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Fabrication and Simulation of Silicon Nanowire pH Sensor for Diabetes Mellitus Detection

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ABSTRACT

Diabetes Mellitus (DM) is a disease failed to control the balance of blood sugar level due to lack of insulin thereby it effect human health. In Malaysia, there are around 3.9 millions people aged 18 years old and above have diabetes according to National Health and Morbidity Survey 2019. Silicon Nanowire is a nanostructure which has ultra-high sensitivity and non-radioactive that has potential given good performances when applied on pH sensor and biosensor. Silicon nanowire pH sensor and biosensor is an electronic sensor that investigated to improve the sensitivity and accuracy for detecting DM. This project consists of two parts, which are fabrication of silicon nanowire pH sensor and simulation of silicon nanowire biosensor as preliminary study. In fabrication, silicon nanowire of pH sensor is fabricated by conventional lithography process, reaction ion etching (RIE) and metallization to achieved the width of 100 nm silicon nanowire. The pH6, pH7, pH10 and DI water as analytes to analysis the current-voltage (I-V) characteristics of silicon nanowire pH sensor. In second part, the silicon nanowire biosensor as preliminary study is done simulation by Silvaco ATLAS devices simulator. The silicon nanowire with 30 nm in height and 20 nm in width of biosensor is designed and simulated to analyze the performance in terms of sensitivity. I-V characteristics of silicon nanowire biosensor according to different concentration of negative interface charge is determined. The negative interface charge represent as the Retinol Binding Protein 4 (RBP4) which is used to diagnose DM. The I-V characteristic based on the change in current, resistance and conductance to determine sensitivity. Lastly, the sensitivity of silicon nanowire pH sensor obtained 23.9 pS/pH while the sensitivity of simulated silicon nanowire biosensor obtained 3.91 nS/e.cm^2. The results shown the more negative charge of concentration analyte attached on surface silicon nanowire has been accumulated more current flow from drain terminal to source terminal. It leads to the resistance becomes highest and obtained good sensitivity. In summary, the silicon nanowire pH sensor exhibited good performance and high sensitivity in detection pH level. The simulated silicon nanowire biosensor is capable of detecting biomolecular interactions charges to obtained high sensitive and accuracy result.

Keywords: Diabetes Mellitus, Silicon Nanowire, Biosensor, pH Sensor

1. INTRODUCTION

Diabetes mellitus (DM) is a disease which affect human health and even self-threatening. DM is a metabolic disease due to lack of insulin failed to control the balance of sugar level resulting in the blood sugar cannot provide energy for the body cells to build muscle and tissues [1].

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However, the characteristic of DM not only for glucose and fat, but also of the protein causing imbalances of metabolic system.

In the pre-insulin era, the glucose intake abnormal by the body cell cause high blood glucose level while altered protein metabolism was recognized as the muscle and other protein depletion be found by researcher. After protein breakdown into amino acids, some of them will convert into glucose and helped by insulin that absorb into body cells. Diabetic who person with diabetes needed daily insulin injection to replace the insulin that produced by body thereby it can be control the blood sugar. There are some symptoms occurred on diabetic such as blurry vision, thirsty, urination frequently, weight loss and the most serious symptoms are damage kidney, eyes, blood vessels. Hence, the health care professionals are used fasting plasma glucose (FPG) test, A1C test and random plasma glucose test (RPG) for special cases to diagnose diabetes diseases. Not only that, the market of medical launched new technologies devices to help diabetic manage or test blood sugar level. For example, stick-free glucose testing and continuous glucose monitoring (CGM) [2]. The pH sensor used to measure the Power of hydrogen (pH) value to determine the alkali and acidic of sample. The concentration of hydrogen ions can be reacted in chemical reaction which is important factor for chemical and biosensor applications such as blood pH measurement, water quality monitoring, deoxyribonucleic acid (DNA) sequencing and others [3-4]. The amperometric or potentiometric are the types of pH sensors based on electrochemical reaction [3]. Biosensors defined as sensing and analytical devices that comprised of biological sensing component, transducer, and signal processor. Biosensor is used to detect bacteria, glucose, protein, DNA and others by combining the biological recognition mechanism with physical transduction techniques [5]. There are many types of biosensors such as glucometers, piezoelectric biosensor, immunosensors and DNA biosensor to detect analytes in food industry, medical, and agricultural. Biosensors are more advance in nanofabrication technologies therefore it can be faster in measurements and response time as well as achieved the performance in limit of detection, the sensitivity and selectivity. Retinol Binding Protein 4 (RBP4) as the biomarker for early diabetes due to RBP4 can be found in type 2 diabetes and insulin-resistant mice. Although there are complex and difficult in measuring the level of RBP4 but the current methods are investigated to detect the protein levels by increase conductivity and attachment of antibodies to its surface [6].

