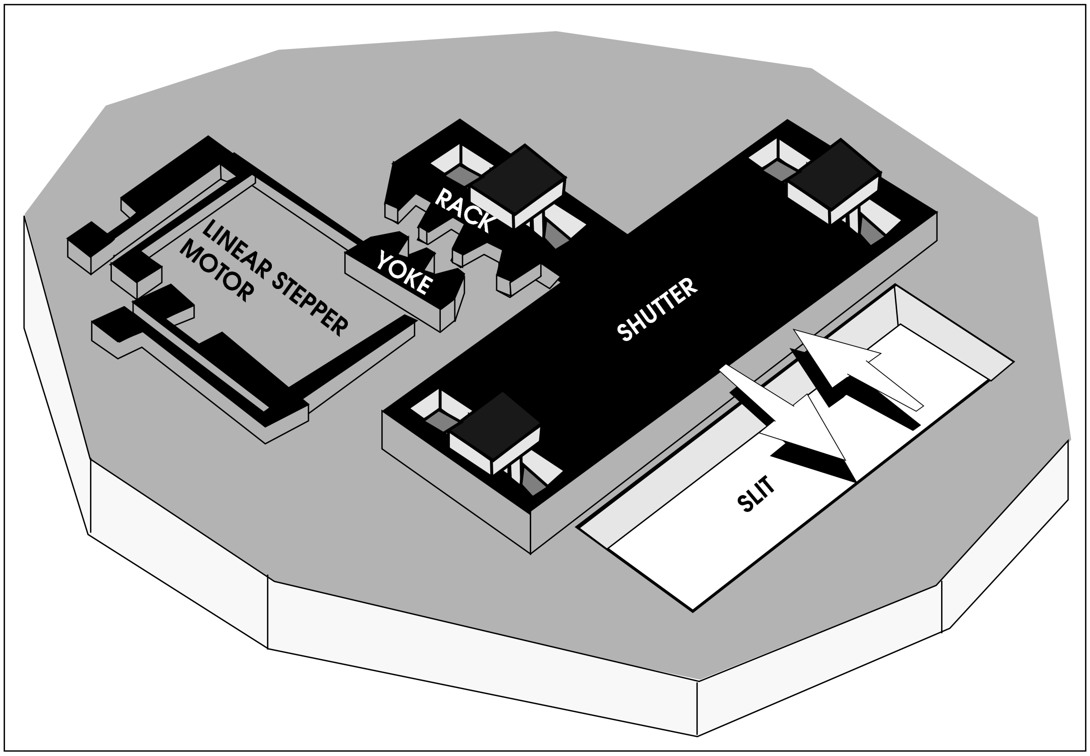

Figure 1. Reconfigurable slit mask layout

A two dimensional array of this design shown in Figure 2, would form a reconfigurable multi-slit mask for MOS studies.

Each shutter is addressed by row/column decoding techniques using integrated diffusion type diodes. Diodes act like switches and are turned on when a forward biasing voltage is applied across them. As is shown in Figure 3, diodes connected in series with the actuators are connected between each overlapping row and column line. By powering and grounding the appropriate lines, the required actuators can be turned on or off.

