Microcantilever-Based Sensors

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Abstract:

Ultrasensitive microcantilevers can act as precise sensors if one measures their nanomechanical responses in different environments. The focus of this project was to detect microcantilever deflection when an intelligent hydrogel, applied to the surface, swells at variable pH levels.

The hydrogel was patterned onto microcantilevers of various sizes using UV photolithography. When the cantilevers were soaked in different buffers, the swelling hydrogel induced surface stress and therefore the bending phenomenon. This deflection was quantified by observing the change in focus with a microscope. The deflection was evident, and differed accordingly at various pH levels.

Introduction:

With the advent of micro and nanotechnologies, miniature sensing devices have featured prominently in today's leading research. Sensors with the capability of detecting chemical and biological analytes are particularly exciting, since they can bring us one step closer to futuristic 'lab-on-a-chip' devices which can theoretically discover imbalances and automatically rectify them. And in the more immediate future, sensor-based devices can also serve as useful external diagnostic tools. Microcantilevers, commonly found in atomic force microscopy, have excellent potential as sensors due to several notable advantages including: ultrasensitivity, ease of mass production, and low cost.

The microcantilevers utilized in this project were placed in arrays on a small 2 x 2 cm^2 silicon microchip. The goal of this project was to develop a microcantilever-based biosensor with the ability to sense minute changes in pH. The design is outlined in the following: an intelligent hydrogel (a polymer which swells when exposed to water), tailored to swell and collapse upon exposure to high and low pH, respectively, was patterned directly onto the cantilevers using photolithography. Dependent upon the amount of swelling due to pH, surface stress would induce the tips of the cantilevers to nanomechanically deflect, or bend, certain amounts. A microscope would then be used to measure the amount of tip deflection, which if present, and in agreement with the pH level, would essentially establish the device as functional. A literal depiction of the sensor is shown in Figure 1.

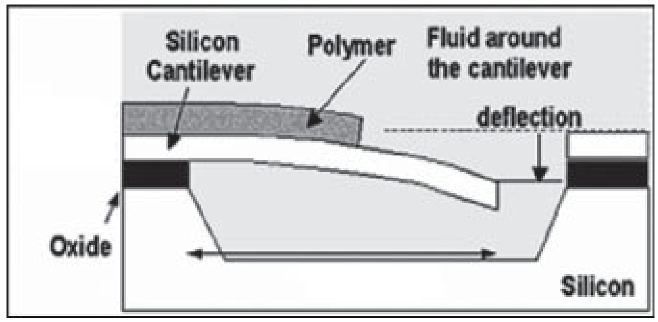

Figure 1: Cantilever deflection induced by swelling hydrogel [2].

Experimental Procedure:

A. Application of Hydrogel to Cantilevers: The first step of this experiment was to functionalize the cantilevers' bare silcon surfaces (as seen in Figure 2)

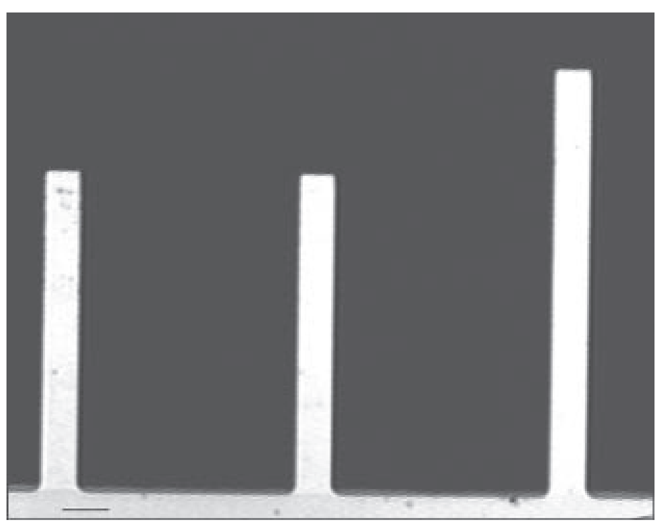

Figure 2: Cantilevers, rightmost dim. 10 x 100 µm.