In twenty-first century, the technology had been improved rapidly causes the quality of human daily life increase, especially in medical field. Recently, the detection method of the DM can help a lot of diabetes patient. They can diagnose the diabetes diseases whether is type 1 or type 2 by FPG, A1C and RPG at Health care centre and even diagnose the blood sugar level by themselves with the smart pen and CGM. Glucose monitoring are the modern diabetes treatment to control the blood sugar level of the diabetic. The devices can provide the glucose concentration and remind diabetic to intake appropriate amount of food to control the balance of blood sugar level. Although the device or test are advance and helpful but there are still have some weakness and problem in blood test or glucose monitoring. The problem of glucose monitoring is lack of universal insurance coverage and psychological concern for users. Users will start false confidence and frustrate about the wrong information and not accuracy data for hyperglycemia or hypoglycemia [6].

In addition, the blood test in laboratory normally is expensive due to high technology equipment to proper analyses blood sample of diabetic as well as the blood test make diabetic not convenient since it took long time to undergo blood test. pH as the parameter to study the cell dynamics in biological system [7]. Field-effect Transistor (FET)-based pH sensor is popular at 90's due to it has potential for ultra-high sensitivity and portability. However, it has limitation of sensitivity and difficult detect the biomolecular analytes [8]. Silicon nanowire pH sensor is developed to achieve the high sensitivity for detection level of different pH solution. As biosensors are ability to response and analyse the result in short time period and it has good reversibility and biocompatibility causes it have wide attention [9] [10].

Based on the problem statement mentioned at above, this project proposes the development, demonstration and simulation of the performance of silicon nanowire pH sensor and biosensor for DM detection. This project is expected to be the better solution to resolve the problem of sensitivity and other issues of DM monitoring. To perhaps the next generation of silicon nanowire biosensor can be developed and produce a high sensitivity of DM monitoring.

2. METHODS

2.1 Fabrication Process of Silicon Nanowire pH Sensor

The flow chart in Figure 1 shows the fabrication process and electrical characterization of silicon nanowire pH sensor.

