Liquid Metal Interconnects for Conformable Sensor Packaging Enabling Inertial Measurements of Animals and Soft Robots

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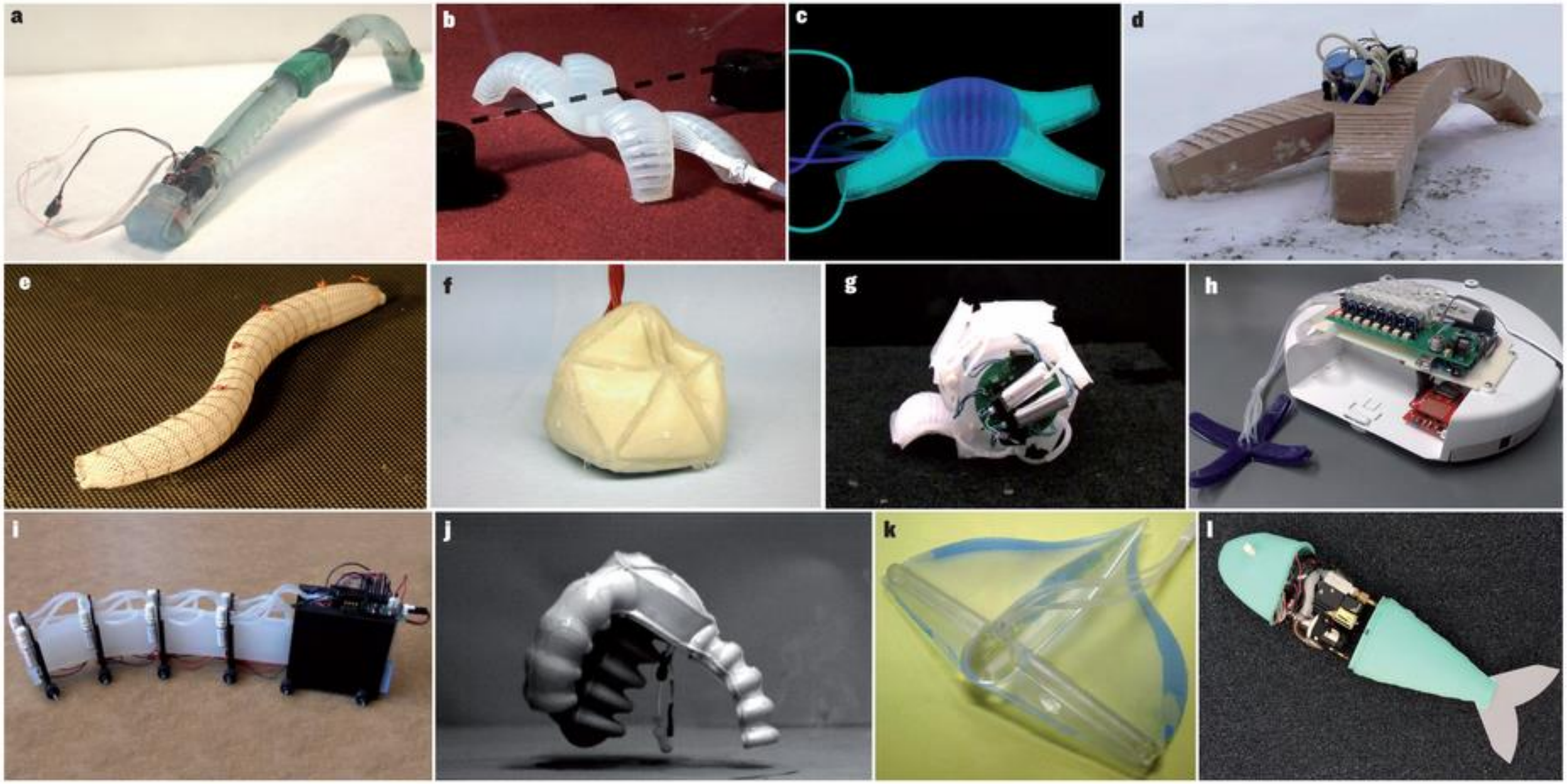
What is a Soft Robot?

- Compliant body.
- Conforms to the environment rather than manipulating it.
- The idea is:
  - Safe around people
  - Locomotion in unstructured environments
  - Low ordered control

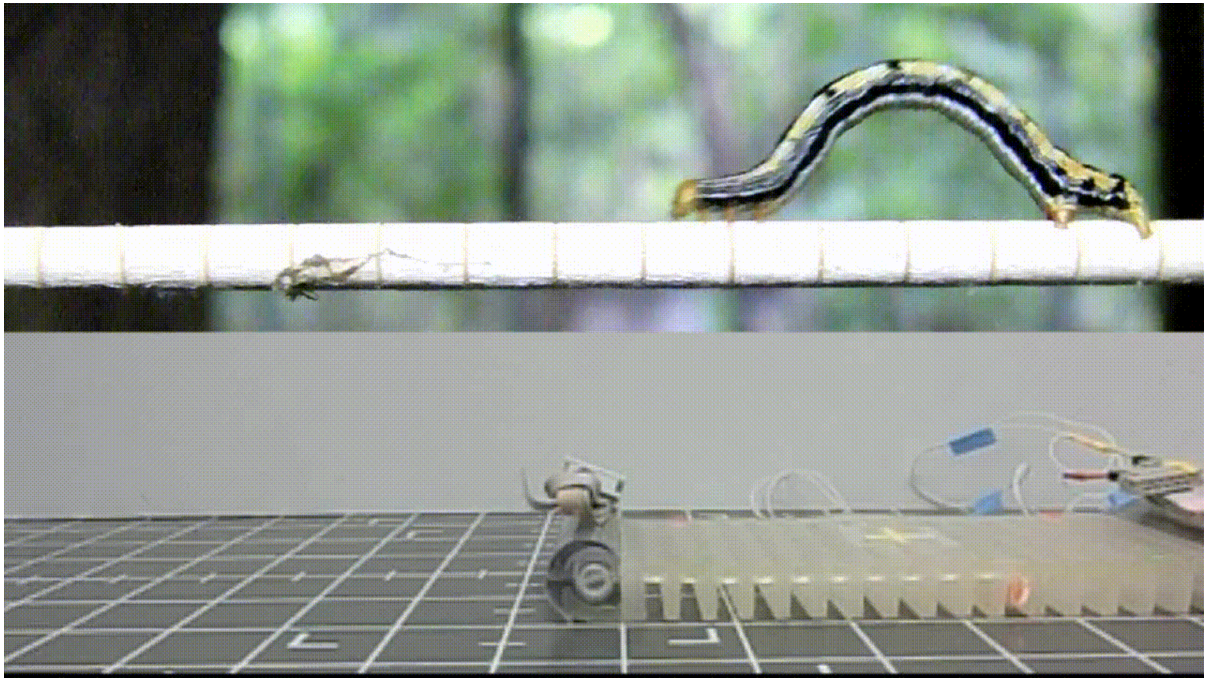
Soft Robots



Rus, Daniela, and Michael T. Tolley. "Design, fabrication and control of soft robots." *Nature* 521.7553 (2015): 467-475.

Motivation: Soft Robot Locomotion

- De-coupled Control requires sensing the position state and configuration.
- Inertial measurement of strategic points.



