LOCALIZED LUBRICATION (LOC-LUB): A Novel Method of Lubricant Application to MEMS Devices

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INTRODUCTION

Microelectromechanical systems (MEMS) are growing at a fast pace in the development of electromechanical devices, though the performance of some MEMS devices (especially actuators) is limited due to large surface area to volume ratios, causing tribological issues of stiction, adhesion and friction predominant.

Common lubrication methods often coat entire surfaces, and require hermetic packaging as well as elaborate processes. These methods are effective in lubricating in-plane surfaces and their effectiveness in lubricating sidewalls is not well known and requires further research in this direction

Ultra-thin organic molecular films such as PFPE have been proposed as lubricants for MEMS devices, and have been found to be effective. [1]

The objective of the present invention is to successfully lubricate the specific portions locally, particularly sidewalls, of a MEMS device without affecting the functionality of the entire device.

a) A feasibility study was done on silicon wafers under reciprocating sliding wear to compare the effectiveness of the method with the other common methods of dip-coating and vapour deposition. A custom made reciprocating sliding wear tester was used to conduct friction and wear tests in a flat-on-flat mode at a load of 0.5 N and sliding speed of 5 mm/s. The wear life was defined as the number of cycles at which the coefficient of friction exceeds 0.3 for a sustained period of time. Tests were conducted on various surfaces, for a duration of 6 hours. Samples which showed good properties were put through an extended test of 60 hours (540,000 cycles). A comparison was also made between the localized lubrication method and other common lubrication methods such as dip-coating and vapour deposition.

EXPERIMENTAL PROCEDURE

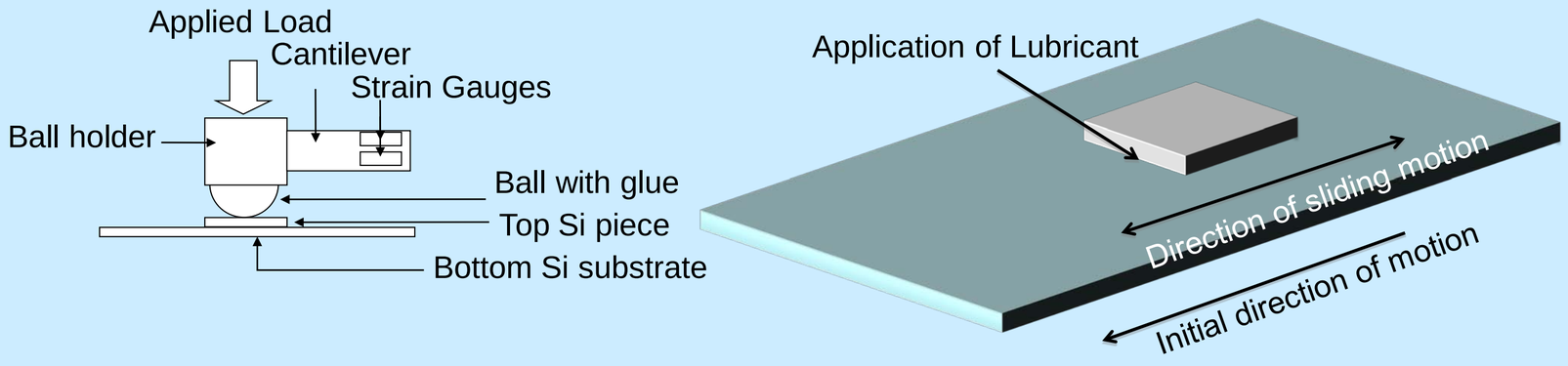


Figure 1: Schematics of setup for feasibility study of "Loc-Lub" Method

b) On actual MEMS devices (Figure 2), PFPE lubricant (4.0 wt%) was dispensed to a local selected area using a syringe-needle system coupled with an air pressure dispenser which applied a shot of pressure in order to release a micro-drop of lubricant onto the surface.

The amount of lubricant dispensed was approximately 0.1 µl per droplet. A video imaging system was used to locate the area to be lubricated and also to confirm the delivery of the lubricant. Stiction and sliding friction tests were done to evaluate the performance of the device prior to and after lubrication, and to investigate the effectiveness of the method.

