POLYMERIC MECHANICAL SENSORS WITH STRAIN GAUGE READOUT IN A MICROFLUIDIC SYSTEM

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Abstract

Micrometer sized cantilevers can be used as highly sensitive bio/chemical sensors and are usually fabricated in silicon. In this work, we have realized for the first time a bio/chemical sensor platform consisting of an array of four SU-8 cantilevers integrated into a microfluidic system, also fabricated in the polymer SU-8. The cantilevers have built-in strain gauges, which provides a simple electrical read-out of surface stress changes. Two of the cantilevers are used as reference cantilevers, whereas the other two cantilevers will be used for specific molecular recognition. The cantilevers are connected forming two Wheatstone bridges. With this set-up, common-mode rejection of noise from the surroundings is obtained, reducing the noise and the drift considerably. The cantilever device is fabricated as two separate parts, which are subsequently bonded together using SU-8 as glue. The measured noise level indicates that the device is suitable for molecular recognition measurements.

Keywords: biosensors, microfluidics, piezoresistive read-out, polymer cantilevers.

Introduction

Molecular layers are known to induce a surface stress change when they bind to a surface due to van der Waals, electrostatic or steric interactions. Cantilever sensors are based on this principle. A reason for the growing interest in the development of sensors based on the cantilever principle is the possibility of performing local, high resolution and label-free molecular recognition measurements on a portable device. Normally, micrometer-sized cantilevers designed for atomic force microscopy (AFM) imaging are used in cantilever-based bio/chemical detection[1,2]. Changes in the surface stress of a material on one side of the cantilever gives rise to a cantilever deflection, which is typically monitored by optical techniques. This optical read-out method, though very sensitive, is difficult to integrate into a microliquid handling system. To overcome this kind of problems we have previously developed cantilever-based sensors with piezoresistive read-out[3]. This detection scheme is suitable for fabricating large arrays of sensors for simultaneous multiple detection. In our previous work the cantilever-based sensor has been realized in silicon based materials and the piezoresistor has been made of poly-silicon. As an innovation, the sensors presented in this work are fabricated in the polymer SU-8[4]. SU-8 is an epoxy-based photoresist. It has a high chemical resistance,

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which makes it a suitable component material. Furthermore, it is compatible with conventional microfabrication techniques. Recently, the use of SU-8 polymer has experienced a rapid growth in the field of micro electro mechanical systems, where especially passive devices for microliquid handling are being realized. Also, AFM probes[5] and cantilevers with an integrated gold resistor[6] have been fabricated in SU-8.

2. Principle of operation

When molecules bind to the surface of a cantilever, the surface stress σ_s changes due to molecular interactions. In our devices changes in surface stress are picked up by a strain gauge resistor, which is built into the cantilever. The surface stress changes cause a deformation of the resistor, which is reflected as a change in the resistance. The relative change in resistance, $\Delta R/R$, is proportional to the gauge factor (K) of the piezoresistor and inversely proportional to Young's modulus (E) of the cantilever material.

In the present design the resistors are fabricated in gold. Usually, silicon is used to fabricate the piezoresistor due to its high gauge factor. The gauge factor for polycrystalline silicon is 15 times higher than that for metals (below 2). However, Young's modulus is 40 times smaller for SU-8 than it is for silicon. Thus, the relative change in resistance for a given surface stress, and thereby the sensitivity, can potentially be higher for a gold resistor in a polymeric cantilever than for a poly-silicon resistor in a silicon-based cantilever.

3. Design and fabrication

In the present design four cantilevers are integrated in a microchannel in order to facilitate measurements on small liquid sample volumes. Two of the cantilevers are intended to be used as reference cantilevers, whereas the other two cantilevers will be used for specific molecular recognition. The cantilevers are connected forming two Wheatstone bridges. This set-up highly reduces noise and drift contributions. The wiring on the chip is encapsulated in SU-8 material to allow measurements in liquid. The gold resistors on the substrate and on the cantilevers are designed to have a resistance of approximately 240 Ω. The cantilevers are designed to have a spring constant of approximately 4 N/m and a resonance frequency of 57 kHz. The volume in the channel is 0.24 μL. The channel is connected to two circular containers with a diameter of 1.2 mm to be used as liquid inlet and outlet.

