Microfabrication of Heterogeneous, Optimized Compliant Mechanisms

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Fig. 1. Single-material Heatuator with selective doping on one arm (G.K. Ananthasuresh)

Compliant Mechanisms

- Monolithic micromachined structures
- Devices that deform flexibly to achieve useful work when actuated

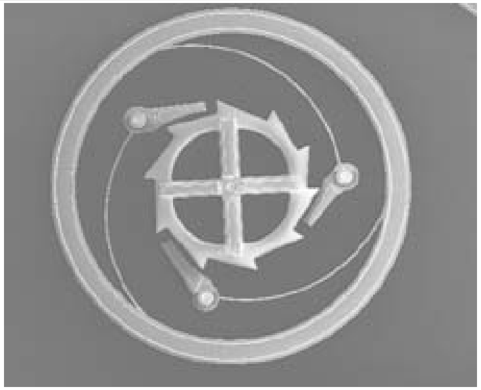


Fig. 2. Micro-compliant clutches (BYU)

Examples:

- Compliant overrunning clutches offer high torque and minimizes problems with assembly
- Micro-compliant pantographs can amplify force and motion at the micro scale

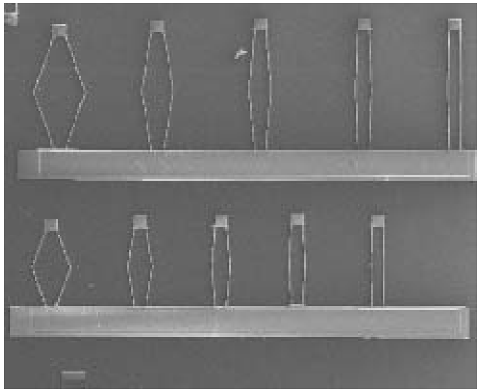


Fig. 3. Micro-compliant pantographs (BYU)

Micro-electro-mechanical Systems (MEMS)

- Structures that have static or moveable parts with some dimensions on the micron scale
- Devices combining electrical and mechanical components
- Transducers: devices that converts input energy of one form into output energy of another

Question: What if MEMS are made to contain properties of compliant mechanisms?

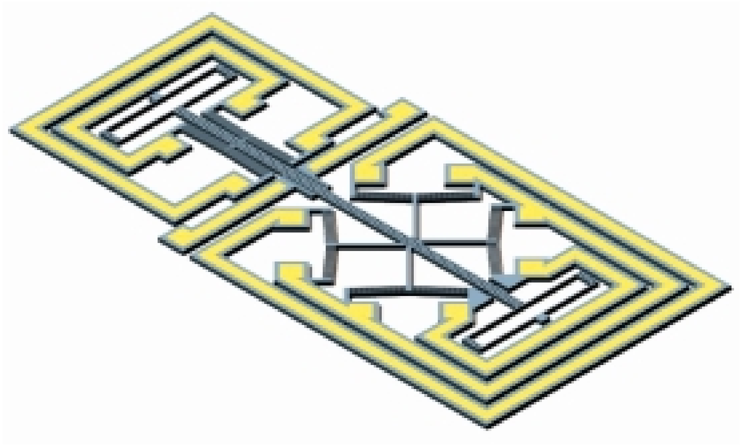


Fig. 4. Electro-thermal linear micromotor using v-beams (J. Maloney – U.Maryland)

Electro-thermal-compliant (ETC) Actuators

- MEMS devices that are based on joule heating-induced thermal expansion
- With input of electrical power yields large forces and deflections
- Micro-mechanical structures that perform micro-manipulation and micro-positioning tasks

