NEW DEVICES FOR INVESTIGATING HAIR CELL MECHANICAL PROPERTIES

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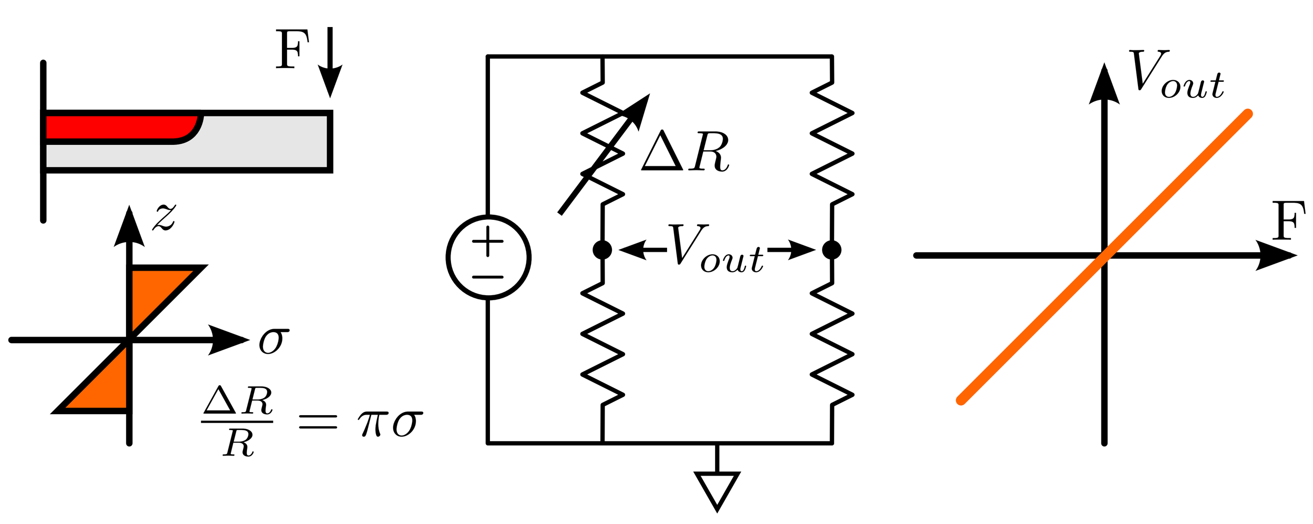
Motivation

Hair cell mechanics are typically probed using flexible glass fibers. These fibers are individually produced, mounted on a macroscale actuator, and their deflections are measured optically **[1-2]**. The fibers can be difficult to fabricate, calibrate, and use experimentally due to the need for optical detection. They are also generally limited to frequencies below 2 kHz.

We are developing an alternative MEMS-based force probe. The probes are mass produced from silicon using conventional microelectronic processing techniques. Force and displacement are measured electronically using a piezoresistive strain gauge. An on-chip, microactuator enables high speed operation in liquid.

