Observing Receptor Layer Swelling on Piezoresistive Devices

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Abstract:

A surface stress sensor converts forces that are applied to its surface into a measurable, electrical signal. Polymers have been deposited onto a Membrane-Type Surface stress Sensor (MSS) chip as a receptor layer of target molecules. Under gaseous conditions, the polymer layer swells, which directly affects the sensitivity of the sensor. An improved understanding of how to recreate the swelling on a flat silicon surface and MSS chip will be instrumental in optimizing the sensitivity of the MSS chip, creating a further step towards personalized medicine and efficient agricultural techniques.

Summary of Research:

Cantilever surface stress sensors are commonly used, especially in biological and chemical applications [1]. Different polymer layers can be coated on a cantilever beam which can directly affect what is detected [1]. The deflection of the cantilever can be measured optically, using a laser, or electronically, using a piezoresistor. When a stress is applied to the surface of the sensor, a piezoresistor can measure changes in electrical resistance. The sensitivity of the piezoresistor is heavily influenced by its location on the cantilever and the overall sensor geometry. To improve the sensitivity and reliability of the piezoresistor reading, an MSS chip was designed and created [2].

The MSS chip contains an adsorbate membrane that is suspended by four piezoresistive beams [2]. There are two different piezoresistive designs on the chip in order to ensure an optimal reading. The membrane is clamped down on the four beams which enables deflection to be measured in four directions, this can be seen in Figure 1 [1].

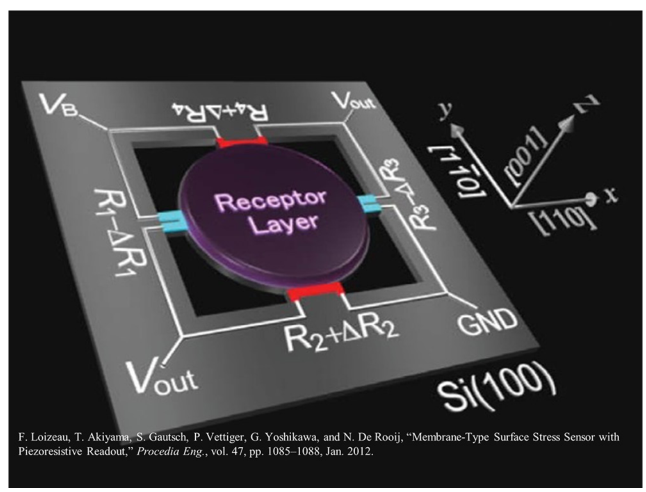
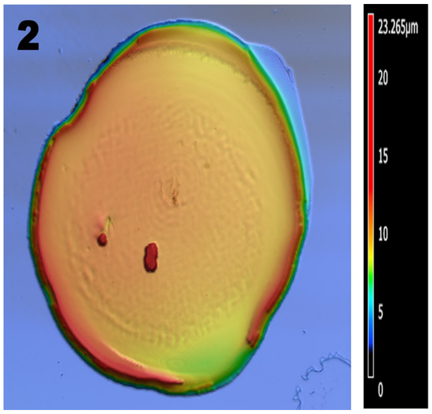
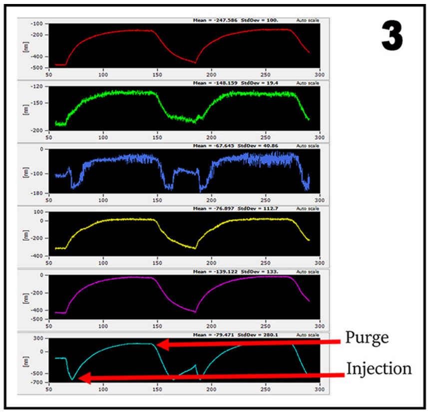


Figure 1: A schematic of the MSS chip [1].

Since the piezoresistive bridges are all clamped, the beams can measure accurate profile of the applied surface stress [2]. The MSS chip works by absorbing surrounding gasses and then produces an electrical signal that can be evaluated [2]. As a result, prior experimentation found that an MSS chip is up to 100 times more sensitive than a conventional piezoresistive cantilever beam [3]. Different polymers can be deposited onto the suspended membrane using inkjet spotting which can then be tailored for use in detecting desired substances.





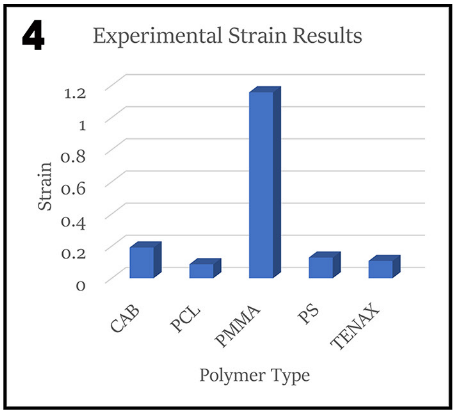


Figure 2, left: A smooth, round polymer (PMMA) deposited on a silicon surface. Figure 3, middle: Phase monitor graph depicting gas injection and purging. Figure 4, right: Experimental polymer strain values when exposed to water.

Since the piezoresistor measures induced surface stresses, changes in the surface characteristics of the polymer affect the chips sensitivity. It is still unknown how different polymers react when in contact with different gasses. This project focused on creating an experimental setup to better understand the gas-polymer swelling relationship.

Conclusions and Future Steps:

The first focus of this project was to utilize an inkjet spotter to create round, flat polymer droplets. The inkjet spotter deposits polymer solutions at different rates and sizes. An optimal recipe was created that deposited 400 shots of polymer onto a desired surface. An example of the deposited polymer shape is shown in Figure 2.

The next focus was to monitor the polymer swelling under different gaseous conditions. Polymer swelling is difficult to see with the human eye, but there are tools and techniques to observe surface changes in real time at the nanoscale level. The tool used for these experiments is the Digital Holographic Microscope (DHM). This technology allows for real time monitoring of the polymer swelling process. Therefore, it is easy to track and record the exact moment when gas is being injected into and purged from the polymer layer. A LabVIEW program was created that cyclically introduced gas into the system every other two minutes and ran for eight minutes total. Once all of the images were recorded for each experiment, the surface profiles of the polymer layers were analyzed using a laser microscope. Figure 3 illustrates the moments when gas was injected into and purged from the system.

The final focus was to compare the surface characteristics of the polymer under normal conditions and when swelled. This comparison allowed for the calculations of the strain of each polymer experienced under specific gaseous conditions. Strain was calculated by subtracting the deformation recorded by the phase monitor from the initial average surface height of the polymer divided by the initial average surface height. By calculating the strain, insight can be gained into ensuring the right polymer is coming into contact with target gasses for their desired application. Examples of polymer-gas strain calculations are shown in Figure 4.

In the future, a variety of polymer-gas interactions will be recorded and analyzed using this experimental setup to build a library of these relationships. Isolating polymers according to their ideal strain characteristics using a certain gas will be crucial for controlling the swelling effects on MSS piezoresistors. Different inkjet recipes will also be used to create different polymer shapes and sizes. Additionally, efforts will be made to better understand the root causes and effects of polymer swelling. Modeling the polymer-gas swelling relationship is the ideal way to determine which gas should be introduced to which polymer. Building the library of these interactions is an instrumental step to most accurately model this phenomenon which will create a step closer towards personalized medicine and agricultural techniques.

References:

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