FABRICATION OF MICROMECHANICAL DEVICES: PIN JOINTS, SLIDERS, SPRINGS, AND MICROMOTORS

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ABSTRACT

Movable pin joints, springs, sliders and motors have been constructed using silicon fabrication technology. The movable mechanical elements are built using sacrificial layers that are later removed to allow translation and rotation of the structures [1]. The devices obtained physical movement and the rotors of the motors spun with compressed air, but electrical rotation of the motors was not accomplished.

INTRODUCTION

Micromachining will become a very important part of integrated circuits and miniaturization in the near future. At present, the only constraint holding back the miniaturization of sensors and actuators are the physical sensors themselves. Many of the materials and processes needed for integrated circuit processing can be modified to create microsensors and actuators. These structures complement the IC process and provide a way to incorporate mechanical motion with electronic control [1]. This may lead to a new class of microsystems having significant impact on engineering design [2].

Several structures of interest to this project have been designed and fabricated using micromachining techniques, such as pin joints, sliders, springs, and the most complex, a micromotor [1]. The basis of micromachining fabrication is to etch away sacrificial layers in order to produce free structures. These structures can then move to perform mechanical tasks.

A pin joint is formed by etching a circle with a hole in the center out of a polysilicon layer on oxide. Depositing or growing another layer of oxide, etching a hole through the underlying oxide in the center of the circle, and adding another layer of polysilicon will form the hub and holds the joint to the substrate. Etching all of the oxide away allows rotation. A slider is formed by building guides along the sliding member to prohibit movement in that direction. The springs are simply a linear strip of polysilicon attached to the substrate at one end. The micromotor is a glorified pin joint, with the addition of rotors and stators for electrical control. Figure 1 shows the cross sections and aerial images of a pin-joint, slider, and motor.