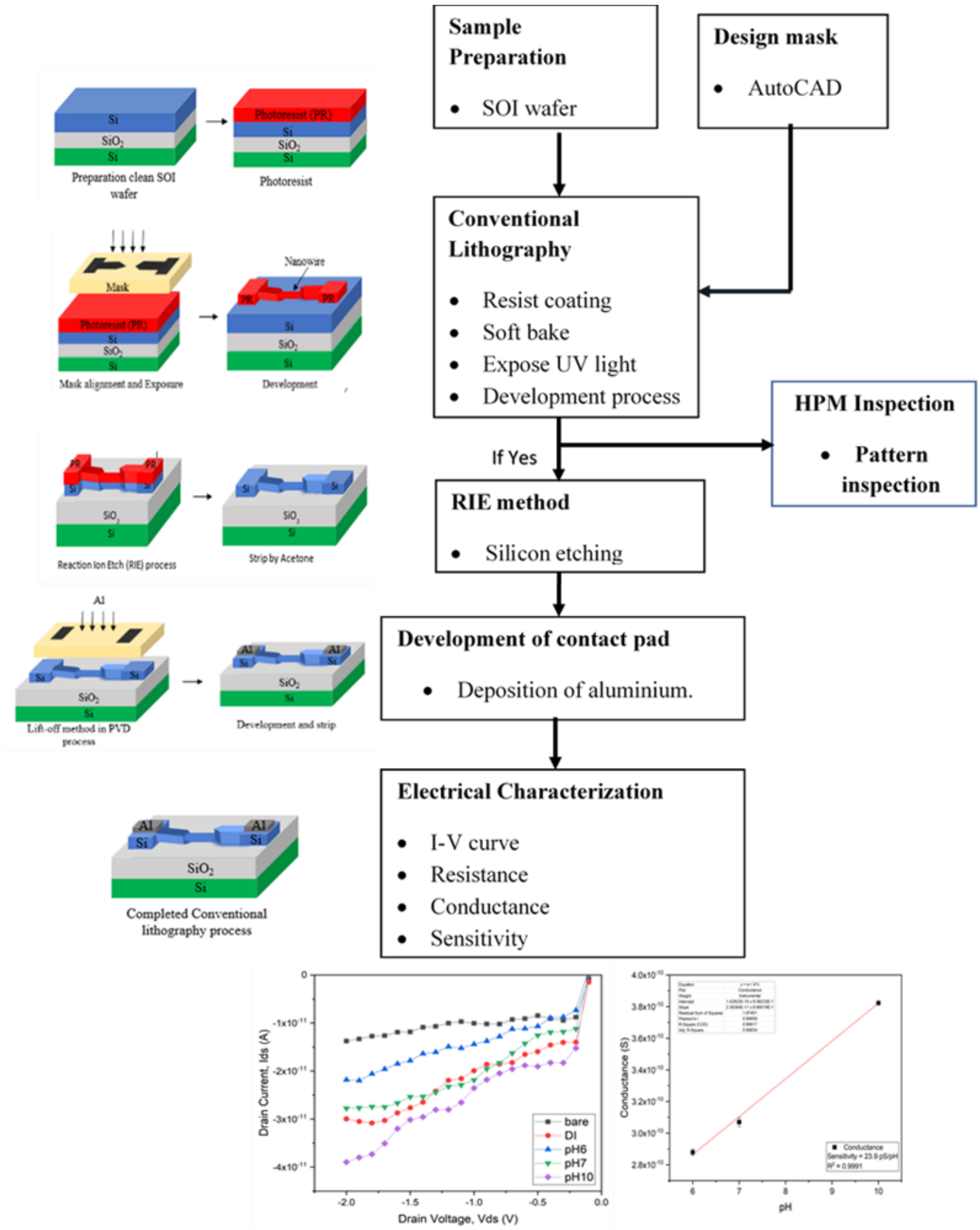

Figure 1. Fabrication process of silicon nanowire pH sensor.

The silicon-on-insulator (SOI) wafer as substrate was cleaned before undergoes conventional lithography process. The DI water, RCA-01 solution, RCA-2 solution, acetone and hydrofluoric acid (HF) are the solution used to clean wafer. RCA-1 solution used to remove surface contaminants from wafer while RCA-2 solution used to remove metallic contaminants from the wafer. The purpose of wafer cleaning process is removed organic and inorganic contaminants on surface of wafer. In conventional lithography stage, the sample was coated with a layer of photoresist and taken to soft bake process. The purpose of soft bake is driving off the solvent and solidifies the film. Then the sample was exposed by ultraviolet (UV) light to transfer mask pattern from chrome mask to the sample surface. The exposed area of photoresist is soluble due to the positive photoresist used and the soluble areas were developed by developer. After development process, High Power Microscope (HPM) was used to inspect the pattern of nanowire and the hard bake process was taken to improve the adhesion of resist to sample surface. Next, the reactive ion etching (RIE) used to etch pattern of silicon nanowire. Then, the structure of silicon nanowire was inspected by HPM. The samples undergo metallization process to develop contact pad by Aluminium to form the drain terminal and source terminal. The formation of contact pad is taken by lift-off method with physical vapor deposition (PVD). Lastly, the electrical characteristic of silicon nanowire is analysed by observes the I-V curve and determines the resistance, conductance and sensitivity.

2.2 Silvaco ATLAS simulation of silicon nanowire biosensor

In this work, Silvaco ATLAS device simulator is used to simulate the silicon nanowire biosensor according to different concentrations of interface charge density, Q_F as represented the biomolecular interaction charge during the actual experiment. The simulated electrical characteristics are analysed to evaluate the resistance, conductance and sensitivity of simulated silicon nanowire biosensor. Figure 2 shows the simulation process of silicon nanowire biosensor.