Piezoresistive Sensing

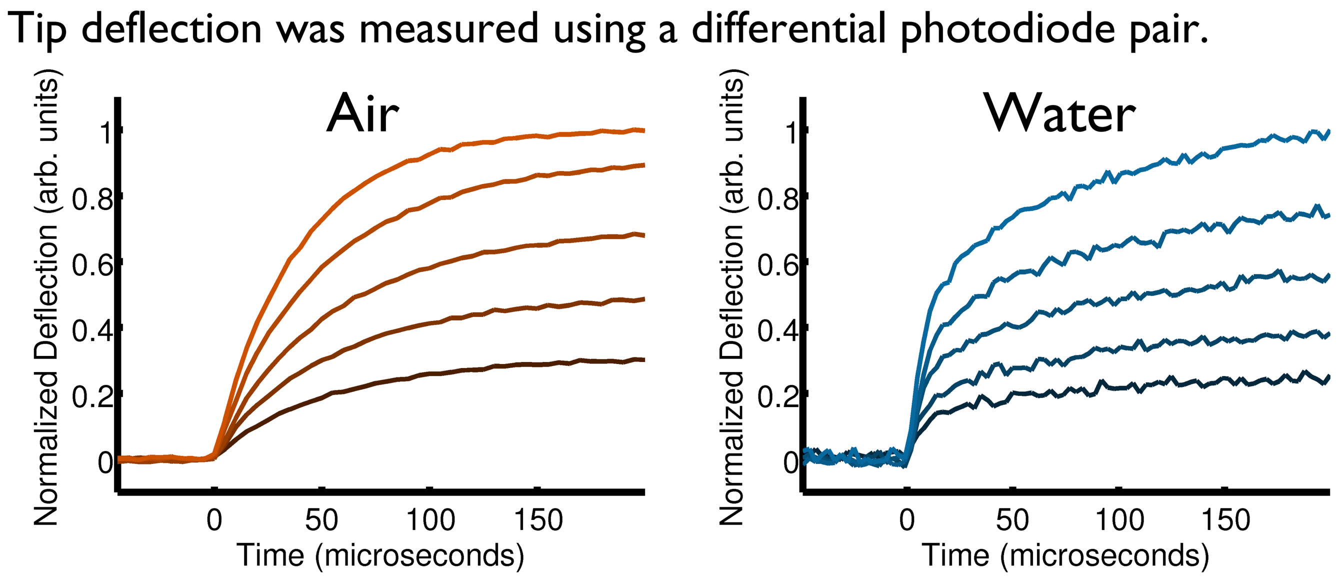


$$\frac{\Delta R}{R} = \pi\sigma$$

Doped silicon is used as a highly sensitive strain gauge. The resistance change is measured using a Wheatstone bridge circuit.

Thermal Actuator Step Response

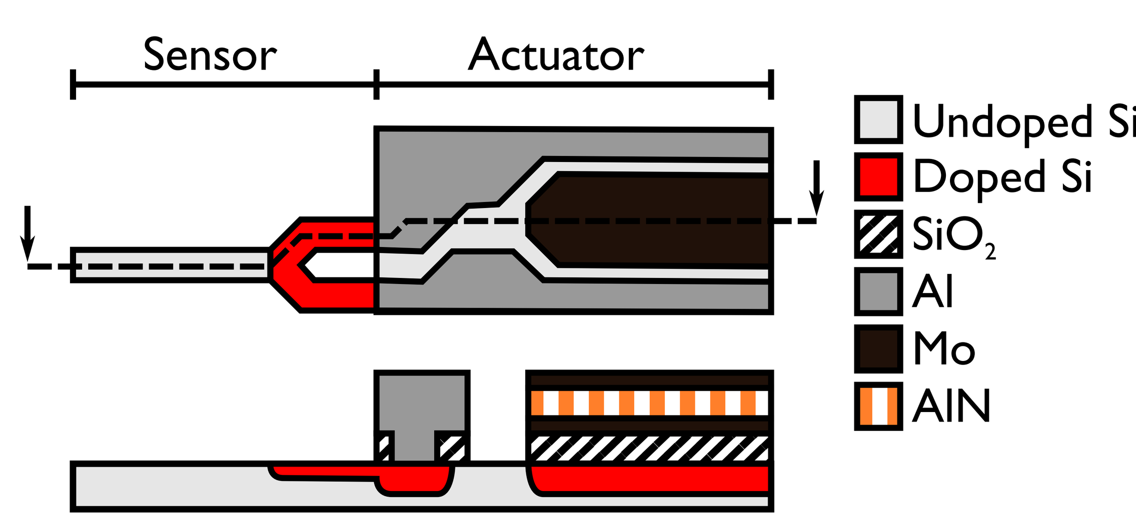
Tip deflection was measured using a differential photodiode pair.