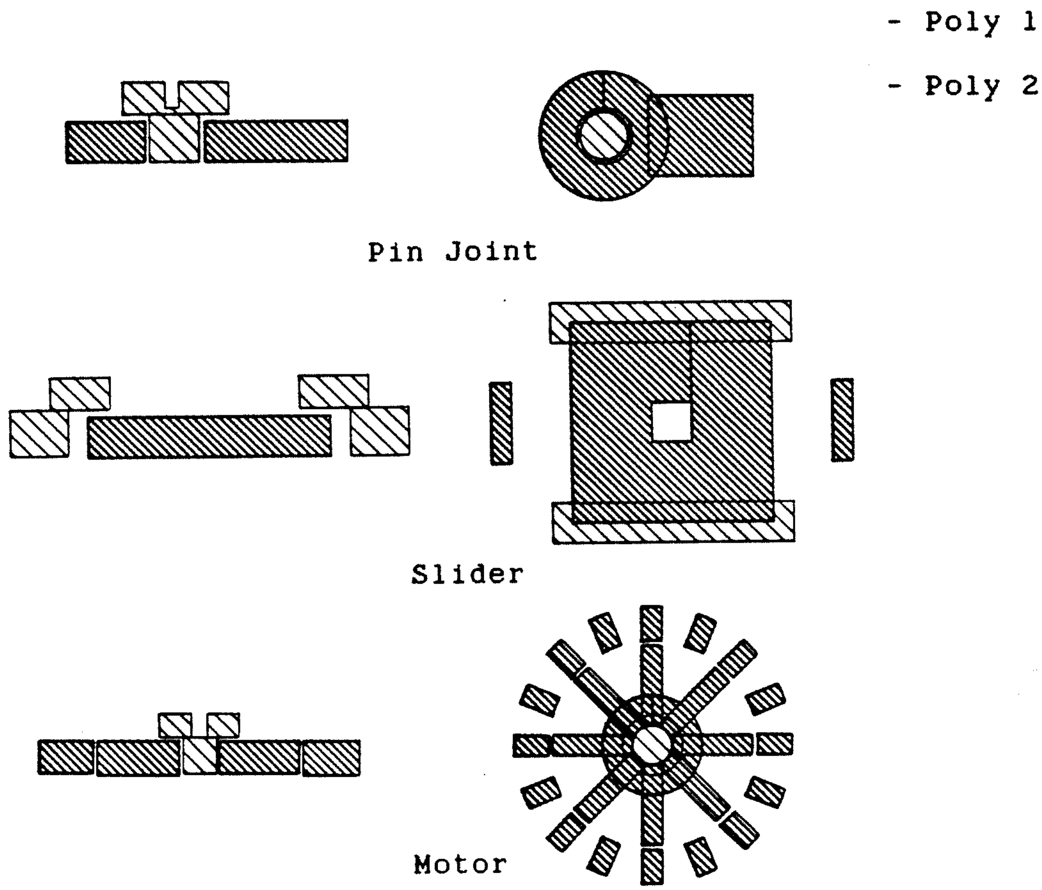

Figure 1: Cross sections and aerial images

The electrical rotation of the motor can be accomplished by the application of a potential to opposing stators while the remaining stators are grounded. This induces a charge on the rotor poles which, when the potentials on the stator poles are indexed to the neighboring site, creates an attractive force causing the rotor to follow the field. When the potentials are applied sequentially around the stators, a continuous rotation can occur. This is shown graphically in Figure 2 [3,4].

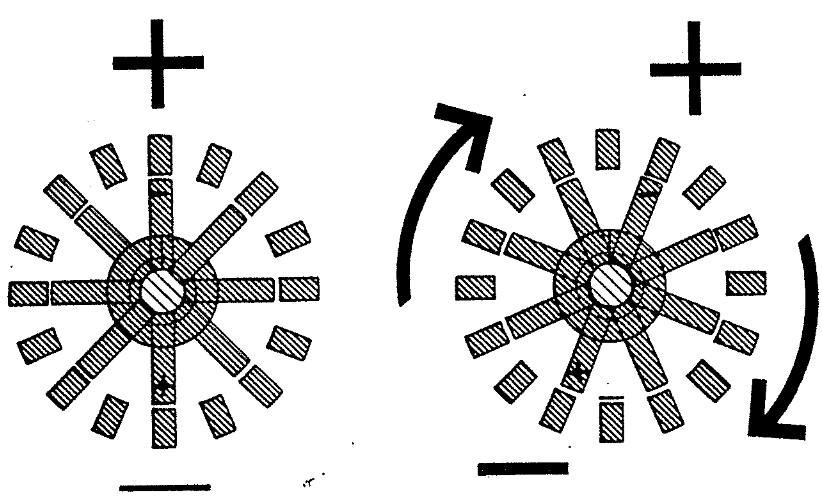

Figure 2: Rotation of the Motor

The original motor constructed by Fan, Tai, and Muller at the University of California, Berkeley, is shown in Figure 3 [5]. It consists of two polysilicon layers and two sacrificial oxide layers. This motor did turn electrically, but only with potentials in excess of 100 volts across the rotor/stator gap. It can be seen in this design that friction between the rotor and substrate would play a significant role to restrict the turning as well as possible columbic forces between the rotor and the substrate.

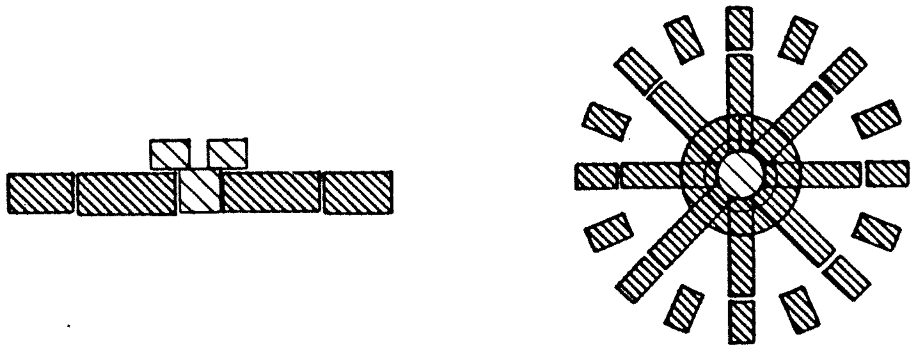

Figure 3: Fan, Tai, Muller Motor

In an effort to reduce these factors, additional design and processing steps were taken. Previous projects at RIT have attempted to lessen the frictional forces [3], but these were not used and an entirely new design was incorporated. In addition, the purely mechanical elements were fabricated on-chip. The friction of the rotor is reduced by the addition of stand-off bumps on the rotor and the charges reduced by the addition of a ground plane which would isolate the structure from the substrate. This ground plane is made of nitride over oxide, which would protect the motor from both electrical and dopant sources in the substrate. A cross section of this new design, inspired from others already created, is shown in Figure 4 [1,2,5,6].