The 3D structure of simulated silicon nanowire biosensor is modelled and declared by ATLAS command language such as mesh, region, model and solution in DeckBuild area. The X.MESH, Y.MESH and Z.MESH statement are declared the structure location in microns of horizontal, vertical and rotational lines. There are 4 regions which are substrate, buried oxide (BOx), source and drain, nanowire are declared by the position parameters and assigned with the materials, dopant and concentration. The biomolecules interface charge density has fixed from 0×10^{10} cm^{-2} and -6×10^{10} cm^{-2} to -9×10^{10} cm^{-2} which is defined the charge density interfaces between semiconductors and insulators. The simulation of silicon nanowire biosensor required several models to construct the structure of simulated silicon nanowire biosensor such as Lombardi (CVT) model used for non-planar device structures, Shockley-Read-Hall (SRH) model used as carrier generation and recombination model as well as fixed carrier lifetimes, Bandgap Narrowing (BGN), Fermi-Dirac and Selberherr's model used for temperature dependent parameters.

ATLAS ability calculated electrical characteristic of simulated silicon nanowire biosensor by calculate the current flow silicon nanowire from drain to source. The drain voltage in range of -2 V with 0.1 V steps is used to simulate silicon nanowire biosensor. The drain voltage ramped up from 0 V to -2 V by increasing 2 times of previous voltage due to voltage step sizes is limited. For example, voltage ramped from 0 V to 0.0625 V and increased to 0.1250 V. The simulation is executed difficultly and obtained output inaccuracy when voltage step size is too large. After that, the simulation is done in DeckBuild area and the output file is interfaced to the TonyPlot which is visualization tools. The electrical characteristic such as current-voltage (I-V) is obtained from the TonyPlot and the resistance, conductance and sensitivity of simulated silicon nanowire biosensor are ability analysed from the I-V characteristics.