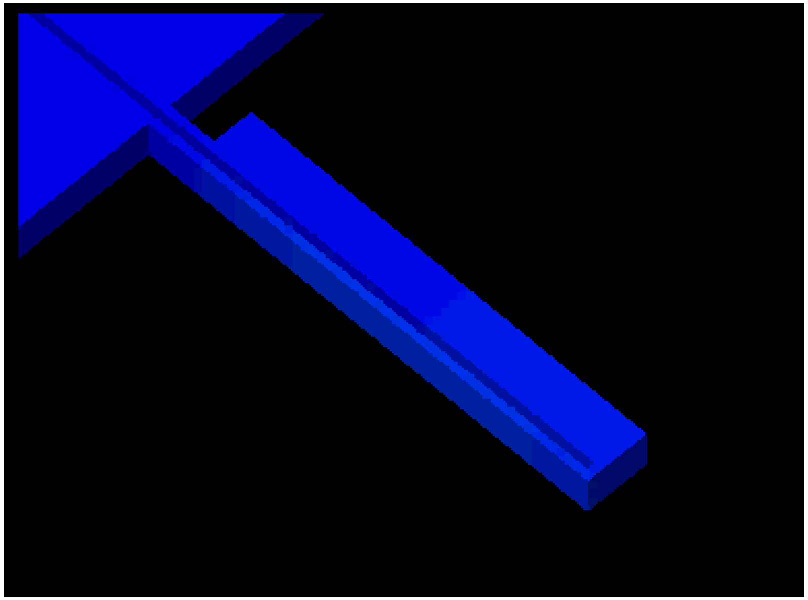


Fig. 5. Heatuator: electro-thermal in-plane actuation – composed of a single material (J. Maloney – U.Maryland)

Two-material ETC Mechanism

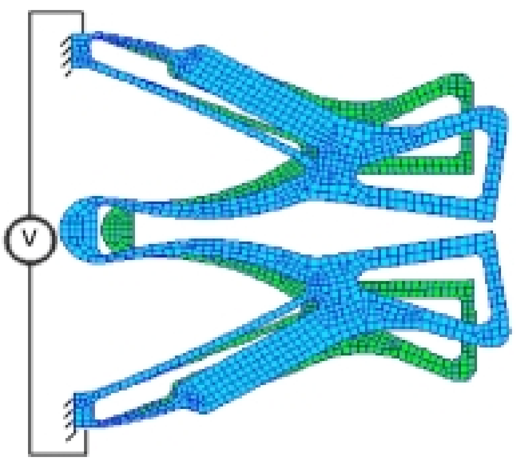


Fig. 6. Single material crimping
mechanism acting as a micro-gripper embedded with ETC actuation (G.K. Ananthasuresh)

