MICROMACHINING: THE FABRICATION OF A MICROMOTOR

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ABSTRACT

Micromachining techniques were used to fabricate two versions of a small electromechanical device, a Micromotor. This structure, originally developed by a pair of graduate students at the University of California at Berkeley, then modified by a fifth year student a Rochester Institute of Technology, was formed through multiple polysilicon depositions. After an etch of approximately two hours, the rotors were shown to have released, and moved by mechanical means, however, movement was not achieved through electrical means.

INTRODUCTION

Micromachining is a newly emerging field in which Integrated Circuit processing techniques are utilized to fabricate miniature mechanical devices on a semiconductor surface through the selective removal of material. Much of the research that has been done in this field has been involved with the formation purely mechanical devices, such as diaphragms, springs, cantilever beams, and gear wheels, which can be used to form sensors and actuators, however, the potential usefulness of these devices increases dramatically when the electrical properties of the semiconductor material are also considered [1,2]. By utilizing both the electrical and mechanical properties of the semiconductor, an intimate link can be created between controlling electrical devices and slave mechanical structures, which are both located on a single chip. A Micromotor, as developed by Tai, Fan, and Muller at the University of California at Berkeley, is one such electromechanical microstructure [3].

A cross section of the Tai-Fan motor is shown in Figure 1. A double polysilicon low pressure chemical vapor deposition (LPCVD) process was used to form the device on the silicon substrates [2,3]. The first of these polysilicon layers formed the rotor and the stator array; the second a flange that held the motor on the substrate and served as the axle of the motor. Where necessary, the polysilicon layers were isolated from the substrate and each other by an LPCVD phosphosilicate glass (PSG), chosen for its high etch rate in buffered oxide etch (BOE) solutions. The rotor was finally released through the selective removal of these PSG layers in BOE.

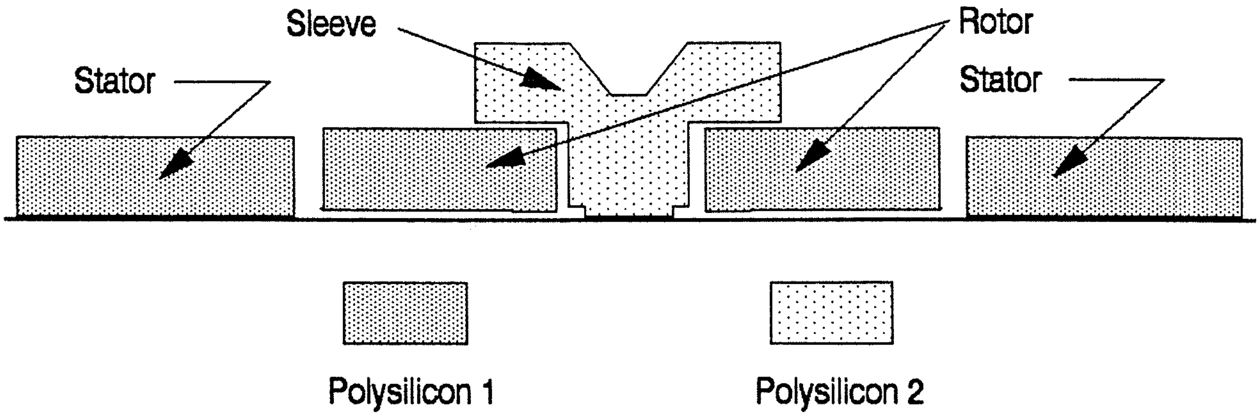

Figure 1: Cross-sectional view of Tai-Fan Micromotor

The rotation of this motor, although stuttered, was achieved by the application of equal and opposite electric potentials to a pair of collinear stator poles while the remaining stator poles were grounded [2]. This induced a net charge on the nearest rotor poles, and thus created a force of attraction between the rotor and stator poles. Theoretically, rotation is sustained by the sequential application of these electric potentials around the stator array, as depicted in Figure 2.

