Piezoresistive Cantilevers Optimized for kHz Force Sensing in Aqueous Solutions

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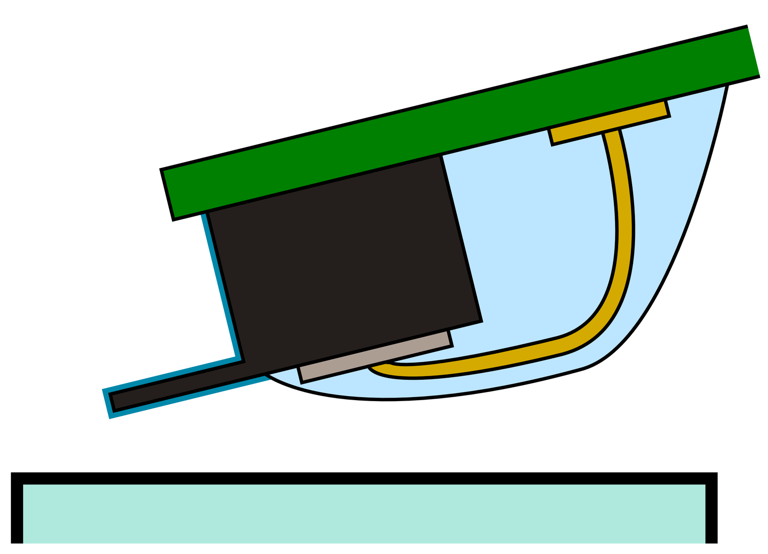
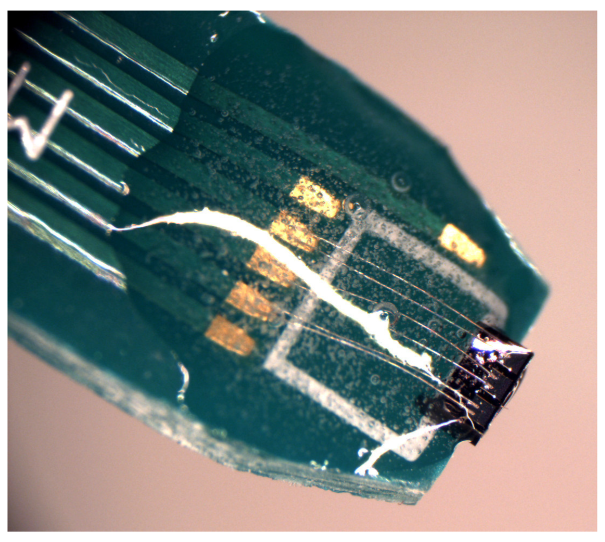
Introduction

Our senses of touch and hearing are based on rapid, mechanically induced changes in protein conformation. However, the molecular basis of mechanotransduction is poorly understood, in part due to the difficulty in measuring molecular forces at the microsecond scale. A microfabricated force probe with microsecond time resolution, pN force resolution and nm displacement resolution would be valuable in this context.

Optical approaches to force sensing generally limit the minimum force probe size to > 5 microns and have a time resolution on the order of 100 microseconds [1]. Piezoresistive detection enables smaller probes and avoids the need for careful optical alignment or a specialized microscope. In this work we demonstrate that piezoresistive cantilevers can be passivated and submerged in ionic media with negligible impact on resolution.

