Polymer Nanowire Based Impedance Biosensor

N. Das[1], C. Roy Chaudhuri[*1]
[1] Department of Electronics and Telecommunication Engineering, Bengal Engineering and Science University Shibpur, Howrah-711103,
[*1] Department of Electronics and Telecommunication Engineering, Bengal Engineering and Science University Shibpur, Howrah-711103
*Corresponding author: narentitun@gmail.com

Abstract: In this paper, we have proposed impedance biosensor based on polymer nanowire(made of polyaniline) for efficient electric field mediated capture of biomolecules. The proposed structure with 20µm*20µm*1µm electrodes in which polymer (polyaniline) has been incorporated in one electrode was simulated using COMSOL Multiphysics software for studying the distribution of electric field lines on the sensor surface. Existing polymer nanowire based biosensors fail to achieve high sensitivity for low surface to volume ratio as the whole length of the nanowire is exposed to the analyte .Also biosensors are dependent on diffusion mediated capture of biomolecules. Results for low concentration the percentage volume coverage by biomolecules is less. In the proposed structure, the problem of low sensitivity has been overcome by proper design of electrodes which enable electric field mediated capture over a small volume of the nanowire so that the percentage volume occupied by biomolecules is larger than the conventional cases.

Keywords:
Microelectrode,Electrospinning,Polyaniline,Impedance Biosensor.

1. Introduction

Nanoscale sensors have been attracting considerable attention in recent years. The application of nanowires has been the topic of significant recent research. Interest in nanowire-based biosensors derives primarily from the potential for such sensors to be label-and reagent-free; direct electrical sensing with nanowires could ultimately deliver a real-time device with the attributes of small size, low cost, and potential for high-throughput measurements[1]. Although the use of nanowires offers the prospect of high sensitivity and rapid detection, the ability to incorporate nanowires into sensor device architectures is limited by the difficulty in manipulating and locating the nanostructures with respect to the microelectrodes. A variety of conducting polymers have shown promise as sensor materials because their properties can be tailored to detect a wide range of biological compounds. Conducting polymers also have attractive features such as mechanical flexibility, ease of processing, and modifiable electrical conductivity. Biosensors based on inorganic nanomaterials require complicated processing conditions for functionalization with bio-recognition elements such as antibodies due to the low-biocompatibility of inorganic nanomaterials[4].

In contrast, organic nanomaterials such as polyaniline (PANI) are more easily modified with biomolecules than inorganic nanomaterials .During the functionalization of the PANI surface, the covalent bond between PANI and the antibody enables the direct measurement of the physical change of conductance, capacitance, or impedance upon the binding of antibodies to target proteins .To date, it has been developed various conducting polymer nanowire fabrication methods such as e-beam lithography, focused ion beam etching, dip-pen lithography, electrospinning , mechanical break junction, hydrodynamically focused stream, and nanopore template[3]. Although these techniques enable to fabricate nanostructures of conducting polymer. Electrospinning is the easiest method of obtaining isolated and relatively long polymer nanowires[2]. Here we use electrospinning to fabricate polyaniline nanowires that are then used to detect different kind of biological component on biological systems. Due to the small size, uniform diameter, and large surface area of the electrospun wire, true saturation is seen in the resistance changes upon exposure to the various kind of biological analyte making them useful as reliable sensors. The electrospinning technique is simple and cheap and is attractive in the fabrication of low cost rapid response sensors.

In the previous reported cases,existing nanowire based biosensors are depend on diffusion mediated capture of biomolecules. Also the whole length of the nanowire is exposed to the analyte and for low concentration the percentage volume coverage by biomolecules is less.In this paper we proposed a structure which arises the problem of low sensitivity has been overcome by proper design of electrodes which enable electric field mediated capture over a small volume of the nanowire,so that the percentage volume occupied by biomolecules is larger than the conventional cases.

2. Use of COMSOL Multiphysics

A few 3D structures are first simulated using COMSOL Multiphysics (version 3.5a) [‘Conductive Media DC’ under MEMS module] to optimize the design of electrode structure to be fabricated for achieving high sensitivity. High sensitivity has been verified by observing the electric field line pattern obtained in the entire liquid column.

2.1. Structure 1:

The cross sectional view of structure is shown in figure1. First we design two electrodes (20µm*20µm*1µm) which are separated by a distance of 980µm.

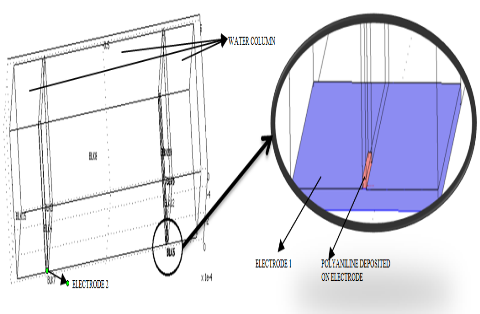

Figure 1. Cross-sectional view of structure 1

A polyaniline nanowire is deposited on the middle portion of one of the electrodes.We use three water columns (500µm*500µm*µm) of which two water columns are placed on the two electrodes and the third water column is placed between the two water columns.

