A Walking Silicon Robot

(May 2009)

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***Abstract*—The goal of this project was to design and implement a MEMS process for the creation of a walking silicon robot using the equipment available at RIT. An attempt was carried out to create a mobility system based on the thermal expansion of polyimide joints as demonstrated by Ebefors. The designed process was successfully implemented through the oxidation of the joint surfaces. Issues with the Al resistor and polyimide lithography prevented the successful completion of the rest of the process.**

***Index Terms*—MEMS, robot,**

XXIII. Introduction

ROBOTICS is the integration of systems for mobility, sensing, actuation, processing, and power to produce a machine that can accomplish a task. Robots are used for performing tasks that demand high accuracy, that are highly repetitive or dull, and that are dangerous to humans. Micro-robotics is the design and creation of robots on the sub millimeter scale. Creating micro-robotics systems decreases costs and increases reliability. The objective of this project was to design and implement a MEMS process for the creation of a micro-robotic mobility system.

The planned mobility system was based on the thermal expansion of polyimide joints as demonstrated by Ebefors. [1] Fig. 1 shows an image of the leg created by Ebefors, while Fig. 2 shows a close up of the polyimide joints. This system was chosen over other propulsion methods for three reasons. The first reason is that it is capable of moving at appreciable speeds. The second reason is that such a mechanism does not require the robot to be on a specialized surface. Finally such a system has also been demonstrated to have the ability to carry significant loads. [1]

XXIV. Leg Actuation

The leg actuation of such a system is due to the fact that the joint grooves etched in the substrate are wider at the top then at the bottom as seen in Figure 3. During curing of the polyimide, the top of the joint shrinks a greater absolute distance than the bottom causing the leg to rotate out of the substrate plane (Fig. 3). Later during heating the polyimide similarly expands more at the top than at the bottom, rotating the leg back towards the substrate. The angle of the leg alpha, with respect to the substrate plane, is given by the following equation [2], where N is the number of joints, e is the shrinkage during curing, and alpha T is the thermal expansion.

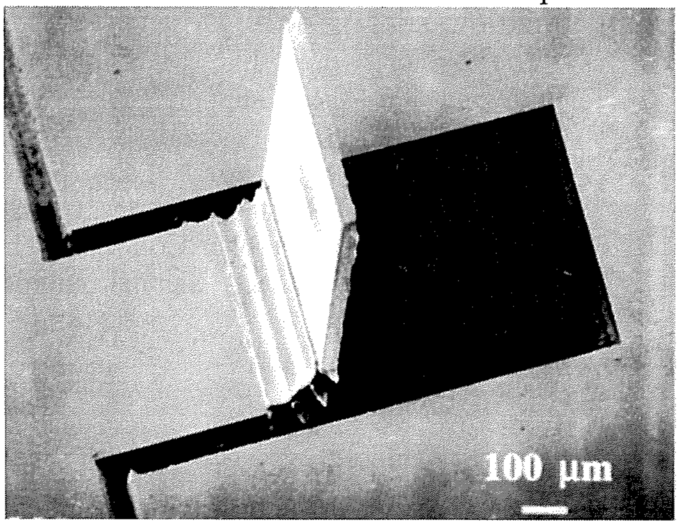

Fig. 1. SEM of Leg created by Ebefors [2]

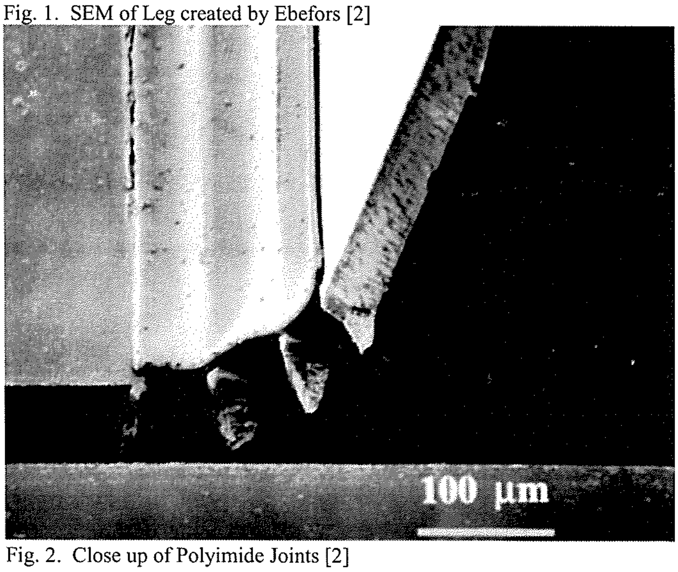

Fig. 2. Close up of Polyimide Joints [2]

$$\alpha = 2 \bullet N\left[90° - 54.74° - \arcsin\left(\cos(54.74°) \bullet \left(1 - \varepsilon + \alpha_T \bullet \Delta T\right)\right)\right]$$

