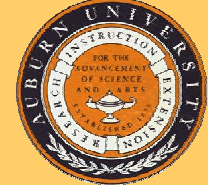




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Passivating Properties of Molecular and Nanoscale Layers

W. R. Ashurst, Ph.D.

Chemical Engineering Department

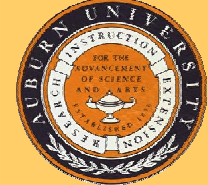
Auburn University

IEEE Holm Conference

September 27, 2006



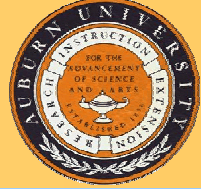
Outline



- Surface forces and scaling
- Monolayer coatings for MEMS
- Thin film coatings for MEMS
- Future of thin film coatings
- Conclusions and acknowledgements



What are MEMS reliability issues?

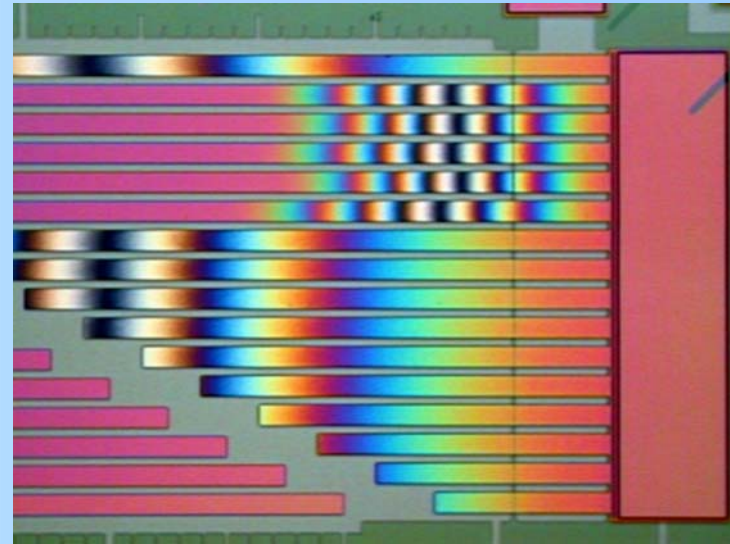


How long will they last?

- High frequency
- Plastic loading
- (asperities)

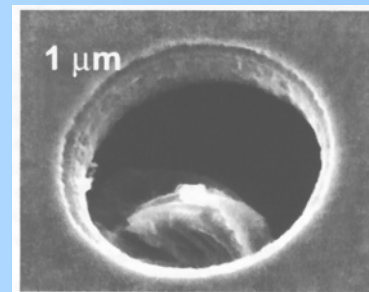
Why do they fail?

- Adhesion (Stiction)
- Friction
- Wear
- Fatigue
- Charge trapping
- and others...