$\tau = 57 \pm 10\ \mu s$

$\tau_1 = 7.9 \pm 1.2\ \mu s$
$\tau_2 = 96 \pm 11\ \mu s$

Design Overview



We have designed and fabricated three design types:
- no actuator - piezoelectric actuator - thermal actuator

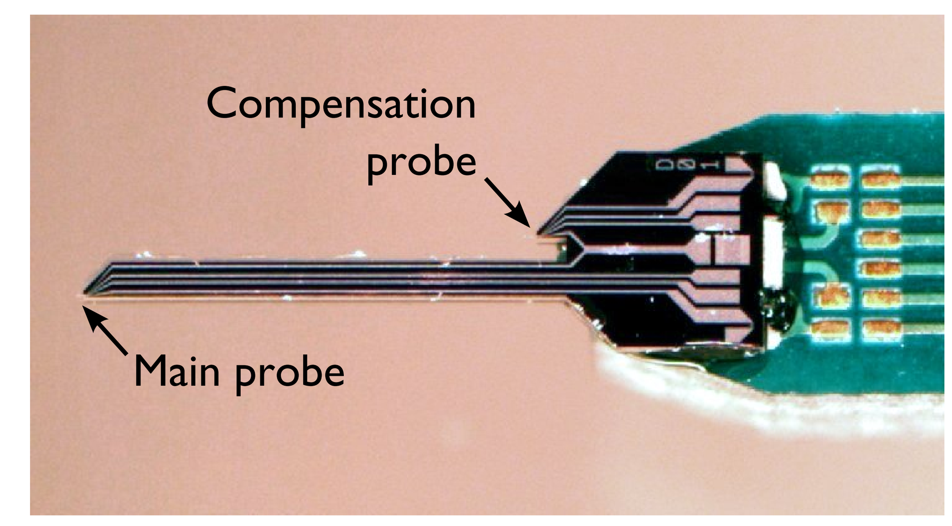
The piezoresistor is designed to optimize force resolution while satisfying a constraint set (e.g. resonant frequency in liquid, tip temperature induced by Joule heating) using techniques that we have developed **[3-4]**. Similar probes have been used to study nematode mechanics **[5]**.

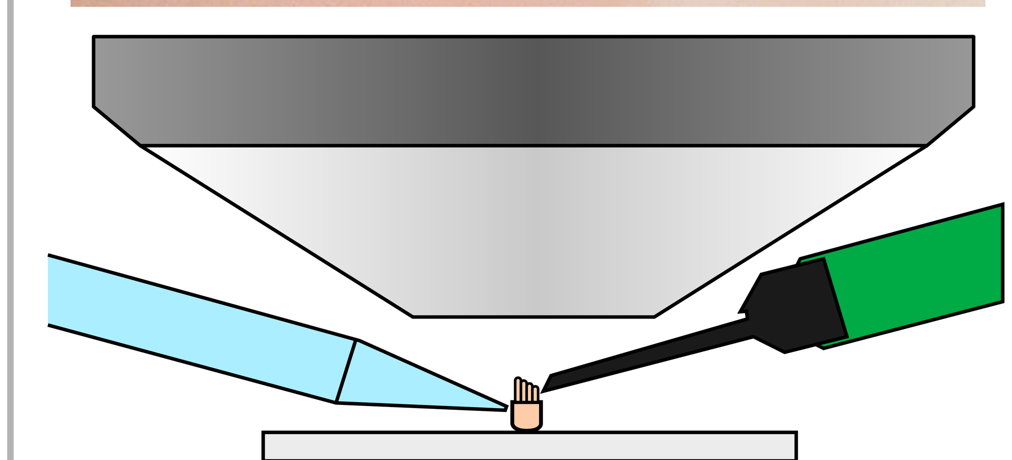
In order to minimize stiffness for a given resonant frequency, the probes are made as thin (300 nm) and narrow (1-2 um) as possible:

