Design Considerations and Working Principle of a Cantilever Glucose Sensor Using MEMS

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***Abstract*— Detection of chemicals is required for many industries including the medical felids. MEMS sensors bring a novel solution for that requirement in small devices with its high sensitivity. One aspect of these sensors is that they can be customized for most applications. While they seem like the perfect solution, they are not without flaws. There are many aspects to chemical sensors. They can be simple or highly complex. In most cases, they are very accurate. It is possible, for example, for a cantilever sensor to detect mass changes in picograms. In this paper, some important design parameters to be considered for the optimization of a contilever beam glucose sensor performance are presented. Also the underlyning principle for this sensor is also simulated. This sensor works on the principle that a shift in resonance frequency of the cantilever beam indicates the amount of chemical absorbed which in turn indicates the presence of glucose molecules. This can be achieved by keeping the spring constant which is one of the parameters in defining resonance frequency constant. With this parameter kept constant, a change in mass which is the other resonance frequency parameter will cause a corresponding shift in resonance frequency and suggests the presence of specific molecules using a polymer engineered to selectively bind with only glucose molecules.**

***Index Terms*— Cantilever sensor, Design considerations, Glucose, MEMS, Resonance frequency**

I. INTRODUCTION

The detection of chemicals using other chemicals is the basis for the chemical detection method. It is based on calculated and known reactions between certain chemicals. When specific chemicals interact a reaction occurs. Effects of these reactions are known and can be used to determine what chemical caused the reaction. These effects are often exploited by, but not limited to, the use of polymers. In the broad sense, a polymer is a laboratory made chemical that can be used for a variety of purposes including controlled, calculated reactions [1],[2]. Polymers for MEMS can be engineered to be sensitive only to specific types of chemicals. When these chemicals are present near the polymer, they get absorbed (or adsorbed) onto it and change one or a few of the properties (e.g., illuminescence, color, opacity, conductivity, resistivity, etc.) of the polymers. This effect is particularly useful and is utilized in several different ways. A far more robust method of using polymers, however, is with cantilever sensing elements. Cantilever elements also rely on polymer absorption, but utilize it differently. When the polymer absorbs the desired chemical, it changes the mass of the cantilever, which in turn changes the fundamental frequency of the cantilever. The main principle behind cantilever sensors is with the measuring of change the resonance frequency[3]. Resonance frequency is the frequency at which a vibrating body produces the largest amplitude. This frequency is dependent on the spring constant of the body and its dynamic mass as expressed in the equation below

$$F_o = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \tag{1}$$

Where

F_o = Natural Frequency
m = Mass of material
k = Spring constant defined by the following equation

$$K = \frac{EWT^3}{4L^3} \tag{2}$$

Where

W = beam width
T = beam thickness
L = beam length
E = Young's modulus of elasicity

Should one of these parameters change,the resonant frequency will accordingly change. This is the basis behind using change in resonant frequency as a means of chemical detection. Alteration in the mass of a vibrating cantilever changes the total mass which in turn shifts the resonant frequency to some other frequency. By measuring this shift, one can determine the amount of mass tha was added to the cantilever assuming the spring constant remains constant. If the cantilever is selective to the kind of analyte it absorbs, then in addition to detecting the chemical if present,the sensor can also detect the concentration of it. This method of chemical detection is highly accurate. Some experiments have successfully demonstrated the ability to detect a change in mass of as little as 0.7picograms[4]. In this report,however,some important design parameters for the optimization of a cantilever glucose sensor performance will be discussed. Also the basic principle governing this sensor operation is simulated.

II. DESIGN CONSIDERATIONS

Optimization of sensor performance requires a number of considerations including some parameters that directly affect the sensing element. In this chapter, a spotlight is put on some significant parameters worth considering to improve the sensor performance. These parameters are Cantilever actuation methods, Polymer thickness, Feed back loop and Residual stress.

