

Design and Fabrication of a Micro-bearing Assembly to Study Rotor Friction

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Abstract— The objective of this investigation was to design and fabricate a metrology tool for measuring the wear in micro-bearings. The critical component of the tool was a silicon test bed consisting of a bearing shaft and a set of microchannels to direct an air stream onto the fins of a micro-rotor assembled onto the bearing shaft. By driving the micro-rotor pneumatically, surface interactions between the bearing and the rotor can be studied over time. The silicon test bed mates to a custom aluminum chuck which has provisions for sealing the test bed and supplying air pressure from an external source. The silicon test bed was successfully fabricated by bulk micromachining using Deep Reactive Ion Etching (DRIE). Test rotors were also fabricated using DRIE and manually placed onto the bearing shaft of the test bed. A glass cover slide, held in place by the aluminum chuck, was used to seal the top of the test bed. Test rotors were successfully rotated using a minimum input air pressure of 0.5 psi.

Index Terms—Bearing wear, friction, micromotor.

I. INTRODUCTION

In the field of microsystems technology microactuators often contain surfaces that must roll or slide over other surfaces. A micromotor consisting of a movable rotor set on a bearing shaft is a prime example. In order to optimize the performance of such a micromotor it is critical that bearing wear be thoroughly understood. Currently, very little is known about the wear characteristics of microscopic rotors and bearing surfaces. The first step in achieving greater understanding of micro-bearing wear is the development of a testing fixture and methodology for accurately measuring wear.

The effect of bearing wear on the micromotor performance has been studied [1], [2] and is known to be a current limitation of the technology. In order to influence bearing lifetimes through design, bearing

experimental testing. Previous testing [2] was done by surface micromachining techniques with rotors of 100 μm in diameter.

In this paper, the microrotor and microbearing components were to be fabricated using bulk micromachining techniques, and assembled manually. The dimensions of the components were larger than in previous studies in order to achieve a workable prototype through manual assembly. Manual assembly also allowed the placement and subsequent testing of a variety of rotor structures, on a standard bearing testbed.

II. DESIGN

Figure 1 shows the dimensional layout of the rotor component. The bearing layout is shown in figure 2 and consist of 3 mm air inlets leading to microchannels. The microchannels led to the center of the design where the rotor was to be seated on the 396 μm bearing hub.

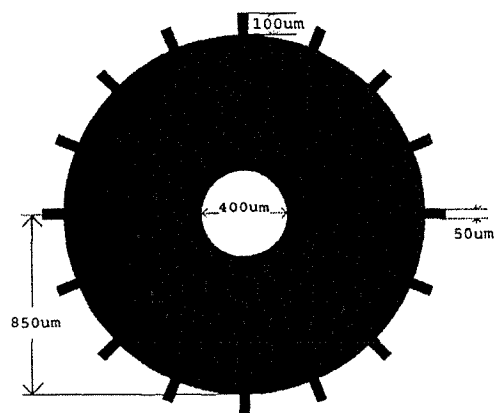


Fig. 1. Design of rotor.

wear characteristics must first be understood through

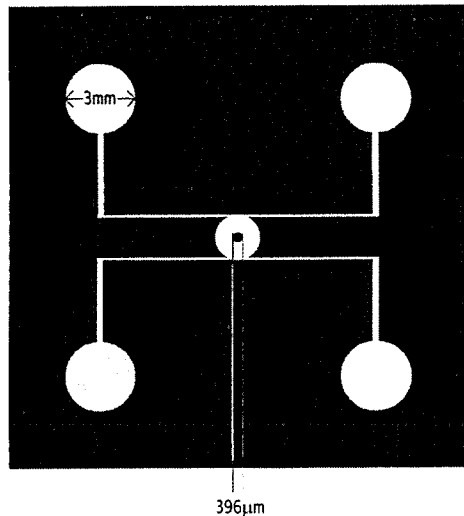


Fig 2. Bearing testbed layout.