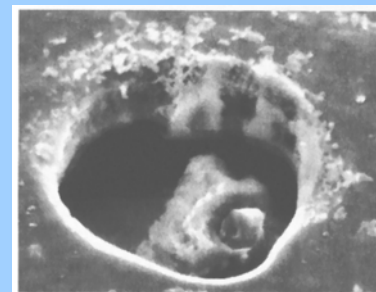


100 μm

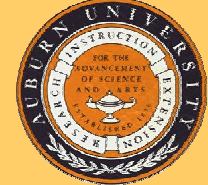
Pin joint on microengine gear



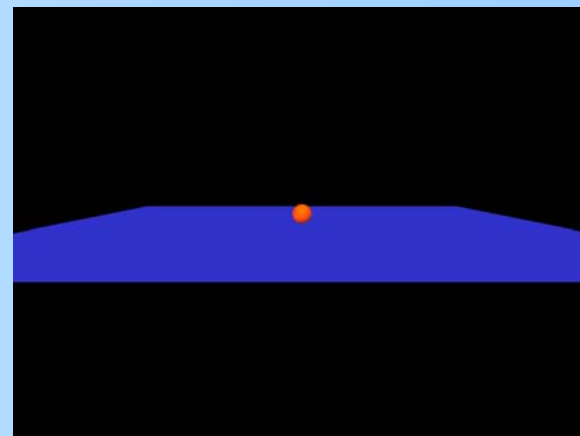
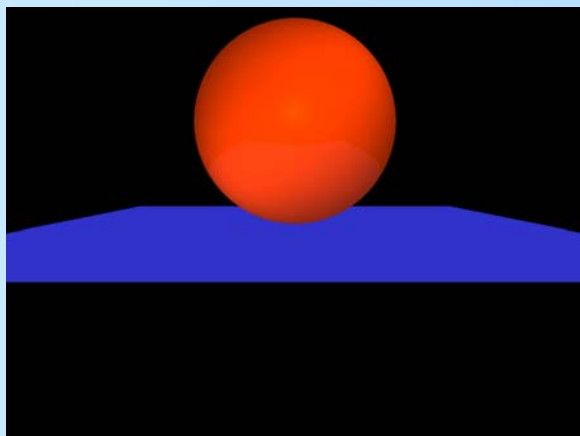
Control



After $\sim 10^6$ cycles



Scaling and Size



$$F_{cap} \cong 4\pi R\gamma \cos \theta$$

$$F_{vdw} \cong \frac{AR}{6D^2}$$

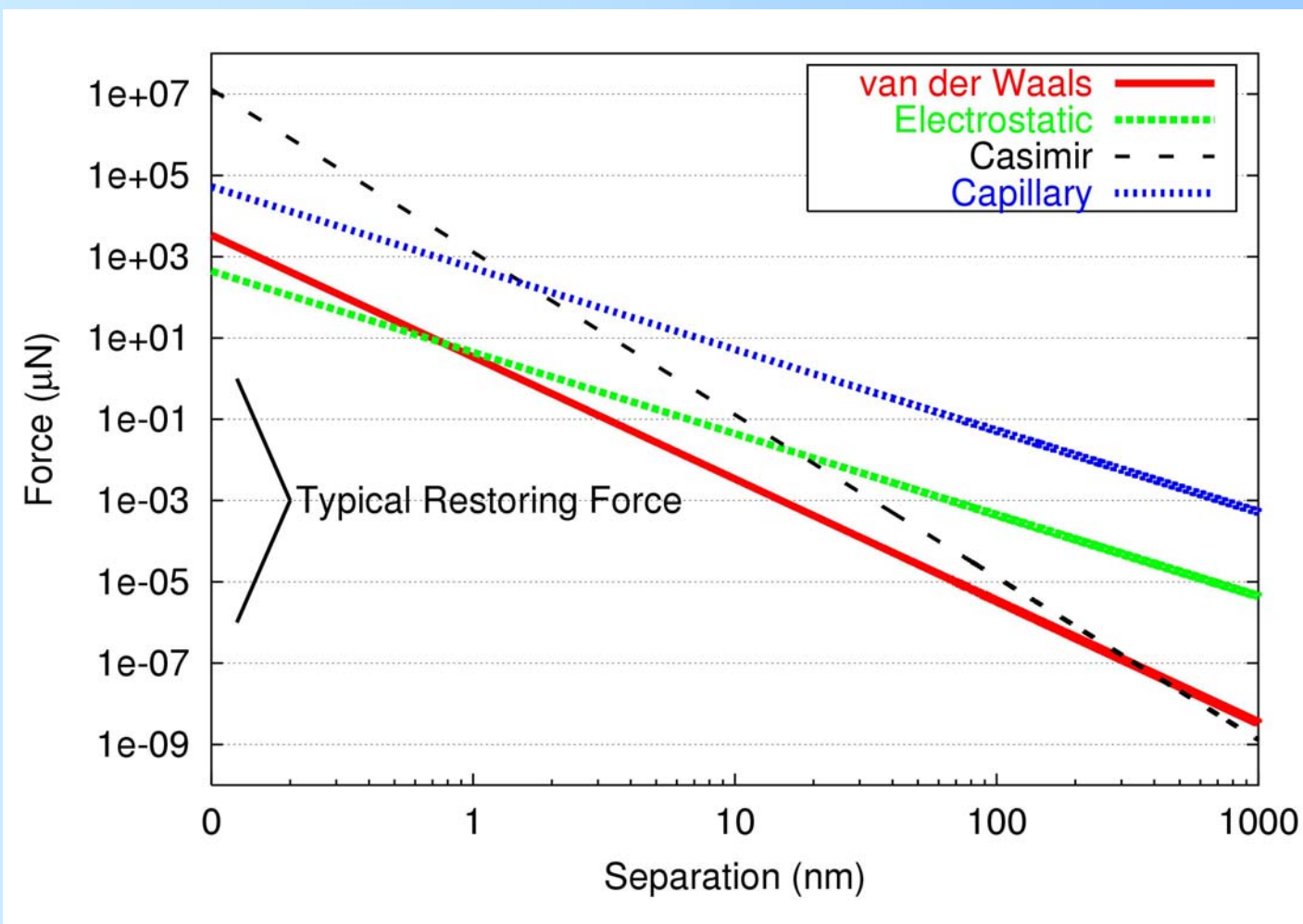
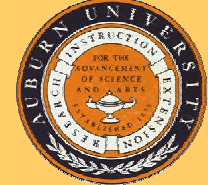
$$F_g = \frac{4}{3}\pi R^3 \rho g$$