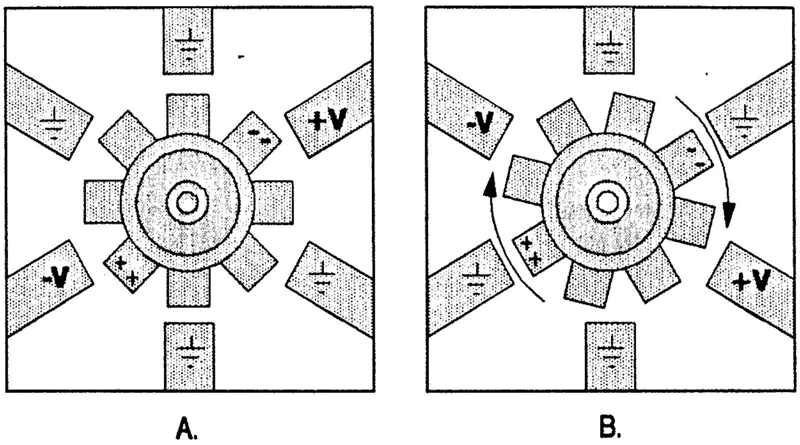

Figure 2: Electrical Operation of a Micromotor

In an effort to reduce the frictional forces apparent between the rotor and the substrate in the Tai-Fan motor, and thereby lessen the potential required to turn the device, Stephen Clemens, a fifth year Microelectronic Engineering student at Rochester Institute of Technology, redesigned the motor so that less surface to surface contact area existed between the rotor and the underlying material [1]. This was accomplished by the addition of a third polysilicon layer which formed a pedestal for the rotor to rest on, as shown in Figure 3. This redesigned version also included the allowance for isotropic etch processes, so that device could be fabricated through the use of the standard wet and plasma etch chemistries available at RIT. The fabrication and comparison of the Clemens and Tai-Fan motors is the subject of this paper.

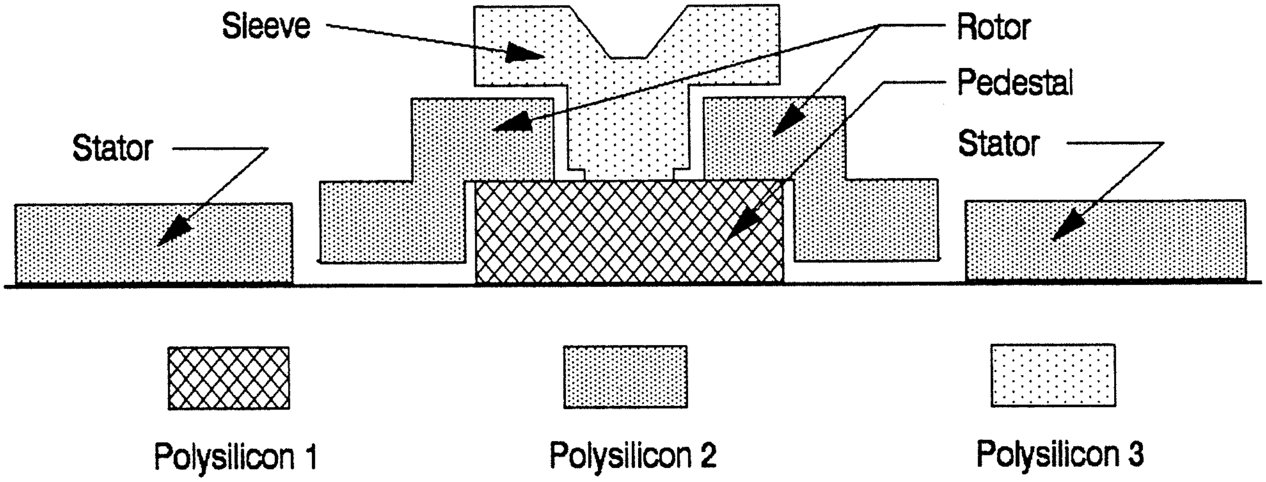

Figure 3: Cross-sectional view of Clemens Micromotor

EXPERIMENT

Steve Clemens' MANN files were modified to create a master reticle set on five inch, high resolution emulsion plates, using a MANN 3000 pattern generator as the electronic interface [1]. Since the Tai-Fan design was implemented by the omission of the first two levels from the Clemens design, a single reticle set was created for use in both designs, however, separate reticles had to be created for the first levels of each design, so that the necessary alignment targets could be included for use with the GCA 4800 stepper. For diagnostic purposes, overlay verniers and line-space resolution targets were also included for each level. A total of seven master reticles was required.