A. Bearing Process Flow

The bearing testbed was fabricated from a single side polished <100> silicon wafer, using DRIE anisotropic bulk etching. The etch mask consisted of approximately 7 µm of AZ9260 photoresist. After an HMDS prime, AZ9260 photoresist was spin cast on the wafer at a speed of 3000 RPM for 45 seconds, yielding a thickness of 7 µm. A soft bake was performed on a contact hotplate at 90 degrees C for 60 seconds. The photoresist was then exposed on a GCA 6700 g-line stepper with a dose of 2500 mJ/cm². The PEB (Post Exposure Bake) was omitted. Immersion development of was done with MF CD-26 TMAH developer for a time of 180 seconds. The wafer was not hard baked in order to prevent resist reflow and dimensional distortion. The exposed silicon was then etched using an STS DRIE (Deep Reactive Ion Etch) system. The system etched the silicon using a Bosch process where cycles consisting of etch (SF₆ gas) and Passivation (C₄F₈ gas) were performed. 388 cycles were used for an estimated etch depth of 450 µm into the 500 µm wafer. Once the bearing test bed was etched, the wafers were diced into 2 cm x 2cm square die. A Dremel drill was used to break the remaining 3 mm diameter, 50µm thin membrane so air could be forced through the backside of the testbed. Figure 3 shows the process flow for the bearing testbed.



Pattern 7 µm photoresist



Etch silicon 450 µm (DRIE)



Strip resist and dice wafer

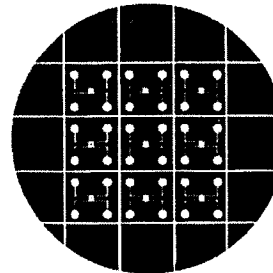


Fig 3. Process flow for micro bearing testbed.

B. Rotor Process Flow

The rotors were designed to be etched from <100> silicon wafers. However, the desired rotor thickness was 300 µm, and 100 mm wafers have a standard thickness of about 500 µm. 75 mm wafers have a nominal thickness of about 300 µm making them preferable for rotor fabrication. 75mm double side polished wafers were used for the fabrication process. Figure 4 shows the process flow for the fabrication of the rotors.

A target value of 400 nm of SiO₂ was thermally grown on the 75 mm double side polished wafers using wet oxidation. After an HMDS prime, Shipley 812 photoresist was coated to a thickness of 1.2 µm, and a softbake was done on a contact hotplate at 90 degrees C for 60 seconds. The photoresist was then exposed on a GCA 6700 g-line stepper with a dose of 100 mJ/cm². A post exposure bake of 110 degrees C for 45 seconds was done prior to immersion development in MF CD-26 TMAH developer. 30 seconds of development time was sufficient to clear the exposed regions of the photoresist. A hard bake was then performed at 120 degrees C for 120 seconds, and the SiO₂ was etched in BOE (Buffered Oxide Etch) for 4 minutes.

It was necessary to adhere the 75 mm wafer to a 100 mm wafer in order for the wafer to be transported into the etch chamber of the STS DRIE. The adhesion layer

used was 7 μm of AZ9260 photoresist. The 75 mm wafer was then placed atop the freshly coated 7 μm of photoresist, and the wafer stack was baked on a contact hotplate for 15 minutes at 120 degrees C. The 75mm wafer was then etched through completely ($\approx 300 \mu\text{m}$) using the STS DRIE, and the rotors were released in acetone.

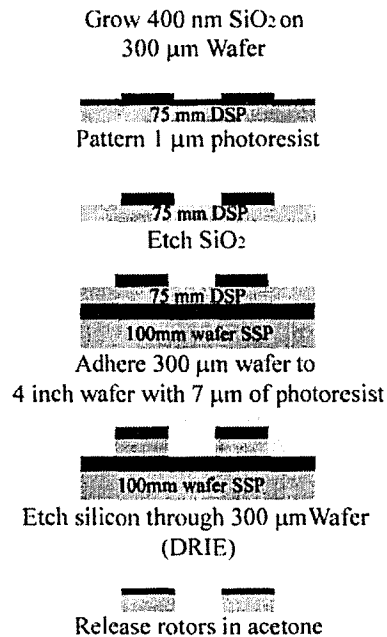


Fig 4. Process flow for rotor fabrication.

