Design of Electrode for Biosensor to Make It Self-POWER

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Abstract- *Sensors are sophisticated devices that are frequently used to detect and respond to electrical or optical signals. Biomedical sensors are used to gain the information on body and pathology. Biomedical sensors are also used to monitor the safety of medicines, food, environmental conditions and other substances. The sensor was constructed by functionalizing an oxygen sensor with glucose oxidase and inserting it into the external part that used for monitoring. However, there continues to be several challenges related to the achievement of accurate and reliable glucose monitoring. Further technical improvements in glucose biosensors, standardization of the analytical goals for their performance, and continuously assessing and training lay users are required. The project describe the design of electrode of a self-powered glucose biosensor that is capable of generating high voltage. Simulation is done is Comsol multi-physics. The most commonly used enzymes are the glucose selective enzymes, glucose oxidase and glucose dehydrogenase and oxygen reducing enzymes, laccase and bilirubin oxidase as the bioanode and biocathode enzymes.*

Keywords- GLUCOSE BIOSENSOR, CANTILEVER ELECTRODE, POINT-OF-CARE TESTING, SELF-MONITORING OF BLOOD GLUCOSE

I. INTRODUCTION

MEMS are fabricated by microelectronics manufacturing techniques. They are coupled devices since they consist of small scale electrical and mechanical components for specific purpose. The mechanical behavior of MEMS is in general coupled with the electrical behavior. Sensors are sophisticated devices that are frequently used to detect and respond to electrical or optical signals. A Sensor converts the physical parameter into a signal which can be measured electrically. Sensor principles are based on physical or chemical effects. Here we describe the characterization of a self-powered glucose biosensor that is capable of generating electrical power from the biochemical energy stored in glucose to serve as the primary source of power for microelectronic devices. The most commonly used enzymes are the glucose selective enzymes, glucose oxidase and glucose dehydrogenase and oxygen reducing enzymes, laccase and bilirubin oxidase as the bioanode and biocathode enzymes. Significant research efforts have been made to develop enzymatic-based biofuel cells, which generate bioelectricity via oxidation-reduction (redox) reactions.

A biosensor can be defined as a "compact analytical device or unit incorporating a biological or biologically derived sensitive recognition element integrated or associated with a physio-chemical transducer". There are three main parts of a biosensor: (i) the biological recognition elements that differentiate the target molecules in the presence of various chemicals, (ii) a transducer that converts the biorecognition event into a measurable signal, and (iii) a signal processing system that converts the signal into a readable form. The molecular recognition elements include receptors, enzymes, antibodies, nucleic acids, microorganisms and lectins. The five principal transducer classes are electrochemical, optical, thermometric, piezoelectric, and magnetic .The majority of the current glucose biosensors are of the electrochemical type, because of their better sensitivity, reproducibility, and easy maintenance as well as their low cost. Electrochemical sensors may be subdivided into potentiometric, amperometric, or conductometric types Enzymatic amperometric glucose biosensors are the most common devices commercially available, and have been widely studied over the last few decades. Amperometric sensors monitor currents generated when electrons are exchanged either directly or indirectly between a biological system and an electrode.