Motivation: Biomechanics

– Caterpillar Nociceptive Strike Reflex

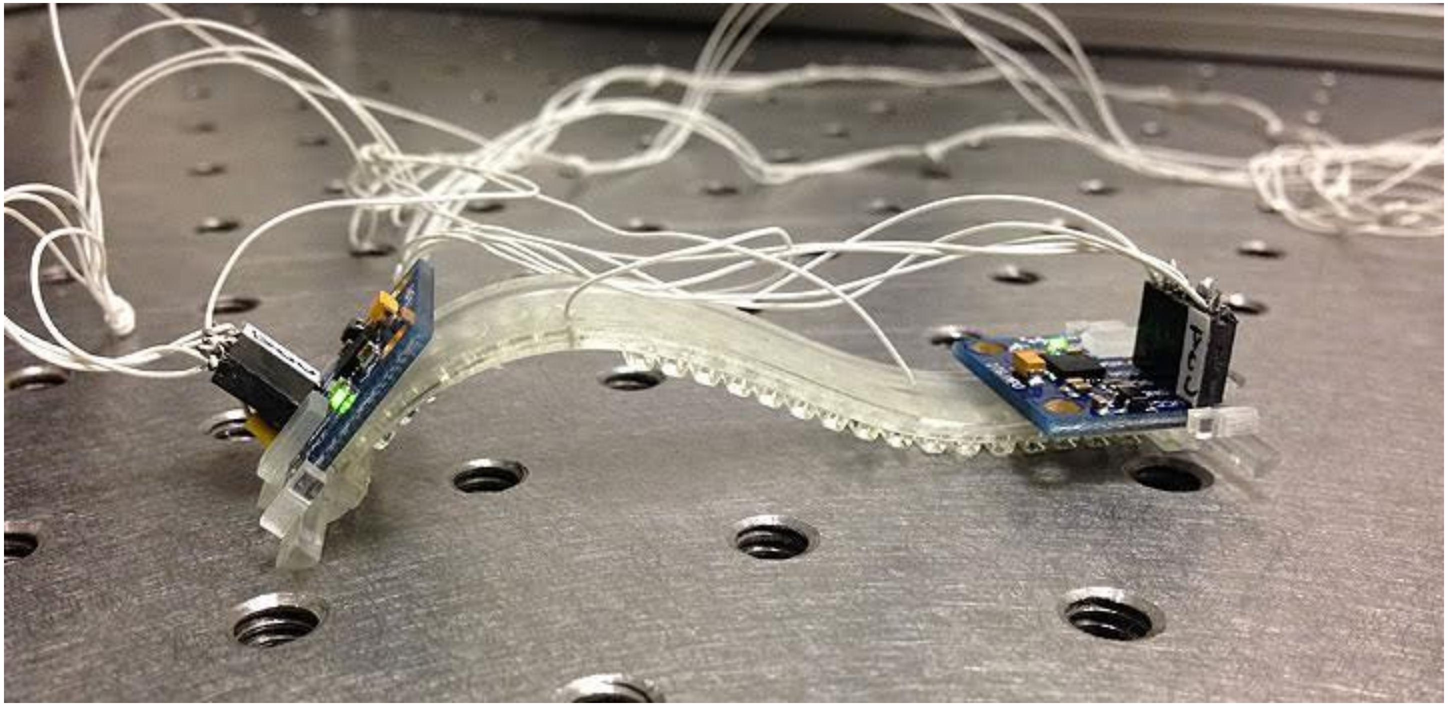
- There is an interest in directly measuring the motion of the caterpillar to determine how it is so fast.
- van Griethuijsen, Linnea I., Kelly M. Banks, and Barry A. Trimmer. "Spatial accuracy of a rapid defense behavior in caterpillars." *Journal of Experimental Biology* 216.3 (2013): 379-387.

– Fish Swimming

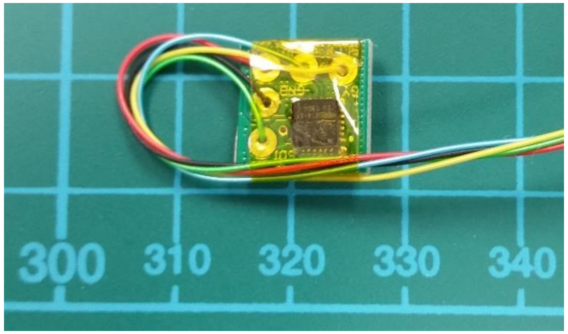
- Direct inertial measurement of swimming fish is difficult because of the flexible body and aquatic environment.
- https://sites.tufts.edu/tytelllab/

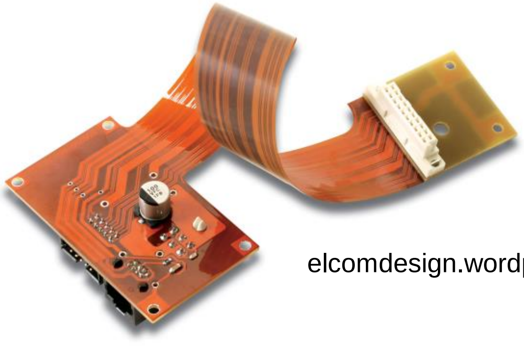
Hard Circuits on a Soft Robot

- PCB package technology limits the 'soft' functionality of soft-robots.



Why cant we use Flex Circuits or PCBs?





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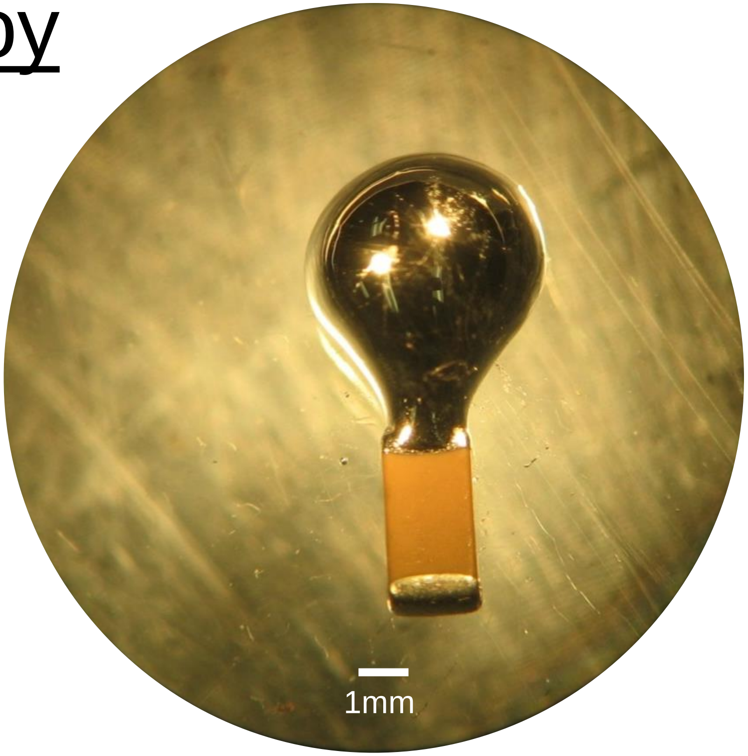
- Not extensible or compressible (only bending)
- Not meant for dynamic bending
- Surface mount solder breaks in bending
- Need a package that can deform in 6 degrees of freedom.

eGaIn Liquid Metal for Interconnects

<u>Eutectic Gallium Indium Alloy</u>

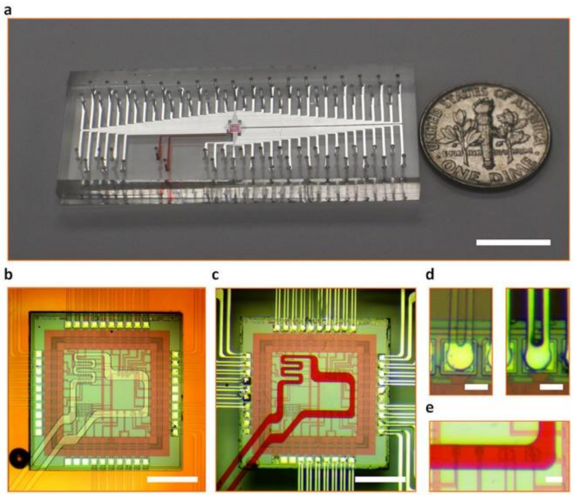
- Properties:
  - Liquid @ room temp.
  - Melting point at 15.7 °C µ
  - 6.25 g/mL at 25 °C
- Cost: $14.7/gram
- Supplier: Sigma Aldrich
- Hazzard: H314 (corrosive)