$$\frac{F_{cap}}{F_g} \propto \frac{1}{R^2}$$

Scaling size by a factor of 10^{-4} results in a factor of 10^8 increase of the ratio of surface forces to body forces!



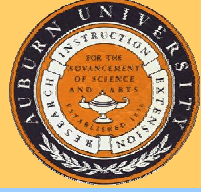
Interfacial Forces



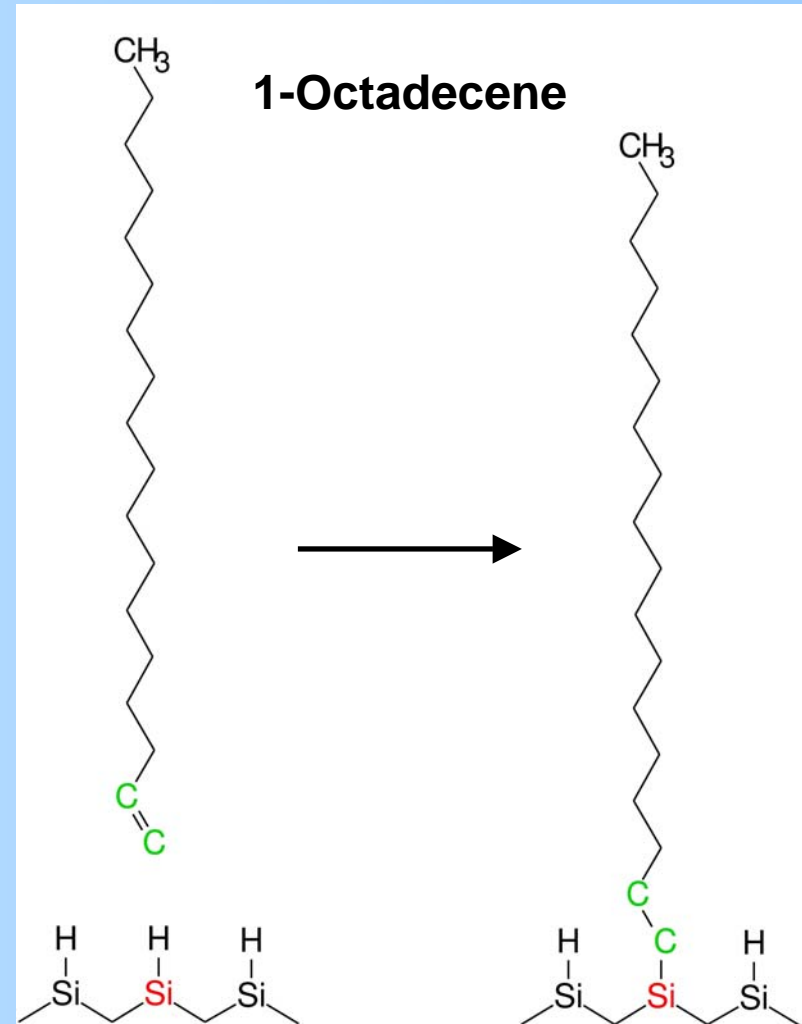
Force calculations assume two, 1 μm square, flat silicon surfaces, a distance d apart from each other.