XXV. Planned Process

The planned process is given in Table 1. Diagrams of the process steps are provided in Figure 4. The process was successfully implemented as follows through step 11. The wafers first have a 500Å pad oxide grown on them followed by the deposition of 1500Å of LPCVD nitride using the standard factory recipe. Next the wafers go through contact photolithography and are patterned with the joint grooves mask. The nitride in the exposed areas on the wafers is then etched in the LAM-490 using the FACNIT recipe edited to 4 minutes of etch time (no over etch). The underlying pad oxide is then removed by a 1-minute dip in 10:1 BOE etch followed by a 5 minute rinse and SRD. The resist is then put through the standard resist strip followed by SRD. An RCA clean is then done to ensure a clean surface. The joint grooves are then etched in KOH at 75°C for 42 minutes to get 50 µm deep joints. The wafers then go through a special decontamination clean of 5:1:1 H_2O:H_2O_2:HCl at 70°C for 20 minutes. (Manual Process Bench 2) This is followed by a 10 min rinse and an RCA clean. A 1.5 µm wet thermal oxide (Recipe 170 – 1100°C 4hr 46min) is then grown in the Bruce Furnace.

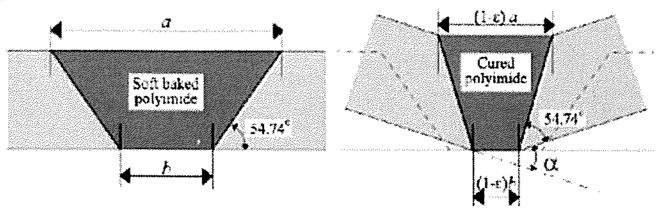

Fig. 4. Diagram of Soft baked and Cured Polyimide Joints [3]

Table 1 – Proposed Process

Step	Action
1	Get Wafers
2	Grow 500A Pad Ox
3	Deposit 1500A Nitride LPCVD
4	Photo 1: Joint V Grooves
5a	Etch oxynitride, 1 min BOE dip, rinse, SRD
5b	Plasma Etch Nitride – LAM-490
6	Wet Etch Pad Oxide, Rinse, SRD
7	Strip Resist
8	Etch V-grooves in KOH
9	Decontamination Clean
10	RCA Clean
11	Grow 1.5um Thermal Oxide
12	Photo 2: Metal Liftoff
13	Sputter 1um Aluminum
14	Ultrasonic Liftoff
15	Coat Polyimide
16a	Evaporate Thin Aluminum
16b	Photo 3: Polyimide
17	Coat ProTEK or Black Wax
18	Photo 4: Backside Etch
19	Plasma Etch Nitride – LAM-490
20	Wet Etch Pad Oxide, Rinse, SRD
21	Strip Resist
22	Etch Backside in KOH
23	Decontamination Clean
24	RCA Clean
25	Dice Robot
26	BOE etch to release legs, rinse, air dry
27	Remove ProTEK or Black Wax
28	Cure polyimide
29	Test

XXVI. Process Challenges

A. Metal Liftoff

Initially a lift off process for creating the aluminum resistor, which was to heat the polyimide, using ImageOn solid negative resist was planned. This method was chosen because the use of a solid resist would prevent having to directly pattern into the joint trenches. Unfortunately, the resist would not adhere to the substrate during develop as seen in Fig. 5.

B. Metal Lithography

Subsequently it was decided to instead first sputter aluminum and then do lithography and etch. This method was chosen over attempting to do a liftoff using a liftoff liquid resist due to expected issues with pooling and thickness

variation along the trench walls. Doing lithography after the aluminum deposition would provide greater process latitude because any resist thickness would be acceptable. This method was first attempted using HPR504 positive resist coated at 5000, 3000, and 1500 RPM. Issues found at all three speeds included waving and edge breaks as seen in Figures 6a and 6b respectively.