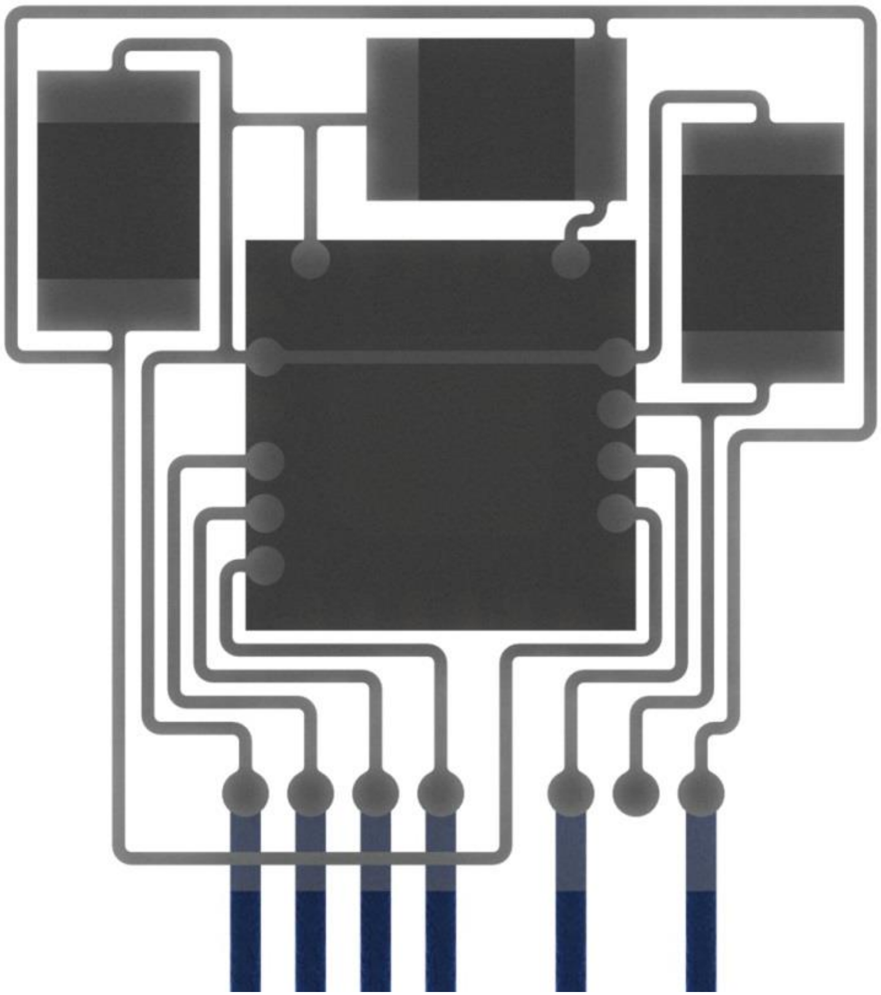
Prior Art: eGaIn and Conformal Packaging

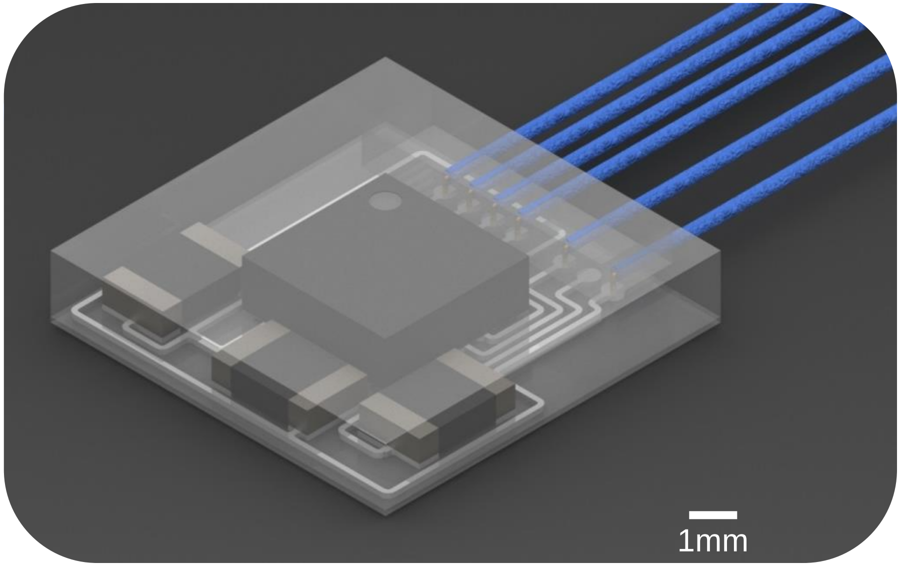
- eGaIn is used prolifically in the design of soft sensors and micro-electronics.
  - Dickey, Michael D., et al. "Eutectic Gallium-Indium (EGaIn): A Liquid Metal Alloy for the Formation of Stable Structures in Microchannels at Room Temperature."*Advanced Functional Materials* 18.7 (2008): 1097-1104.
  - Tabatabai, Arya, et al. "Liquid-phase gallium–indium alloy electronics with microcontact printing." *Langmuir* 29.20 (2013): 6194-6200.
  - Tabatabai, Arya, et al. "Liquid-phase gallium–indium alloy electronics with microcontact printing." *Langmuir* 29.20 (2013): 6194-6200.

- Packaging of solid state ICs:
  - Zhang, Bowei, et al. "Flexible packaging of solid-state integrated circuit chips with elastomeric microfluidics." *Scientific reports* 3 (2013).