Ten (111) p-type silicon device quality wafers were prepared using the RCA cleaning process. After cleaning, the wafers were separated into three groups, the Clemens' design substrates, the Tai-Fan design substrates, and the control wafers, and processed accordingly. An oxide layer of approximately 1000 Angstroms was grown on the three Clemens' design wafers, and patterned to form the contact cut for the polysilicon pedestal. The first polysilicon layer, approximately 5500 Angstroms in thickness, was then deposited and patterned to complete the polysilicon pedestal. After completion of the pedestal on the Clemens' wafers, processing for the two designs was identical. A 1000 Angstrom oxide layer was grown and patterned to form the contact cuts for the stator array. The second polysilicon layer, approximately 4000 Angstroms in thickness, was then deposited and patterned to form the rotor and stator array. A 1000 Angstrom oxide layer was grown and patterned to form the upper sleeve contact cut. The final polysilicon layer, again approximately 4000 Angstroms in thickness, was deposited and patterned to form the upper sleeve. The sacrificial oxide layers were then removed, and the devices were tested.

In all instances, the oxide layers were etched with a BOE solution, and the polysilicon was etched in a Tegal Plasma Etcher, with an etchant chemistry of sulfur hexafluoride and oxygen, in a ratio of three to one. Also, KTI-820 positive photoresist and ZX-934 developer was used for image transfer.

RESULTS/DISCUSSION

A GCA 4800 stepper was used as the exposure tool for this project, due to its relatively high resolution and alignment capabilities. These were of concern because of the designed 1.5 micron gap between the rotor and the stator array and the 2.0 micron gap between the upper sleeve and the rotor. Since this stepper utilized an indirect alignment method, the baseline error had to be corrected at each exposure step in order to produce acceptable overlay. A focus and exposure check was performed, along with the baseline correction, to insure that the optimal exposure conditions were utilized. These precautions kept alignment errors below 1.5 microns and the resolution close to 1.0 microns, in most cases.

The initial oxide layer for the Clemens' design wafers was grown at 1100 degrees Celsius, for 11 minutes. This produced an oxide thickness of nearly 2000 Angstroms, as opposed to the desired 1000 Angstroms. The oxide thickness was measured on a Nanospec. Although this was twice as much oxide as was desired, the main requirement of this layer was that it be substantially thinner than the first polysilicon layer, and therefore it was not reworked. The remainder of the oxide layers were grown at 950 degrees Celsius for 25 minutes in dry oxygen, producing thicknesses of approximately 800 Angstroms.

The first polysilicon layer for the pedestal was approximately 5500 Angstroms in thickness, as determined through the use of an Alpha Step profilometer. This layer was slightly thicker than originally desired to account for the thicker oxide layer. The second two depositions both produced layers of approximately 4000 Angstroms.

A concern was introduced at each of the polysilicon deposition steps, since there was a delay of up to three days between the time that the wafers were cleaned and when the polysilicon was deposited. The concern was that a native oxide would form an interface under the polysilicon and serve to lift it off when the sacrificial layers were removed. This, however, was not the case.

Upon completion of the final lithography step, the oxide layers were removed in a BOE solution, by taking advantage of the isotropic nature of the etch. Since the necessary etch time was not known, one wafer was taken from each design group and step etched in forty minute increments, for a total of five hours and twenty minutes. After the wafers were thoroughly rinsed in deionized water, they were baked in a nitrogen ambient at 450 degrees Celsius, for 15 minutes, to completely dry the surfaces. Inspection of the wafers indicated that a maximum etch time of approximately five hours existed, due to the deterioration and lifting off of the polysilicon stator array. It was impossible, however, to determine whether or not the rotor had released through simple optical inspection.

To determine if the rotor had released, a micromanipulator probe station was used. A fine probe tip was placed next to a given rotor, and slowly moved into contact with it. Movement was carefully continued until the rotor either broke off or rotated. As the rotors were stressed by the application of a vertical force, they were shown to bend, by the discoloration seen through the microscope on the probe station, indicative of the successful undercutting of the polysilicon. By checking across the wafers those rotors that were etched for two hours or more were shown to have indeed released, with no dependance on the design.