A significant difference for the fabrication of the rotors, was the incorporation of SiO₂ for the etch mask. It was known that the etch process developed for the STS DRIE was more selective when SiO₂ was used as the masking material. Although the etch for the rotor structures was not as deep as the etch for the bearing testbed (300 μm vs. 450 μm), thermal heating during the etch process degraded the selectivity, making the Novolac based resist insufficient. The thermal heating during the etch occurred because the helium backside cooling was unable to properly cool the 75 mm wafer which was adhered to a 100 mm wafer with AZ9260 photoresist (7 μm).

C. Aluminum Fixture For Sealing and Pneumatic Driving

Once the bearing testbed was fabricated and the 3 mm air inlets were drilled through, the testbed was aligned on an aluminum chuck with 4 o-rings with an inner diameter 3.68 mm and a width of 1.78 mm. Three glass cover slides of thickness 225 μm were placed on top of the bearing test bed to provide a pneumatic seal for the microchannels and to ensure the rotor remained on the

hub. An additional o-ring of was used to distribute the pressure from the top portion of the aluminum fixture upon the tightening of the connecting screws. A schematic of the aluminum fixture can be seen in figure 5.

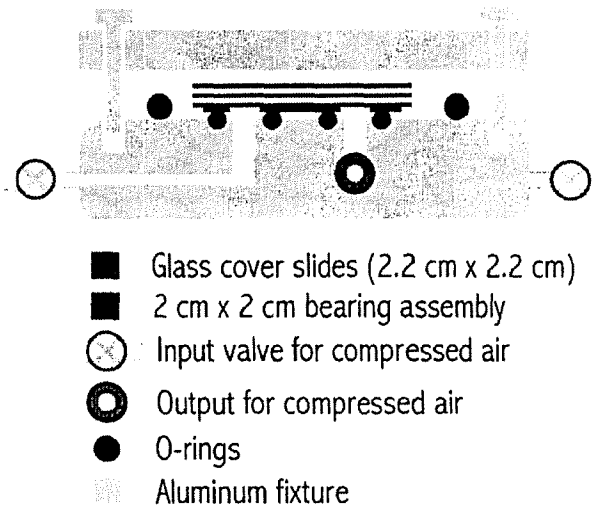


Fig. 5. Schematic of aluminum fixture for pneumatic testing.

The screws were tightened by hand, sealing the testbed making it possible drive the rotor with compressed air. The microchannels were designed to direct air flow to the fins of a rotor.

III. EXPERIMENTAL RESULTS

The bearing testbed was etched to an actual depth of $\approx 390 \mu\text{m}$, while the rotors were measured to be $\approx 300 \mu\text{m}$. The rotor fit into the bearing testbed and was imaged using a Philips 525 SEM, and can be seen in figure 6. The SEM in figure 7 illustrates the 3 mm air inlet along with the microchannels.

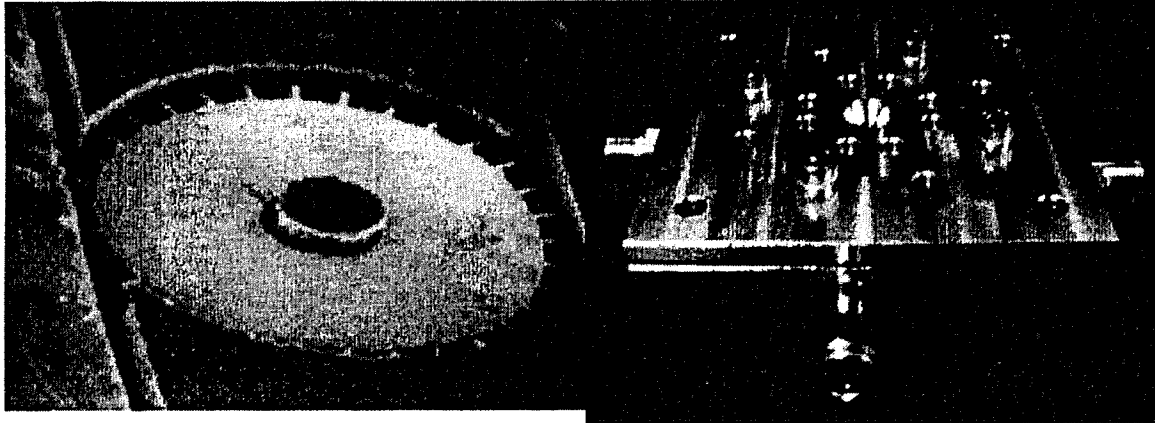


Fig. 6. SEM of rotor placed in bearing.