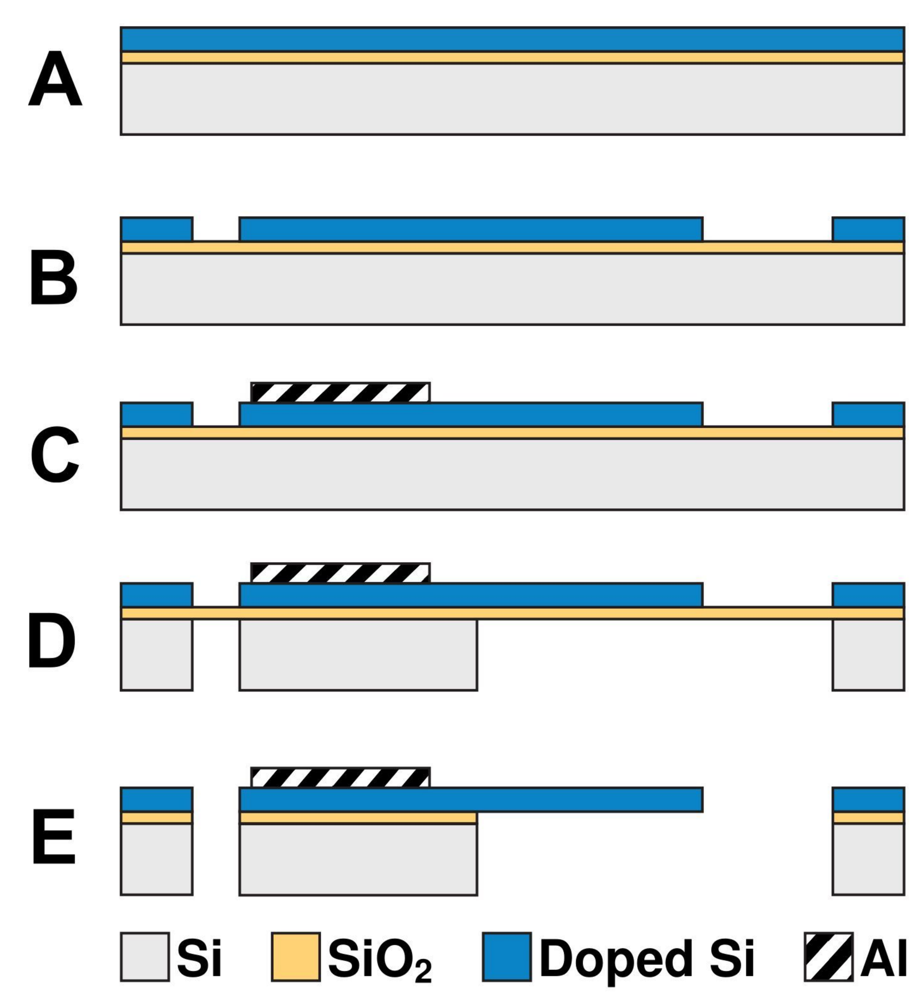
Cantilever Packaging and Passivation





Cartoon (left) and micrograph (right) of a packaged cantilever. The silicon die is epoxied and wirebonded to a custom PCB. After encapsulating the wires with epoxy, the cantilever is passivated with 200 nm of parylene N. The PCB is mounted on a custom, angled fixture (10 degrees) and the sample is placed on a high precision three-axis stage.

Device Design, Fabrication and Methods



(A) The starting SOI wafer (340 nm thick device layer) is heavily doped using phosphorus diffusion (800C, 35 min).
(B) The cantilever is defined using reactive ion etching (RIE).
(C) Al is deposited and etched back to define the bondpads.
(D) The backside of the wafer is patterned and etched via DRIE.
(E) The buried oxide is etched via RIE to release the cantilevers. A forming gas anneal (450C, 30 min) improves the contacts.

The cantilevers were designed using an iterative optimizer [2] to minimize the minimum detectable force (MDF).

We designed a range of cantilevers, with resonant frequencies from 10 kHz to 1 MHz. In this study, we characterized a single cantilever in detail.

L (um)	W (um)	T (nm)	PR L (um)	f0 (kHz)	k (pN/nm)	R (kOhm)
95	6	320	50	42.85	7.1	5.2

The cantilever deflection was measured with a Wheatstone bridge and a high bandwidth instrumentation amplifier (TI INA103). The bridge was biased at 2V using a low noise voltage reference (ADR420). Noise spectra were measured with a spectrum analyzer (HP 3562A) while the cantilever thickness and stiffness were inferred from its resonant frequency, which is measured using laser doppler vibrometry.