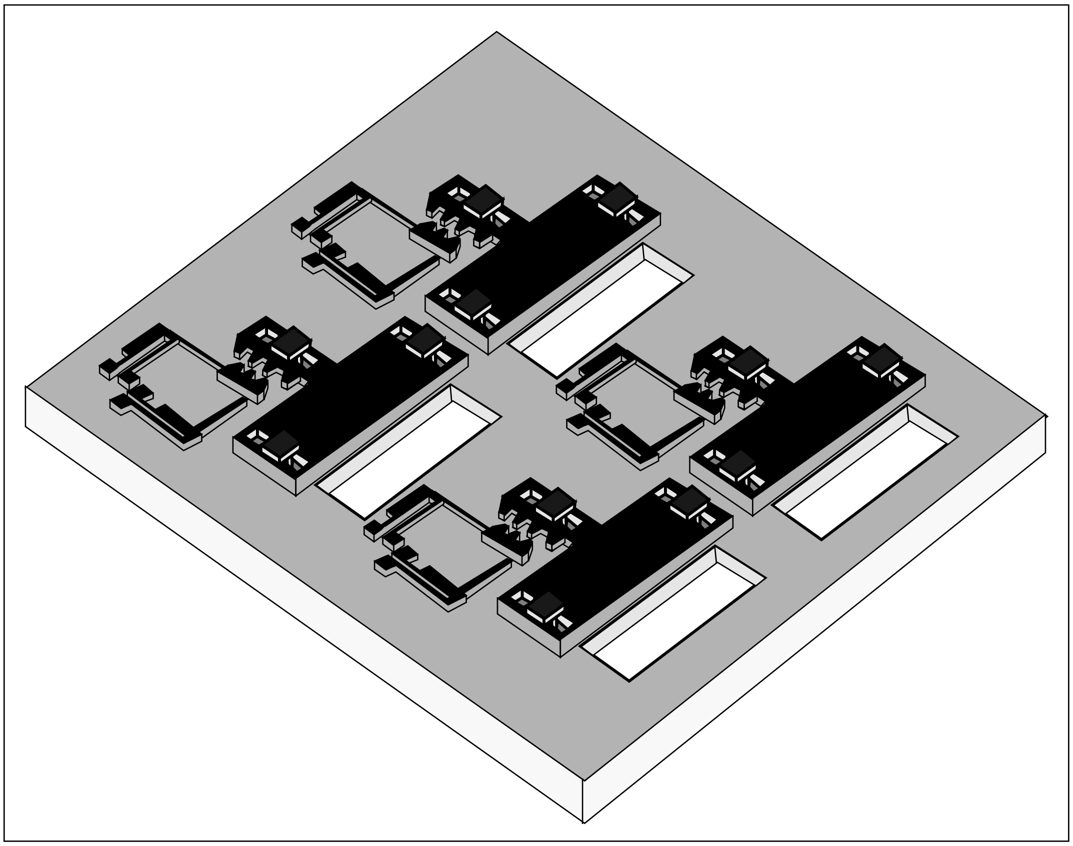

Figure 2. Multi-slit mask

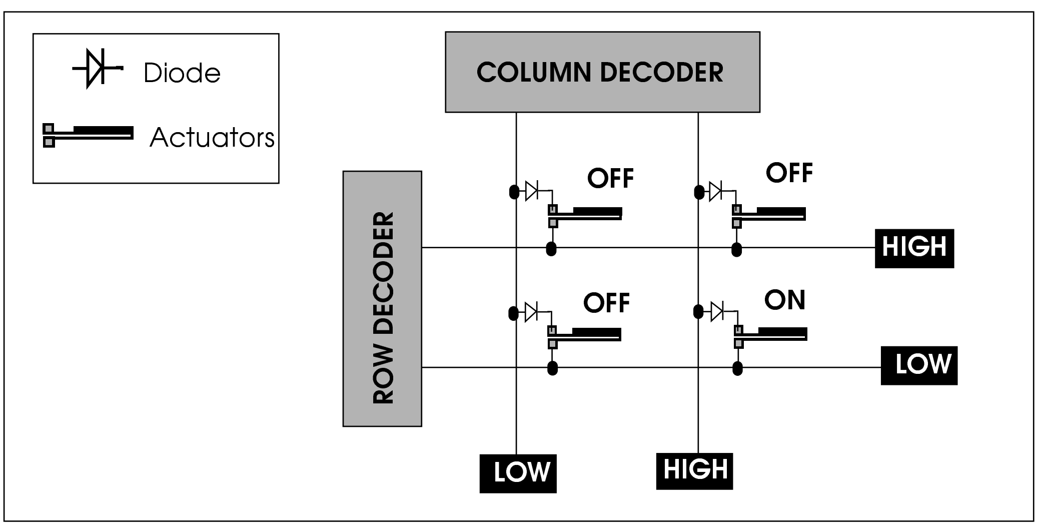

Figure 3. Row/Column addressing of individual actuators

The row/column decoding technique permit one set of actuators to be turned on at a time. Hence, the total time taken to open/close multiple shutters is a sum of the time taken by individual shutters.