The devices are fabricated as two separate parts, which at the end are bonded together using SU-8 as an adhesive layer[7]. The complete process sequence is shown schematically in figure 1.

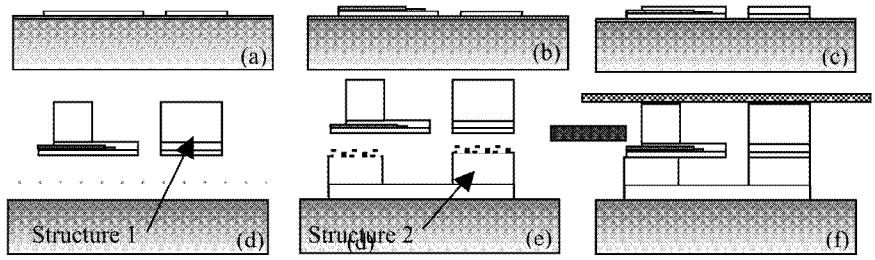

Figure 1. Fabrication process sequence. (a) Evaporation of release layer (Cr/Au/Cr (5nm/50nm/50nm)) and spinning of first layer of SU-8 (1.7 μm thick). Patterning of first SU-8 layer. (b) Wiring (Ti/Au (2 nm/0.8 μm)) and resistors (Ti/Au (20 nm/40 nm)) definition. (c) Patterning of second SU-8 layer. Contact holes are allowed for wiring of the chip. (d) A third SU-8 layer defines the upper part of the channel. Release of finished structure 1 by wet Cr etch. (e) Spinning of SU-8 glue on structure 2 and gluing of structure 1 and 2. (f) Sealing of the chip and external wiring.

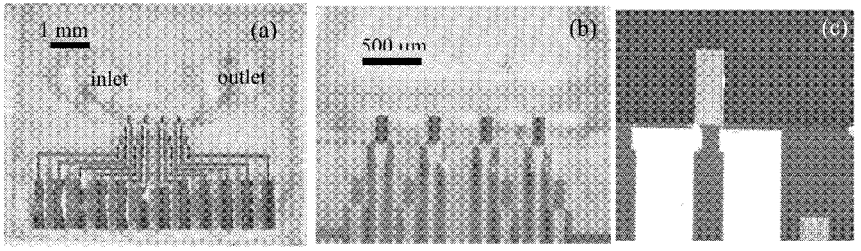

Figure 2. Optical images of the final device (before sealing with a lid). (a) The complete device and (b) detail of the cantilever array in the channel. Gold resistors both in the cantilevers and on the substrate can be seen. (c) Optical image of the encapsulated resistors both in the cantilever and substrate.

5. Characterization

The SU-8 cantilevers were characterized to measure its sensitivity and noise level. In order to find an estimate of the sensitivity of the sensor, the resistance change of the gold strain gauge has been measured as a function of the bending of the cantilever. A micromanipulator was used to bend the cantilever by applying a point force at its apex. A deflection sensitivity of 1 x 10^{-7} nm^{-1} was measured which implies for a gauge factor of 2 as expected.

The device was characterized with respect to 1/f and Johnson noise for different supply voltages. We found a cut-off frequency for the 1/f noise at around 1 kHz. By using

lock-in techniques with a signal around 3 kHz the only inherent noise source is Johnson noise. Considering this noise level and the measured gauge factor of 2, a minimum surface stress of 5 x 10^{-4} N/m can be detected. This means that polymeric cantilevers sensors are potentially a factor of 2 more sensitive than the best devices we have made with polysilicon resistors. To compare with molecular recognition measurements, Fritz *et al*[2] report hybridisation of 12-mer oligonucleotides gives rise to a surface stress of 5 x 10^{-3} N/m which could be detected with the present devices.

6. Conclusions

We have realised a bio/chemical sensor platform consisting of an array of four SU-8 cantilevers integrated into a microfluidic system, also fabricated in the polymer SU-8. The cantilevers have built-in strain gauges to measure the surface stress changes on the cantilevers. Noise characterization of the devices implies a minimum detectable surface stress of 5 x 10^{-4} N/m, which makes it appropriate for biological measurements. The use of polymer instead of silicon makes the fabrication process simple, cheap, fast and flexible. The sensor can be made very small and portable making it interesting for 'point of care' analysis. Moreover, the polymer technology might in the future open up for completely new ways of detecting cantilever bending.

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