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Design of Sensitive MEMS Differential Dielectric Sensor for Glucose Measurement

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Abstract - The abstract Sensors used for continuous glucose monitoring (CGM) are commonly realized by electrochemical detection. In this paper, MEMS (Micro Electro Mechanical Systems) differential dielectric glucose sensor measures glucose concentrations through glucose-induced changes like cross linkages in the polymer, variation in the weight of glucose with respect to its concentration in the sample under consideration and glucose concentration making changes in the dielectric properties of a closed beam structure. The simulation results of the sensor are presented using coventor and comsol software. Differential capacitive measurements with the changes in the distance between the two surfaces of the beam for effective rejection of environmental interferences are taken into consideration. The differential capacitance has been obtained from the difference in the displacement between the two surfaces of the sensing and reference closed/fixed beam, allowing determination of the glucose concentrations. The sensitivity of this sensor is now has been increased by varying other sensor parameters like the material of the beam, distance between the two electrodes or surfaces of the beam, increasing its surface area, area of electrode and proper selection of the polymer. Polymer considered in this sensor is - PHEAA-ran-PAAPBA [poly (N – hydroxyethylacrylamide – ran – 3 - acrylamidophenylboronicacid)].

Keywords - MEMS, Glucose Measurement, Dielectric Sensor.

1. Introduction

Diabetes is a metabolic disease characterized by persistent hyperglycemia (high blood sugar levels). Close monitoring of daily blood sugar levels reduces the risk of diabetes-related complications by allowing timely identification and correction of hyperglycemia as well as hypoglycemia (low blood sugar levels), a condition that typically results from excessive insulin intake or inadequate glucose intake. This can be most effectively achieved by continuous glucose monitoring (CGM), which can involve constantly repetitive measurements of glucose levels.

MEMS devices are being used for continuously monitoring glucose levels in diabetic patients. Here, the device consists of two closed or fixed beam structures with each having two surfaces of metal forming upper and lower electrodes. Out of two beams, one is sensing beam and the other is reference beam with sensing polymer and reference polymer layers over the top of upper electrodes respectively with a semi-permeable membrane. The sensor is based on affinity binding principle used in sensors for continuous glucose monitoring (CGM) which are commonly realized by electrochemical detection. The glucose concentration is determined by detecting changes in the weight of glucose molecules in the polymer used as glucose receptors in the sensor induced by binding of glucose molecules with polymer solution. The device is capable of measuring relevant glucose concentrations in the samples under consideration. Here, we present a MEMS differential dielectric sensor, which determines glucose concentrations via differential capacitive measurements by variable beam displacement which is due to force exerted by the weight of glucose molecules that gets induced in glucose-affinity polymer.

The sensor involves mechanical parts and affords structural simplicity, facilitates miniaturization, and offers better structural simplicity. Affinity glucose sensing technique offers excellent rejection of environmental interferences while allowing accurate glucose detection. In the above mentioned work, we are going to present sensitivity results by changing some parameters of the sensor and get more accurate simulation results for continuous glucose level measurement using coventor software. This parameter includes changing area of

electrodes, changing distance between the electrodes, using different beam material, etc.

2. Related Work on Glucose Sensor

Glucose measurement has become an influencing term. There has been glucose measurement techniques developed for monitoring the glucose levels. Instances of MEMS technology has been discussed further. Commonly, glucose measurement is done by using a cantilever beam method and by dielectric affinity sensor which we are going to consider for further developmental work that depends on the polymer material responsible for detecting glucose levels.

X. Huang, C. LeDuc, Y. Ravussin, S. Li, B. Song, Q. Wang,D.Accili, R. Leibel and Q. Lin [3] has designed an MEMS affinity glucose sensor that measures glucose concentrations via glucose-induced changes in the dielectric properties of a synthetic polymer. The sensor involves no mechanical moving parts for structural simplicity, and uses differential measurements for effective rejection of environmental interferences, thereby enabling accurate glucose detection. Our in-vitro and in-vivo experimental data demonstrate that this sensor can potentially be used for highly stable continuous glucose monitoring in diabetes care.

