Development and Testing of New Micromachines

AN UNDERGRADUATE THESIS PROPOSAL SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR ENSC 498

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UNDERGRADUATE THESIS PROPOSAL

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TITLE OF PROJECT: *Development and Testing of New Micromachines*

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Abstract

Micro-Electro-Mechanical-Systems (MEMS), or more simply, micromachines, are believed by many people to be the next logical step in the silicon revolution. This relatively new technology exploits the existing microelectronics infrastructure to create complex mechanical devices with sizes of a few microns. These micromachines can provide functions such as sensing, communication, and actuation. Furthermore, extensive applications for micromachines can be found in both commercial and defence systems.

For several years, ENSC 494, a special topics course, has been offered to teach students about the design, fabrication, and testing of micromachines using MUMPs^{TM} technology offered by CRONOS. The Multi-User MEMS Processes, or MUMPs, is a well-established commercial program that provides the international industrial, governmental, and academic communities with cost-effective access to surface micromachining. During the summer of 2001, I took ENSC 494 and was among the class of students who designed 3 new sets of surface micromachines, namely the gear, the bi-stable switch, and the vertical mirror designs.

In my thesis, I will briefly describe each of the designs and focus on the testing results of these micromachines. Possible explanations for each outcome will be given and discussed in detail. Although it turns out that all 3 newly designed micromachines seem to have their shortcomings, the work involved in my thesis will prove to be an asset in further research of surface micromachining using the same type of technology.

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1. Introduction

The work involved in my thesis is a continuation of the three projects done in ENSC 494, a Special Topics Course, offered in the summer of 2001. During that summer, the class of students were asked to search for new ways of designing three different types of micromachines (gear, bi-stable switch, vertical mirror), since all previous designs of theses micromachines had failed so far. Using the MUMPS™ technology offered by CRONOS, various approaches had been tried, and three new sets of designs for the micromachines were sent to CRONOS for fabrication at the beginning of September 2001.

Nevertheless, the three projects initiated in ENSC 494 are yet to be completed. After the fabrication process, these designs need to be tested against the expected outcomes and the final results need to be investigated. Being part of the two teams who designed the bi-stable switch, I possess the technical expertise necessary to carry out the unfinished tasks left behind by the course. In my thesis, I will test and investigate all three sets of micromachine designs, seeking results and possible explanations.

The Multi-User MEMS[1] Processes, or MUMPs™, is a well-established, commercial program that provides the international industrial, governmental and academic communities with cost-effective access to surface micromachining. MUMPs, a program offered exclusively by CRONOS, is designed for general purpose micromachining by various users who wish to design and fabricate MEMS devices. Since its inception in December 1992, MUMPs has become the industry standard for surface micromachining with more than 150 commercial, government and academic organizations worldwide utilizing MUMPs for prototyping activities and a seamless transition into manufacturing. MUMPs is a three-layer polysilicon surface micromachining process involving the methods of deposition, pattern, and etching.

[1] MEMS = Micro-Electro-Mechanical Systems, also referred to as micromachines.

2. Designs & Functional Specifications

Using Cadence, three groups of people from ENSC 494 designed three different types of micro-machines to accomplish individual goals. The following discusses the functional specifications of each design.

2.1 Mechanical Gear Design

The first set of micromachines, designed by the group Lone Ranger, is the basic MEMS motor, consisting of a gear and an actuator. In this design, the actuator used is a linear thermal actuator, also called a *heatuator*. The linear actuator has some type of hook, pawl, or shuttle at the displacing end, which is intended to mesh with the gear and rotate it as the actuator bends. Quick and close repetition of actuation and release (returning to the original position of the actuator with respect to the gear) will give the gear a semblance of continuous rotating motion, though in reality, it is stop-and-start.

Similar implementations for micromachined gears were made in the past when ENSC 494 was offered. However, no success was achieved in those designs due to several design mistakes. The most prominent mistake made was the use of single polysilicon thickness gear teeth, resulting in the teeth slipping under the shuttle/hook of the linear actuator.

In order to solve the problem, double polysilicon thickness gear teeth are employed, and the shuttle/hook of the linear actuator are reinforced to provide greater torque. Furthermore, other possibilities of implementing the design are tried out. Some of these implementations also include either an active or passive *stopper* which is a separate pawl activated at an angle 180 degrees opposite to the pawl/shuttle activation. These active or passive stoppers hold the gear at a specific orientation to help the pawl/shuttle-to-tooth matching on the subsequent actuation.

