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Performance Metrics of Nanowire Biosensor for Disease Detection

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Abstract

In this paper, various performance metrics are analysed to check the functionality of Nanowire biosensor. Performance metrics like settling time, sensitivity of the Nanowire biosensor plays a vital role in the disease detection. They are analysed with the help of analyte concentration. The analyte may be either DNA or protein. Sensitivity is mainly responsible for the accurate results in disease detection. This type of biosensor promises the electrical detection of biomolecules with high sensitivity. Here we discuss about the biosensor functionality with respect to the device parameters, physical environment and transient capture of biomolecules. The charged biomolecules detection is taken into account leaving the effect of surface state. This is characterized as the response of the sensor in terms of settling time and sensitivity. Settling time denotes the time taken for stable signal change.With the help of analyte concentration, graph is plotted between setting time and analyte concentration to define the time taken for stable signal change. Sensitivity is obtained by the relative change in sensor characteristics with the binding of target molecules. It is responsible for the attachment of receptor molecules by conducatance modulation through analyte and buffer ion concentration.

Keywords: Analyte, Biosensor, Nanowire, Sensitivity

1. INTRODUCTION

Nowadays disease diagnosis and treatment are the widespread problems in our society. Early detection of any disease can be cured at the earliest decreasing the mortality rate. Hence the new technology is needed to detect the disease at the earliest. Biosensors are such devices that can detect any type of disease with the help of the analyte like DNA, Protein and RNA. Biosensor is the analytical device that combines the biological component with physiochemical transducer. The elements of biosensor are analyte, bio element and transducer. An ideal biosensor should have characteristics like accuracy, resolution and speed of the response. Biosensor[1] provides 2 functions. They are 1. Conversion of bioreceptors to electrical signal and 2. Identification of the target molecules.

2. NANOWIRE SENSOR

Nanowire[2] diameter is comparable with the size of most biological and chemical species. Specific receptor proteins can be linked to the Nanowire active surface for binding the charged biological and chemical molecules. This receptor modified surface changes the properties of the Nanowire surface. In addition, Nanowire has very large surface area to volume ratio. Therefore, Nanowires are used as ultra-sensitive sensors that can sense chemicals, pH, DNA, with single molecule detection sensitivity.

2.1 Structure of Nanowire sensor

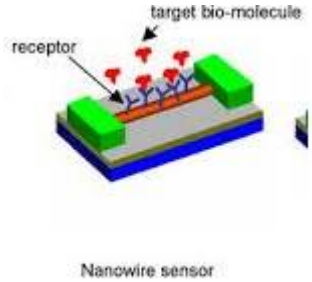

Fig.1. Structure of Cylindrical Nanowire sensor[5]

Sensors consist of source and drain regions placed above the gate. Gate consists of receptors that capture the unknown molecules diffusing the target molecules.

The unknown molecules surround the gate of target molecules. The currents in nanowire sensor are in tens of nanometer dimension accounting for large area. Thus for disease detection, sensor should have high sensitivity. Immersion of Nanowires in water, pH material swims around the electrolyte.

2.2 Modeling of Nanowire sensor

i) Transient capture of target molecules:

Time dynamics of molecular capture on sensor surface are essentially two step process: transport of target molecules and the subsequent conjugation with its receptor molecules with the target molecules.

The Diffusion-Capture [3] model is widely used to describe this transient capture of molecules. This model provides the diffusion limited molecular support and the conjugated target-receptor treatment of first-order chemical reaction.