Until now, we have designed and tested individual shutters with a built-in actuation mechanism. The following sections of this report discuss the design and test results of the work we have performed so far.

DESIGN

The design of the shutter and actuation mechanism is based on a 3 polysilicon layer surface micromachining technology [1]. The design is a combination of a sliding shutter with an actuation rack and a linear stepper motor as shown in Figure 1. The stepper motor consists of two orthogonally placed thermal actuator arrays connected to a yoke. The yoke and actuation rack have mating teeth structures to couple the motor with the shutter. By timing the two actuator arrays appropriately, the shutter can be moved in either direction as shown in Figure 1. Under quiescent conditions, friction between the shutter and the underlying substrate is used for locking the shutter in place [2].

Overview of the 3 poly surface micromachining technology

Surface micromachining refers to fabrication of mechanical structures on the surface of a silicon wafer using processes adapted from the IC fabrication techniques. Three dimensional structures are constructed by depositing multiple layers of poly (polysilicon) separated by glass (SiO_2) on the wafer. After processing is complete, glass is etched away leaving only the poly structures remaining as shown in Figure 4. The complexity of mechanical structures that can be constructed by this technique is dependent on the number of structural poly layers available. The prototype shutter/actuator was constructed using the commercially available 3 poly process called MUMPS provided by MCNC, North Carolina [1].

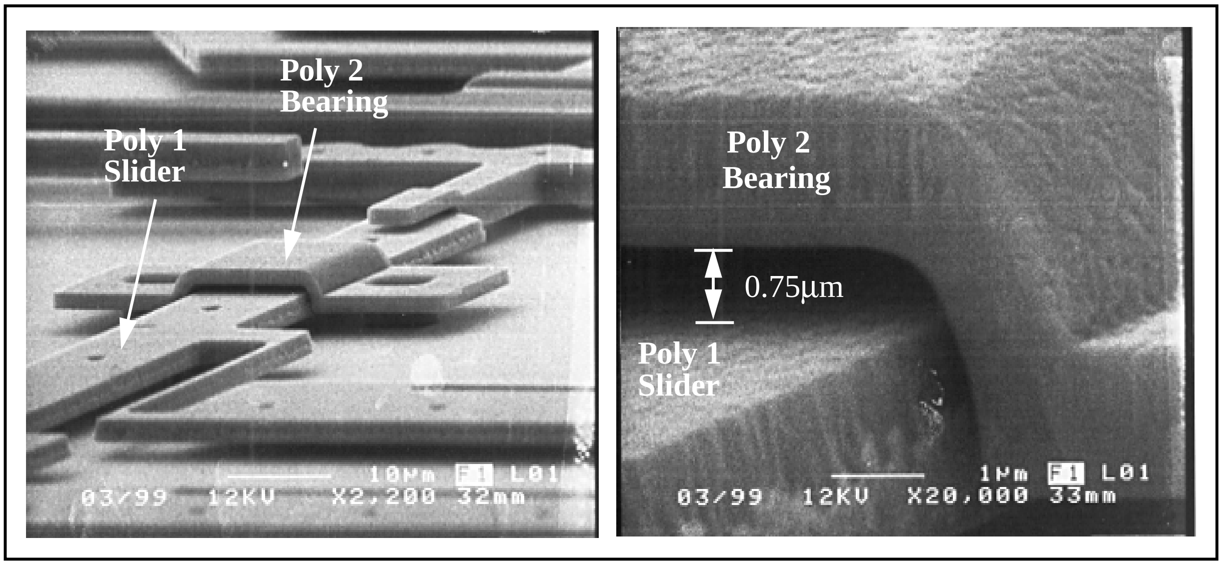

Figure 4. (a) SEM micrograph of a surface micromachined poly 1 slider and a poly 2 bearing (b) Enlarged view of the slider/bearing separation