One of these implementations is shown in Fig.1. The mechanism above the leftmost gear is a toothed shuttle, which is to move to the left, move upwards (according to Fig.1), release horizontally (moves to the right), and then release vertically (comes down), in order to create a *four squares* movement.

Because gears are the fundamental elements to many larger scale mechanical designs, the success of this project will bring about many future design possibilities in surface micromachining via MUMPs technology.

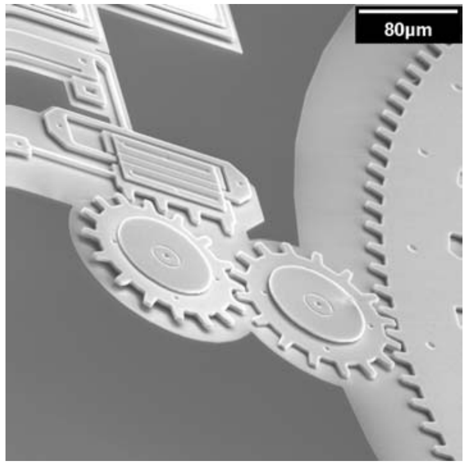

FIG.1: MICROMACHINED GEAR DESIGN (PHOTO COURTESY OF SFU IMMR)

Many other variations to the design shown in Fig. 1 are built and fabricated. All of these gear designs will be carefully tested, and the results will be reported.

2.2 Bi-Stable Switch Design

The second set of micromachines, designed by the group Team Slayer, consists of bi-stable switches. Technically speaking, a bi-stable switch is any switch that can toggle between two stable states in response to momentary applications of force. In other words, the switch should provide two stable output levels using a single input action that requires no knowledge of the prior switch state. The property of needing only momentary actuations makes bi-stable switches useful in many applications.

A classic example of a micromachined bi-stable switch application is found in the optical routers of a fibre-optics communication network. Frequently, the optical routers use a mono-stable switch, which rests at one stable state when no power is applied and a second unstable state when a constant input of power is applied and maintained. The use of such a mono-stable switch has the disadvantages of high power consumption and increased heat dissipation. A more convenient and economically beneficial design would be the one that employs a bi-stable switch, which can change from state to state via a single actuation. Many other similar applications of a bi-stable switch can also be found in telecommunication.

The proposed design from Team Slayer for a bi-stable switch involves a ratchet wheel (centre), a rectangular platform with a protruding bar (top), a pawl (right), and a lever arm controlled by linear actuators (left). The conceptual diagram of this bi-stable switch is shown in Fig. 2.

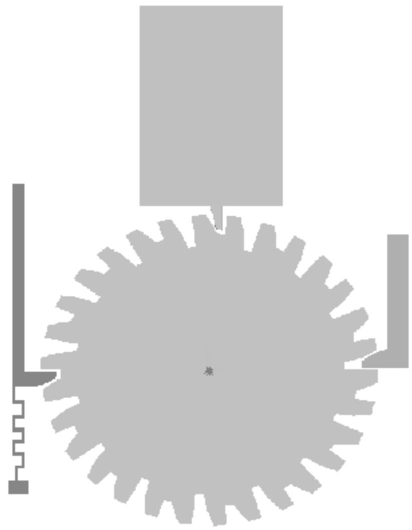

FIG. 2: MICROMACHINED BI-STABLE SWITCH DESIGN

The ratchet wheel at the centre of Fig. 2 has been designed so that every second tooth is deeper. Because of this deep-shallow tooth design, depending on the resting position of the protruding bar, the platform will have different heights representing one of the two stable states. Clearly, this configuration does not allow for the wheel to move freely because the protrusion of the platform will cause the system to bind. Moreover, the pawl on the right will lock the wheel in position, ensuring that the two states are stable.

The sequence of activation for which the bi-stable switch will move is as follows:

1. Pull out the platform from the ratchet wheel.
2. Engage the lever arm on the left.
3. Move the lever arm upwards, hence rotating the wheel by one tooth.
4. Disengage the lever arm, returning to the starting position.
5. Release the platform.

Several alternative implementations to the design shown in Fig. 2 are also fabricated. All these implementations will be tested and investigated.

2.3 Vertical Mirror Design

The third and final project, designed by the group Vertically Challenged, deals with the development of a micromachined mirror that can be raised vertically. The idea is to build a shiny metal surface capable of reflecting and redirecting optical signals, and through some kinds of linear actuation force, the metal surface can rise vertically to certain desired angle.