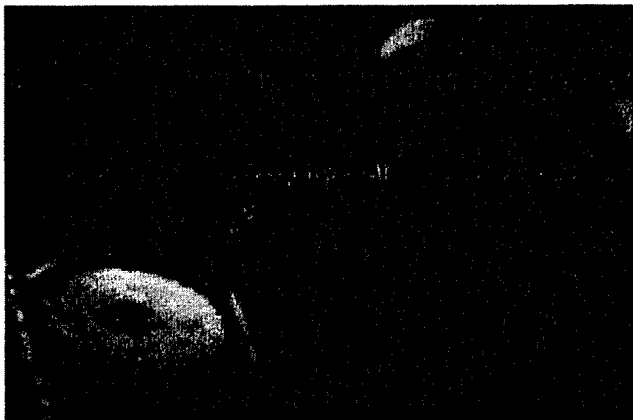


Fig. 7. SEM showing air 3 mm air inlet and microchannels.

Fig. 8. Photograph of aluminum fixture containing bearing test bed and rotor.

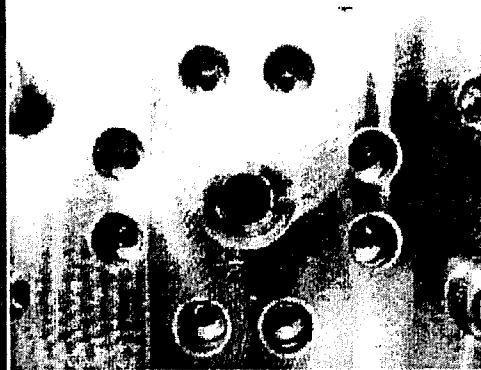


Fig. 9 Viewport on aluminum fixture exposing the 1.9 mm rotor in the bearing testbed.

Once assembled into the aluminum fixture shown in figure 8, the rotor was rotated by pressurizing two air inlets located diagonally from one another. A high-speed camera was used to capture the rotor motion. A 2000 frames per second video capture was done, however the teeth of the rotor were blurry and no rotational speed measurement could be obtained. When only one air inlet was pressurized (up to 40 psi), the rotor was pushed against the hub and rotation did not occur. However, when two inlets were pressurized, a minimum pressure of 0.5 psi on each inlet was sufficient to cause rotation of the rotor.

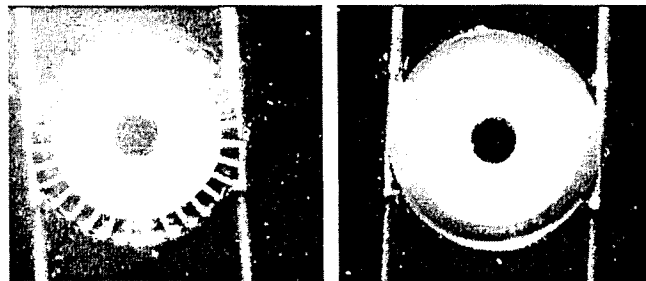


Fig. 10. One air inlet pressurized (left) two air inlets pressurized (right).

The image to the left in figure 10 shows an optical capture for the pressurization of a single air inlet, while the image capture on the right shows the pressurization of both air inlets. Both images were taken from a video capture that had a frame rate of 60 frames per second.

IV. CONCLUSION

A test bed for analyzing rotor friction has been designed, fabricated and a successfully tested. Rotation was achieved using a minimum input pressure of 0.5 psi. The successful operation of the designed testbed will enable a variety of tribological tests, such as lifetime

tests, to be conducted in the future.

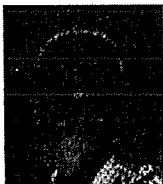
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