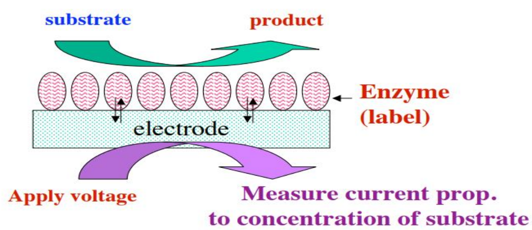

Fig-1: Sensor Design

II. GLUCOSE MONITORING

2.1. Glucose Monitoring Methods in Blood

As a preventative treatment or cure for diabetes is yet to be developed, managing the life impeding conditions of this disease is currently the most successful means for its control. Monitoring glucose levels in blood, as a disease marker, has proven to prolong life expectancy by enabling diabetics to manage episodes of hypo- or hyperglycaemia, hence providing better control over their condition and preventing some of the debilitating side effects. In addition, glucose monitoring can be used to optimise patient treatment strategies, and provide an insight into the effect of medications, exercise and diet on the patient. Although blood-glucose monitoring is the gold standard medium for glucose sampling, measurements carried out in this fluid are invasive. Blood-glucose concentrations are typically in the range of 4.9–6.9 mM for healthy patients, increasing to up to 40 mM in diabetics after glucose intake. Electrochemical sensors were chosen for blood-glucose measurements due to their high sensitivity, on the order of μM to mM, good reproducibility and ease of fabrication at relatively low cost . GOx was employed as the enzymatic basis for the sensor, owed to its high selectivity for glucose. Less common enzymes, such as hexokinase and glucose-1dehydrogenase were also used for glucose measurements, but GOx can tolerate extreme changes in pH, temperature and ionic strength in comparison with other enzymes. Withstanding these conditions can be important during any manufacturing processes, making it a prime candidate for glucose monitoring devices. GOx catalyses the oxidation of glucose to gluconolactone in the presence of oxygen, while producing hydrogen peroxide (H2O2) and water as by-products. Gluconolactone further undergoes a reaction with water to produce the carboxylic acid product, gluconic acid. GOx requires a redox cofactor to carry out this oxidation process, where flavin adenine dinucleotide (FAD+) is employed. FAD+ is an electron acceptor which becomes reduced to FADH2 during the redox reaction. Subsequent reaction with oxygen to produce H2O2 regenerates the FAD+ cofactor. This reaction occurs at the anode, where the number of transferred electrons can be correlated to the amount of H2O2 produced and hence the concentration of glucose[9].

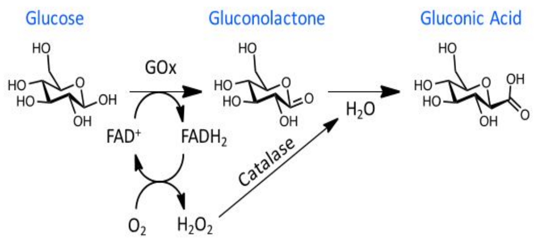

Fig-2: Conversion Of Glucose To Gluconic Acid Using Glucose Oxidase.

In the sensor design it present indirect quantification of glucose concentrations was achieved by placing a thin layer of the GOx enzyme on a platinum electrode via a semipermeable dialysis membrane. This sensor measured the decrease in oxygen concentration and the liberation of hydrogen peroxide, which was proportional to the glucose concentration. The main obstacle to overcome with this approach was the interference of other electroactive species present in blood, such as ascorbic acid and urea.

III. LITERATURE REVIEW

Tanmay Kulkarni and Gymama Slaughter[1] showed the characterization of a self- powered glucose biosensor that is capable of generating electrical power from the biochemical energy stored in glucose to serve as the primary source of power for microelectronic devices. One self-powered glucose biosensor is based on MWCNTs modified with PQQ-GDH and laccase at the bioanode and biocathod .Other employed bilirubin oxidase at the biocathode. The use of bilirubin oxidase biocathode resulted in a 3-fold increase in performance for a single biofuel cell capable of driving a charge pump circuit and enabling the system to function effectively under physiological conditions.

G. Slaughter, T. Kulkarni[2] showed a self-powered glucose biosensor(SPGS) system is fabricated and in vitro characterization of the power generation and charging frequency characteristics in glucose analyte. The bioelectrodes consist of compressed network of three-dimensional multi-walled carbon nanotubes with redox enzymes,pyroquinoline quinone glucose dehydrogenase(PQQ-GDH) and laccase functioning as the anodic and cathodic catalyst. This demonstrate a stable self-powering glucose bio-sensing system constructed by combining a charge pump IC and a capacitor functioning as a transducer with a glucose biofuel cell.

A. Achelia and R. Serhane [7] it presents the studies of mechanical behavior of MEMS cantilever beam made of poly-silicon material, using the coupling of three application modes (plane strain, electrostatics and the moving mesh) of COMSOL Multi-physics software. The cantilevers playing a key role in Micro Electro-Mechanical Systems (MEMS) devices (switches, resonators, etc) working under potential shock.

G. Slaughter, T. Kulkarni[3] it has different types of glucose biofuel cells with emphasis on enzymatic glucose biofuel cells. Unlike conventional fuel cells, which use fuel such as ethanol, methanol, formic acid, etc. to generate electricity, enzymatic glucose biofuel cells convert chemical energy stored in glucose into electricity.