A design like the vertical mirror is very desirable in the optical communication world. It can be used as a mean to change the angle of a reflected beam in multiplexing and de-multiplexing optical signals.

In the previous design of the vertical mirror, a linear stepper motor was used to provide long-range horizontal movement. A linear stepper motor is a micromachine that makes use of two banks of linear actuators to provide consistent horizontal displacement. A schematic diagram of a linear stepper motor is shown in Fig. 3.

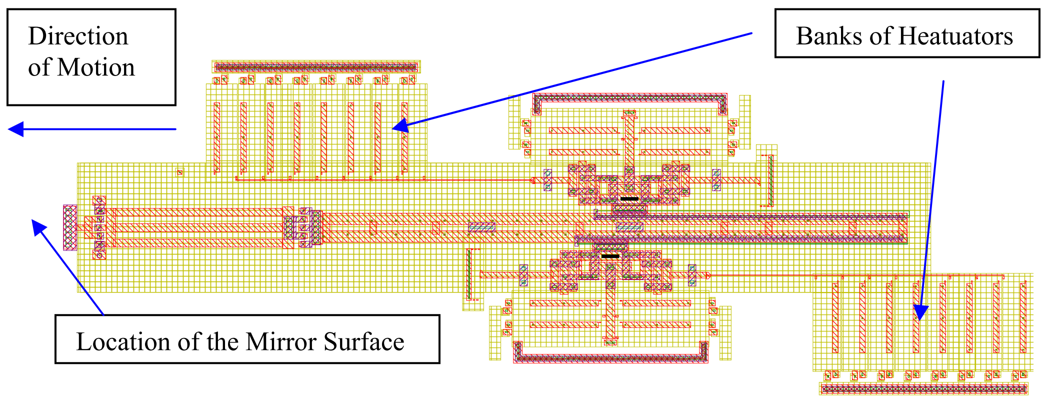

FIG. 3: DIAGRAM OF A LINEAR STEPPER MOTOR

Though this design seems very feasible, an error is incorporated within the fabrication process. During fabrication, the joint between the mirror and the stepper motor would sag down due to topography and etching (shown in Fig. 4). As a result, the mirror is stuck and the horizontal force from the stepper motor cannot move the mirror. To overcome this problem, an initial upward vertical force applying to the joint is desired in order to raise the mirror to a position ready for the stepper motor (see Fig. 5).