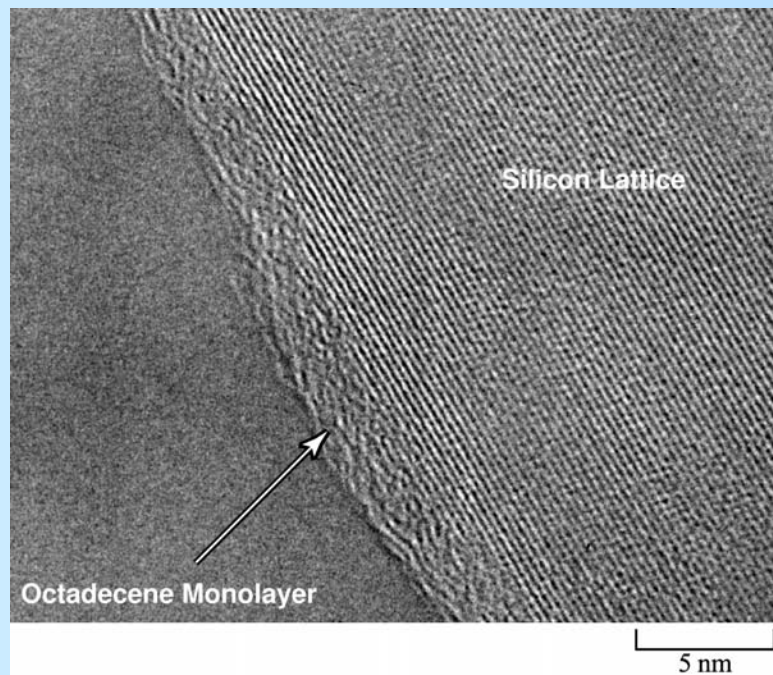
Alkene Based Monolayers



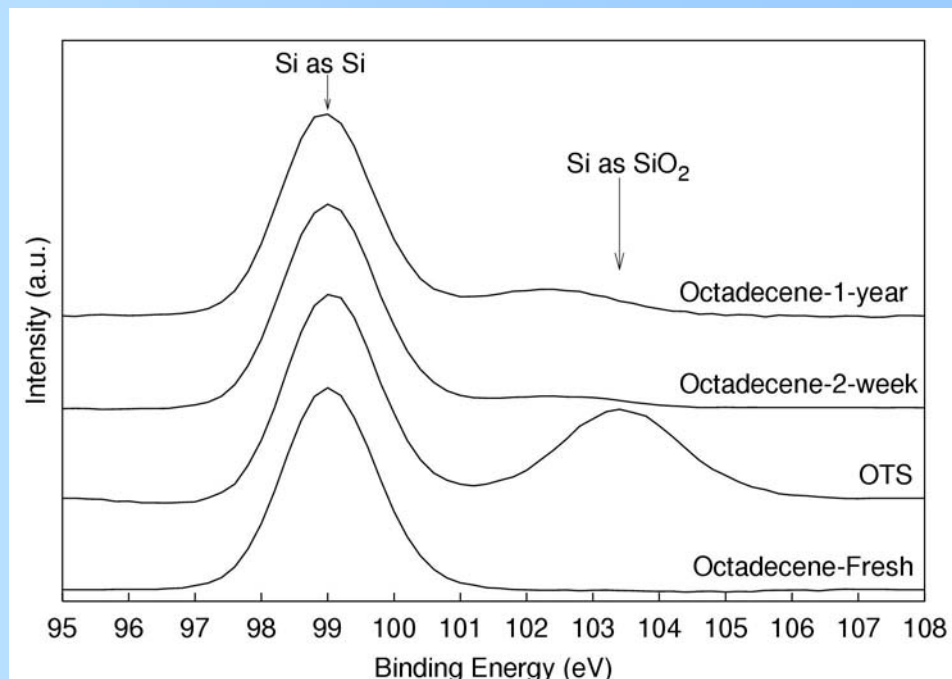
- Based on the reaction of a primary alkene and H-terminated silicon
- Annealing in vacuum produces SiC
- No oxide layer
- Stable for extended periods in air
- Can passivate silicon surface to oxidation
- Good for MEMS (anti-stiction, lubrication)



Octadecene Passivation Properties



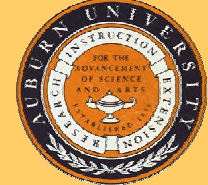
TEM analysis of an octadecene coating on a polysilicon grain. The film thickness is about 2 to 2.5 nm.