The differential sensor uses poly (N hydroxyethylacrylamide- ran-3-acrylamidophenylboronic acid) (PHEAA-ran-PAAPBA) as the glucose sensitive polymer, which recognizes glucose by specific affinity binding. The fabrication of the device started with deposition and patterning of a thin film gold layer to form bottom electrodes (1mm×1mm×100nm) as well as resistive temperature sensors on a silicon substrate coated with silicon oxide.

Xian Huang, Siqi Li, Jerome Schultz, Qian Wang, and Qiao Lin [1], also developed a sensor which consists of a vibrating Parylene diaphragm, which is remotely driven by a magnetic field and situated inside a microchamber. A viscosity change in the sensing solution in microchamber, causes a detectable change in the Parylene diaphragm vibration which can be measured capacitively. They also designed a biocompatible sensor [2, 7] based on a micro-cantilever or membrane situated inside micro chambers. A change in viscosity induced by the binding of poly (acrylamide-ran-3-acrylamidophenylboronic acid) with glucose is determined by the damped vibration of the cantilever or the membrane in the devices. The cantilever-based sensor has been used to measure physiologically relevant glucose concentrations.

The cantilever-based sensor has been used to measure physiologically relevant glucose concentrations from 0 to 324 mg/dl. The response time was improved using the membrane-based sensor.

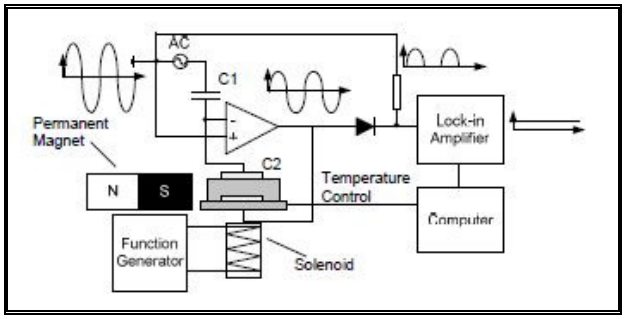

Figure 1. Block Diagram

3. Device Design and Fabrication

3.1 Tables and Figures

The Block Diagram of this sensor is shown in figure 2 and its working is discussed in the following section.

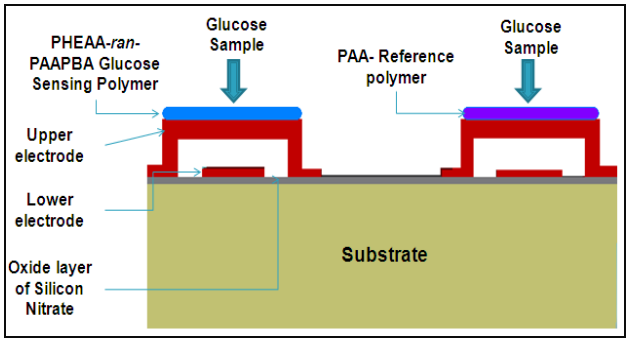

Figure 2 – Block diagram of the sensor

The first step in this process is to design the differential dielectric sensor based on two closed/fixed beams forming 2 pairs of electrodes, which can be fabricated by MEMS technology and layers of sensing and a reference polymers sealed by a semi-permeable membranes (Figure 2). The upper electrode bends downwards due to the weight of glucose molecules induced in the sensing polymer on sensing beam. The sensing polymer PHEAA-ran-PAAPBA is considered to be present over the sensing beam's upper electrode on left beam after the fabrication of the device, whereas the reference polymer PAA is considered on reference beam surrounded by semi-permeable membranes to provide mechanical support to polymers and allow glucose molecules to induce in the polymer from the glucose sample. These membranes

prevent the polymers from spilling off and allow them to effectively resist mechanical disturbances.