Package Design

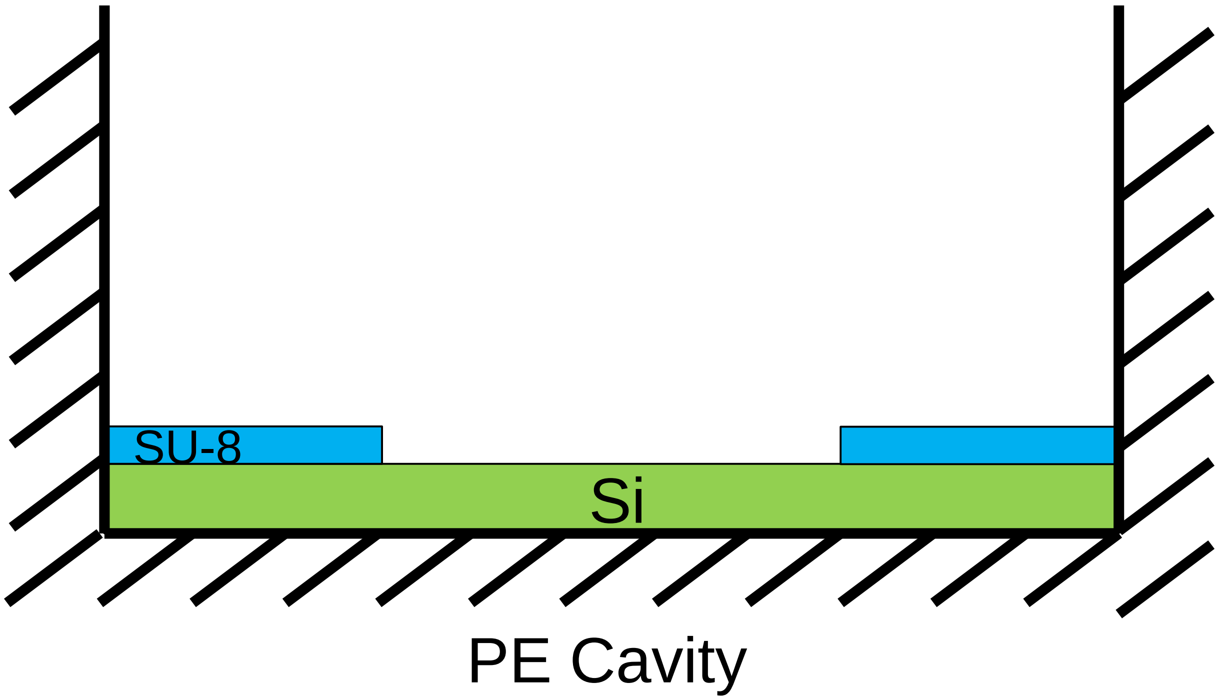


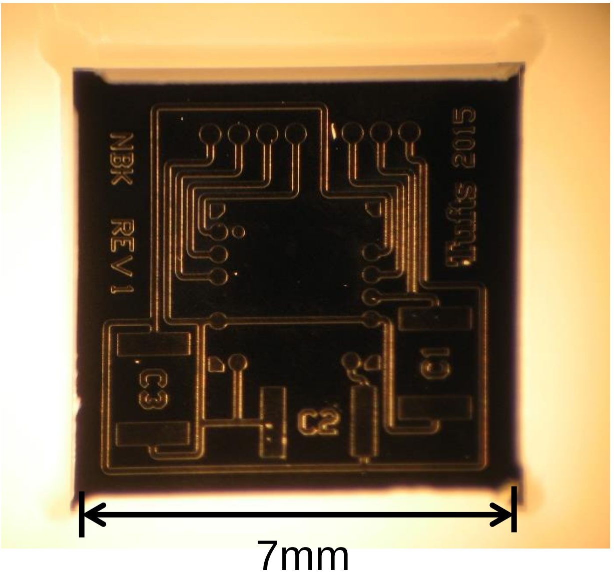


- 7x7x2 mm PDMS package
- 1x IMU 9250
- 1x 10nF Capacitor 0805
- 2x 0.1µF Capacitor 0805
- 6x 90µm O.D. stranded wire

Step 1: Fabricate Micro-Channel Mold

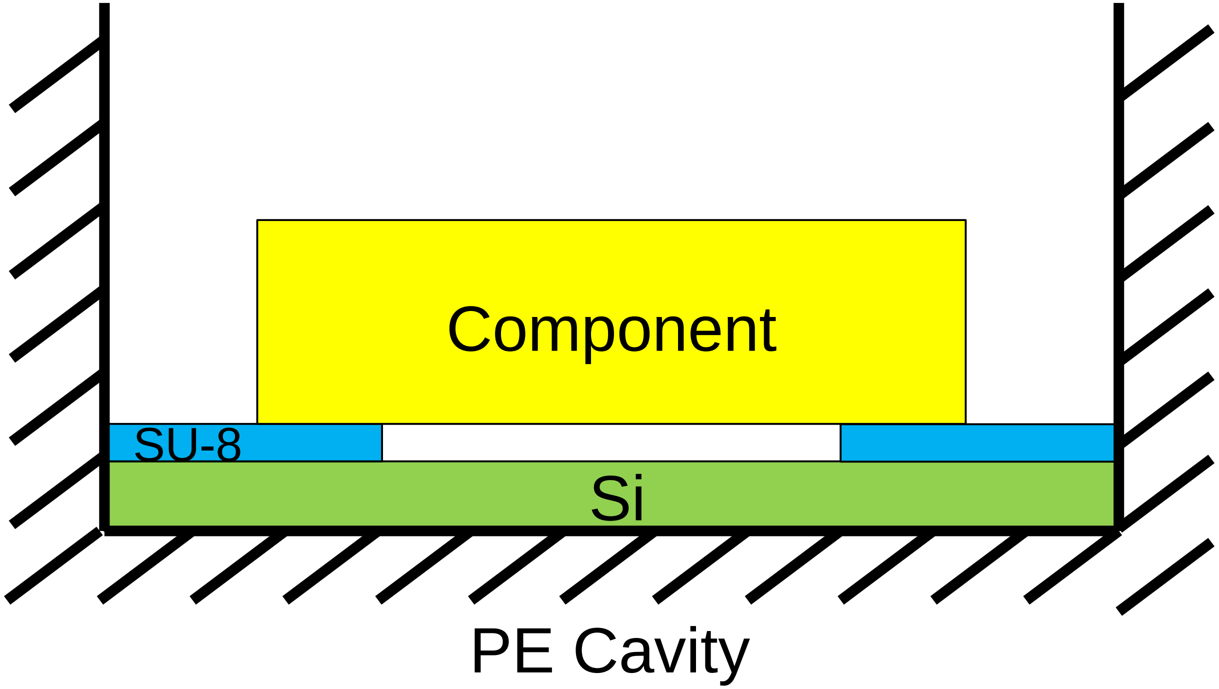
- Photo-lithography of SU-8 on silicon.
- 100x50 µm channels