Subdomain conditions applied are as follows:

Electrodes -Conductivity35.5*10^6s/m
Nanowire(polyaniline)-Conductivity 500s/m
Liquid column -Conductivity 0.00027s/m

Boundary conditions applied are as follows:

All faces of electrode 1 – 5 V.
All faces of electrode 2 – 0V.
All external faces – electric insulation.
All internal faces – continuity.

For simulation of the structure, a potential difference was applied between the two electrodes. After simulation, the current flow distribution obtained is shown in Fig. 2.It shows the streamline current flow distribution between the two electrodes through the liquid column.

It is observed that the electric field in every point of the liquid column on the structure is high enough to detect biomolecules very efficiently. Parts adjacent portion of the electrodes have the maximum current density and electric field.when we move away from the electrodes total current density and electric field are gradually decreases.

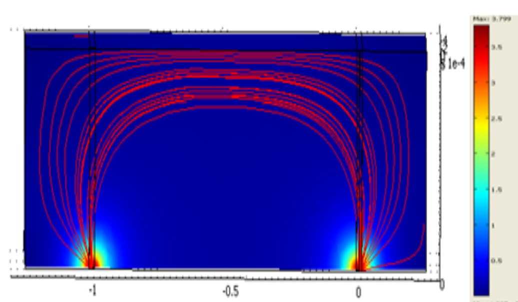

Fig 2: current flow distribution of structure 1

2.2. Structure 2

The cross sectional view of structure 2 is shown in fig 3. The figure has has square cells having dimension 20*20*20nm having conductivity 0.000027 S/m on the top of of polyaniline nanowire. Subdomain and boundary conditions are same as before.

After simulation, the current flow distributions of Structure 2 is shown in Fig. 4. The variation in current as we move along the electrode surface away from the electrode in Structure 2.We observe that the current decreases on the top lateral surface as we move away from the electrodes in both structures.

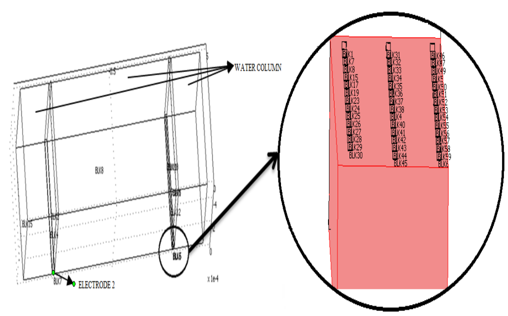

Fig 3: Cross sectional view of structure 2

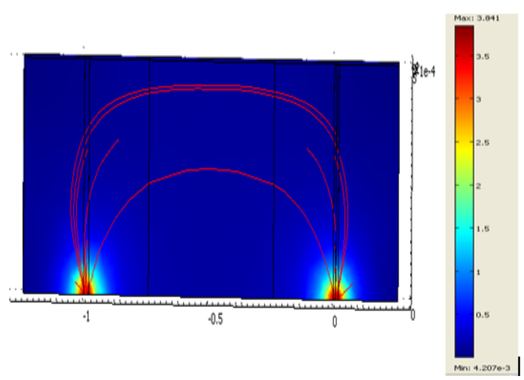

Fig 4: current flow distribution of structure2

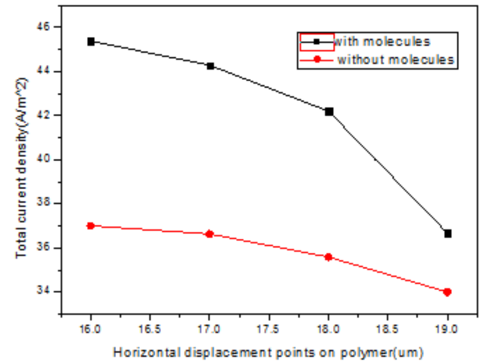

Fig 5: current density comparison with and without molecule.

3. Results and Discussion

Fig 5 shows current density comparison with molecule and without molecule. We observe that compared to Structure 1, and structure 2 current density decreases in both .Due to the presence of the square molecules on nanowire in structure 2 current density increases compare to structure 1.

4.Conclusion

In this paper, we have proposed an impedance biosensor based on polymer nanowire(made of polyaniline) for efficient electric field mediated capture of biomolecules. A 3D multiphysics modelling of polymer nanowire based biosensor was done to investigate streamline current flow distribution and electric field in every point of the water column. As a result,this device shows very high sensitivity by proper design of electrodes which enable electric field mediated capture over a small volume of the nanowire so that the percentage volume occupied by biomolecules is larger than the conventional cases. Hence the developed sensor is used to detect biomlecules very efficiently with very high sensitivity than all existing reports of electrical sensors for nanowire based impedance biosensor.

5.References

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