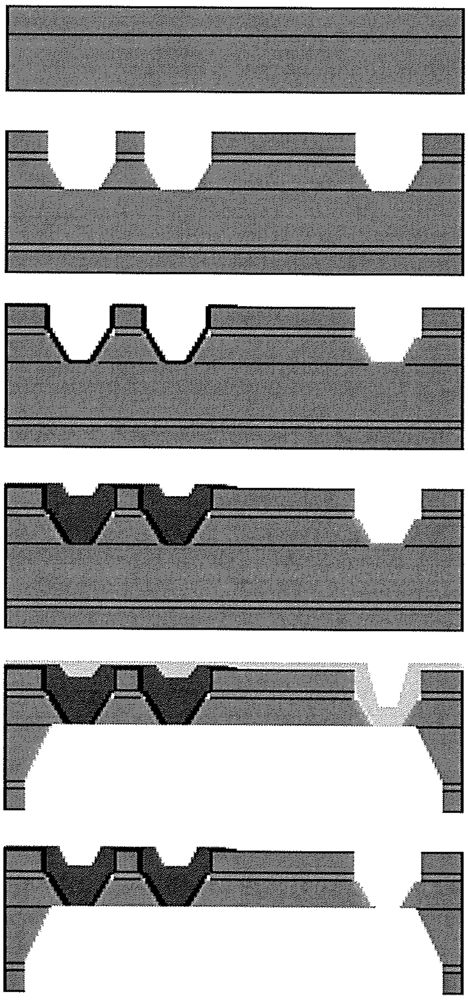

Fig. 4. Diagram of process steps, Gray=Si, Blue=SiO2, Orange=Si3N4, Black=Al, Red=Polyimide, Green=Black Wax or ProTek

It was then attempted to use AZ9260, a thick resist, to overcome the edge break issues. The coat recipe would deliver approximately a 10 um thick resist layer on a flat wafer. The waving issue was reduced, but despite the thickness the edge breaks were still present. It was then decided to take some SEM images to try and determine the reason the resists were not continuous over the edges. It was found that there was indeed a lip at the edge of around a half a micron as seen in Figure 7. This helped to explain the issue with the HPR504 resist but not with the thick resist. It was then decided to try to use an even thicker resist coat by double coating the AZ9260. This proved successful in coating over the trench edge but would not properly develop away as seen in Figure 8. It is believed that the age of the resist caused it to no longer be functional.