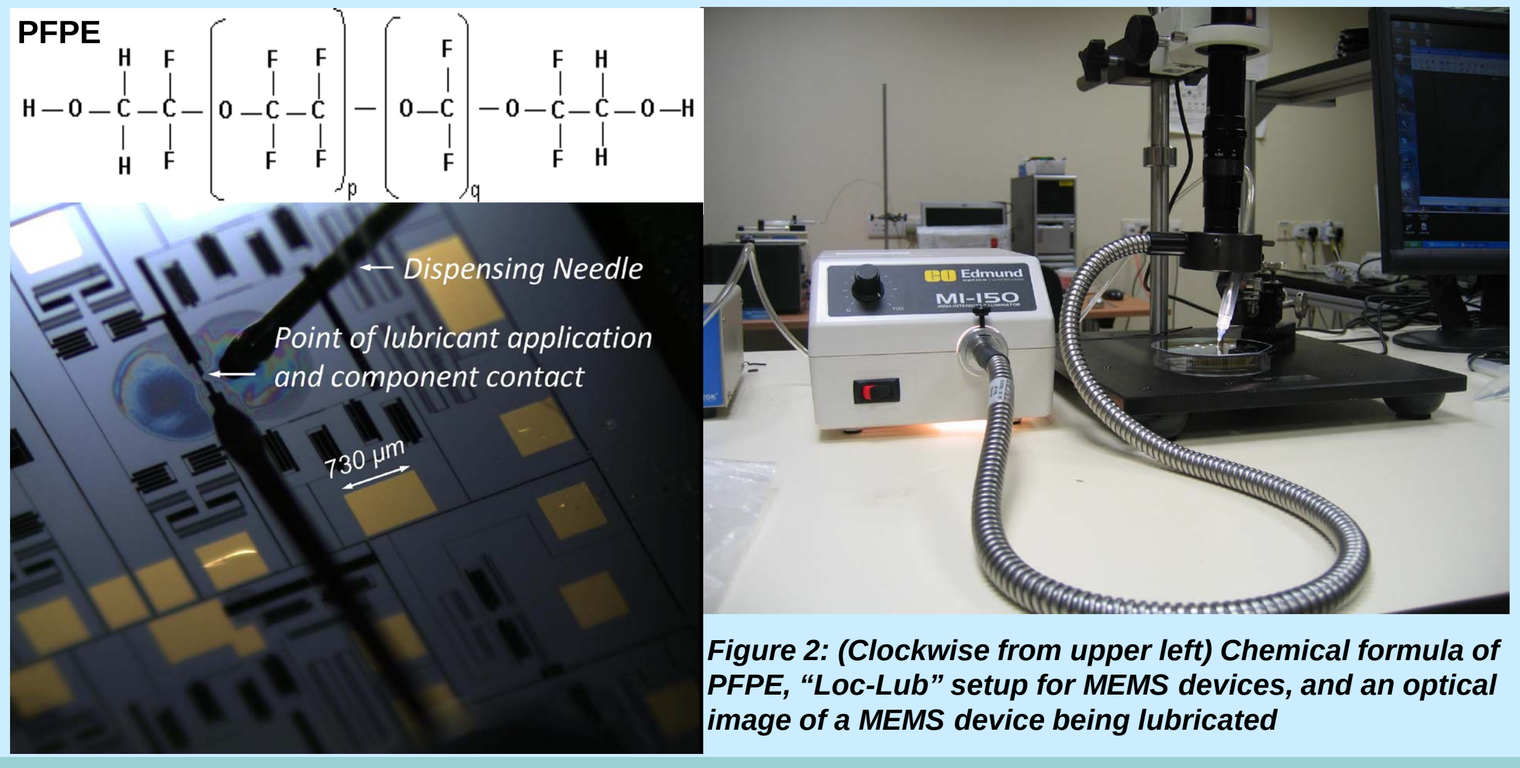


Figure 2: (Clockwise from upper left) Chemical formula of PFPE, "Loc-Lub" setup for MEMS devices, and an optical image of a MEMS device being lubricated