Danielle Bruen, Colm Delaney, Larisa Florea [9] and Dermot Diamond[9] showed highlights recent advances towards non-invasive and continuous glucose monitoring devices, with a particular focus placed on monitoring glucose concentrations in alternative physiological fluids to blood.

III. DESIGN OF ELECTRODE

3.1 Cantilever electrode

MEMS are fabricated by microelectronics manufacturing techniques. They are coupled devices since they consist of small scale electrical and mechanical components for specific purpose. The mechanical behavior of MEMS is in general coupled with the electrical behavior. A cantilever is a rigid structural element, such as a beam or a plate, co-ordinate at one end to a support. Membranes, bridges and cantilevers are the basic's mechanical structures of MEMS. Their typical dimension varies from a few micrometers to a few millimeters. A structure having a cantilever configuration is a basic element of most MEMS actuators and sensors such as switches, capacitive pressure sensors, accelerometers, filters, resonators and many others [4]. The major advantages are their versatility and fabrication steps simplicity. The interest in cantilevers has driven investigations from various aspect including static and dynamic performances under certain influences such as potential fields. The electrostatic actuation is commonly used in MEMS devices, where pull-in voltage represents a topic of high interest in the study of micro-beams such as suspended cantilevers.

In MEMS, the shock due to electrical actuation can cause failures inducing large deflection of cantilevers, which may lead to device failure. Therefore, the concern of designers is to investigate how to prevent such problems. For this purpose, several analytical and numerical methods of modeling were used as a design tool for understanding the mechanical behavior of microstructures.

In this paper, we present the mechanical behavior simulation of MEMS based cantilever beam made of poly-silicon; which is the most common structural materials used for a large variety of MEMS applications. In this simulation we have used COMSOL MULTIPHYSICS through the couplings of three modes: -

The plane strain and electrostatics (ES) modes from MEMS module.

- Moving mesh (ALE) from COMSOL module.

The main objective of this study is to acquire MEMS devices design ability in terms of design rules and multidisciplinary approach in order to build reliable microsystem[7].

From the literature we have to note that different shape of cantilevers is used as shown in figure 1; mostly they have a characteristic length around 0.5 mm, thickness ranging from 3 to 8 µm and electrode gaps nearby 10 µm.