XPS analysis of octadecene coatings on Si(100) as a function of the film age. This shows that the coating protects the substrate from oxidation.



Octadecene Fatigue Properties



Muhlstein, Stach, and Ritchie

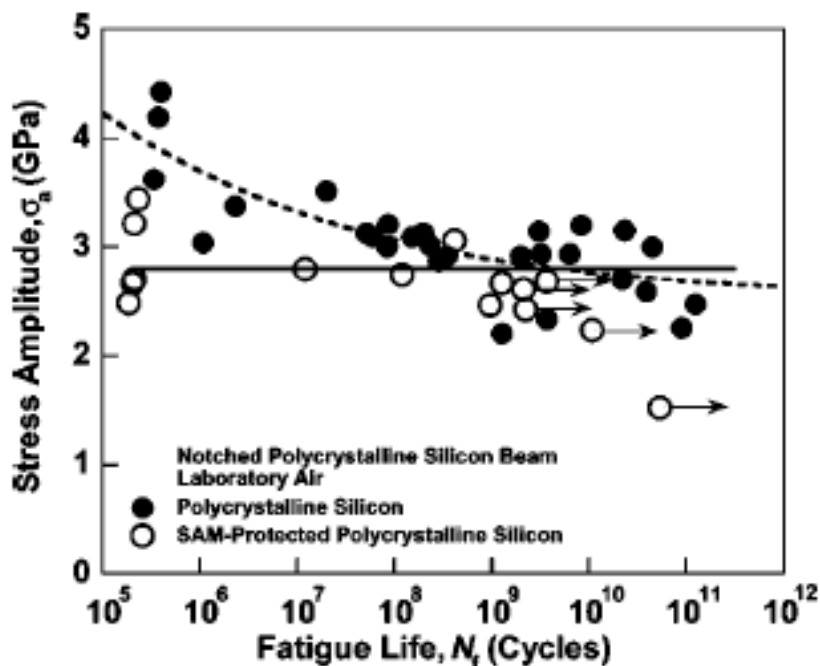
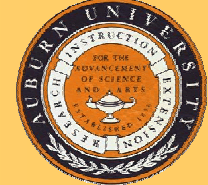


FIG. 5. Comparison of the fatigue behavior of uncoated and SAM-coated polycrystalline silicon thin films, showing the respective S/N curves. Note the reduced susceptibility of the coated polysilicon films to fatigue failure compared to uncoated polysilicon. Horizontal arrows indicate samples that had not failed.

- Octadecene coated devices (open circles) exhibited longer lifetimes than uncoated (filled circles) devices.
- Interestingly, octadecene coated devices also exhibited lower single cycle strength, probably due to lack of a smoothing oxide layer to mitigate stress concentration effects.



Other Thin Passivating Layers

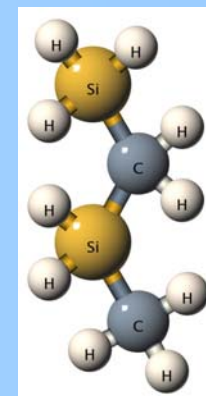
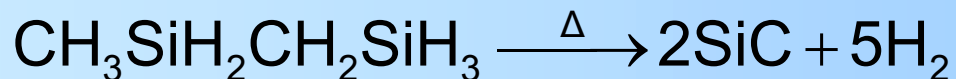


Why SiC?

	Hardness	Elastic Modulus	Fracture Toughness
β -SiC	24 GPa	440 GPa	4.6 MPa m ^{1/2}
Si(100)	9.5 GPa	130 GPa	0.95 MPa m ^{1/2}

SiC is one of the toughest and most chemically inert materials that can be easily deposited today.