Shutter Design

The designed shutter is a 300µm by 1.2mm rectangular plate made of POLY1. The toothed rack is connected along the central axis. This allows a uniform distribution of force to the shutter for actuation. In order to permit the shutter to translate in only one axis, three flange type guide rails, were incorporated (see Figure 5) [3]. As shown, two guide rails are placed along the shutter edges while the third one is placed at the center of the rack. These three guide rails allow the shutter to move in one axis and at the same time prevent the shutter form pivoting about its center of gravity during translation. The flange of the guide rail is made of POLY2 with a 0.75µm separation from POLY1.

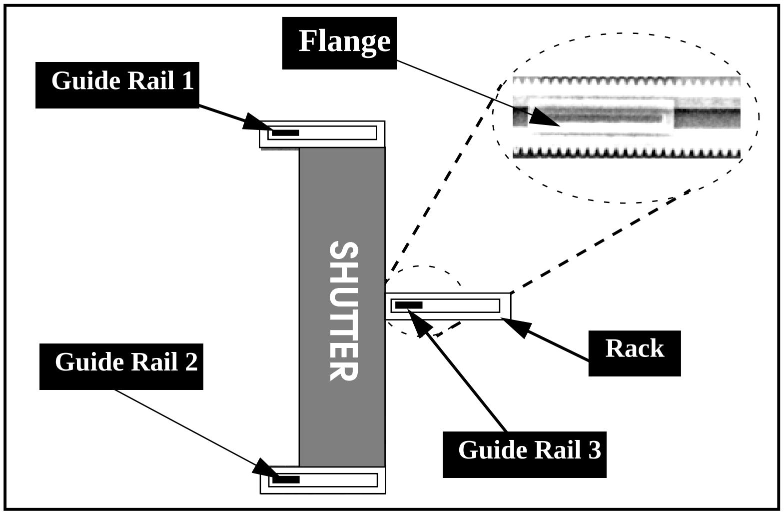

Figure 5. Shutter design

Linear Stepper Motor

The actuation mechanism is a linear stepper motor using thermal microactuators [4]. The actuators work on the principle of thermal expansion. The actuator is a U-shaped structure made of polysilicon with one arm wider than the other [5]. On passing a current through this structure, the narrower arm experiences a higher ohmic heating than the wider one. Consequently, the free end deflects as illustrated in Figure 6. Literature reports that such actuators are capable of generating around 5μN of force for 25mW of electrical power [6]. In order to attain greater driving force, these actuators can be coupled in a parallel arrangement [4].

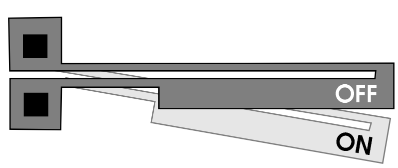

Figure 6. Operation of a U-shaped thermal microactuator

Figure 7 shows the layout view of the stepper mechanism. The mechanism consists of two sets of actuator arrays and a yoke. Array A consists of seven actuators and the array B comprises of 3 actuators connected in a parallel manner. The two arrays are arranged orthogonally and connected to the yoke via a flexure and a sliding joint. As a result of the orthogonal arrangement of the actuators, the yoke can be made to traverse in a clockwise or anti-clockwise path by appropriately timing the actuation signals.

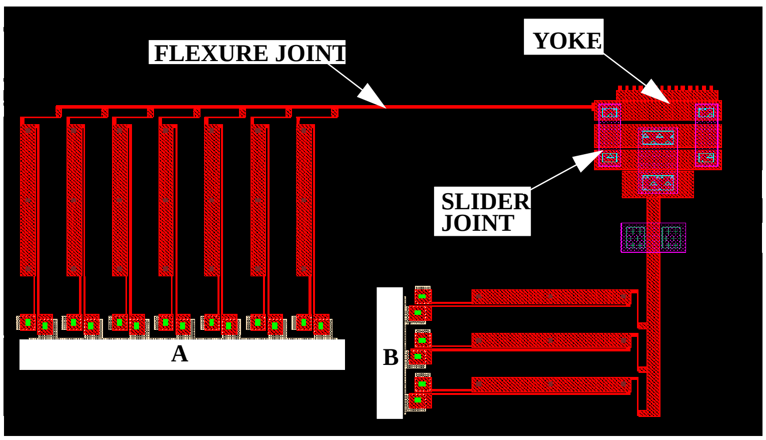

Figure 7. Linear stepper motor

The overall design is illustrated in Figure 8 and an SEM micrograph of the fabricated device is shown in Figure 9.