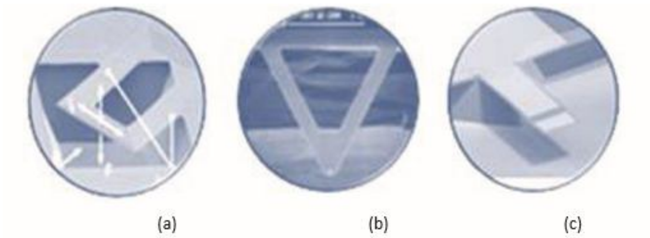

Fig-3: Different Types Of Micro-cantilevers Used In MEMS Devices

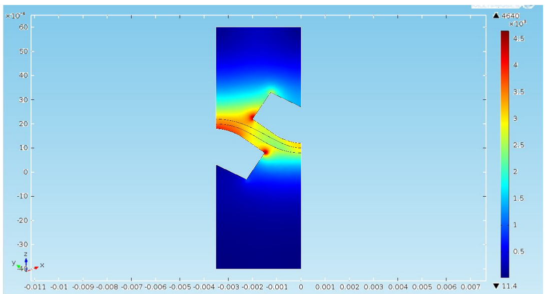

Fig-4 Design Of Eletrode

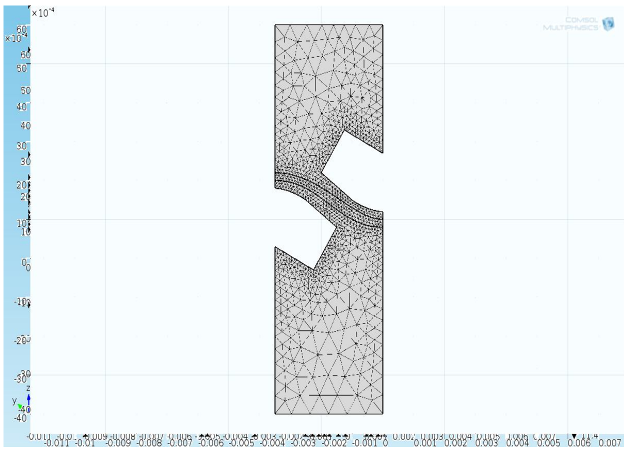

Fig -5 Electrode in mesh form

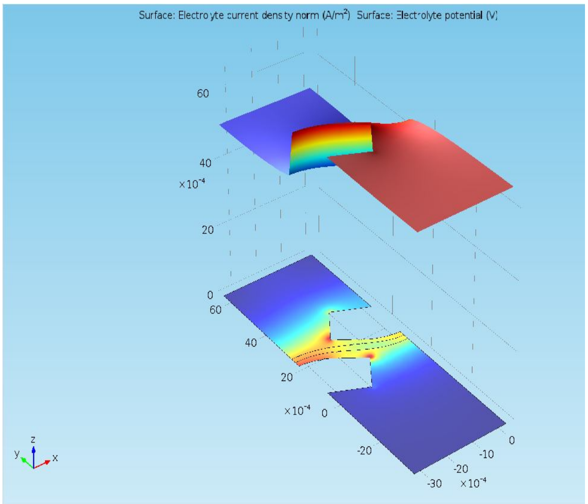

Fig 6 Size of electrode

As we see in the fig 4 it is a design of electrode in that it divided into 3 parts the upper one is anode lower one is cathode and middle one is output.and it also contain the air gap in anode and cathode because air gap helps to generate the high voltage . in this firstly we have to set the range limit after that when blood passes through that air gap if the glucose level is in that limit which we have set then it get laps and it generate the frequency. For make it self powered we have to defined in various frequency level. After that in fig 6 that electrode convert into mesh form with the help of geometry in comsol multiphysics and in fig 7 it shows the height of electrode as we reduced the height of electrode to generate the high voltage.

It below show the parameter of electrode:

K_a 50[S/m] Conductivity, anolyte
K_c 100[S/m] Conductivity, catholyte
K_m 3[S/m] Conductivity, membrane
T 90[degC] Temperature
i0_c 1[mA/m^2] Exchange current density, cathode
E_pol 1.19[V] Cell polarization voltage

IV. RESULT

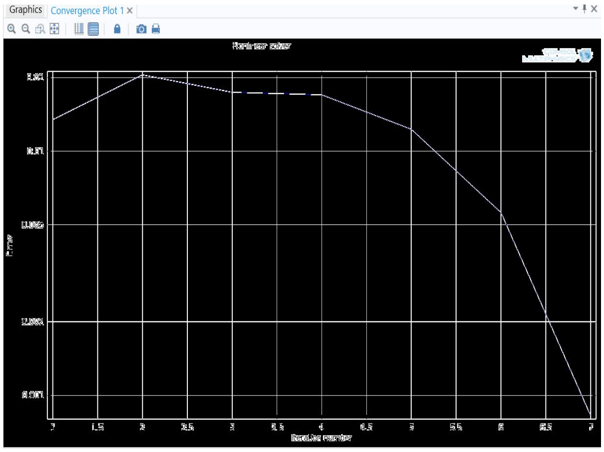

Fig 7 conductivity of electrode

In the above figure it show the result of conductivity of electrode between the anode and cathode. Conductivity specified the material conducts electricity, calculated as the ratio of the current density in the material to the electric field which causes the flow of current.

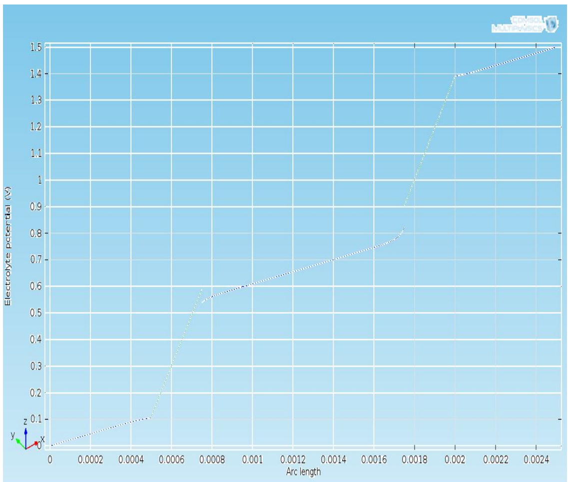

fig 8- output of voltage

Above fig show the output of voltage in electrode in this we perform the operation in two stages here first we give input to anode that is E_pol 1.19V Cell polarization voltage. As by apply input to anode it it then generate the self powered voltage to the output.and it also increased the average current density as shown im fig 9.