How? CVD style pyrolysis of disilabutane (DSB)

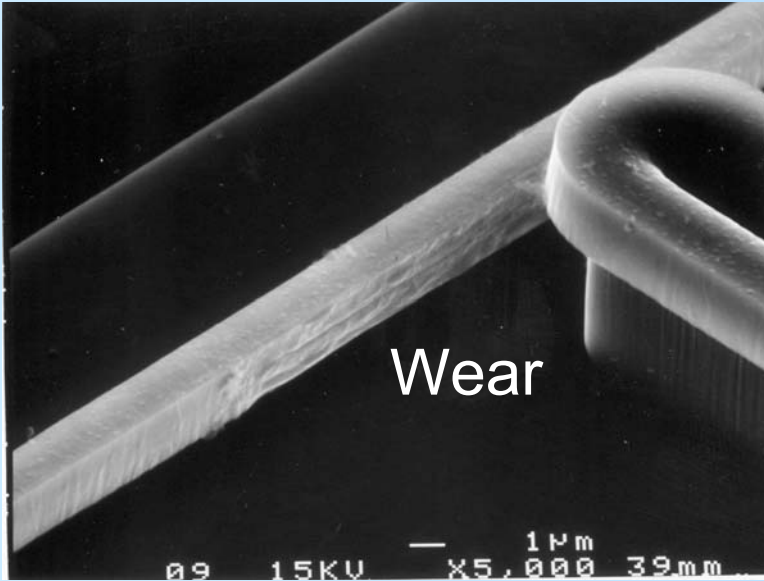
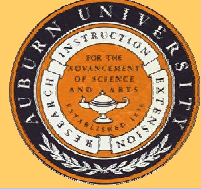


Existing polysilicon microstructures are released and treated with the octadecene process. A thin (10-40 nm) LPCVD film of SiC from DSB is deposited on the structures and the microdevices are then used to study wear.

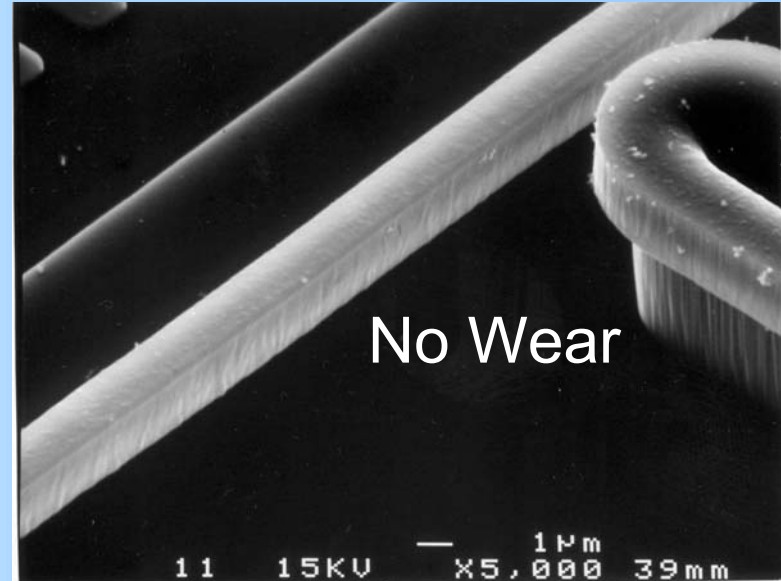
SiC Coating for Wear Control



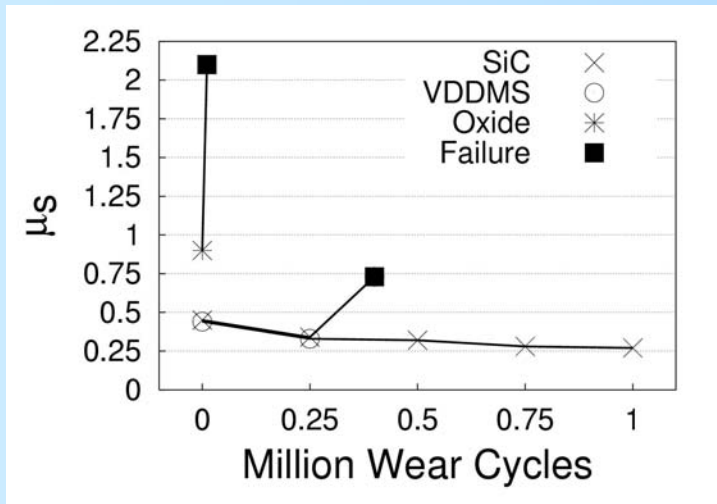
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VDDMS Coated