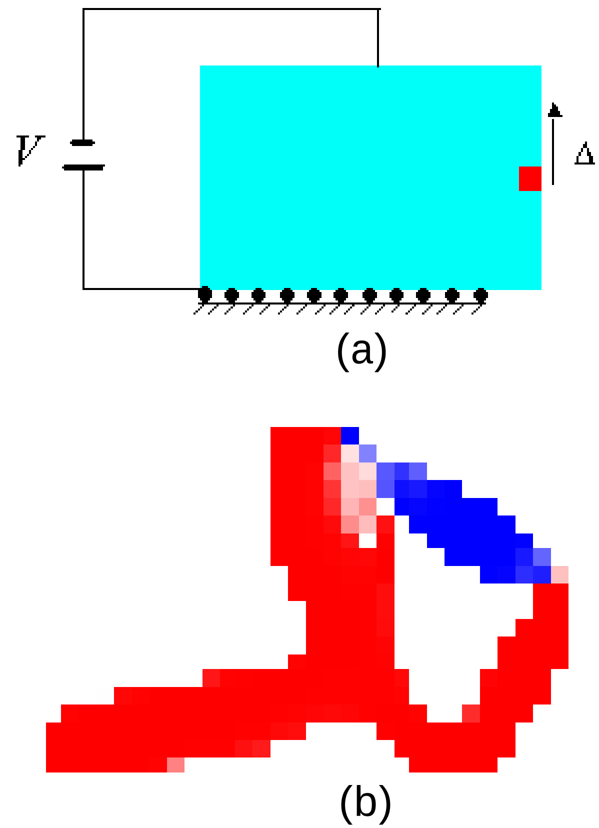
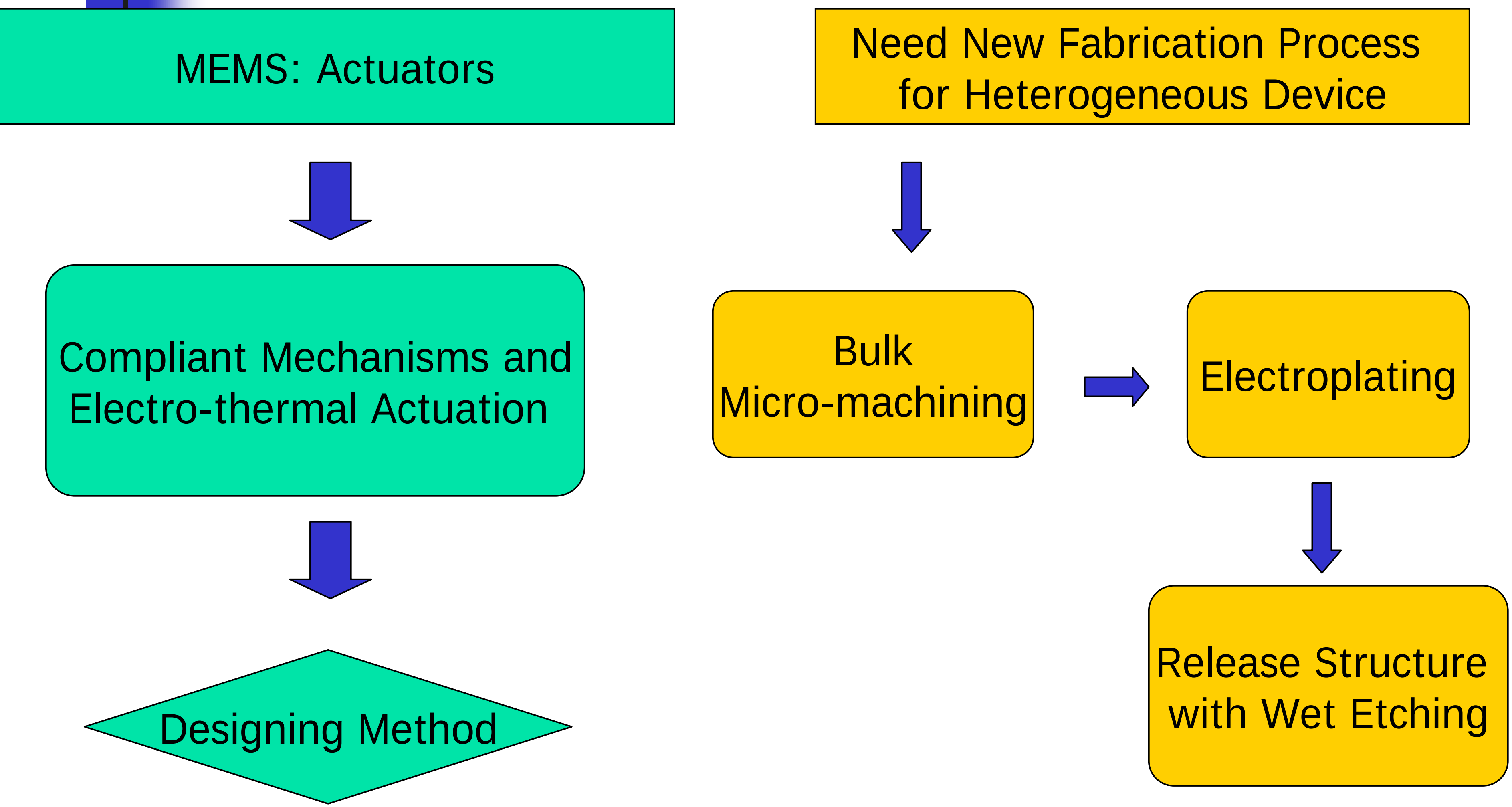


Fig. 7. (a) Basic model of two material topology optimized compliant mechanism, (b) simulation showing displacement

Flow Chart of Manufacturing Process for Two-material Compliant MEMS

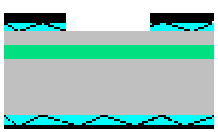


Creating the Cavity With Bulk Micro-machining

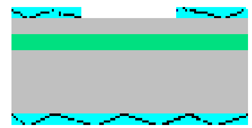
Silicon on Insulator wafer

Deposition of nitride using LPCVD and then spin photoresist (positive)

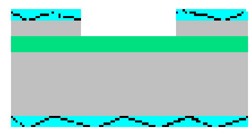
Transfer desired pattern onto the photoresist with chromium mask (ultra-violet light exposure)



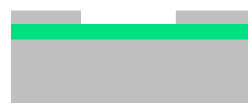
Plasma etching of silicon nitride layer



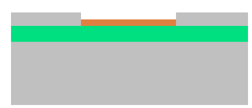
Remove the photoresist



Wet chemical etching of silicon with KOH solution



Remove silicon nitride layer



Electron beam evaporation of seed layer onto silicon

Fig. 8. Cavity created on SOI wafer with lithography, etching and e-beam techniques