Results and Discussion

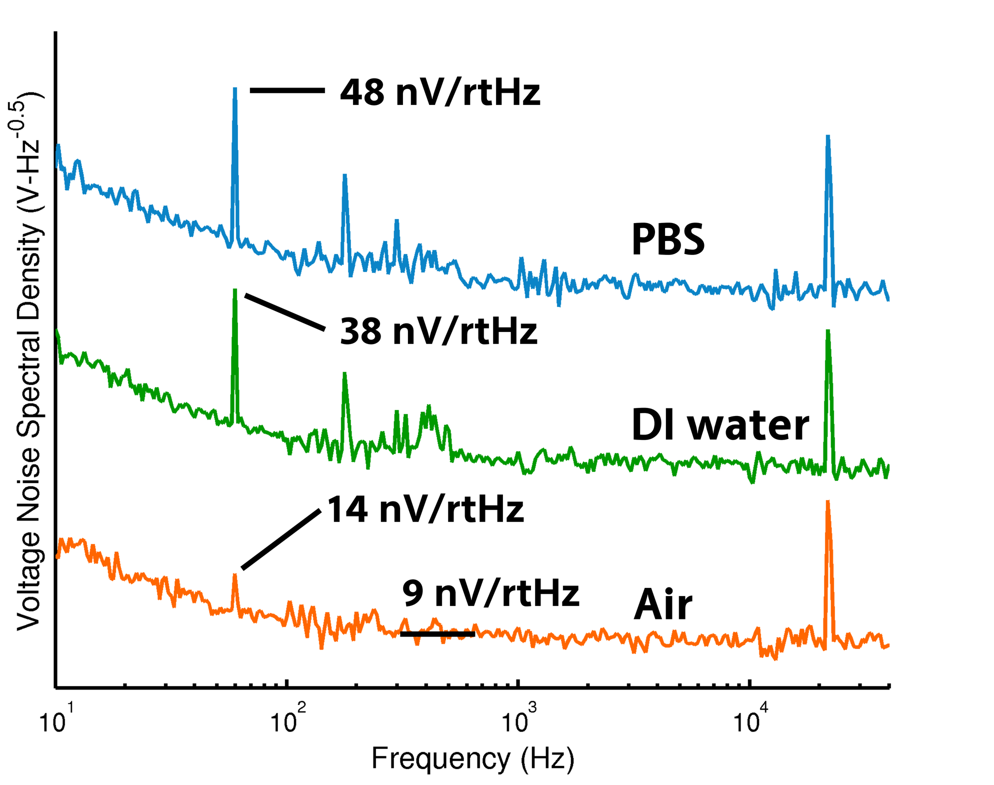


Figure 1. Measured voltage noise spectra in air, deionized (DI) water, and phosphate buffered saline (PBS). Noise in solution is largely unchanged except for increased electromagnetic noise coupling. Spectra are offset for clarity.

