POLYSILICON-BASED PIEZORESISTIVE MICROCANTILEVER FOR BIOLOGICAL SENSING

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I. Introduction

With the advancement of miniaturization technologies there is increasing interest in the field of biosensor research on miniaturized platforms. The conventional biosensors need extensive packaging, complex electronic interfacing and regular maintenance. The drawbacks faced with the conventional biosensors can be reduced with miniaturization such MEMS devices that integrates electronics and micromechanical structure and it is also essential for in vivo physiological monitoring, low analyte requirement (in µl), non-hazardous procedures, quick response , multiple specificity sensor arrays, sensor portability. MEMS devices such as microcantilever-based biosensors are rapidly becoming an enabling sensing technology for a variety of biological applications due to its applicability, high sensitivity, versatility and low cost. Microcantilever-based biosensor have wide applications in the field of medicine such as screening of diseases[1-3], blood glucose monitoring[4, 5] and chemical and biological agents detection[6, 7].

In this paper, first the theoretical consideration for polysilicon-based piezoresistive(PZR) microcantilever is explained. Then a finite element modeling is used to provide for analysis and simulation of the performance and geometrical parameters. The finite element model is also used to analyze the electrical and mechanical response of the piezoresistive microcantilever by using Coventorware, software for MEMS simulation. Effects of geometric parameters on displacement, sensitivity of piezoresistive microcantilever and fabrication process are also explained.

II. Design Consideration

A piezoresistive microcantilever is designed based on the concept of adsorption of analyte/species on the functionalized surface of the microcantilever which resulting in the deflection of the microcantilever beam**(Fig.1)**.

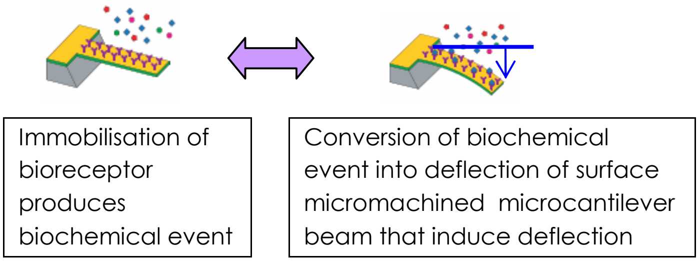

Fig. 1 Schematic illustration of microcantilever beam that induce deflection

The structure of the PZR microcantilever is shown in **Fig. 2**.

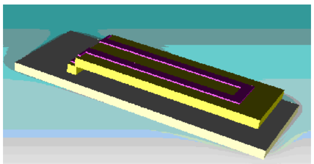

Fig. 2. A solid 3-D model of piezoresistive microcantilever

Three model of PZR microcantilever (110µm x 75µm, 140µm x 75µm, 170µm x 75µm) consists of a multi-layer Polysilicon (Poly1) /Silicon Nitride(SiN) /Polysilicon(Poly 2) . The first layer of Polysilicon acts as microcantilever beam. Meanwhile the Silicon Nitride layer acts as an insulator providing isolation between Poly1 and Poly2. A doped-polysilicon piezoresistive layer on the top surface of the microcantilever is to record the stress change occurs at the surface of the microcantilever. The displacement and corresponding surface stress causes the piezoresistor to change the resistance, which can be measured by external electronic circuit. The relationship between the surface stress and the relative change in resistance $\Delta R/ R$ for a piezoresistor is given by[8],

$$\frac{\Delta R}{R}=-K\left(\frac{1}{E_1h_1+E_2h_2}+\frac{Z_T^2}{E_1h_1\left(\left(Z_T-(h_1+h_2)+\frac{h_1}{2}\right)^2+\frac{1}{3}\left(\frac{h_1}{2}\right)^2\right)+E_2h_2\left(\left(Z_T-(h_1+h_2)+\frac{h_2}{2}\right)^2\right)}\right)\ x\Delta\sigma$$

Where, $E_{1,}h_1$, is Young's modulus and thickness of the polysilicon cantilever beam, $E_{2,}$ h_2, is Young's modulus and thickness of the piezoresistor, Z_T is the distance from neutral axis to top of thecantilever beam containing piezoresistor and K is the gauge factor of piezoresistor (which only applies when the length of the Polysilicon piezoresistor is the same as the cantilever length).