Electroplating Theory

- Potential exists between cathode and ions in gold solution
- External voltage creates ion concentration gradient across diffusion region
- Reduction of SOI wafer at cathode with gold ions

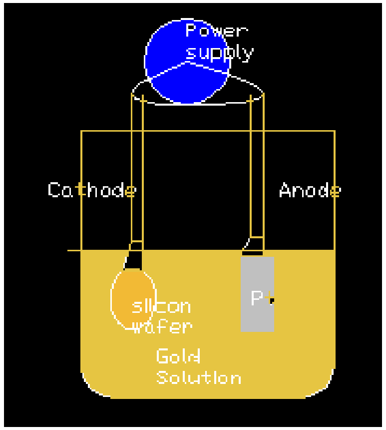


Fig. 9. Electrochemical Cell

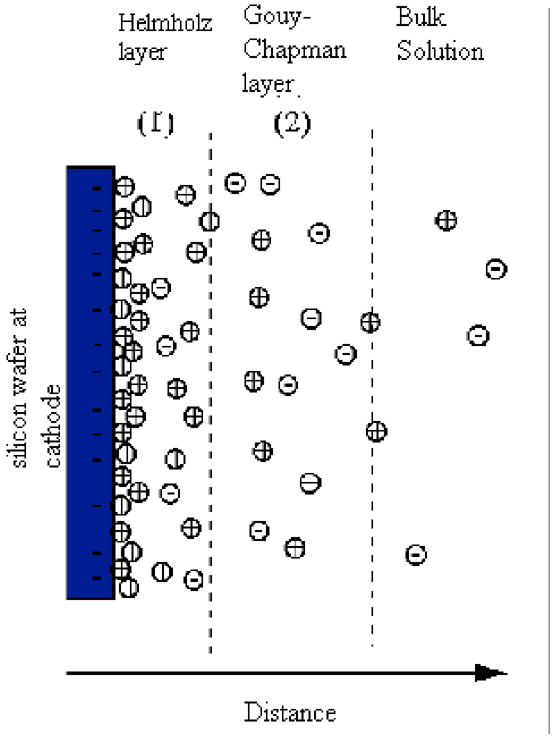


Fig. 10. Electroplating model

Electroplating Gold

Adjusting parameters for obtaining *high-resolution morphology*

- Current density
- Electroplated area
- Temperature
- Forced convective techniques

Solutions to Non-uniform Gold Deposits

1. Reduce the current density applied
2. Maximize the reaction kinetics of electroplating
    - Control electroplated area
    - Stir
    - Heat

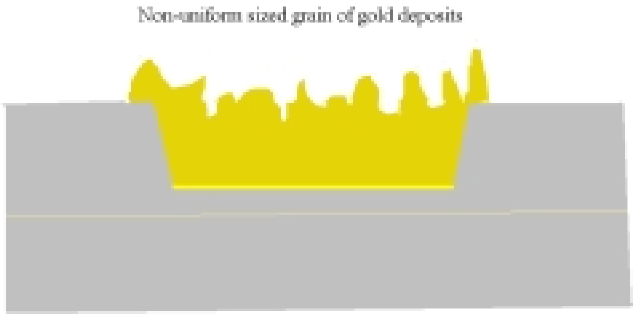


Fig. 11

Morphology of Gold Deposits

Top View of Gold Deposits

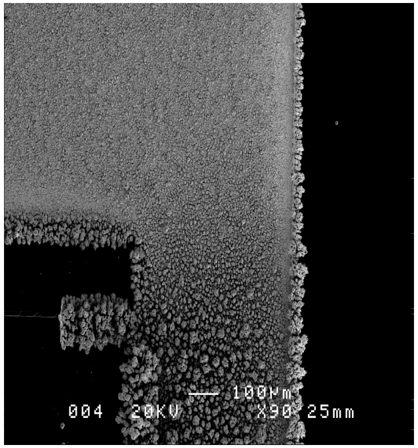


Fig. 12. SEM: Gold Deposits at 10 mA

Reason for electroplating uniform gold deposits: the ***performance*** of ETC devices depends on *electrical, mechanical, and thermal* boundary conditions