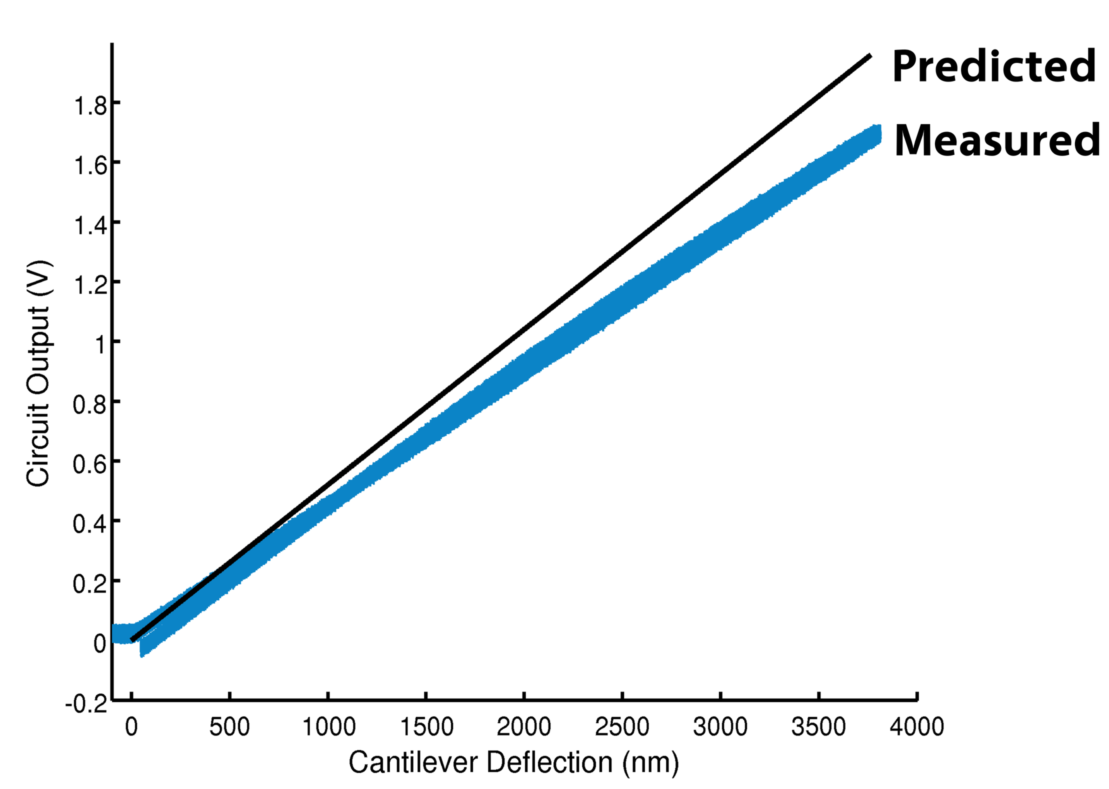


Figure 2. Displacement-voltage response of the cantilever in PBS compared with the predicted sensitivity. The predicted displacement sensitivity is accurate for small displacements.