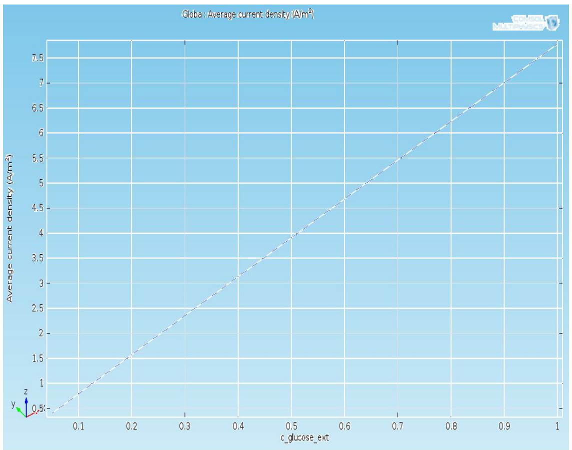

Fig-9 Output of average current density

Observation

The outcomes of the proposed work is

1. The area of electrode has reduced
2. Getting higher value of voltage.
3. The Average Current Density & Voltage increase with the increase in no of stages.

V. APPLICATION

1) In the discipline of medical science, the applications of biosensors are growing rapidly. Glucose biosensors are widely used in clinical applications for diagnosis of diabetes mellitus, which requires precise control over blood-glucose levels.
2) Glucose biosensors have evolved to be more reliable, rapid, and accurate and are also more compact and easy to use.
3) The monitoring of glucose levels in fermentation, bioreactors, and to control glucose in vegetal raw material and food products.
4) Enzymatic glucose biosensor use an electrode instead of O_2 to take up the electrons needed to oxidize glucose and produce an electronic current in proportion to glucose concentration.
5) It also helps remove oxygen from food packaging, or D-glucose from egg white to prevent browning.

VI. CONCLUSION AND FUTURE SCOPE

Here we design the electrode for biosensor to make it self powered. The ratio of voltage to area of electrode will get reduced to generate higher value of voltage. We achieve smaller area of electrode by the chemical properties is used for designing of electrode. We perform our operation in 2 stages. It shows the as we increase the stages we would generate that much of high value of voltage and also increased average current density. Major fundamental have been made for enhancing the capabilities and improving the reliability of glucose measuring devices. It results in advance including the use of nano materials for improved electrical contact between the redox center of GOx and electrode supports, GOx is a new “painless” in vitro testing, artificial receptors for glucose, advanced biocompatible membrane materials. In this work we have used the application of COMSOL Mutli-physics in aim to predict more specifically the real mechanical behavior of cantilevers. Moreover, a series of static simulation was carried out using the developed COMSOL Mutli-physics model in order to determine values of pull-in voltage for cantilever beam, additionally the dimensions and position of actuation electrode was considered. This method is not limited to cantilever structure; this analysis can also be done in other models of MEMS devices. Finally, we consider the modeling and simulation of cantilever beam in 2D. Moreover, we will take into account the time and other factors such as temperature, variation of materials.

Future scope is the enormous activity in the field of glucose biosensors is a reflection of the major clinical importance. . Major fundamental and technological advances have been made for enhancing the capabilities and improving the reliability of glucose measuring devices. Such intensive activity has been attributed to the tremendous economic prospects and fascinating research opportunities associated with glucose monitoring. The success of glucose blood meters has stimulated considerable interest in in-vitro and in-vivo devices for monitoring other physiologically important compounds.

As this field enters its fifth decade of intense research, we expect significant efforts that couple the fundamental sciences with technological advances. This stretching of the ingenuity of researchers will result in advances including the use of nanomaterials for improved electrical contact between the redox center of GOx and electrode supports, enhanced “genetically engineered” GOx, new “painless” invitro testing, artificial (biomimetic) receptors for glucose, advanced biocompatible membrane materials, the coupling of minimally invasive monitoring with compact insulin delivery system, new innovative approaches for noninvasive monitoring, and miniaturized long-term implants.

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BIOGRAPHIES

Ms. Sonali V. Turale received the B.E degree in Electronics Engg in the year 2015 from RTMNU, Nagpur, India. She is currently doing M.Tech. Degree in (VLSI)
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