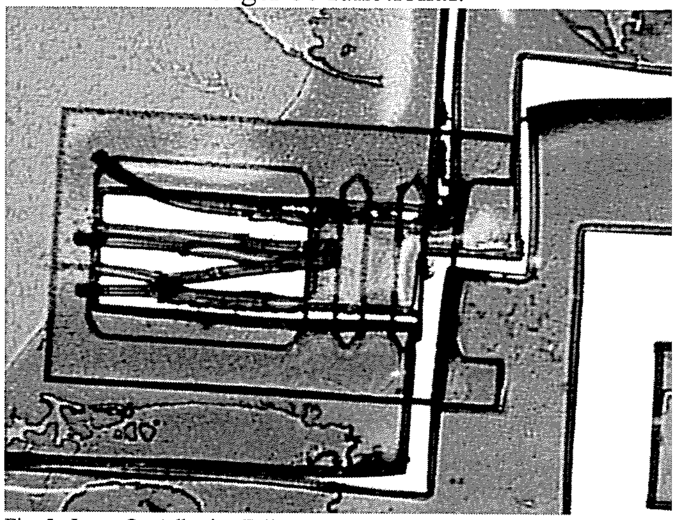

Fig. 5. ImageOn Adhesion Failure

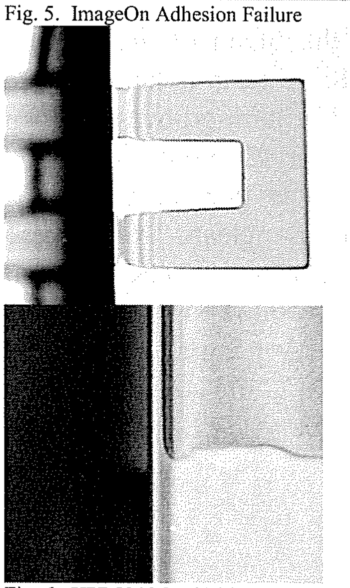

Fig. 6. HPR504 Metal Lithography Issues (a) waves (b) edge breaks

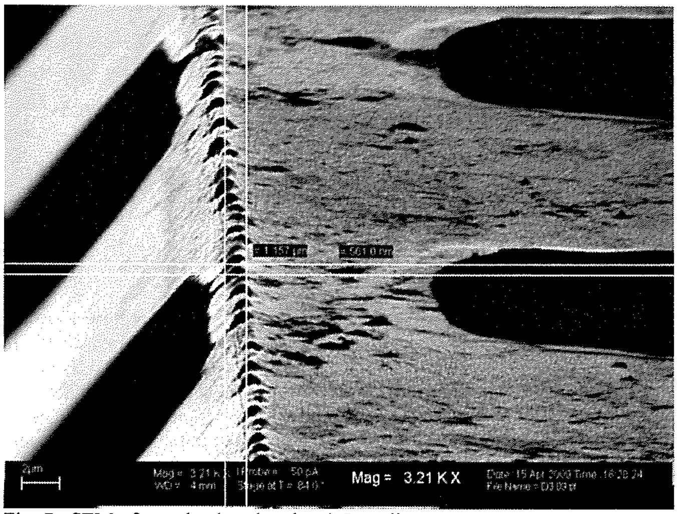

Fig. 7. SEM of trench edge showing 0.5 μm lip

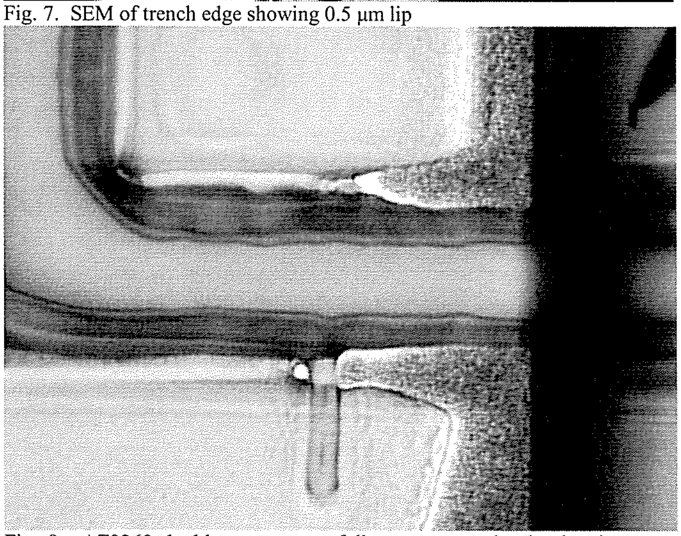

Fig. 8. AZ9260 double coat successfully covers trench edge but is not removed properly by developer

C. *Polyimide Lithography and Etching*

At that time it was decided to move on and try the rest of the proposed process starting with the polyimide. This process also proved to be troublesome. A thin Al coating of 1-2 KÅ was evaporated on top of the polyimide. HPR504 photoresist was then spin coated on the SVG track using the standard coat recipe without any HMDS or a soft bake. The aluminum is then etched leaving behind aluminum to mask the polyimide etch as seen in Fig. 9. It was learned that the wafer must be processed through to etching at least the Al or outgassing will mildly distort the Al surface. It was also learned that the wafer must not go through any baking steps subsequent to coating the Al or outgassing will severely distort the surface making it impossible to align to. Any baking also causes the polyimide to etch more slowly as seen in Fig. 10 compared to Fig.11.

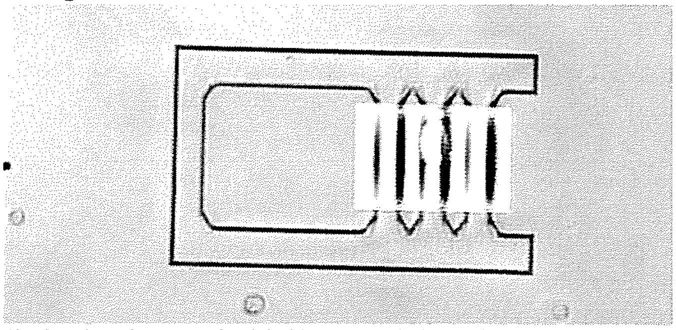

Fig. 9. Al mask on top of Polyimide, Pre Polyimide Etch

The major issue with the polyimide etching was that the thin aluminum coating was being removed during the etching of the polyimide in developer as seen in Figures 10 and 11 compared to Fig. 9. Baking increases the amount and rate at which the Al is removed. Unfortunately there was not enough time or polyimide left to find a solution to this issue. It is hypothesized that the thinness of the aluminum coating and reasonable adhesion to the polyimide caused it to be removed along with the polyimide. A further experiment would use a thicker aluminum that would hopefully prevent its breakage.