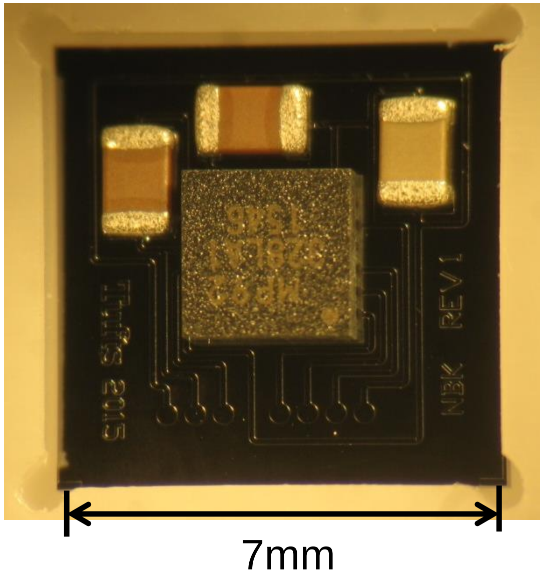




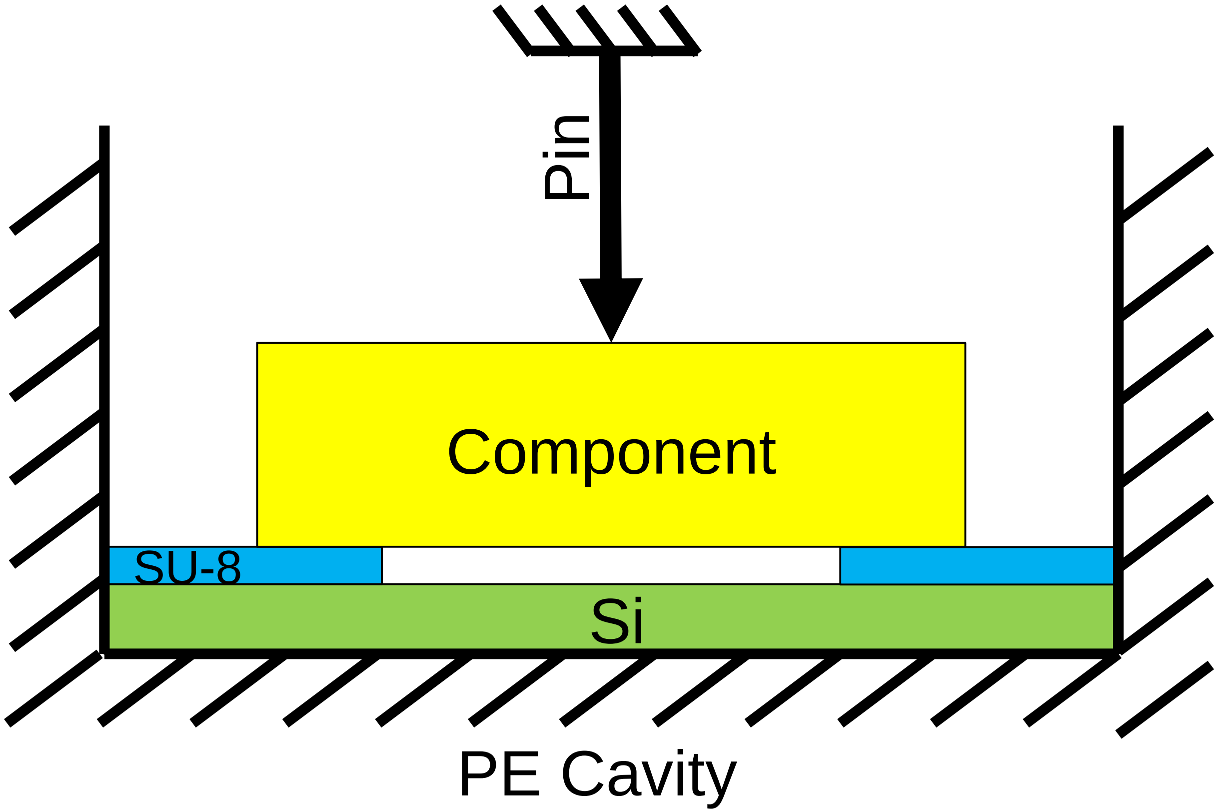
Step 2: Place Components

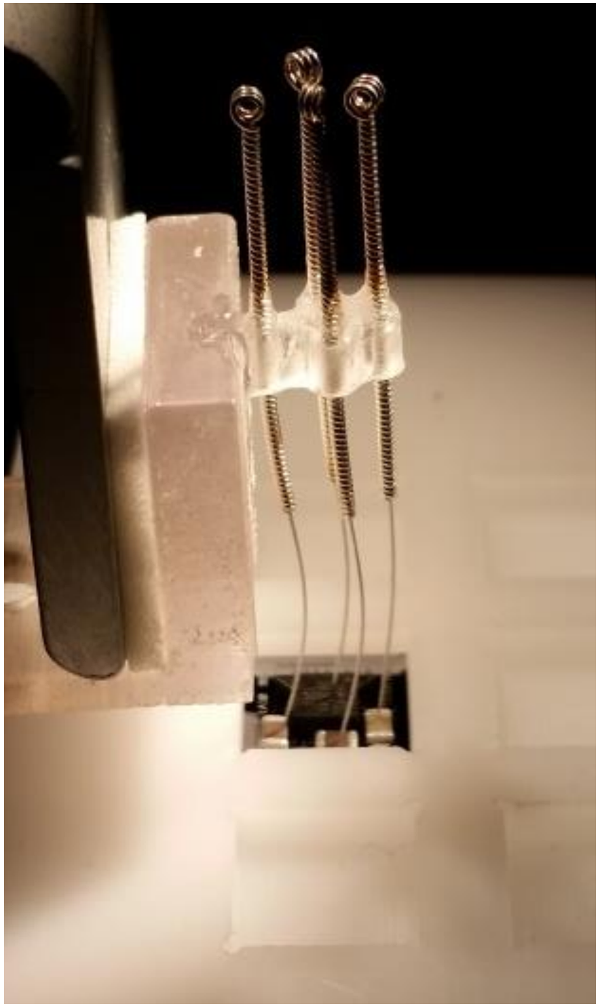
- Manually place with forceps under microscope.