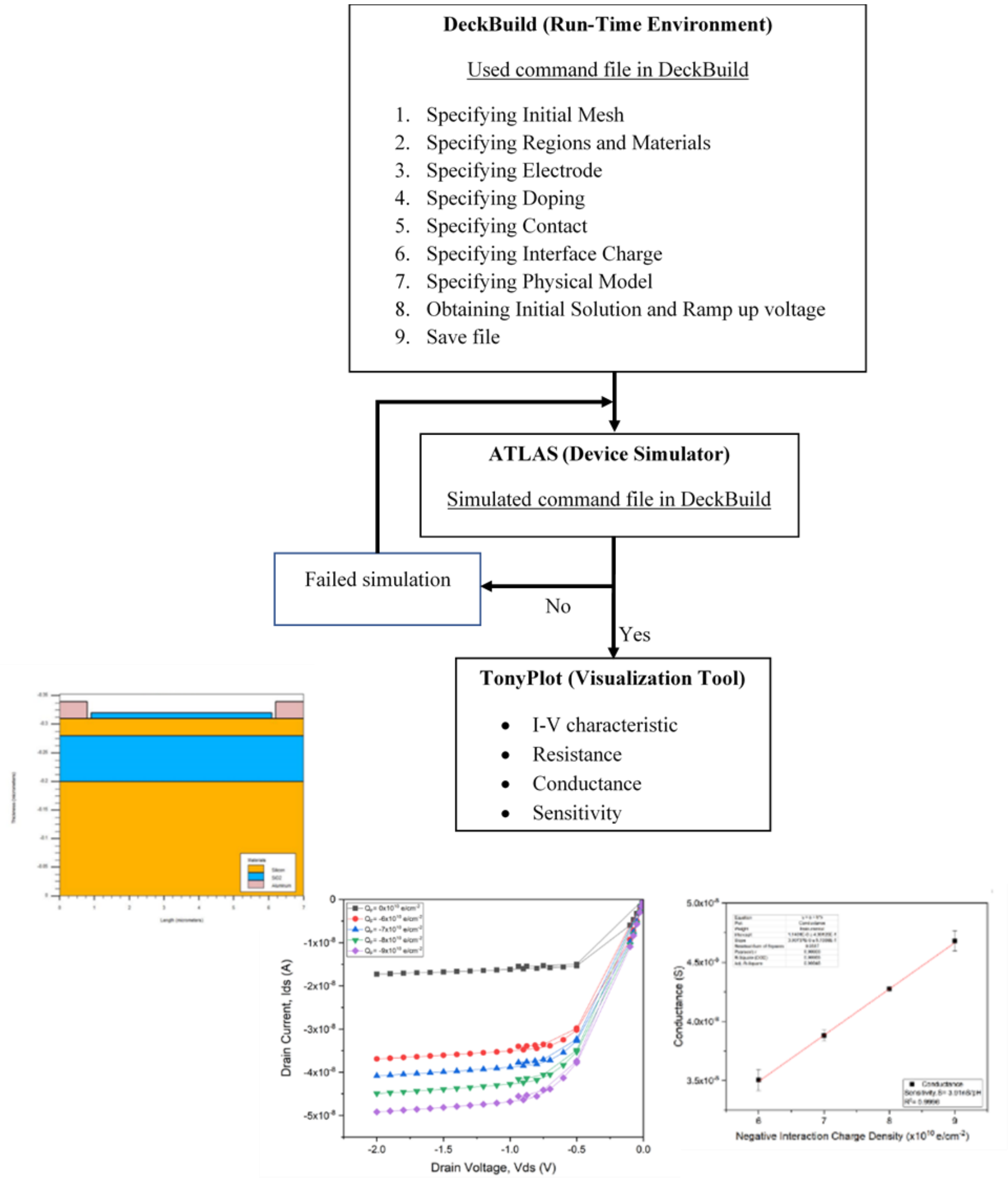

Figure 2. Simulation process of silicon nanowire biosensor.

2.3 Sensitivity Calculation and Analysis

The performance of silicon nanowire for detection analyte shows the important of sensitivity as a parameter. Sensitivity is the main key to determine the nanostructure sensor has good physical and electrical properties. Sensitivity can be determined by the change in current with different various analyte through the slope calibration curve. The straight line equation from mathematic are utilised to determine sensitivity [11]. The equation of straight line is given:

$$Y = mX + C \quad (1)$$

where m is gradient represented sensitivity. Therefore, the ratio of difference of current to difference of concentration of analyte can be calculated.

The equation for determined sensitivity of silicon nanowire pH sensor according to various pH solution:

Sensitivity = Δ Conductance (S) / Δ pH (2)

The equation for determined sensitivity of silicon nanowire biosensor according to different negative concentration interface charges density:

Sensitivity = Δ Conductance (S) / Δ Negative concentration interface charge density (3)

3. RESULTS AND DISCUSSION

In this research, the silicon nanowire pH sensor was characterized using HPM and Keithley 6487 Pico ammeter. The function of HPM is to inspect the pattern of silicon nanowire after development process and after RIE process. The electrical characteristic is tested the IV of silicon nanowire pH sensor to study the resistance, conductance and sensitivity for silicon nanowire pH sensor. Besides, the silicon nanowire biosensor was modelled using Silvaco Atlas software simulator and the structure of silicon nanowire biosensors are able viewed in 2D and 3D. The electrical characteristic was simulated the IV of silicon nanowire biosensor to study the resistance, conductance and sensitivity for biosensor with silicon nanowire in simulation method.

3.1 Sensitivity Calculation and Analysis

The pattern structure of silicon nanowire, which is array nanowire, it consists of 10 nanowires in one array. Figure 3 shows the normal developed or desired pattern structure of (a) array nanowire and (b) cross section view. The nanowire pattern structures are remained, and photoresist area is normal developed on surface of sample. While, Figure 4 shows the under-developed resist of (a) array nanowire and (b) cross section view. The time in development process is shorter, leading the pattern structure of silicon nanowire in under-developed resist condition. It can be observed by HPM which is the photoresist developed incompletely on the surface of sample. To resolve the under-developed resist, the development process had to carried out one more cycle so that develop complete the remain photoresist [12].