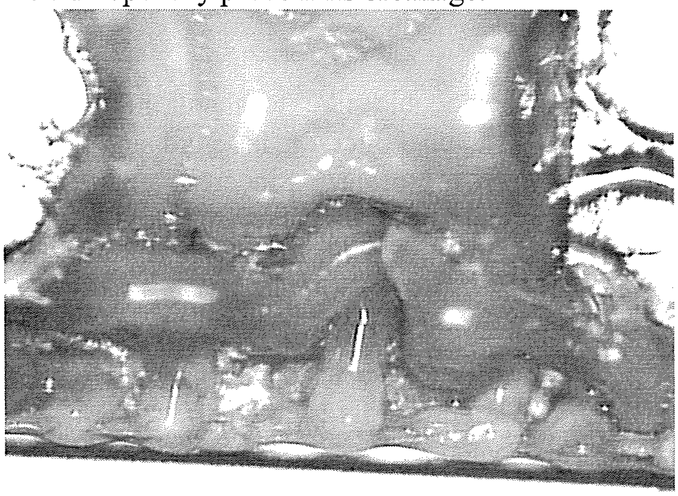

Fig. 10. Baked Polyimide, 4th 50 sec develop

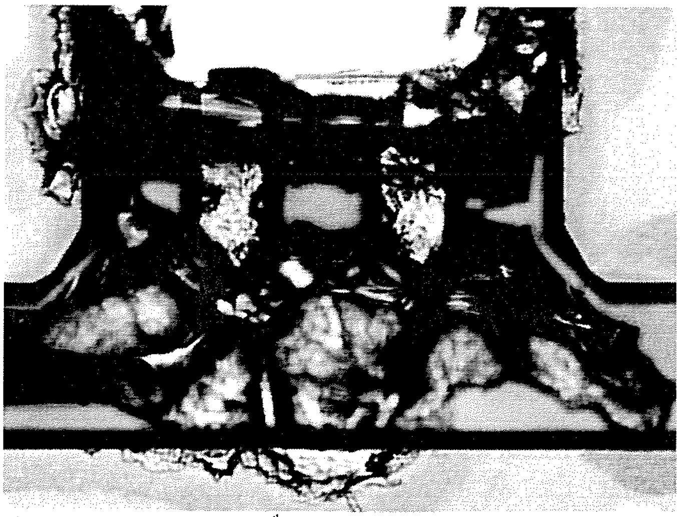

Fig. 11. Unbaked Polyimide, 4th 50 sec develop

XXVII. Conclusion

An attempt was carried out to create a mobility system based on the thermal expansion of polyimide joints as demonstrated by Ebefors. The designed process was successfully implemented through the oxidation of the joint surfaces. Issues with the Al resistor and polyimide lithography prevented the successful completion of the rest of the process.

Acknowledgment

The author would like to thank his project advisor Dr. Lynn Fuller for his guidance during the course of the project. Sincere thanks to Dr. Sean Rommel and Prof. Dale Ewbank for their counsel on the metal lithography issues. Special thanks to Ivan Puchades for assisting in processing and to Mike Barth for the SEM images. Finally thanks to the SMFL staff for all their help with processing and equipment issues.

References

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[2] T. Ebefors, *et al.*, "New Small Radius Joints Based on Thermal Shrinkage of Polyimide in V-grooves for Robust Self-assembly 3D Microstructures" *J. Micromech. Microeng.*, **8**, pp. 188-194, 1998

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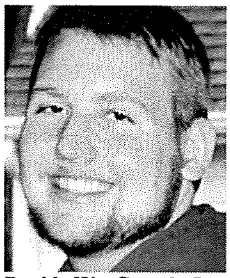

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