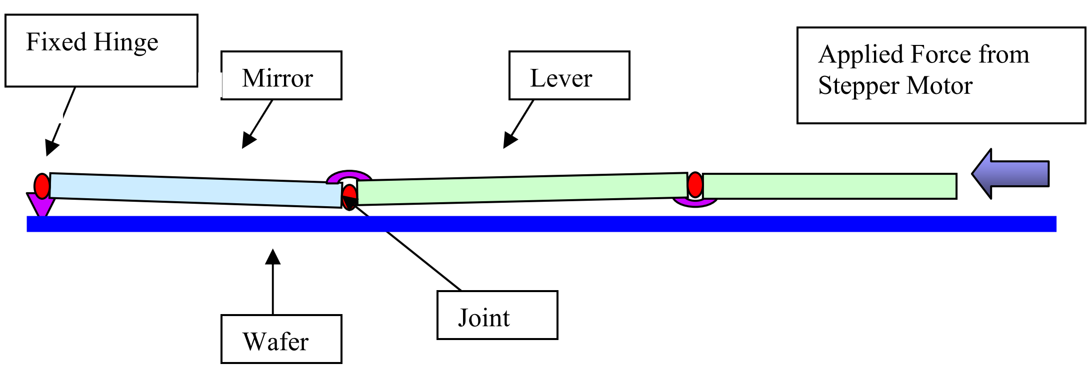

FIG. 4: A SAGGED MIRROR DESIGN DUE TO FABRICATION

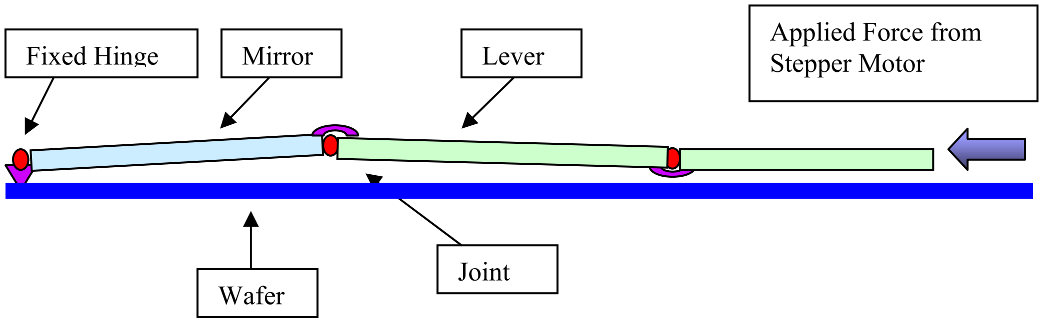

FIG. 5: A MIRROR AFTER THE INITIAL VERTICAL LIFT

The solution proposed to provide the initial vertical force is to design a vertical heatuator as opposed to the conventional heatuator, which can only provide horizontal movement. One way of designing such a vertical heatuator is to use a different arm thickness to provide a different thermal expansion when electric current is applied (similar to the way a conventional heatuator is built). But this time, the thinner arm is sitting on top of the thicker arm (refer to Fig. 6). When an overdriven current is applied, the heatuator will bend downwards and undergo a plastic deformation such that when the current is removed, the heatuator will snap upwards.

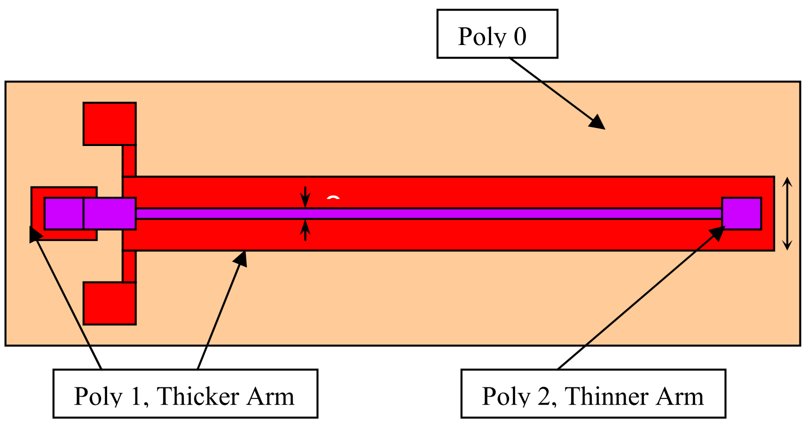

FIG. 6: EXAMPLE OF A VERTICAL HEATUATOR

Two vertical heatuators similar to the one shown in Fig. 6 will be placed underneath the joint between the mirror and the stepper motor. A complete design of the vertical mirror with vertical heatuators is shown in Fig. 7.

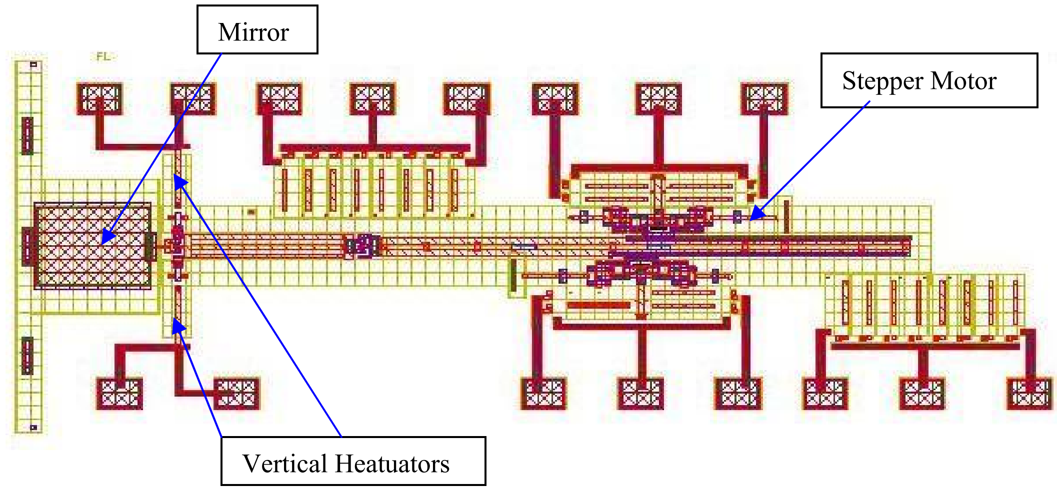

FIG. 7: MICROMACHINED VERTICAL MIRROR DESIGN W/ VERTICAL HEATUATORS

Several other implementations of the vertical heatuator are also made. All of these implementations will be tested and the results will be investigated.