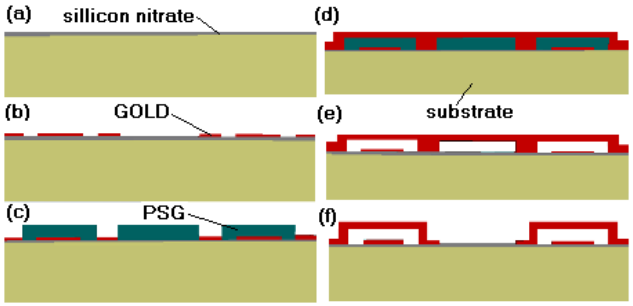

Figure 3. Fabrication Process: - (a) Substrate with oxide layer (Silicon Nitrate). (b) Layer of Gold to form lower electrodes and isolate them from other parts of the beam. (c) Deposition of PSG layer and etching of PSG layer to form anchors of the beam (d) Deposition of gold to form upper electrodes. (e) Deposition of Gold layer to form upper electrodes. (f) Removal of gold layer to isolate two beams.

The fabrication of the device starts with the deposition of layer of silicon nitrate as oxide layer of thickness 4um over substrate (4mm x 0.2mm x 40um) by thermal oxidation method. Layer of gold is deposited by chemical vapor deposit method (5 um in thickness). Sacrificial photo resist layer of phosphosillicate glass is added of 2um thickness. Finally, a layer of 6um thick gold layer is deposited to form upper electrode/beam and the two beams are then isolated by etching method.

4. Sensor Architecture and Working

Sensing polymer - PHEAA-ran-PAAPBA is a synthetic, amphiphilic copolymer containing two components: hydrophobic glucose-sensitive 3-acrylamidophenylboronic acid (AAPBA) segments and hydrophilic and nonionic hydroxyethylacrylamide (HEAA) segments of the copolymer.

When added to an aqueous solution of PHEAA-ran-PAAPBA, glucose binds reversibly to the phenylboronic acid moieties in the AAPBA segments to form strong cyclic boronate ester bonds, resulting in the cross linking of the polymer and hence only the glucose molecules induces in the polymer. When 1ml glucose sample (blood) is dropped on the beams, the sensing polymer reacts only with the glucose molecules and gets induced in the polymer whereas reference polymer don't react with glucose. After some time, the other material would be removed from the beam so that only glucose molecules will remain over the beam.

Positive and negative charges are given to the upper and lower electrodes of each beam forming parallel plate capacitors with some distance between them. Due to additional glucose molecules on sensing beam, the beam bend downwards reducing the distance between the two electrodes which increases the capacitance of sensing beam whereas no change of capacitance in reference beam structure.

The difference between the capacitance of sensing and reference beams is directly proportional to the glucose concentration in the sample under consideration. Increase in the glucose concentration increases the differential capacitance. For simulation purpose, we have considered reference/threshold value of force on the beam due to the weight of glucose molecules present in blood sample on reference beam which is 1.6mg/ml post meal and any increase in the glucose concentration leading to comparatively more beam displacement causes increased differential capacitance between the two beams giving us the increase in the glucose level in the blood sample. Similarly, threshold can be set for glucose measurement during fasting.

5. Materials and Test Setup

PHEAA-ran-PAAPBA is synthesized by free radical polymerization with an HEAA to AAPBA molar ratio of 20 and a molecule weight of 188600. PAA is also synthesized by a similar process as PHEAA-ran-PAAPBA using acryl amide monomer. PHEAA-ran-PAAPBA (284 mg) and PAA (142 mg) were dissolved in PBS (6 ml) to obtain a sensing and a reference solution, respectively.

To characterize the device, a capacitance voltage converter circuit would be used to measure the frequency response of the sensing and the reference polymer (Figure 4). Specifically, this circuit measures the single-module capacitance of the sensing and the reference electrodes under an AC E-field with various frequencies from 0.5 to 100 kHz. The amplitude and the phase of the output voltage from the circuit is captured by a lock-in amplifier (Stanford Research Systems, SR830) to calculate the sensor capacitance.