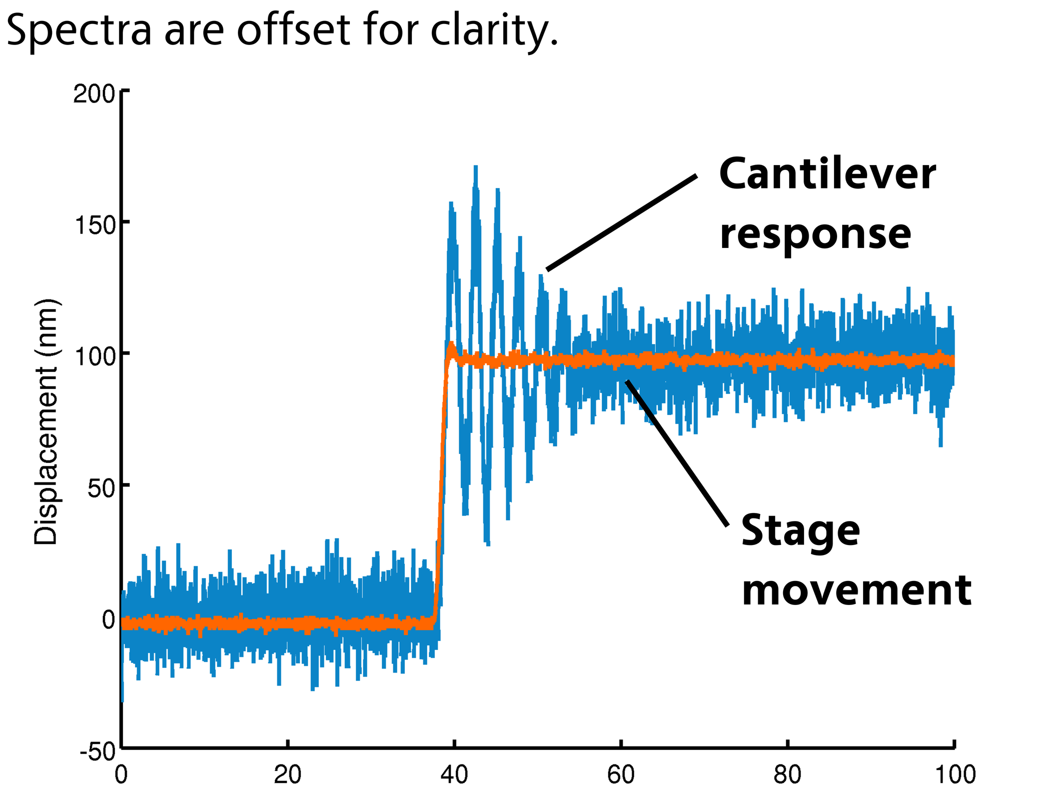


Figure 3. Cantilever response to a 100 nm step in stage movement while immersed in PBS. The cantilever signal was low pass filtered at 10 kHz. RMS displacement noise is 8.9 nm.

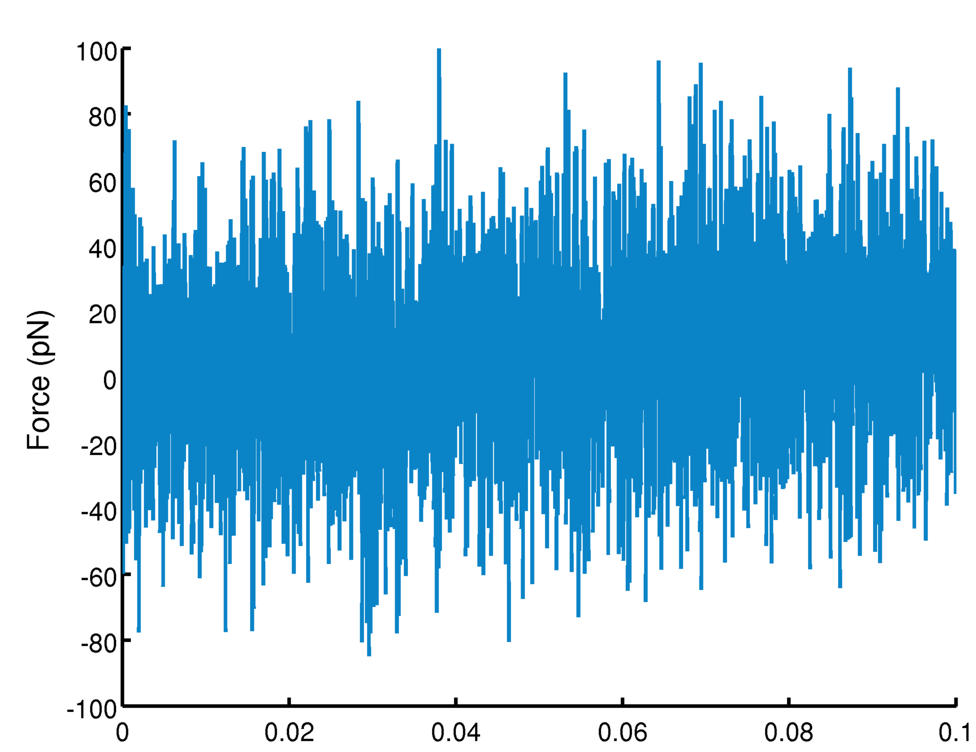


Figure 4. Measured force noise for the cantilever while immersed in PBS. The cantilever signal was low pass filtered at 10 kHz. RMS force noise is 27.6 pN.

Conclusions

We have successfully operated piezoresistive cantilevers in ionic media for several hours with no ill effects. Encapsulating the wirebonds with epoxy and coating the cantilever with 200 nm was sufficient passivation.

Future plans include the characterization of narrower, higher frequency cantilevers and measuring the rupture force of well characterized antibody-antigen systems.

Acknowledgements

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References

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