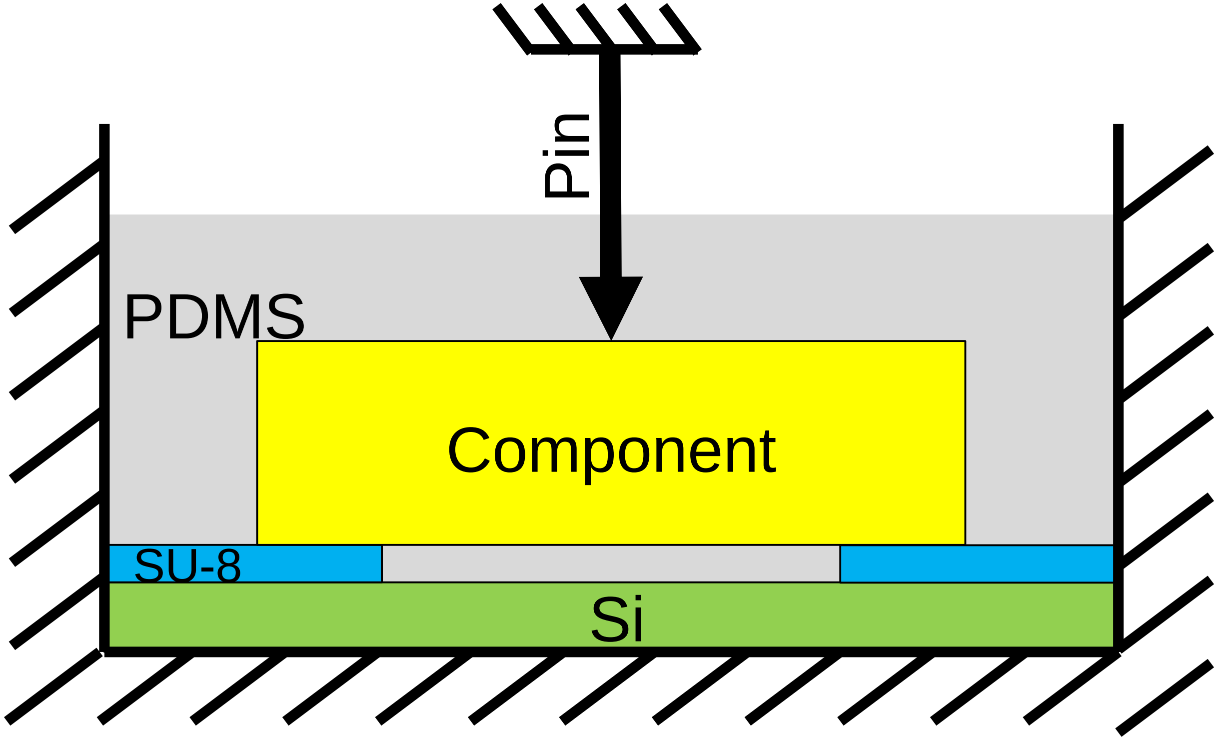


Step 3: Pin Components in Place

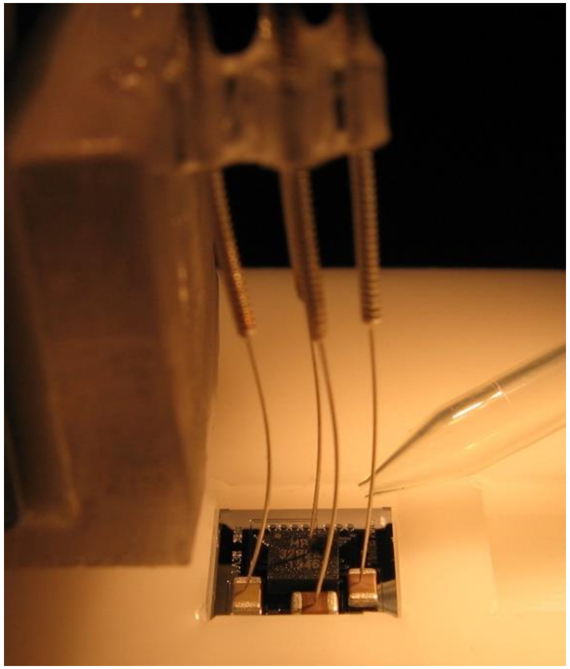




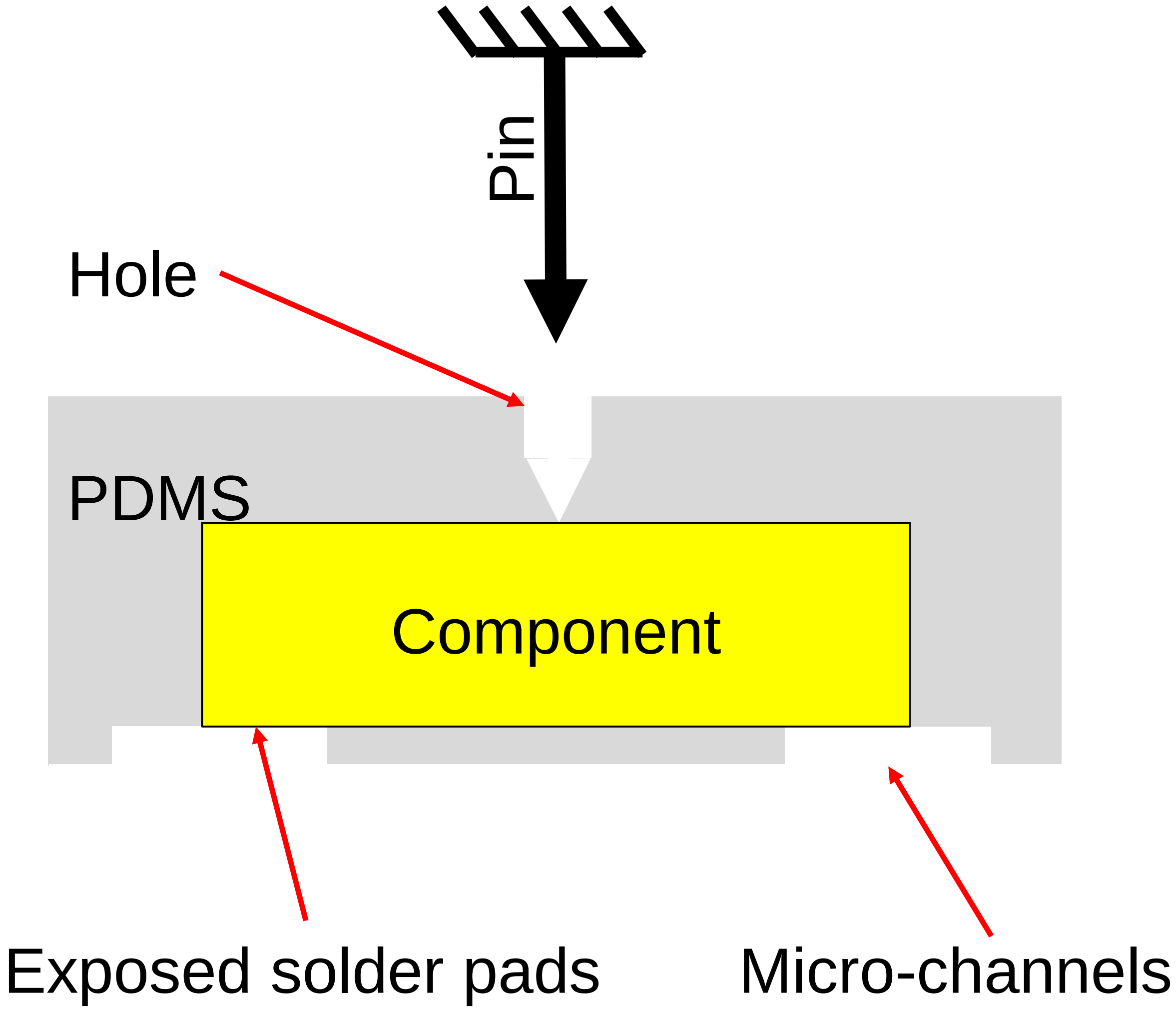
Step 4: Fill with PDMS



- Fill cavity with 25 µL of PDMS using positive displacement pipette.
- Cure in place for > 12 hours @ STP.

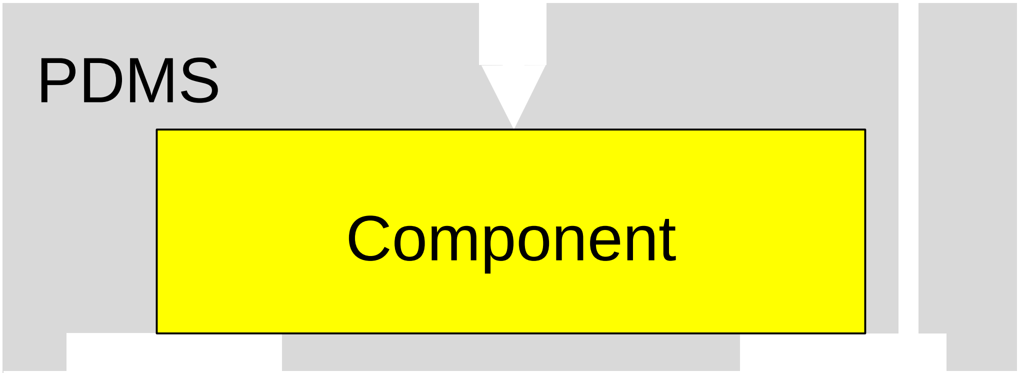


Step 5: De-Mold



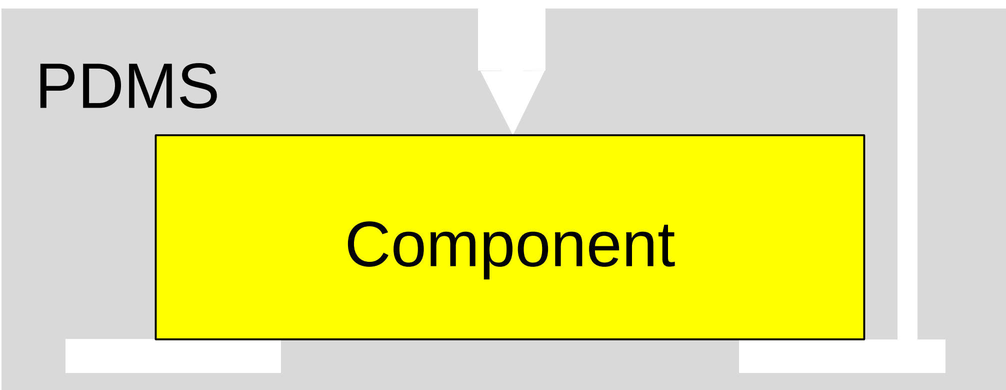
- Raise pins up and out of the way.
- A hole remains where the pin was placed. This can be filled later if desired.
- Extract the package from the mold cavity.

Step 6: Punch Holes for Filling

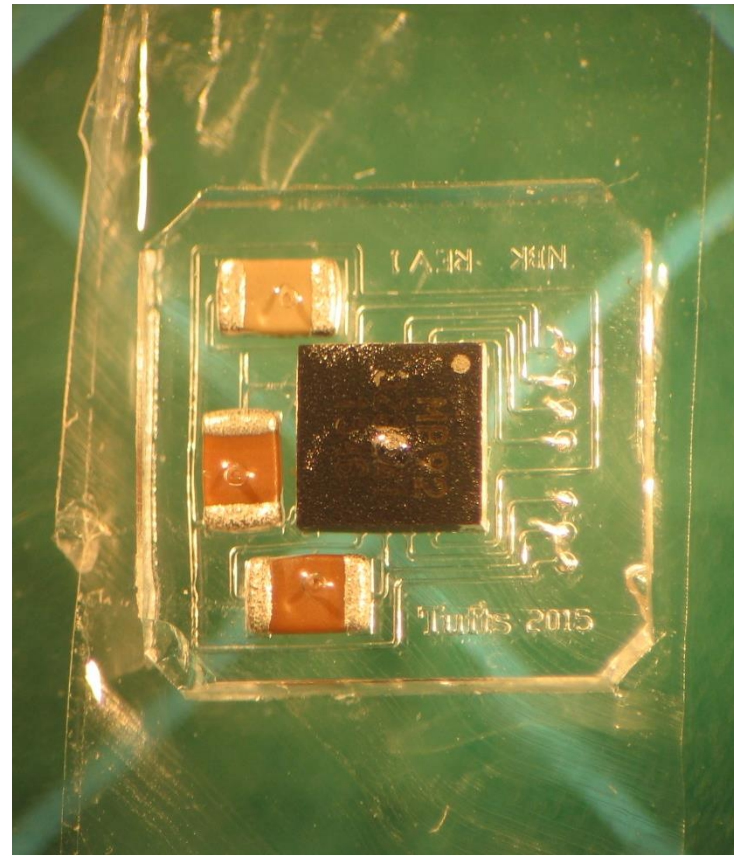


- Holes are punched at each terminal location for filling eGaIn and inserting signal wires.
- Biopsy punches are too big for this application, so a syringe was used to form the holes.