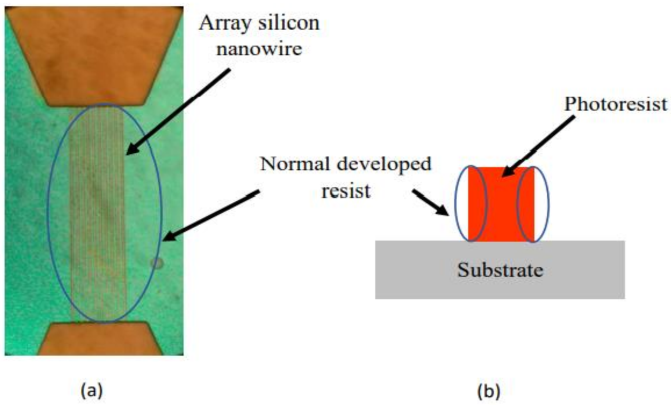

Figure 3. The normal developed or desired pattern structure of (a) array nanowire and (b) cross section view.

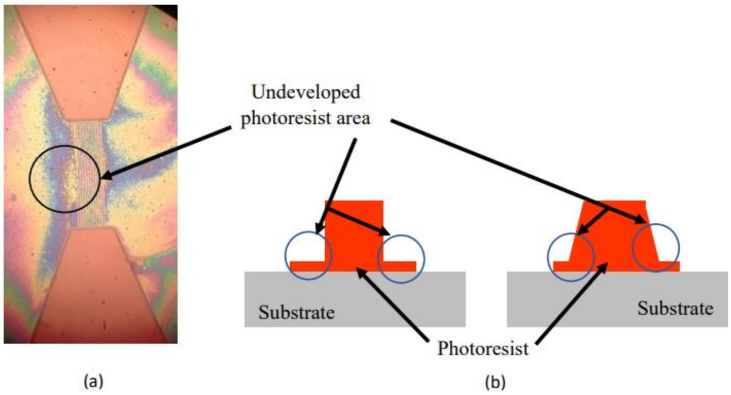

Figure 4. The under-developed resist of (a) array nanowire and (b) cross section view.

Figure 5 shows the over-developed resist of (a) array nanowire and (b) cross section view. The SOI sample immersed in developer solution in long time period and/or developed too many times without inspected by HPM frequently are considered taking longer time in development process. The pattern on surface of sample is lost or damaged due to over-time develop resulting of the photoresist are fully developed. The pattern structure must be removed with acetone is the only way when the area of over-developed resist is too large. To prevent the over-developed resist occurs, the time to immersed in developer solution must be alert and should be inspected the pattern structure of sample wafer by HPM frequently [12]. Figure 6 shows the under-developed resist between contact pads. There existed the undeveloped photoresist area near the contact pad that can be observed by HPM to prove the nanowire structure in under-developed condition. The undeveloped photoresist located between the contact pad can be caused the short circuit between contact pad and damage the structure of nanowire and contact pad during RIE process [12].

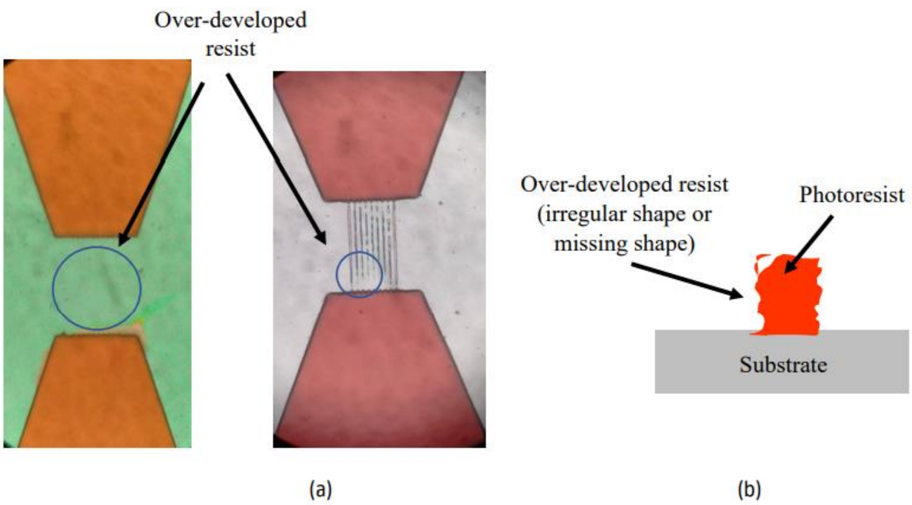

Figure 5. The over-developed resist of (a) array nanowire and (b) cross section view.