Based on the modification of the diffusion capture equation N (t), mathematical models of Nanowire sensor can be developed.

$$N(t) = \rho_0 t\,[A/C_t + 1/k_F N_0]^{-1} \qquad (1)$$

By choosing the appropriate value of C_t [4], Nanowire sensor can be modeled.

$$C_t = [(2\pi D)/((\log(4Dt)^{1/2}+a_0)/a_0]) \qquad (2)$$

Where,
D = Diffusion Coefficient of molecules
C_t = Diffusion concentration with time Varying factor

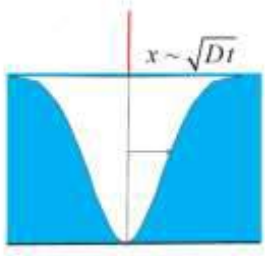

Fig 2 Diffusion changes

In order to model the sensor behavior in transient state, figure 3 shows sensor at the centre, and the analyte with unknown molecules (represented blue). This sensor captures the molecules closer to it. As the distance and analyte concentration increases, the molecules closer to the sensor are being captured (represented white). .

ii) Conductance Modulation of sensor:

The full charge of captured bio-molecules is ineffective in modulating the conductance of sensors due to the electrostatic screening of ions present in the electrolyte. On account of screening, Non-linear Poisson-Boltzmann equation[6] should be solved.

3. SIMULATION OF NANOWIRE SENSOR

The Nanowire biosensor is simulated using biosensor lab [9] tool. The performance metrics like settling time and sensitivity are analysed to review the accuracy in disease detection.The sensor structure can be defined by using

1. Device parameters of the sensor
2. Biological and surface parameters
3. Ambient conditions

3.4 Settling time

As the concentration increases, settling time has large variation for Nanowire and it is more sensitive to concentration of target ions. From the results obtained, Nanowire is found to have higher sensitivity [7] to analyte concentration and easy to construct in real-time applications. Thus diseases are detected with higher accuracy.

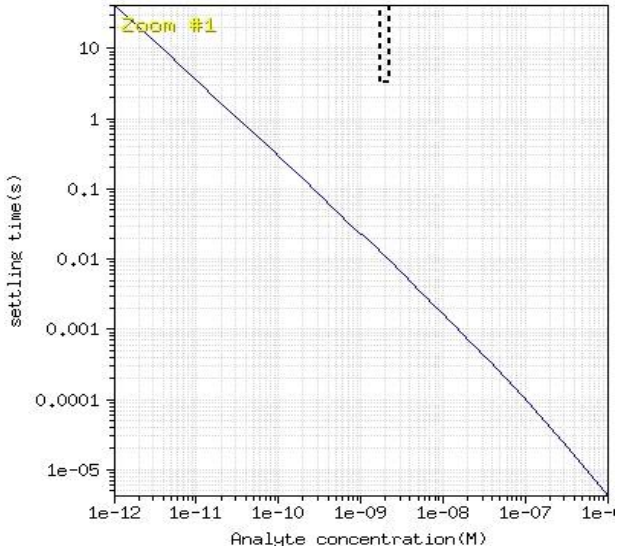

Fig 3 Settling time vs Analyte concentration

It shows the settling time required to capture a given density of target molecules on the surface.

The F`ig 4 represents the transient capture of target molecules. It is useful to study the diffusion limited capture of biomolecules capture on sensor surface for the given analyte density.

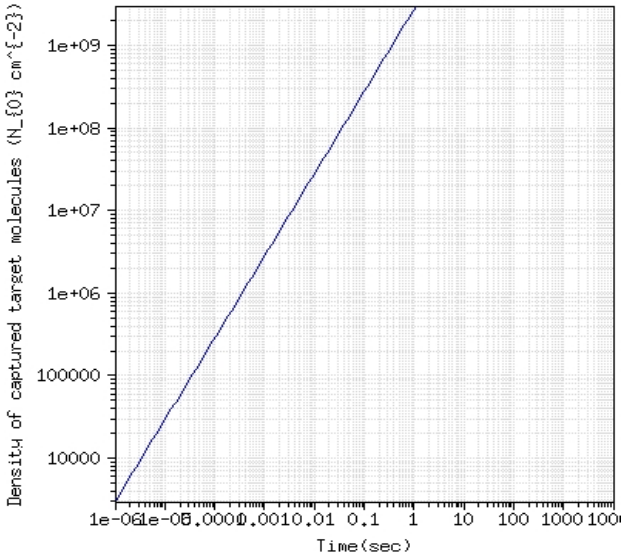

Fig 4 Transient Capture of target molecules

3.2 Sensitivity

Sensitivity corresponds to the relative change in sensor characteristics upon attachment of target molecules on sensor surface. This is determined mainly by the geometry of sensor along with the fluidic environment characteristics.Using Biosensorlab [8], make sure that the parameters are appropriately defined.