A. Cantilever Actuation Methods

In order for the MEMS sensor to function in dynamic, or frequency, response mode, it is necessary for the cantilever to be vibrating. There are several ways of actuating a cantilever into its resonance frequency, which can be classified as direct and indirect actuation methods [5-7]. Indirect methods include using acoustic vibration to shake the sensor much like a piece of paper in front of a speaker vibrates from the compression waves in the air. Another indirect method has a magnetic coat deposited on the cantilever and an inductance coil underneath it to generate magnetic fields that attract and repel the cantilever into vibration. For direct methods, the most common is by the use of a PZT (Pb-Zr-Ti transducer or, as it is sometimes called, piezoelectric z-axis actuating transducer), which is capable of vibrating at different frequencies very accurately depending on the driving voltage [8],[9],[10]. Electrostatic actuation has now proven to be common in recent times due to its numerous advantages over the other actuation methods .Electrostatic actuation makes use of electrostatic force induced by the potential difference between a microactuator and its electrode. As its applied voltage increases, higher electrostatic force results in more displacement. For most cases, both DC bias and AC signal are used to displace a microactuator at the same time.

B. Polymer Thickness

In fabricating cantilever sensors with special coatings it is important to take into account the thickness of this layer. The thickness affects several aspects of the sensor. Mostly, it affects the rate at which the polymer becomes saturated with the suspect analyte [11]. The thicker the polymer, the longer it takes for the polymer to reach saturation. This is not really a problem unless time is a critical factor in the function of the sensor. It is generally preferred to make the coating as thin as possible, however, to minimize other effects. One of the most prominent of these effects is that of residual stresses. A thicker layer of polymeris more reactive to effects of different coefficients of thermal expansion and also it is more sensitive to pressure effects.

C. Feed Back Loop

Because the method of extracting data is usually electrical, there is typically noise present in the results. This noise and errors in the data can be reduced, however, with theuse of feed back loops [12-14]. Feed back loops is a post processing technique used to increase accuracy of the data in which the data are refined several times. It is utilized with computers and special circuit setups.Active feed back loops continuously correct the data being processed so that error is minimized. These can be very complex systems and require a lot of knowledge in electrical engineering.

D. Residual stress

During the fabrication of a multi-layered MEMS device two or more dissimilar layers are deposited on top of one another depending on the process and design. Because of differences in coefficients of thermal expansion (CTE) of the materials, residual stresses will be produced in these layers due to the fabrication processes[15-18]. A lot of the fabrication techniques involve depositing layers at high temperatures (600˚C +). When the fabrication is over and temperatures return to room temperature (~20˚C), different materials will shrink (or expand) by different amounts leading to stress gradients[19], [20]. These gradients will manifest themselves as warping of structures, cracks, or other failure modes. This is a constant design problem that must be taken into account. One method of reducing and/or eliminating residual stresses is by annealing the device after the deposition process. Anneling is a process of heating the device at a certain temperature for a specific time in order to allow for any stress to dissipate. This is a proven process, but requires a lot of experimental verification and takes up valuable production time.

III. WORKING PRINCIPLE

The main principle behind cantilever sensors is with the measuring of change in the resonance frequency. Resonance frequency is the frequency that produces the largest amplitude that a vibrating body can achieve. This frequency is dependent on the spring constant of the body and its dynamic mass as shown in the equation above. When the spring constant is made to be fixed, a shift in resonance frequency will only depend on the dynamic mass of the sensing beam.This change in mass will also in turn depend on the amount of glucose absorbed by the polymer. In this chapter a simulation which shows the verification of the above resonance frequency is performed using COMSOL multiphysics.