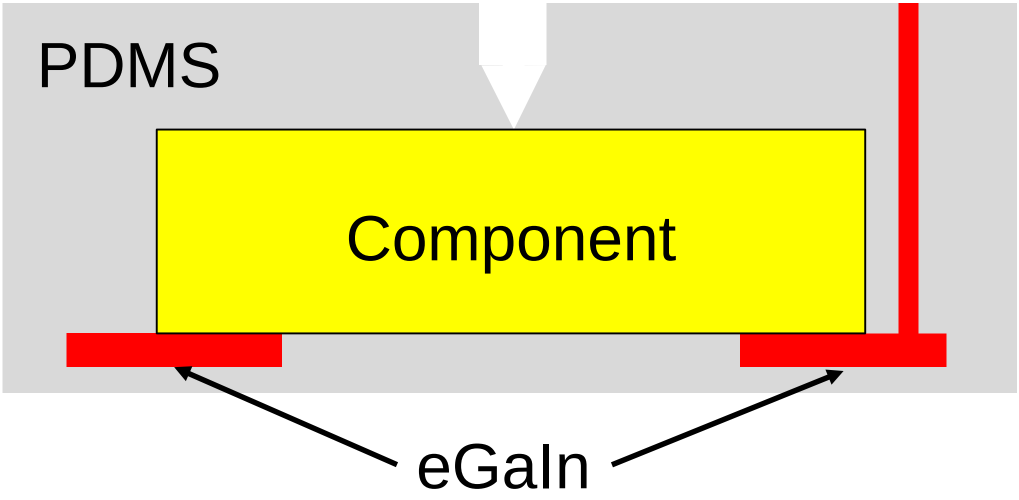
Step 7: Apply PDMS Cover Layer

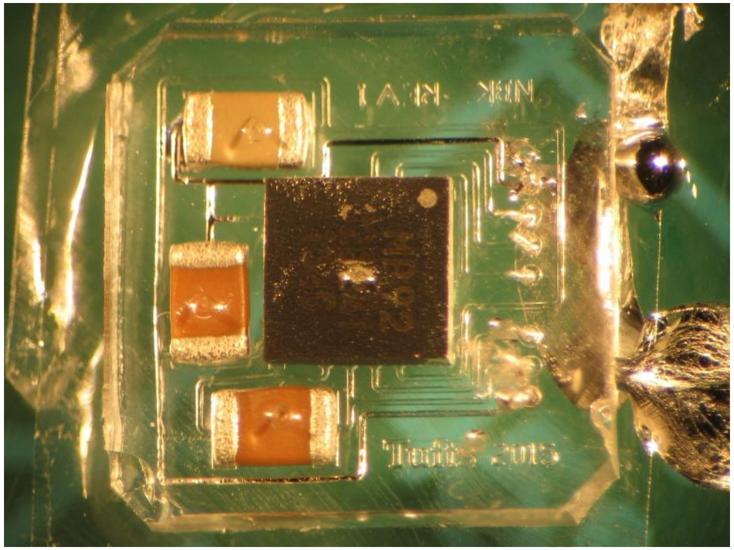


PDMS Thin Film

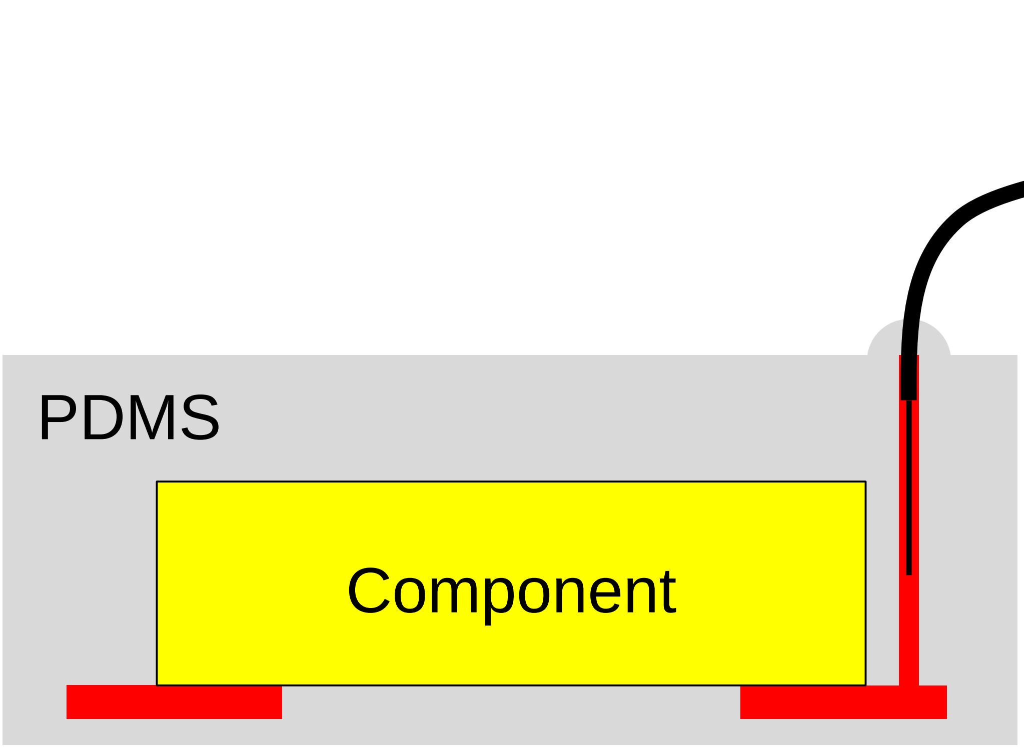


Step 8: Fill with eGaIn



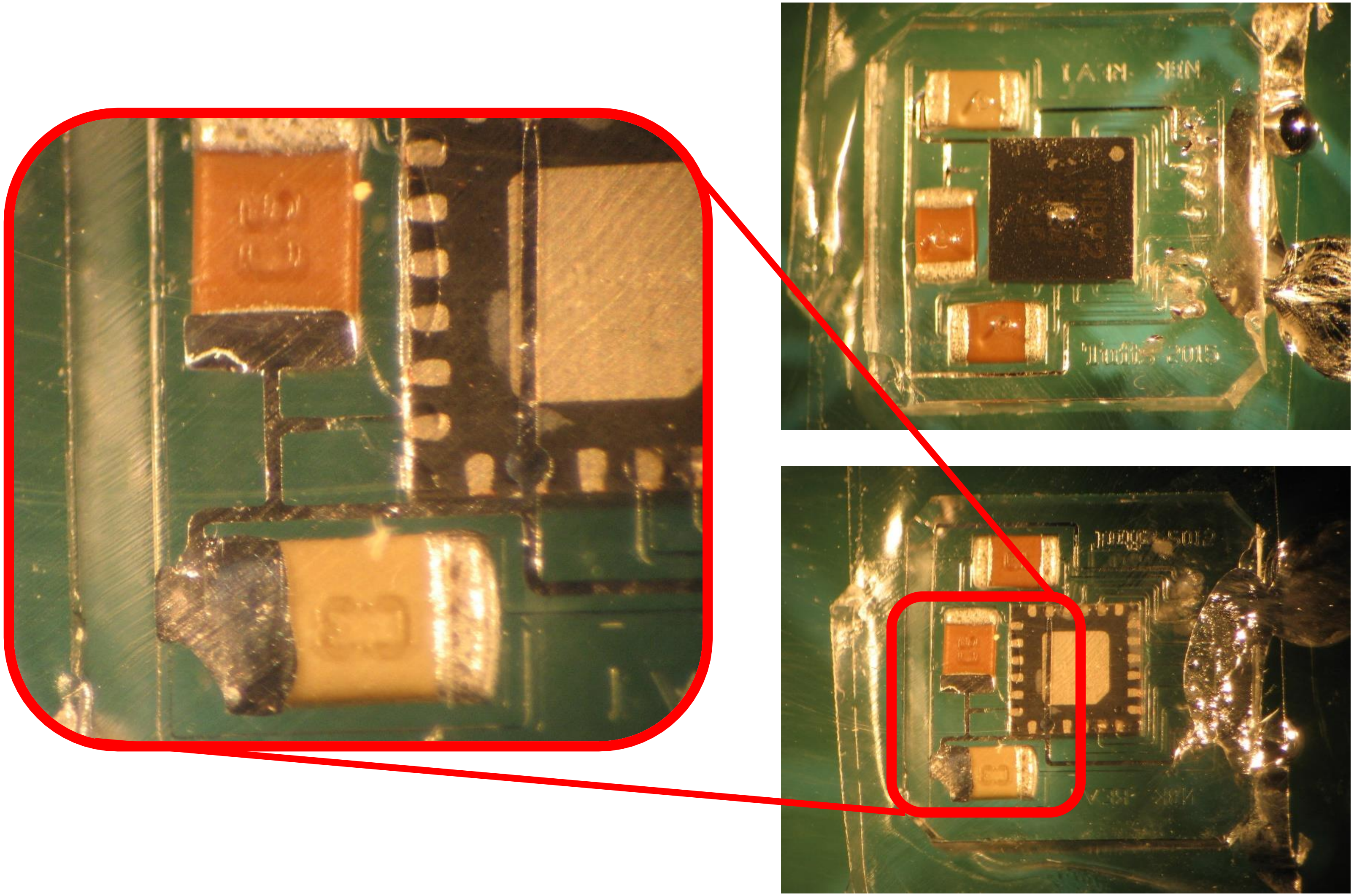


Step 9: Insert Wires and Seal



- Wire leads are inserted for communication with the chip.
- The holes are filled with uncured PDMS.

Result

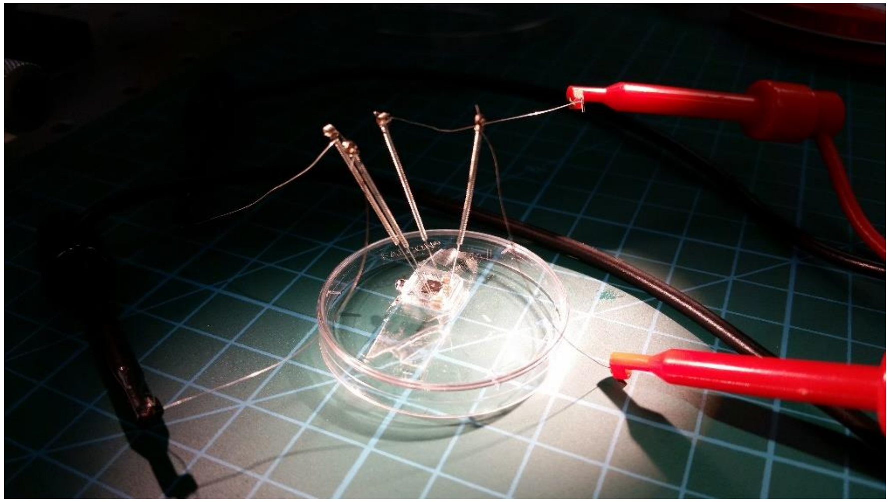


Top

Bottom

Conclusions

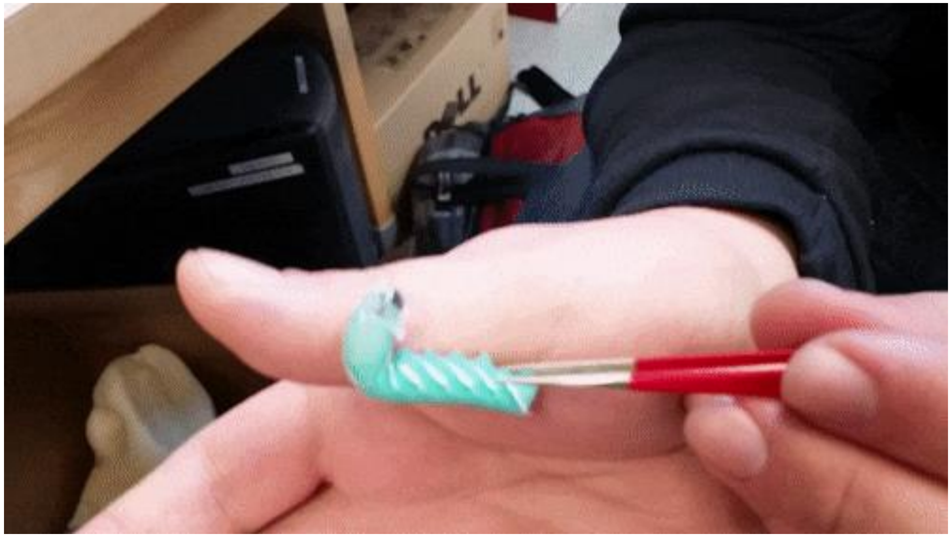
- Communication could not be achieved because of microchannel failure when pressurizing.
- This is possibly due to the air in the channels not diffusing through the PDMS fast enough.



- 4-wire resistance measurements of a single trace shows 0 to 300 kΩ drift.
- Something strange is happening with the eGaIn. Further characterization of the material is required.

Future Work

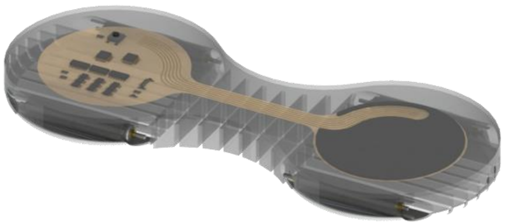