$$k = \frac{Ewt^3}{4l^3} \qquad f_0 = \frac{t}{l^2}\sqrt{\frac{E}{\rho}}$$

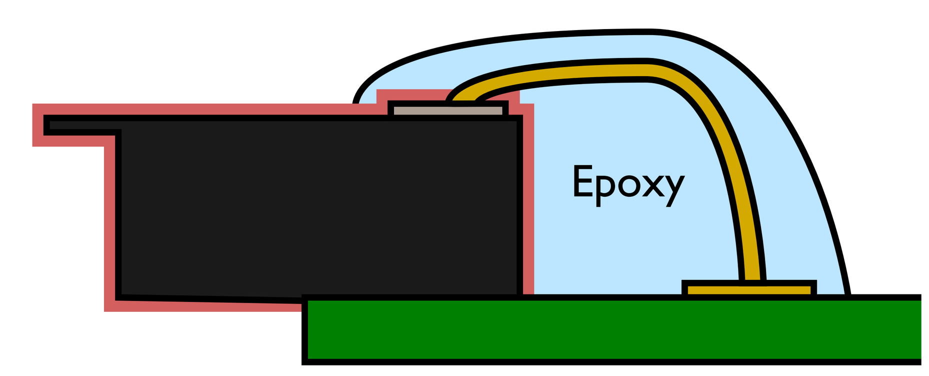
The nominal performance specifications for the probes, including the minimum detectable displacement (MDD) and force (MDF) are tabulated below:

Design #	Length (um)	k (mN/m)	f_{damped} (kHz)	MDD (nm)	MDF (pN)
1	142	0.3	3.3	11	3.3
2	96	1.0	9.7	6.3	6.2
3	75	2.1	19	4.6	9.6
4	61	3.9	32	3.6	14
5	46	9.0	64	2.7	24
6	35	20	124	2.1	42
7	29	36	190	1.7	61

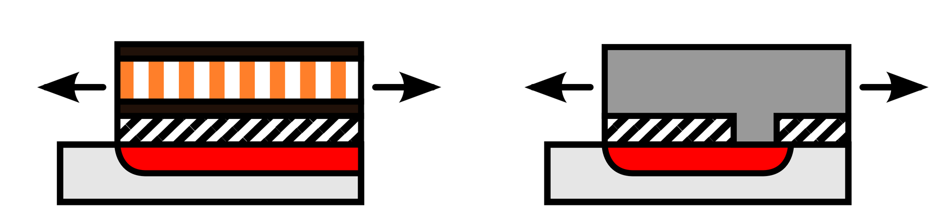




The probes are compatible with upright and inverted microscopes (WD > 1mm), and can be mounted in any orientation.



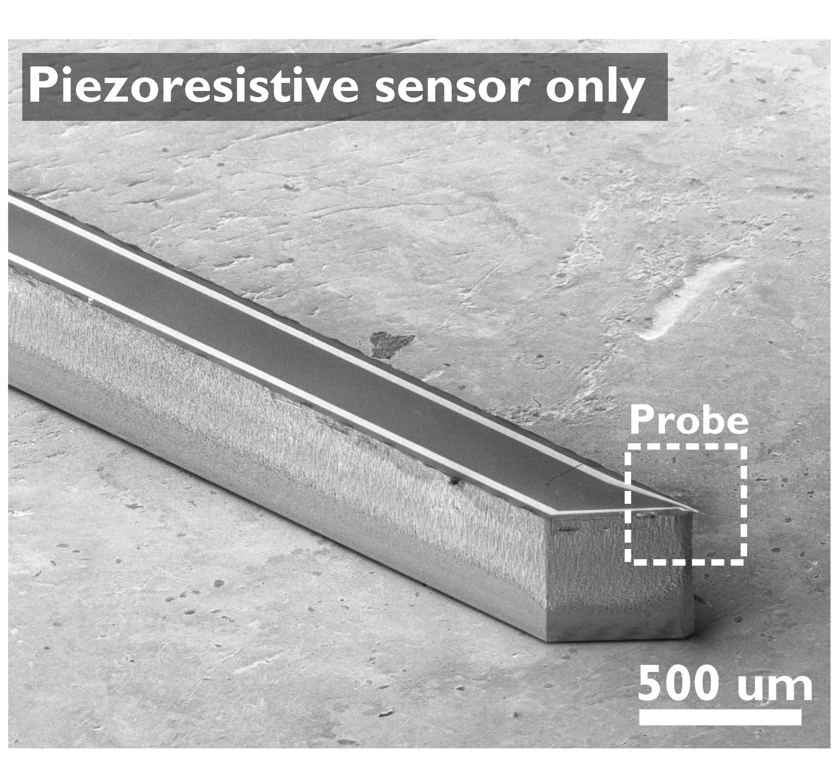
In order to prevent current leakage and corrosion, the probes are passivated with a thin, biocompatible polymer coating (parylene N).