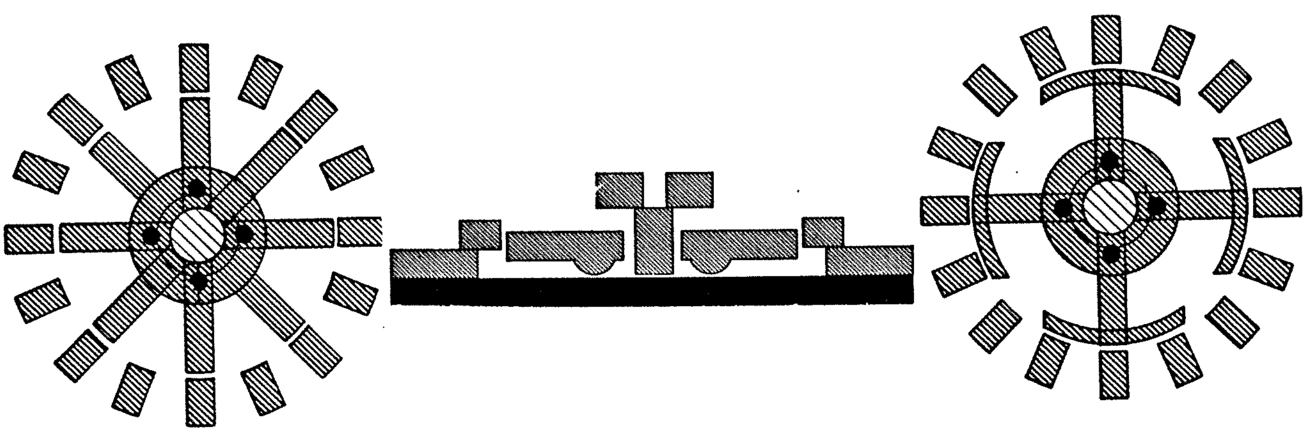

Figure 4: New Design of Micromotor

EXPERIMENT

The micromotor and other structures were constructed on an Apollo computer system using Mentor Graphics Chipgraph design program. A master reticle set was created using a Mann 3000 pattern generator with five inch emulsion plates to be used on a GCA 4800 stepper. A total of two different designs of the motor were created, along with pin joints, springs, and a slider.

Ten 3 inch silicon wafers were used in the processing, five for a polysilicon hub for the motor and five for a nitride hub. Figure 5 provides a graphical view of the step by step fabrication. An oxide layer and a nitride layer was deposited to form the ground plane (5a,b). A spin on glass was used to form the sacrificial oxide (5c). This layer was patterned and etched to form a base and standoff bumps were etched in the oxide (5d). Polysilicon was deposited and highly doped (5e). At this step, the wafers warped and could no longer be used. The next steps would have been performed to complete the processing. A spin on glass layer was used as another sacrificial oxide, and the hole for the hub was etched (5f). The last polysilicon layer was deposited and patterned to form the hub (5g). All the oxide was etched to release the rotor and allow rotation (5h).

Because of the warping problem, eight new wafers were started. The ground plane was eliminated along with thermal oxide being used instead of spin on glass. All of the hubs are now going to be made of polysilicon instead of half polysilicon and half nitride.

One micron of oxide was grown on the wafers using 1200 degrees C for 100 minutes in wet oxygen. The lithography step patterned the bases for the motors, and a 12 minute BOE etch was sufficient to etch the oxide. A second mask was used to pattern the standoff bumps and the wafers were etched for five minutes in BOE in order not to etch through all of the oxide. Two microns of polysilicon was deposited using a 240 minute deposition time. Emulsitone N-250 diffusion source was used to dope the poly n-type. The source was spun for 10 seconds at 3000 rpm and prebaked for 15 minutes at 140 degrees. The drive in consisted of 15 minutes at 1100 degrees followed by a HF dip to remove the remaining source. The polysilicon was patterned and etched using the Tegal 700 with a chemistry of 10 sccm SF_6 and 3.3 sccm O_2. The wafers were etched for 1.5 minutes, rotated 180 degrees and etched for 1.5 minutes longer. 5000 Angstroms of oxide was then grown at 1100 degrees for 60 minutes in wet oxygen. This was patterned and etched in BOE for 14 minutes to clear the hole for the hub of the motors. A final polysilicon deposition for 180 minutes produced 1.5 microns of polysilicon. This layer was patterned and etched in the Tegal 700 as before to form the hub of the motors. Finally, a 3.5 hour etch in BOE released the structures from suspension in the oxide.