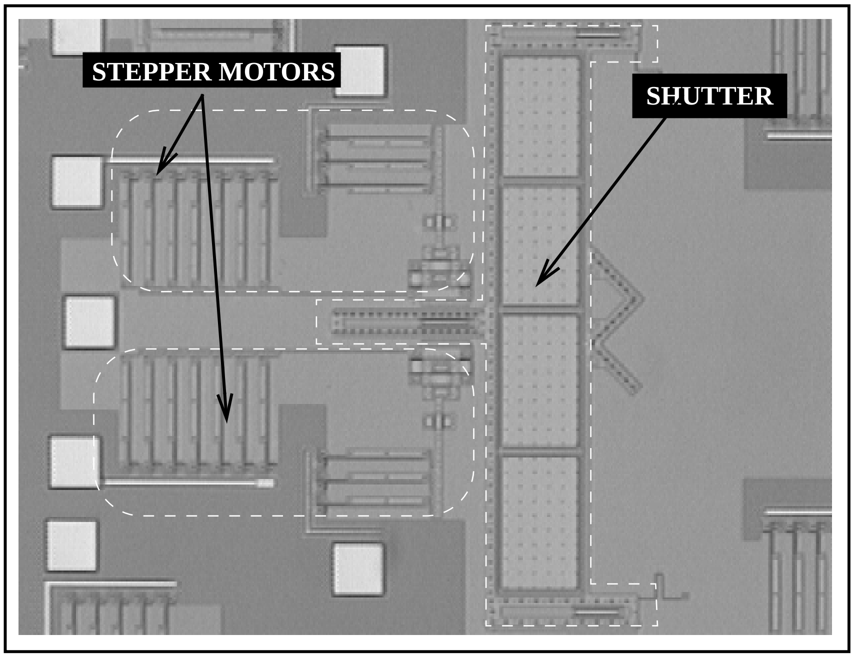

Figure 8. Micrograph showing the top view of the microshutter

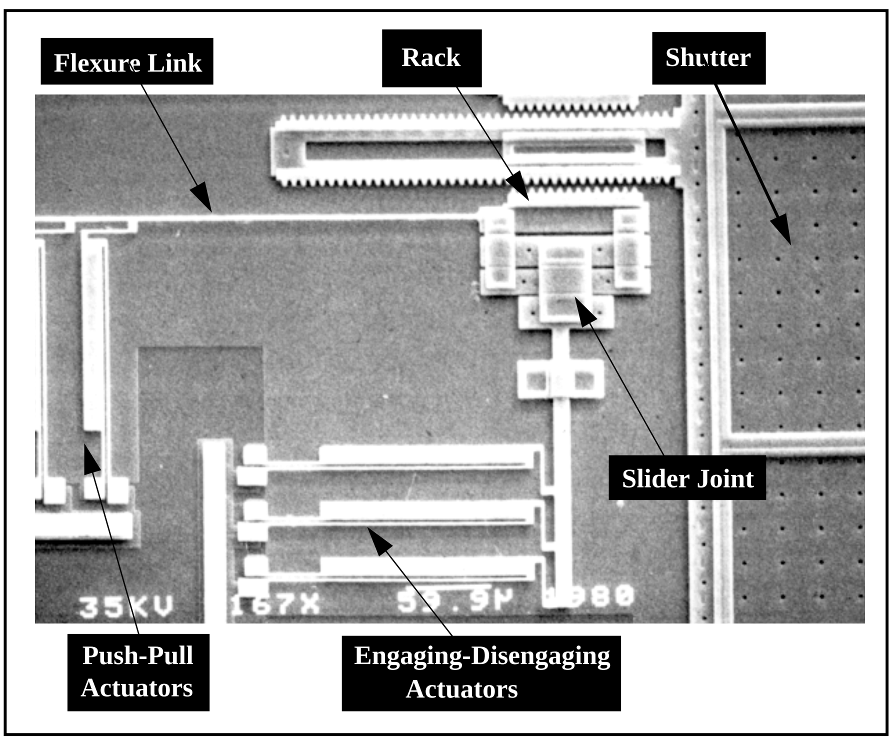

Figure 9. Scanning electron micrograph of the fabricated device

TESTING

In order to test the performance of the microfabricated shutter, an overlapping-phase test-signal was applied to the actuator arrays. The motion of the shutter was observed though an optical microscope. The two-phase signal was generated using a free running 555 timer circuit and a pair of T flip flop's as illustrated in Figure 10. In order to provide sufficient drive current, a single stage transistor switch was added to the output of the flip flop. The timer circuit was designed to operate at 1Hz so that the operation of the mechanism could be inspected visually.

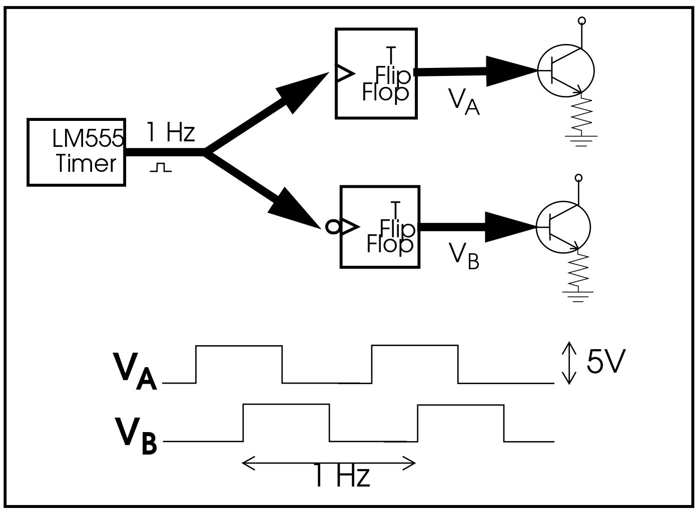

Figure 10. Schematic of timing circuit

The performance of thermal actuators is dependent on a number of design parameters [5,6]. Our actuators were seen to achieve their full stroke of 10µm while drawing 4mA at 6V. Actuator arrays however, being in a parallel connection, require a higher voltage signal to achieve the same stroke as individual actuators. To translate the shutter by 200µm, 20 actuation cycles were required with each cycle consuming approximately 300mW of power. For our design, a 7 actuator array provided sufficient force to overcome friction and drive the 300µm by 1.2mm shutter. However, further work needs to be done to characterize the force requirements of different sized shutters.

Problems Encountered

It was observed that reliable actuation can be provided to the shutter as long as the stroke of the actuators matched the pitch of the gear teeth (see Figure 11a). Any difference between the actuation stroke and gear pitch results in the tips of the rack and yoke teeth to line up with each other and prevent meshing of the teeth (see Figure 11b). Although this meshing problem can be avoided by electronically fine tuning the lateral stroke to match the teeth pitch, a rugged mechanical design would be preferred. New designs are being looked into to address this problem.