SiC Coated
> 1M cycles



SiC coated devices show substantial lifetime improvement and appear to be self lubricating.

SiC Coating for Chemical Passivation

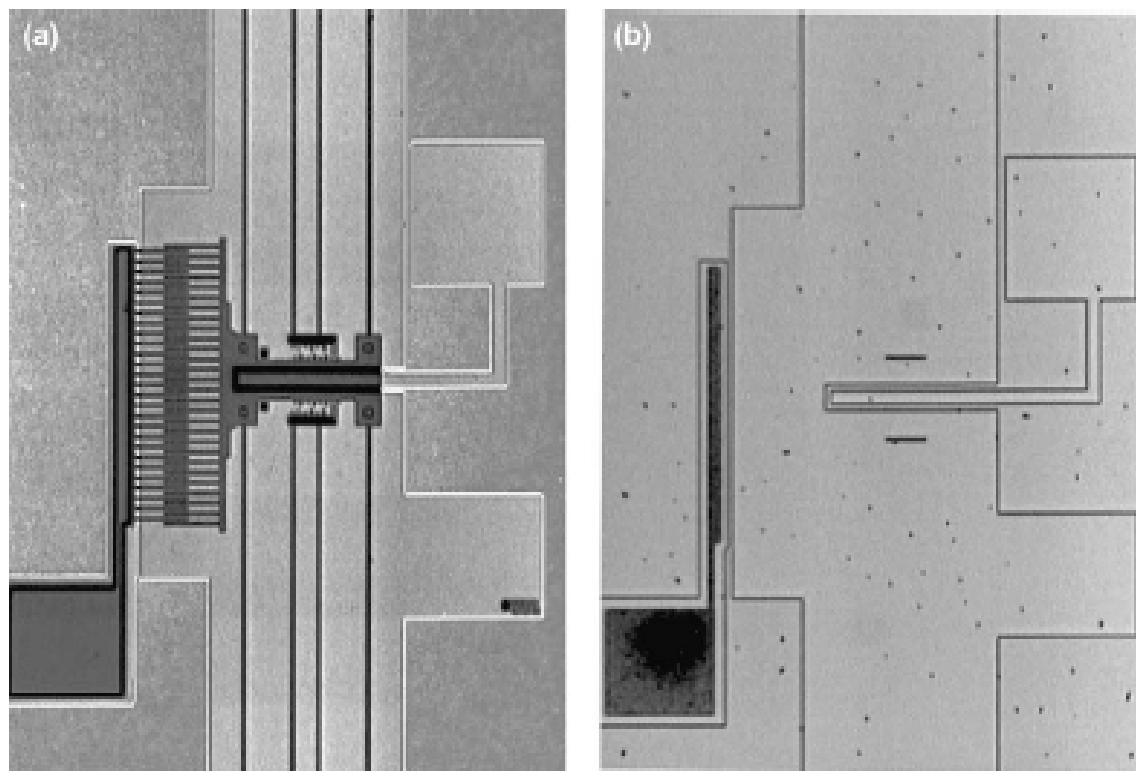


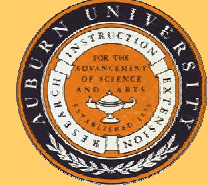
Fig. 10. Optical images of (a) SiC-coated and (b) uncoated polySi micromachines following immersion in hot KOH solution.

C.R. Stoldt et al. /Sensors and Actuators A 97-98 (2002) 410-415

No change in resonance was observed for KOH versus original structures. Similar experiments were carried out with AFM cantilevers, and similar results were obtained.



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