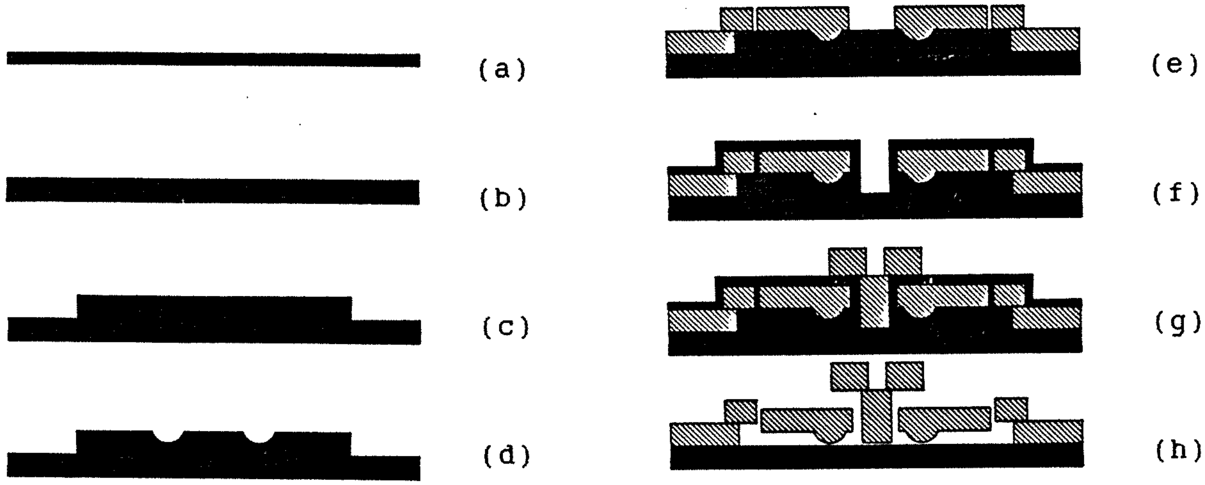

Figure 5: Process Description

RESULTS/DISCUSSION

The final oxide etch to free the polysilicon structures took 3.5 hours and upon inspection under a microscope, some of the structures showed visible rotation. With the use of a probe tip, the devices could be mechanically moved, although this usually resulted in the destruction of the structures from the lack of precision needed to move something in these dimensions. After noticing a rotor of a motor that was visibly free, rotation was attempted with compressed air. Being that the diameter of the rotor was approximately one third that of the compressed air nozzle, precise direction of the air blast was difficult. Once obtained, the rotor spun freely, appearing as a blur under the microscope. This was attempted for the other motor design and similar results were seen.

The final test administered was that of electrical movement of the motors. Equal but opposite voltages were applied to opposite stators and immediately significant current was being drawn, which limited the amount of voltage able to be obtained. According to the design, no current should flow. It was determined that when the polysilicon layer for the rotor/stator was doped, the dopant diffused into the substrate which caused the substrate to be conductive, in essence shorting the stators together.

The other devices, namely pin joints, sliders, and springs, were also tested. The springs had little contact to the substrate and any attempt at movement produced breakage of the springs. The series of connected pin joints provided more resilience upon movement, but eventually broke. The single pin joint swiveled around its hub perfectly, while the slider was still restrained and would not move.

After the tests were completed, scanning electron microscope photographs were taken of all the structures. These photos showed a number of design flaws which were not noticed during the

design of the reticles. Photo 1 shows that the guides for the slider were designed to be too long and they prohibited the slider from moving. If these restraints were shorter than the slider, it would move in the proper way. The springs had no contact to the substrate and subsequently floated away when the final oxide was etched. Photo 2 represents the attached pin joints, and they did not rotate and translate as expected because the connecting members were all made of the same layer of polysilicon. The members should have alternated between first and second layer polysilicon so the joints would work correctly. If these changes were made to the designs, and the doping time was lessened, all of the structures would work without any problem.