Significance of *low current density*: smoother gold surface, uniform-size gold deposits → *better morphology*

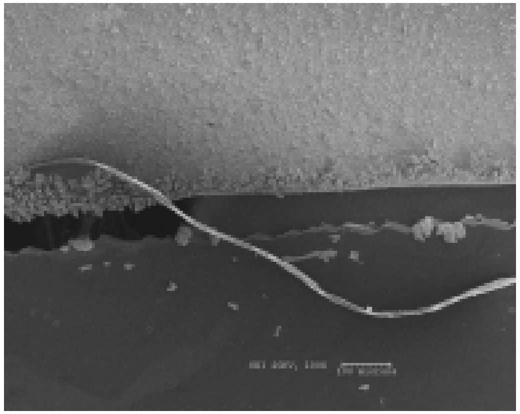


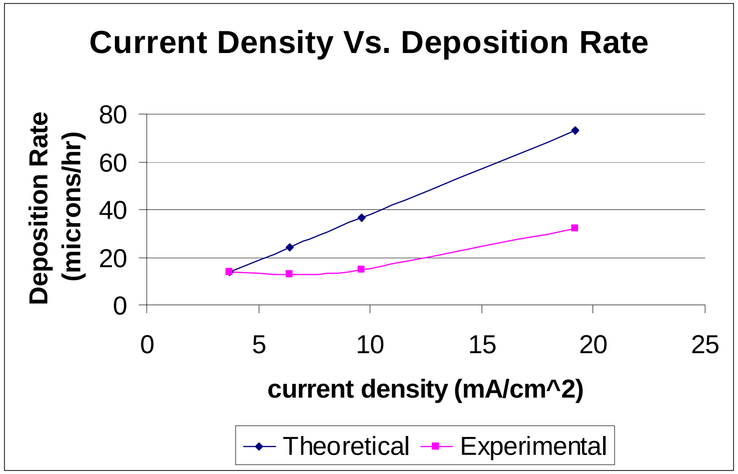
Fig. 13. SEM: Gold Deposits at 2 mA

Optimal Electroplating Conditions

Lower current density works best:

1. produces less hydrogen bubbles
2. keeps the pH of the gold solution constant
3. maintains high current efficiency that is lost from the hydrogen production

- 2mA → yielded about 14 μm/hr plating rates of gold deposits
- Above 2mA current applications → yielded greater plating rates but wider ranges of deposition rates
- Below 2mA →not enough energy to drive chemical reaction