3. Testing Procedures & Schedule

3.1 Testing Approach

After the designs are fabricated by CRONOS, they will arrive in several packages. Each package (or chip) will contain all of the various implementations for all of the designs. The reason for making several copies of the designs is to account for possible fabrication defects as well as any mistake that might be encountered during testing.

All testing will be performed inside the clean room of ENSC. The testing of each design will be carried out in two main steps.

Step 1: Bonding

Before the designs can be tested, proper electrical connections must be made. To do so, a **Bonding Machine** will be used to connect the electric pads on each implementation with the electric connection on the border of the chip. The electric connections on the border of the chip are in turn connected to the pins of the chip.

Step 2: Applying Power

When the implementations are properly bonded, power will be applied through a power source. Depending on the specific design and implementation, a voltage ranging from 4 Volts to 15+ Volts will be applied. The results will be observed under a microscope.

3.2 Schedule

The testing of the three designs will be performed in sequential order rather than simultaneously. In other words, all implementations of the same design will be tested before the test of the next design will take place. This way, all results and data can be easily reported and managed.

The schedule for the entire project is shown in Fig. 8, in the form of a Gantt chart.

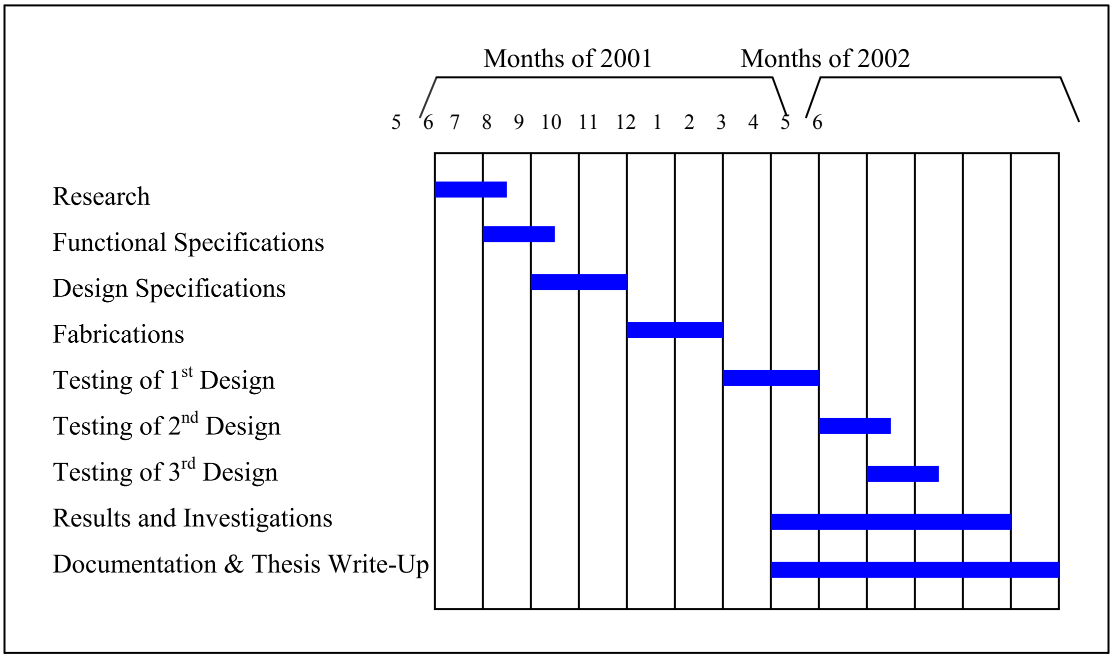

FIG. 8: PROJECT SCHEDULE FOR MY UNDERGRADUATE THESIS

The intended completion date for my thesis project is the end of April 2002. My thesis defence will take place somewhere in the middle of May 2002.

3.3 Budget

Since all design and fabrication costs will be covered by the course, ENSC 494, and all testing facilities are available in the clean room, no external funding is required for my thesis.

4. Conclusion

The work of my thesis will most certainly wrap up the unfinished tasks left behind by the groups in ENSC 494. Most importantly, regardless of the outcome of the testing, the results of my thesis will have a significant impact on the students and other interested people who are trying to design and fabricate surface micromachining devices, using the MUMPS technology offered by CRONOS.

If the results of my work turn out to be positive, then these designs can be used as building blocks for more sophisticated micromachines in the future. The applications for such micro-machines can range from research in the laboratory to products targeting the telecommunication and optical communication markets. Clearly, the work in my thesis will be a valuable asset to many people in the field of surface micromachining.

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