For a range of analyte concentrations, it predicts the relative change in conductance of the Nanowire sensor(at a particular ion concentration).for the given target molecule density, the variation with buffer ion concentration is also shown.

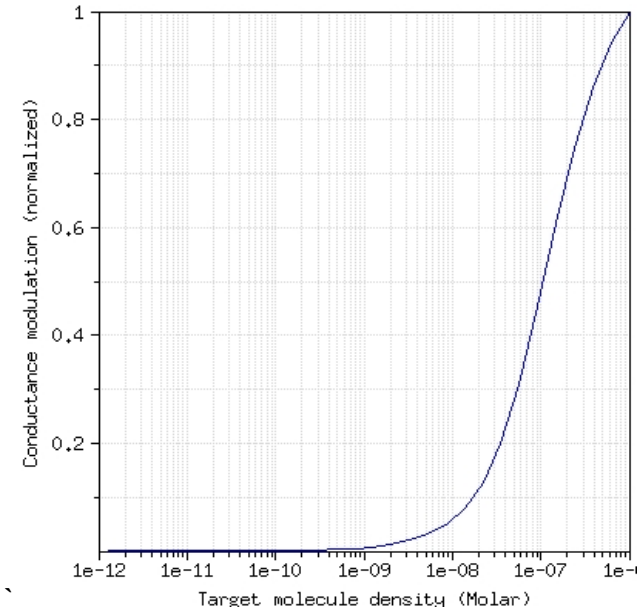

Fig 5 Conductance modulation vs. target molecule density

It provides an estimate of steady state conductance modulation of Nanowire biosensors, at a particular buffer ion concentration.

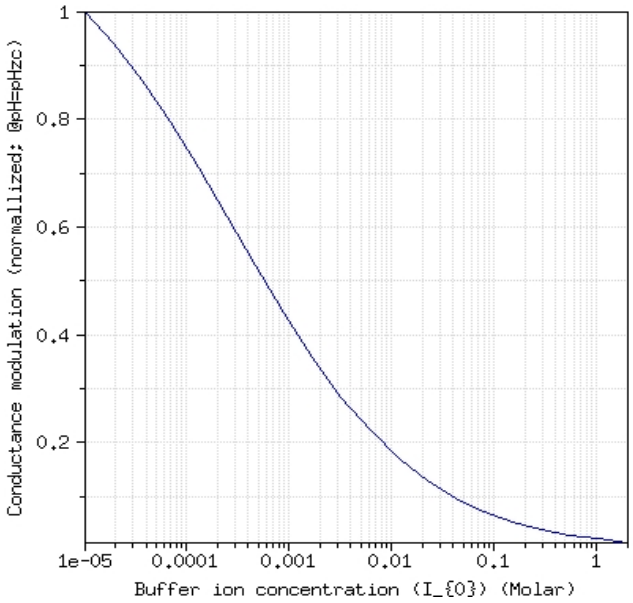

Fig 6 Conductance modulation vs. buffer ion concentration

It provides an estimate of dependence of conductance modulation with buffer ion concentration for a specific bulk receptor density.