Wet Chemical Etching

- Back-side etching of silicon substrate with KOH and black wax

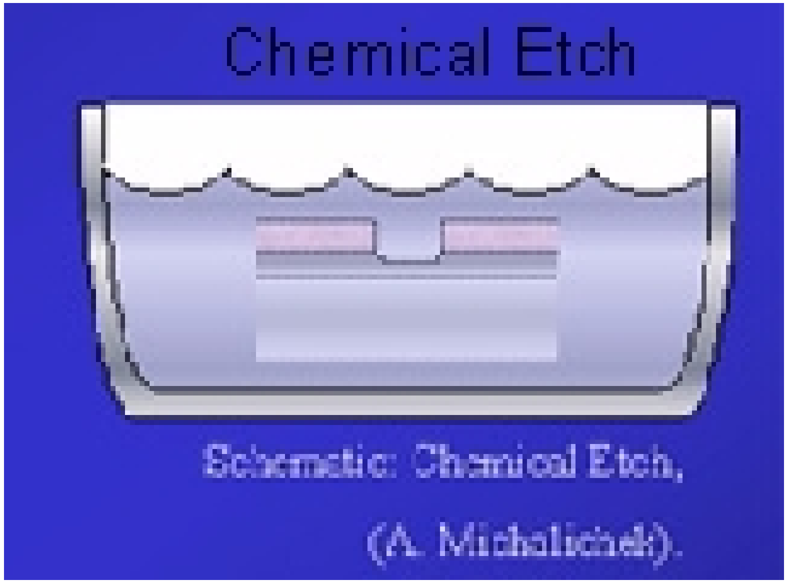


Fig. 14

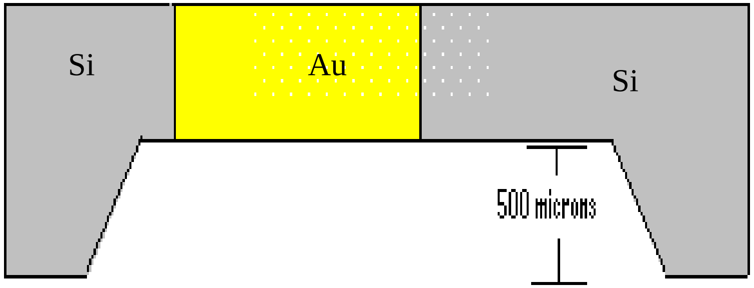
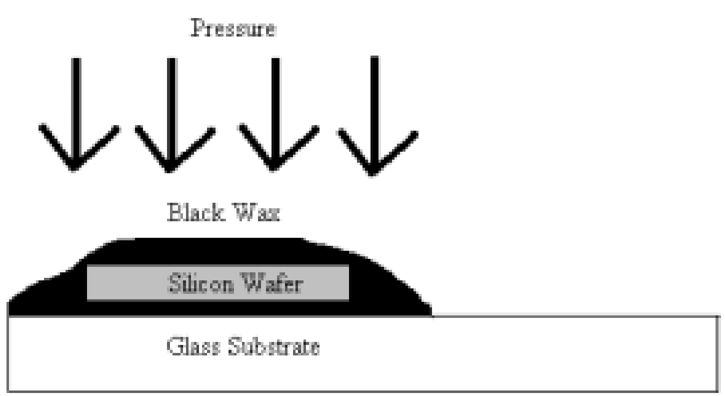


Fig. 15

Results: ~15 hour etching at about 0.56 μm/min

A Novel Masking Method

- Melt black wax on glass
- Apply pressure to press silicon wafer into black wax
- Cover wafer with black wax except for the area of interest
- Immerse Glass substrate attached with silicon wafer into KOH solution
- Remove bubbles off etched surface (e.g. stirring)



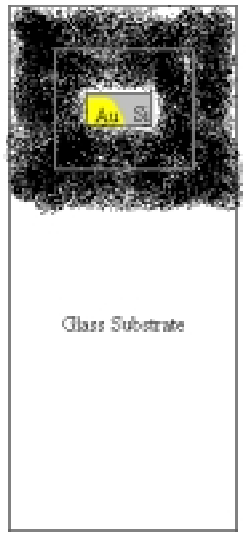


Fig. 16. Masking with Black Wax

Future Work: Electro-thermal Actuation

- Complete microfabrication of compliant microactuator
- Electro-thermal-compliant microactuation by applying voltage
- Determine maximum actuator displacements and forces
- Analyze current and temperature distribution, and thermal properties (e.g. conduction, convection, and radiation) in the two-material structure

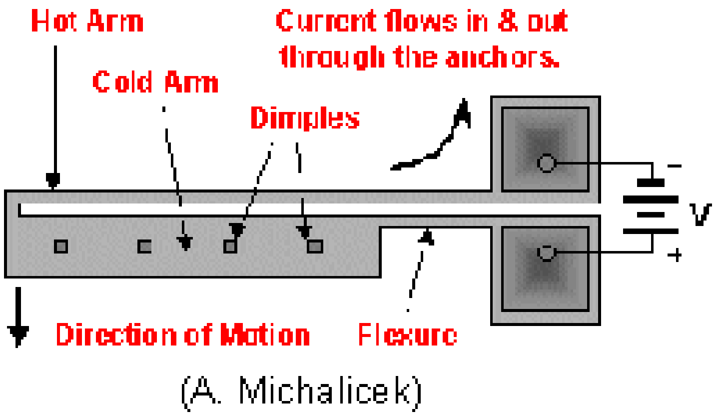


Fig. 16

Vs.

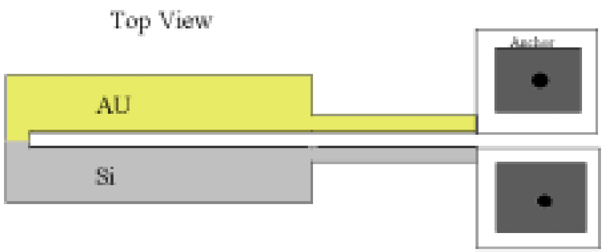


Fig. 17

Heatuators

Acknowledgements

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