Once the rotors were shown to have released, electrical testing, as described in the introduction of this paper, was started. None of the motors that were tested in this manner were shown to rotate by the application of the electric potentials, however, these results were considered inconclusive since only relatively low voltages of up to 25 volts were applied. To determine whether the modifications that Steve Clemens made to the Tai-Fan design made any substantial differences, more time must be placed into the testing of the different structures.

After the motors were tested, they were inspected with a scanning electron microscope (SEM). A representative SEM of the Tai-Fan design at a magnification of 2000 is shown in Figure 4. Surprisingly, there were no observable differences between the two designs. This may have been due to the first oxide layer in the Clemens' design wafers being too thick, and thereby serving to planarize the rotor to some degree. To verify that this was the case, a cross section and further SEM analysis should be done on both designs.

For future work on this project, it is suggested that more than one variation of each design be included. Variations might include changing the width of the gap between the rotor and the stator array, the addition of an aluminum layer to form contacts, and the doping of the polysilicon. Also, the inclusion of several test structures, consisting of non-anchored polysilicon disks of comparable size to the rotor and upper sleeve, could be of great value in monitoring the release process. The placement of the contact pads in an array corresponding to a probe card set-up could also prove beneficial.

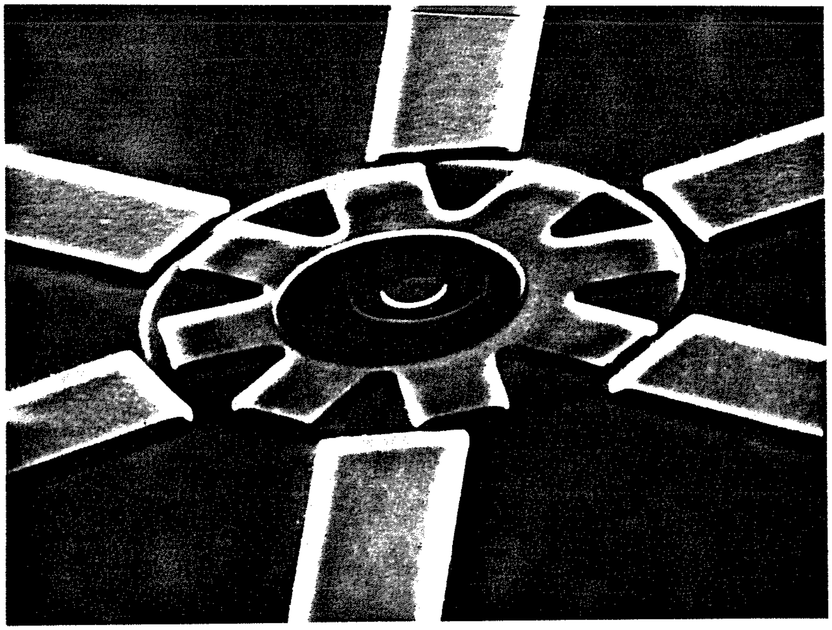

Figure 4: SEM of a Representative Tai-Fan Design Micromotor

CONCLUSION

Two versions of a micromotor were fabricated. The rotors were formed by the low pressure chemical vapor deposition of polysilicon and released by the removal of sacrificial silicon dioxide layers in a buffered oxide etch solution. A critical oxide etch time of approximately two hours was determined, above which the rotors were free to move through the application of a mechanical force. Movement by electrical means was not achieved, however these results were inconclusive, since a wide range of voltages were not tested.

ACKNOWLEDGMENTS

I would like to thank the following people for their contributions to the Micromotor project: Mike Jackson, Rob Pearson, Dr. Richard Lane, Scott Blondell, Ed Sayer, Dave Price, Dr. Richard Muller, and Steve Clemens.

REFERENCES

[1] S. Clemens, RIT Journal of Research, May 1989 (unpublished).

[2] R. Gannon, "Micromachine Magic", Popular Science, March 1989, page 88.

[3] L. S. Fan, Y.U. Tai, R.S. Muller, IEEE Transactions on Electron Devices, Vol 35, No 6, June 1988, page 724.

[4] K.E. Petersen, IEEE Transactions on Electron Devices, Vol 70, No 5, May 1982, page 420.

[5] M. Mehregany, K.J. Gabriel, W.S.N. Trimmer, IEEE Transactions on Electron Devices, Vol 35, No 6, June 1988, page 719.