III. Modeling of PZR Microcantilever

In designing the PZR Microcantilever, CoventorWare^{TM}, a commercial MEMS simulation software, is used to simulate the mechanical-piezoresistive behaviors of the device.The finite element technique was used to solve the differential equations of each physical domain where the differential equations are solved by discretizing the 3-D model into a mesh that consists of a number of elements with a specified number of nodes. After the mesh model is generated MemMech solver was used to analyze the variable stress simulation (**Fig. 3**) with the same conditions of analyte concentration and the same analyze capturing area.

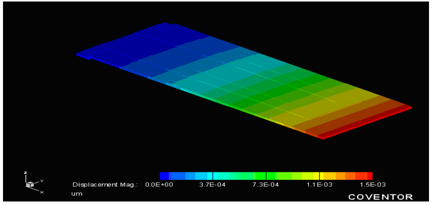

Fig. 3 PZR Microcantilever with applied stress from 2 to 10 Pa of initial state

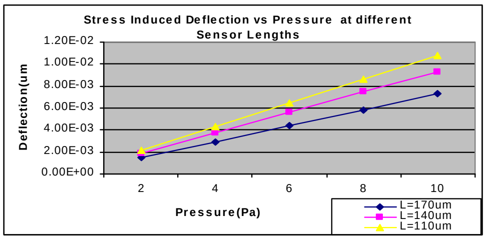

Fig. 4 PZR Microcantilever deflection versus pzr lengths

From **Fig. 4**, it can be observed that when a surface stress is applied onto a microcantilever, the deflection amplitude increases from the support end to the free end of the cantilever.

IV. Fabrication Process

The surface micromachining fabrication involves three essential elements: deposition, lithography and etching. The fabrication process as shown in **Fig.5** is started from patterning a 0.9µm –thick photoresist of borophosphosilicate Glass(BPSG) sacrificial layer on a silicon substrate. The sacrificial layer is a Silicon dioxide material with an addition of boron up to 4% to form borophosphosilicate glass (BPSG) which reduces the viscosity and enables at even lower temperatures. Next, SiN layer are deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD). Another polysilicon layer is then deposited and blanket implanted to achieve a resistor value of 1.2kΩ. Then the electrode pad was patterned and deposited with Aluminum and finally the cantilever beam is released by wet etching.

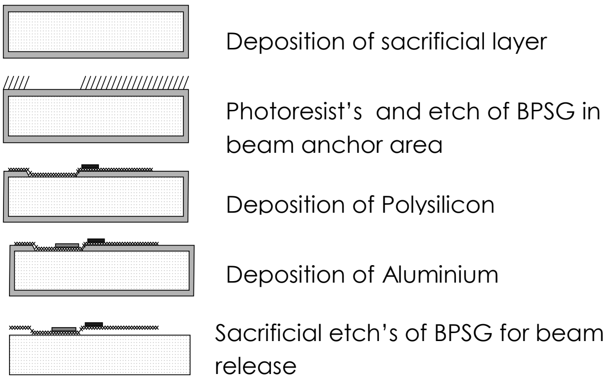

Fig. 5. The fabrication process of PZR Microcantilever sensor

The cross section image of the piezoresistive microcantilever assigned is as shown in **Fig. 6**.

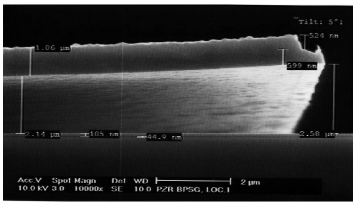

Fig. 6 PZR Microcantilever cross-section

V. Conclusions

From the finite element modeling, by comparing the beam tip deflection behavior at different sensor lengths, it can be observed that the longer the piezoresistor, the larger is the deflection. The range of deflection is from 2nm to 10nm. The surface micromaching is adopted as the fabrication technique and Hydrofluoric acid and Ammonium fluoride based acid have been used as the wet etchant for the microcantilever beam release.

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