This test setup is further simplified using an Σ-Δ capacitance digital converter (CDC) (Analog Devices, AD7746), which applies a square wave at a fixed frequency of 32 kHz to the sensor and converts the amount of charges on the capacitive sensor electrodes to a capacitance value. The CDC can be programmed to obtain either the capacitance difference of the sensing and reference modules or the single-module capacitance solely from the sensing module.

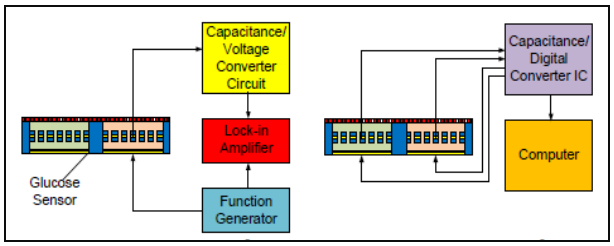

Figure4. Experimental setup uses a capacitance voltage converter or a capacitance digital converter (CDC) to measure the differential capacitance of the glucose sensor.

5. Conclusion

The differential dielectric sensor has been presented that allows accurate glucose detection with improved stability to environmental disturbances. The difference in the displacement of the fixed beams helps to measure glucose levels via the differential capacitance.

This device has been made sensitive by choosing sutiable area of the capacitors keeping overall small size of the device into consideration. The area of each capacitor has been taken 3.2x10-7 m to get the capacitance of pico Farad (pF) range. Here, the beam displacement is noted between 0 um to 1.9 um (total air gap – 2 um) with differential capacitance between 0 F to 494.1072x10-14 F to measure blood glucose between 160mg/dl to 1000mg/dl on Coventor software and between 0 to 1120x10-14 F to measure blood glucose from 160mg/dl to 500mg/dl on Comsol software where thickness of the beam 6 um is kept constant. When beam thickness is decreased to 4 um, there is no result in Comsol. Whereas when thickness is increased to 8 um the range of displacement is reduced to 0.871223 m for 1000mg/dl blood glucose concentration.

Future recommendation in the above mentioned work would be to fabricate and test the device with estimation of its actual cost effectiveness as compared to the devices currently available in the market.

References

[1] Xian Huang, Siqi Li, Jerome Schultz, Qian Wang, and Qiao Lin, “A Capacitive MEMS Viscometric Sensor for Affinity Detection of Glucose.” IEEE Journal of Microelectromechanical Systems, Vol. 18, No. 6, December 2009.

[2] Xian Huang, Siqi Li, Jerome Schultz, Qian Wang, Qiao Lin, “A Biocompatible Affinity MEMS Sensor for Continuous Monitoring of Glucose”. 4th IEEE international conference on nano/micro engineered and molecular systems, January 5-8, 2009, Shenzhen, china.

[3] X. Huang, "A MEMS Differential Affinity Sensor for Continuous Glucose Detection," in IEEE Transducers 2011, Beijing, China, 2011.

[4] S. Li, "Synthesis and Development of Poly(nhydroxyethylacrylamide)-ran-3-acrylamidophenylboronic Acid Polymer Fluid for Potential Application in Affinity Sensing of Glucose," J Diabetes Sci Technol, 5: 1060-7, 2011.

[5] X. Huang, "A Dielectric Affinity Microbiosensor," Appl. Phys. Lett., 96: 033701- 033703, 2010.

[6] Y. Zhao, "A MEMS Viscometric Sensor for Continuous Glucose Monitoring," J. Micromech. Microeng., 17: 2528-2537, 2007.

[7] Xian Huang, Siqi Li, Jerome Schultz, Qian Wang, “A Capacitively Based MEMS Affinity Glucose Sensor.” Transducers 2009, Denver, CO, USA, June 21-25, 2009.

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