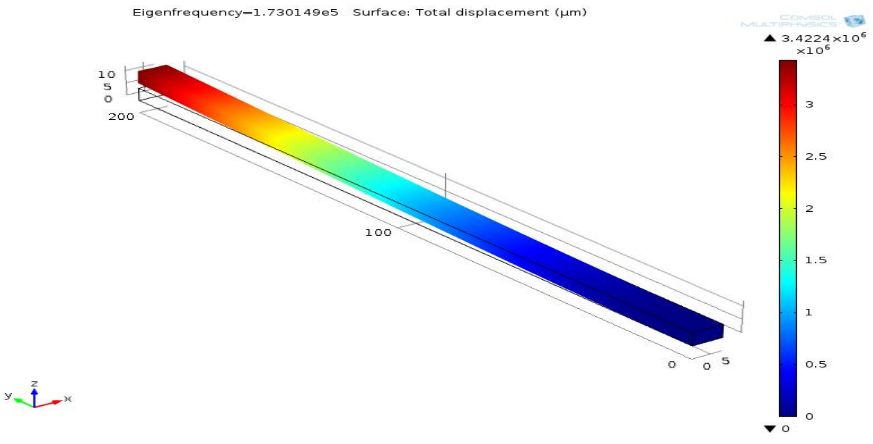

Fig. 1. Displacement Profile of Eigen Frequecy Beam

IV. RESULTS

The eigen frequency simulation using COMSOL has been done as shown in the diagram above. A plot of Frequency against beam length,width and thickness is shown below. From the plot it is proven that the resonace frequency depends on the spring constant and the dynamic mass. Now if the dimensions of the beam (thickness,length and width) are kept constant,then the resonance frequency will only depend on the dynamic mass of the beam which defines the underlyning principle of operation for this glucose sensor.

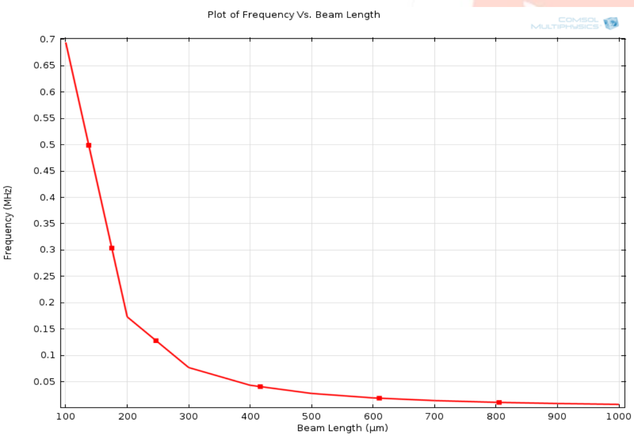

Fig. 2. Polt of Frequency Vs. Beam Length

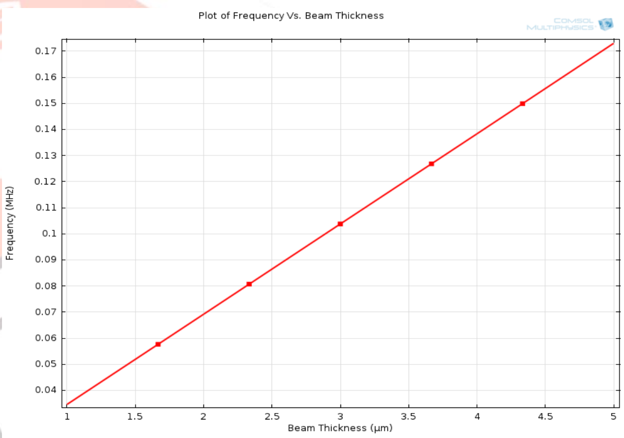

Fig. 3. Polt of Frequency Vs. Beam Thickness

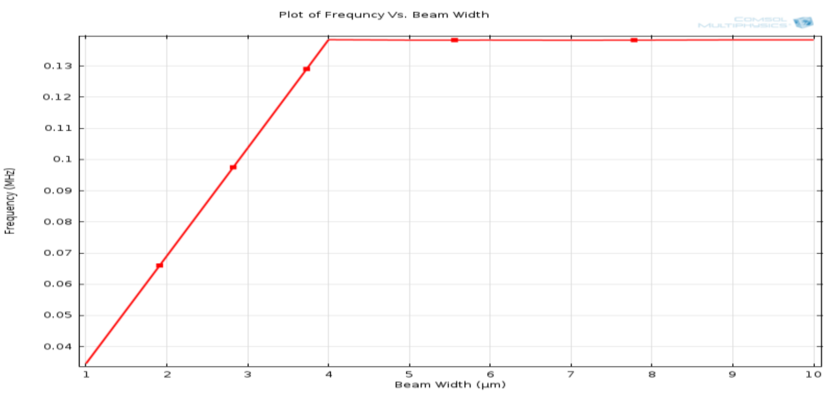

Fig. 3. Polt of Frequency Vs. Beam Width

V. CONCLUSION

Thus some key design parameters worth considering for the optimization of a cantilever beam glucose sensor have been discussed. The simulation results on the other hand verified the operation principle behind this sensor. By modifying the polymer coating, other chemicals may be detected using the same principle of operation.

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