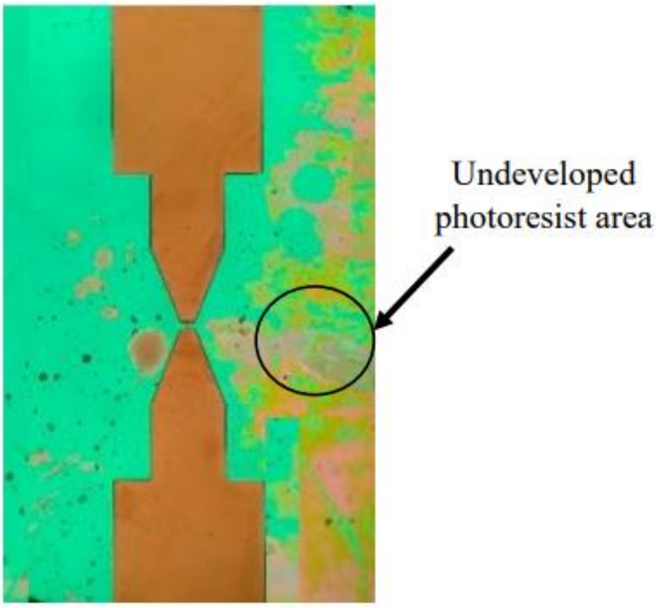

Figure 6. The over-developed resist of (a) array nanowire and (b) cross section view.

3.2 I-V characteristics for various pH solutions

The two probe-source meters used to analysis the electrical characteristics of silicon nanowire pH sensor. The silicon nanowire pH sensor with bare, DI water and various pH solutions are compared in this work. The drain voltage, V_{ds} in range from -2 V to 2 V with 0.1 V step used to test silicon nanowire pH sensor. The pH level detection I-V characteristic of silicon nanowire with positive voltage is shown in Figure 7. In V_{ds} = 2 V, the drain current, I_{ds} of bare, DI water, pH6, pH7 and pH10 are 9.46 pA, 25.82 pA, 22.28 pA, 23.67 pA and 42.41 pA, respectively. The pH10 as alkaline solution has strong current flow compared to other pH level while the bare pH sensor has weak current flow due to no reaction occurs between analyte and silicon nanowire. From the Figure 7, the drain current of pH7 almost same with the I_{ds} of DI water showing the DI water is neutral solution.

From the I-V characteristic for pH level detection, the pH7 is neutral solution as a standard level. The trend for I_{ds} of pH6 is lower than drain current of pH7 and the trend for I_{ds} of pH10 is higher than drain current of pH7. The trend for I_{ds} of DI water is upside down around the trend for I_{ds} of pH7. Last, the bare option has the lowest I_{ds} compared to others. The I_{ds}-V_{ds} characteristic of bare silicon nanowire pH sensor are similar with the characteristic of a MOS transistor [13]. The higher pH value solution, the higher hydroxide ion, H^-, the higher drain current flow through silicon nanowire. In this I-V test, pH contamination and aluminium contact pads may influence the I_{ds} result. The pH contamination such as polluted or expired pH solution and the previous pH solution incompletely clean by DI water then continued testing next pH solution. Moreover, the aluminium contact pads as the issue influences the result due to the contact pads can be diminished when it connected to the micro-needle frequently during test. The presence of oxide on the aluminium pads can be influenced the result due to obstructing the connection of contact pads and diffusion process [14].