with the treatment of a 10% γ-methacryloxypropyl trimethoxysilane/acetone solution for two hours. The purpose of this treatment was to provide an adhesive organic/inorganic interface between the silicon and the hydrogel. The intelligent hydrogel itself was a 1 gram monomer solution made up of methacrylic acid and polyethylene glycol 200-dimethacrylate (80:20 MAA : PEG200DMA mole ratio) with photoiniator 2,2-dimethoxy-2-phenyl acetophenone (10 wt%). Two drops of this solution were next spun at 2000 rpm for 30 seconds directly on the chip. Utilizing UV free-radical photolithography and the corresponding photomask, we were then able to accurately polymerize the monomer on the cantilevers at a power of 2.25 mW for 2 minutes. The instrument used was a Karl Suss mask aligner. Once polymerization was completed, the cantilevers were soaked in DI water in order to remove any unreacted monomer.

B. Observation of Deflection Patterns in pH Range 2-10 Using Microscope: The first step in the second half of the experiment was to make up a series of standard McIlvaine buffer solutions (0.5M constant ionic strength maintained by addition of potassium chloride) ranging from pH 2 through 10, with increments of 0.2 in the 5.8-6.8 range (as the most linear deflection patterns are thought to exist here [1]). Using a glass slide, tape, a hollowed spacer, and a coverslip, we were able to create a well-like apparatus in which the cantilevers could be firmly affixed at the bottom. This apparatus was placed under a 50x Nikon Eclipse ME600 microscope, and 100 μL of each buffer solution was individually pipetted into the well, effectively allowing for the hydrogel coatings to be fully immersed and swell to equilibrium. Once equilibrium was reached, the present buffer was removed and the next buffer pipetted in. As swelling occurred, deflection of the cantilevers was quantified using the change in focal length. Measurements of this kind were taken at 5-minute intervals for 30 minutes, the total time allotted for equilibration of each pH value.

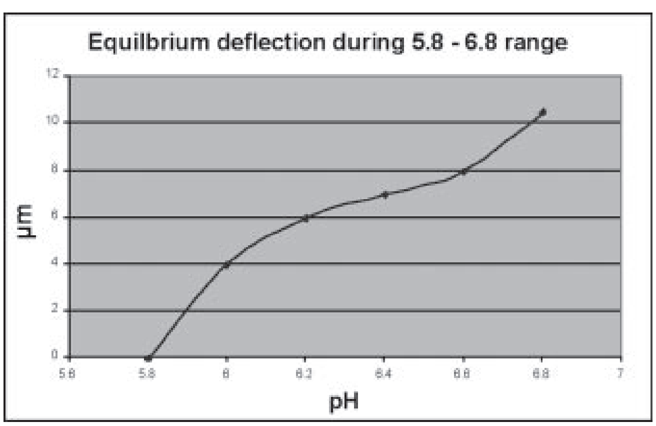

Figure 3: Results of trial 2 show max deflection of 10.5 µm.

Results and Discussion:

The average measurable deflection of three trials over the 5.8-6.8 pH range was 10.833 μm/pH. The results of trial 2 are shown in Figure 3 where the deflection was 10.5 μm. The most important data to derive from these three trials, however, is a sensitivity of 0.0923 ΔpH/μm. From our results, it can be concluded that deflection of the cantilever tips due to hydrogel swelling was certainly evident and established proof-of-concept. It is important to note, however, that after the three aforementioned trials, those later trials using the full range of pH values were not consistent in yielding consistent results, often resulting in hardly any deflection at all. Sources of error may be due to one of several factors: inaccuracy of focal length adjustment, damaging of individual cantilevers due to repeated physical motion, and non-precise ionic strength of buffer solutions. Further, more precise tests for this particular sensor would need to be conducted prior to commercialization.

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References:

[1] R. Bashir, J. Z. Hilt, O. Elibol, A. Gupta, and N. A. Peppas, Appl. Phys. Lett. 81, 16 pp 3093 (2002).

[2] J. Z. Hilt, Novel BioMEMS Sensor Device: Ph-Responsive Hydrogels Integrated With Silicon Microcantilevers, pp 116.