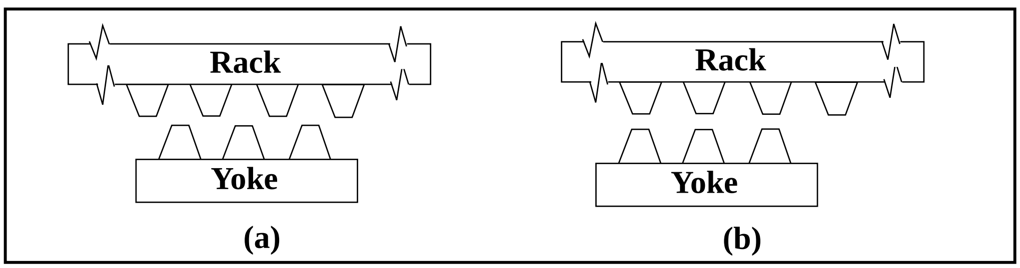

Figure 11. Teeth alignment during actuation for (a) proper meshing and (b) improper meshing

ONGOING WORK

A major concern with the present design is the low fill factor (ratio of slit area to the overall area) of 30%. Optimizing the present design will improve the fill factor but not by a dramatic amount. To take the fill factor closer to the 50% mark, we have redesigned the actuation mechanism. In the new design, vibrating thermal actuators are made to impact the sidewalls of the shutter. As shown in Figure 12, two pairs of thermal actuators are laid out at a 45^o angle to the shutter sidewall. The upper pair causes the shutter to slide up (uncover the slit) while the lower pair causes the shutter to slide down (covering the slit). The actuation mechanism is much simpler and requires lesser real estate. A prototype device based on this design is currently being fabricated.

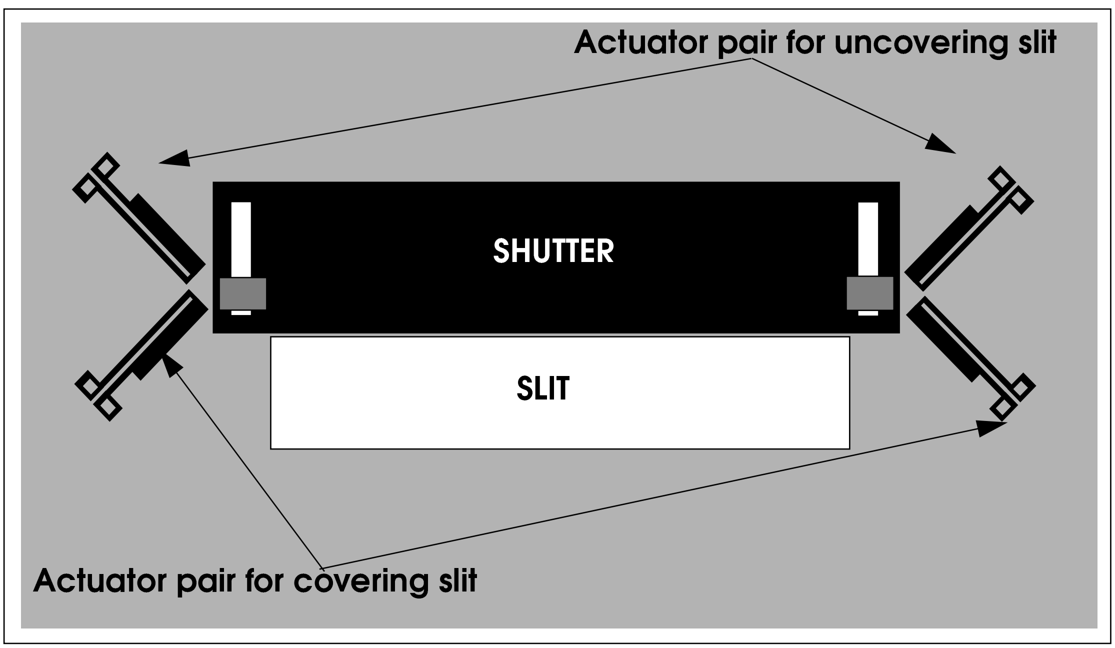

Figure 12. Vibromotor based actuation

CONCLUSION

We have demonstrated a prototype device using a thermal actuator based stepper motor combined with a slider mechanism to translate a shutter. A deep RIE silicon etch process can be combined with our design to create the opening and form the slits. This is being currently investigated. A new vibrating actuator based actuation mechanism has also being explored. The new actuation mechanism is much simpler and would result in a higher fill factor.

ACKNOWLEDGEMENTS

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