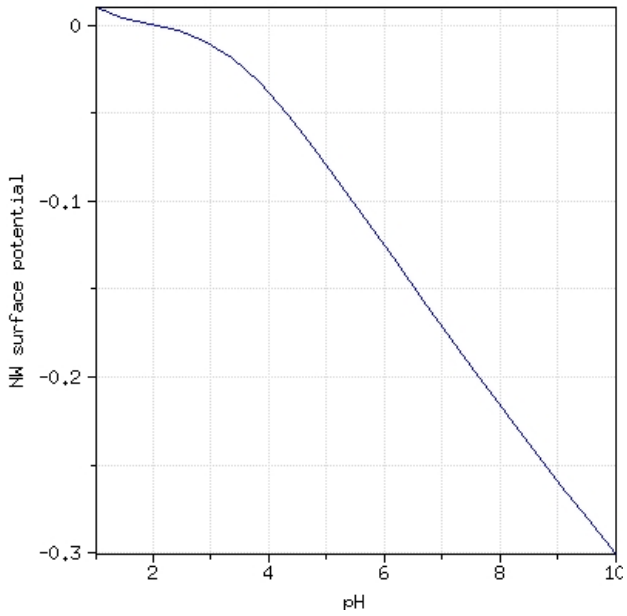

Fig 7 conductance modulation vs. pH

Variation in the H[+] concentration of the buffer results in protonation or deprotonation of hydroxyl groups.

4. SIMULATION DISCUSSION

When the radius decreases the sensor becomes sensitive to analyte and the minimum analyte concentration approaches 10^{-6} (Figure 3) However, the sensor does not depend on the length.
For a given incubation time, sensitivity predicts the surface coverage due to the receptor molecules and the Signal-Noise Ratio due to the physisorption of parasitic molecules on sensor surface.
The settling time is changed with diffusion coefficient of the target molecules (From Fig 4) and from specific time duration, density of captured target molecules remains constant.
The sensitivity is derived by the conductance modulation of the biomolecules (From Fig 5) with respect to the target molecule density.

5. CONCLUSION

Even though many biosensors are available today in the market, Nanowire biosensors are chosen for disease detection and it is presented here. Sensitivity [10] is a precious issue regarding to Bio-medical equipments. MEMS are a best alternative to implement a whole system on single chip. As bio-medical equipmentsrequire high sensitivity to get desired results the device should be very much sensible for low concentration of Biomolecules. It provides high sensitivity and hence applicable for development in real time applications.

References

[1] Friederike J. Gruhl, Bastian E. Rapp, Kerstin Länge,"Biosensors for Diagnostic Applications" in Advances in biochemical engineering/biotechnology-January 2012.
[2] P. E. Sheehan and L. W. Whitman, "Detection limits for nanoscale biosensors",‖ Nano Lett., vol. 5, no. 4, pp. 803–806,2005
[3] Bhenesha shree, R P, Shanmuga Raja P, Kavitha K " Performance analysis of biosensor for cancer detection" in journal of Emerging trends and innovative research, vol5,issue 11, Nov 2018.
[4] S.M. Ushaa, Vivek Eswaran," Modeling and simulation of nanosensors arrays for Automated disease detection and drug delivery unit" in International Journal of Advances in Engineering & Technology, Jan 2012.
[5] P. Vipeesh and N.J.R. Muniraj ," Development and Validation of Matlab Models for Nanowire Sensors" in International Conference on advances in Computing and Communication in 2011 .

[6] Pradeep Ramachandran Nair, Jonghyun Go, Graeme John Landells, Tejas Rajiv Pandit, Muhammad Alam, Xin Jin, Piyush Dak, Ankit Jain,"Biosensor lab " in nanohub.com.
[7] P Nair and alarm, "Design considerations of Silicon Nanowire biosensors " in IEEE Transactions On Electron Devices, Vo. 54, No. 12, Dec 2007.
[8] B.N shobha and N.J.R. Muniraj,"Modeling and analysis of Magntic Nnanoparticle biosensor with DNA and protein biomarkers " in International journal on information technology in 2014.
[9] Santhosh kumar D R and P V rao, "Modeling and Analysis of biosensors for evaluation of its mechanical and electrical properties" in International journal of nanotechnology and applications in vo11 no3 2017.
[10] Gulshan V. Thakare and Anup R. Nage ," A Review On High Sensitive Biosensor Using Mems " in IJAIET in Vol 1 Iss 7 Nov 2014.

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