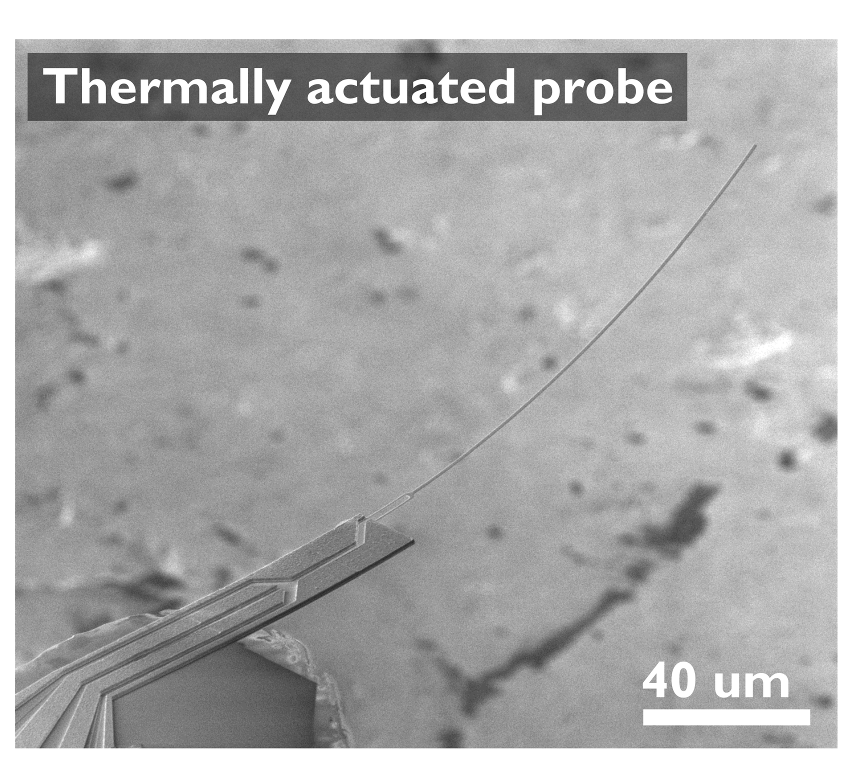


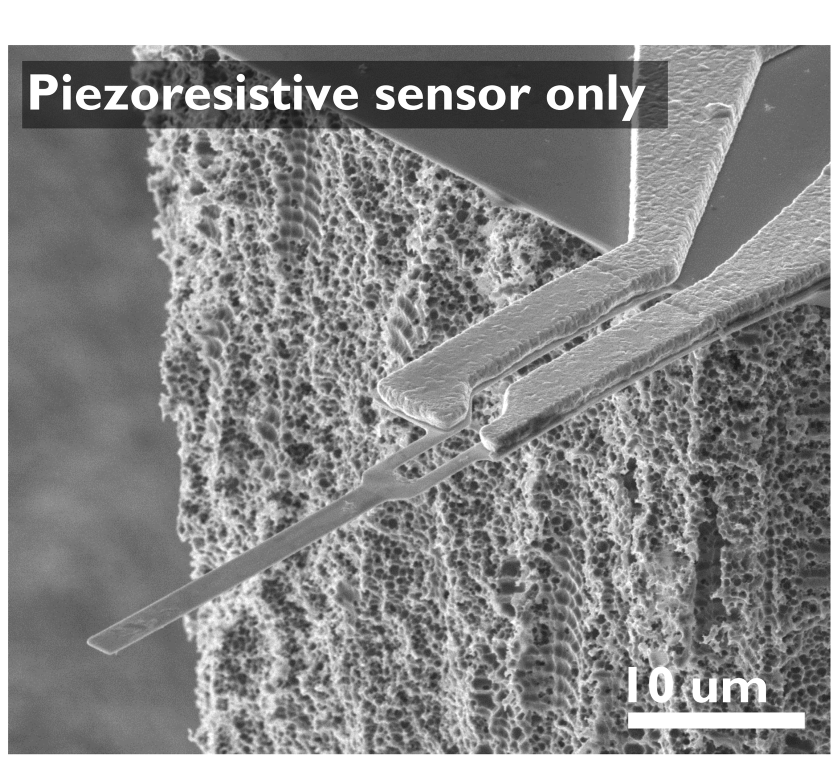
$\Delta z_{tip} \propto \Delta V$ $\qquad$ $\Delta z_{tip} \propto \frac{\Delta V^2}{R_{heater}}$