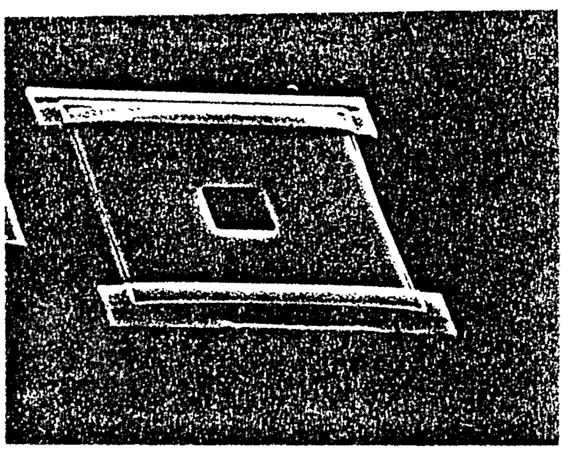

Photo 1: Slider

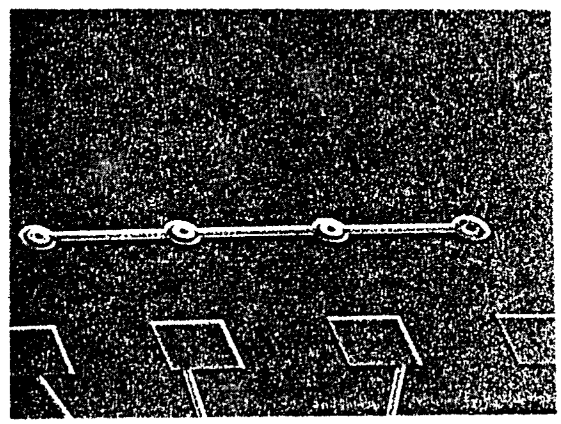

Photo 2: Connected Pin Joints

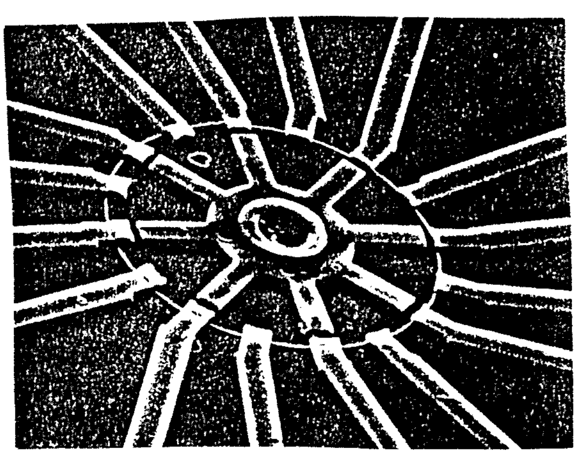

Photo 3: Motor 1

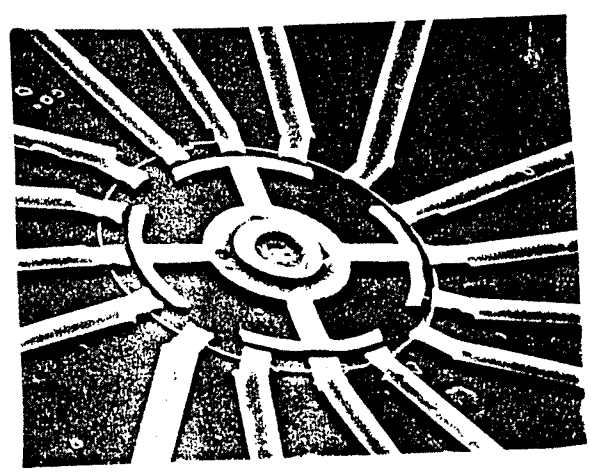

Photo 4: Motor 2

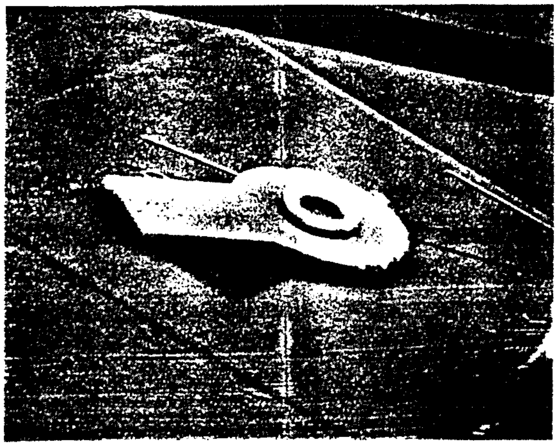

Photo 5: Single Pin Joint

CONCLUSIONS

A single pin joint, connected pin joints, a slider, springs, and two versions of a micromotor were designed and fabricated. Mechanical rotation of the rotors for both motors was obtained using the force of compressed air, but electrical rotation was not completed due that the substrate was conductive from the doping of the rotor/stator polysilicon layer. The single pin joint rotated about its hub as designed, but design flaws in the connected pin joints prohibited their movements. The side restraints on the slider were too long which pinched the ends of the slider and restricted movement. The springs had little contact to the substrate and separated easily when mechanical force was applied.

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