- Venting channels during filling.
- Simplify the process.
- Technique for attaching to animals

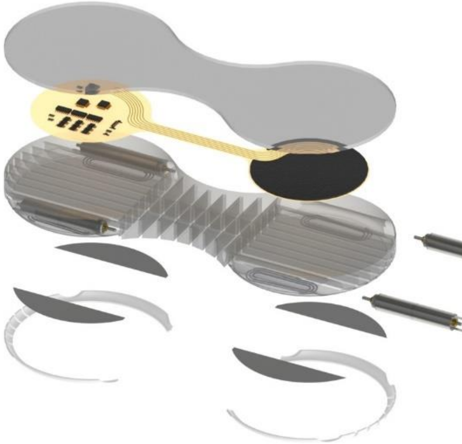


Manduca Sexta with IMU on head exhibiting a strike reflex.

- Inertial measurement of soft robot platform.

Nikolas Kastor, Maxwell Hill, Vishesh Vikas, Robert D. White and Barry Trimmer, "Semi-autonomous Soft Robotic Platform for Terrestrial Locomotion", submitted to the workshop on "New Frontiers and Applications for Soft Robotics" at the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2015), Hamburg, Germany, October 2, 2015. Submitted August 12, 2015.





Acknowledgments

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Daniela Torres

Kevin Ligonde

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Thank you!

Check out our labs!

Microfab:
http://emerald.tufts.edu/~rwhite07/

Soft Material Robotics:
http://ase.tufts.edu/igert/softMaterialRobotics/