RESULTS AND DISCUSSION

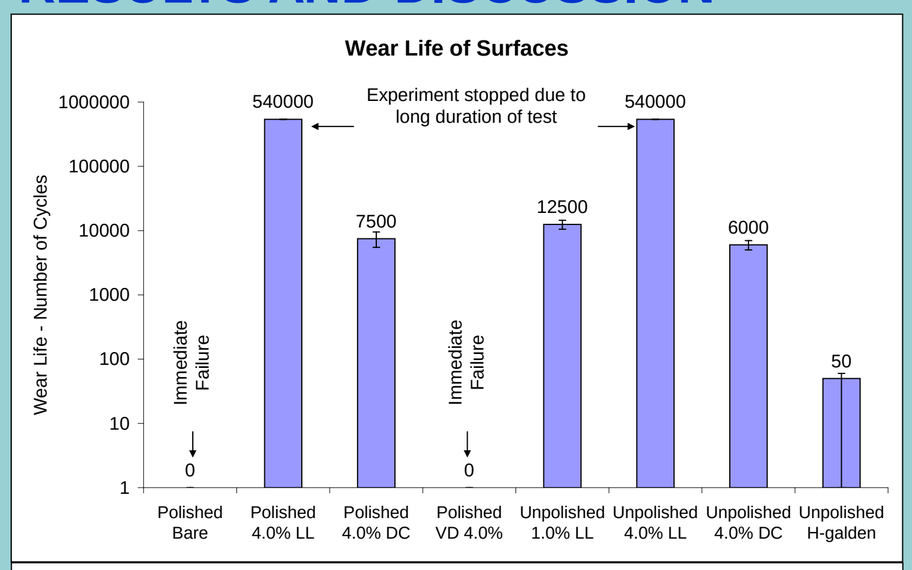
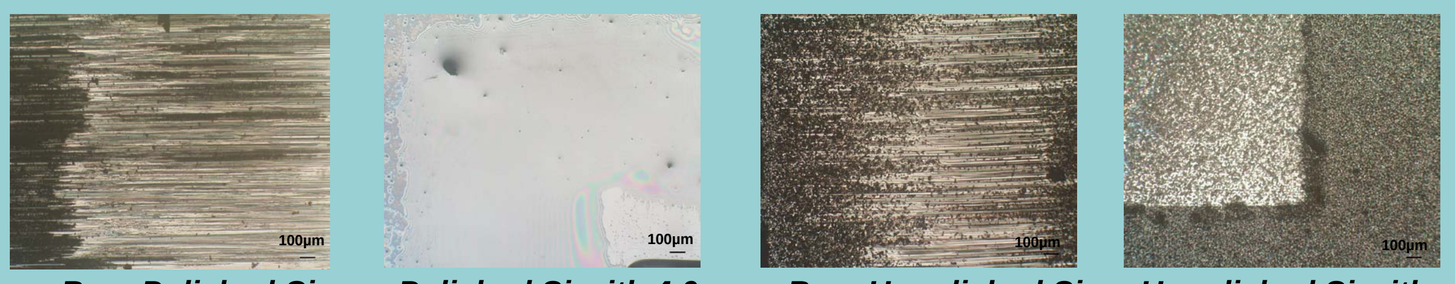


Figure 3: Wear test results and CoF from feasibility study. Wear tests were capped at 540,000 cycles (60 hours). (VD=Vapour Deposition, DC=Dip Coating, LL="Loc-Lub")

- The feasibility study shows a remarkable improvement in the wear life upon dispense of 4.0 wt% PFPE at the interface using the "Loc-Lub" method, from immediate failure on bare surfaces and vapour deposited surfaces to surfaces that remain with low CoF even beyond 60 hours.
- Improved properties were observed on unpolished Si surfaces as compared to polished Si surfaces. In both cases, no scratching was noted to occur on lubricated surfaces as compared to unlubricated surfaces.



Bare Polished Si | ***Polished Si with 4.0 wt% "Loc-Lub"*** | ***Bare Unpolished Si*** | ***Unpolished Si with 4.0 wt% "Loc-Lub"***

Figure 4: Optical Micrographs of wear tracks after feasibility wear tests, at 540,000 cycles

- The "Loc-Lub" method was also successfully implemented on a custom-designed/fabricated MEMS device. The adhesion force between the contacting surfaces was reduced from 240 µN to 32 µN upon localized lubrication using PFPE. In the unlubricated case, an addition force was required to pull the surfaces apart; when lubricated, a reduction in the driving voltage would lead to a separation in the surfaces.
- Unlubricated surfaces, when put into contact and made to slide relatively to each other, were not able to slide when in contact as the frictional forces were too high for relative sliding to occur. Lubricated surfaces had visibly smoother motion under the same driving force, and moved a total of 4 µm in sliding. No visible wear was observed on surfaces after sliding.

(U.S. Provisional Patent 61,314,627 filed on 17 March 2010)

CONCLUSIONS

The "Loc-Lub" method has been found to be an effective method for delivery of lubricant onto a specific location on a micro-device to reduce the stiction, adhesion and friction at that location, without modifying any other part of the device. PFPE at 4.0 wt% was found to provide sufficient lubrication under this method.

ACKNOWLEDGMENTS

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REFERENCES

1) N.Satyanarayana and S.K.Sinha, "*Tribology of PFPE overcoated self-assembled monolayers deposited on Si surface*", **Journal of Physics D: Applied Physics** 38(2005) 3512-3522.