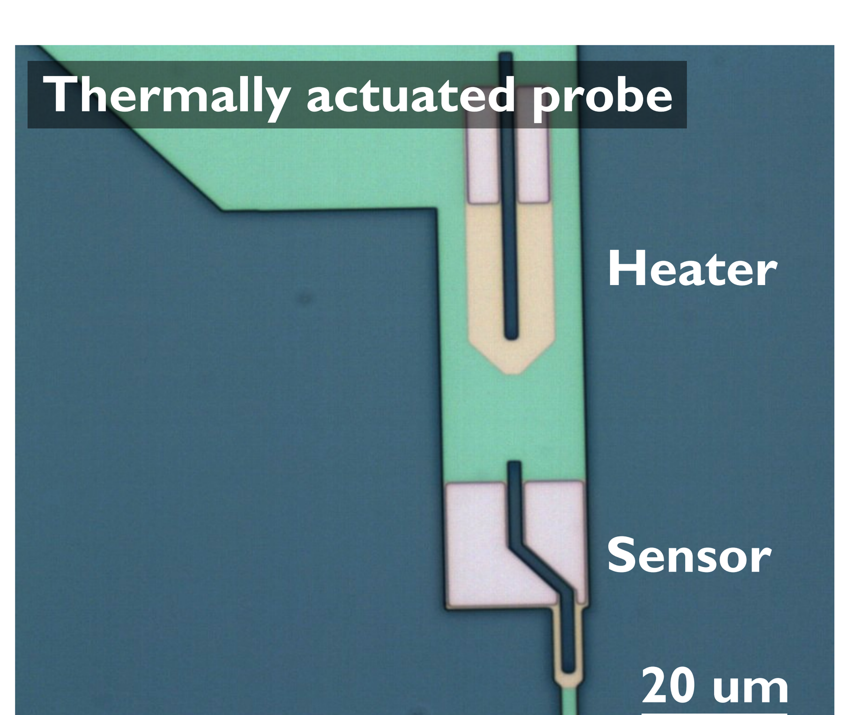
Integrated unimorph actuators are designed to provide 400-1500 nm of maximum tip deflection.

Fabricated Devices

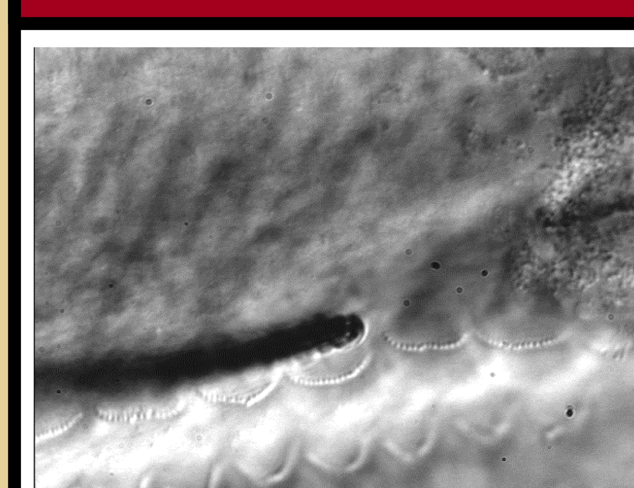








Conclusions and Ongoing Work



Device fabrication for all three design types is complete. We are currently characterizing the probe performance (frequency response, sensor resolution, actuator-sensor crosstalk), integrating closed loop force control, and beginning hair cell measurements.

References

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Acknowledgements

This work was supported by the NIH under grants EB006745 (NIBIB) and DC003896 (NIDCD), the NSF under CAREER Award ECS-0449400 and COINS NSF-NSEC ECS-0425914, a DARPA Young Faculty Award N66001-09-1-2089, and a Stanford Bio-X Grant. JCD was supported in part by National Defense Science and Engineering Graduate (NDSEG) and NSF Graduate Research fellowships.