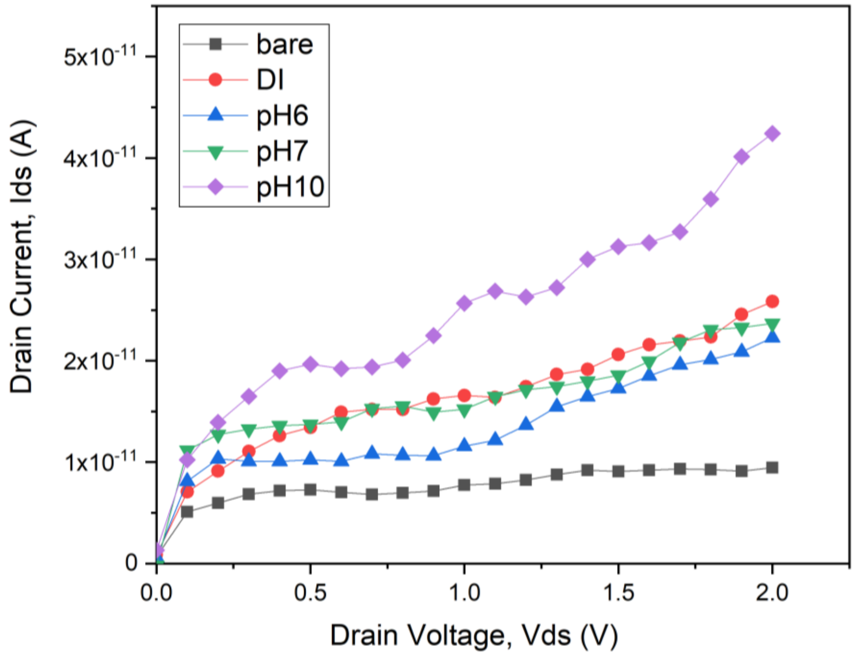

Figure 7. pH level detection of bare, DI water, pH6, pH7 and pH10 with positive voltage.

3.3 Performance Analysis with pH Level Detection

The average of resistance and conductance according to pH level detection are determined from the I-V characteristic which shown in Table 1. The conductance of silicon nanowire pH sensor is inversely proportional to the resistance of silicon nanowire pH sensor. Figure 8 shows the average resistance value of silicon nanowire pH sensor according to pH level detection. The inverse relationship of resistance versus pH level shows the higher pH level conducts the lower resistance of silicon nanowire pH sensor.

Table 1 Resistance and Conductance according to pH level detection

pH level	Average Resistance (Ohm)	Average Conductance (S)
6	3.474×10^{-9}	2.879×10^{-10}
7	3.258×10^{-9}	3.069×10^{-10}
10	2.616×10^{-9}	3.822×10^{-10}

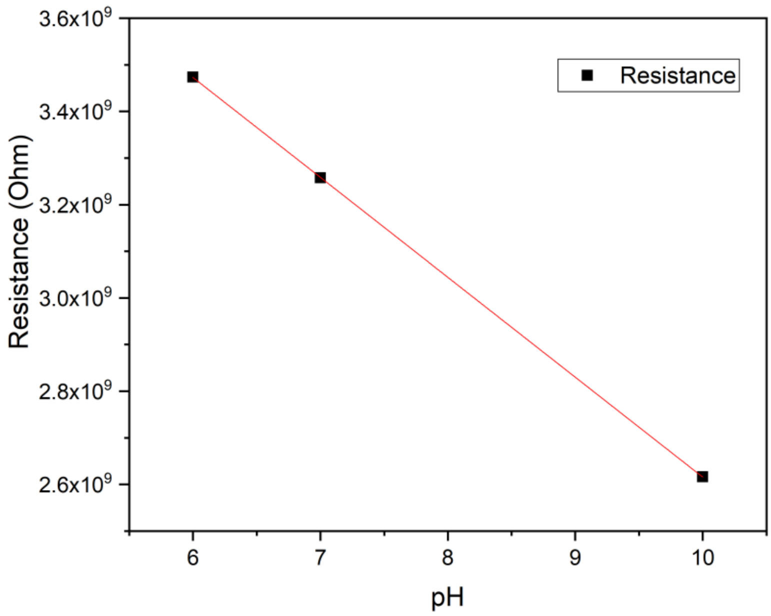

Figure 8. Average resistance value of silicon nanowire pH sensor according to pH level detection.

The average conductance value of silicon nanowire pH sensor according to pH level detection is shown in Figure 9. There is linear relationship of conductance versus pH level shows the higher pH level conducts the higher conductance of silicon nanowire pH sensor. In theoretical, the more concentration of analyte attached on the surface of silicon nanowire is accumulated the charge carrier. Therefore, the higher current flow through silicon nanowire, the higher conductance change inside the silicon nanowire [14]. Sensitivity is the slope calibration curve, which is taken from the average conductance of silicon nanowire pH sensor according to pH level detection. The conductance increased linearly with the pH level of pH6, pH7 and pH10 with the sensitivity of 23.9 pS/pH as shown in Figure 9.

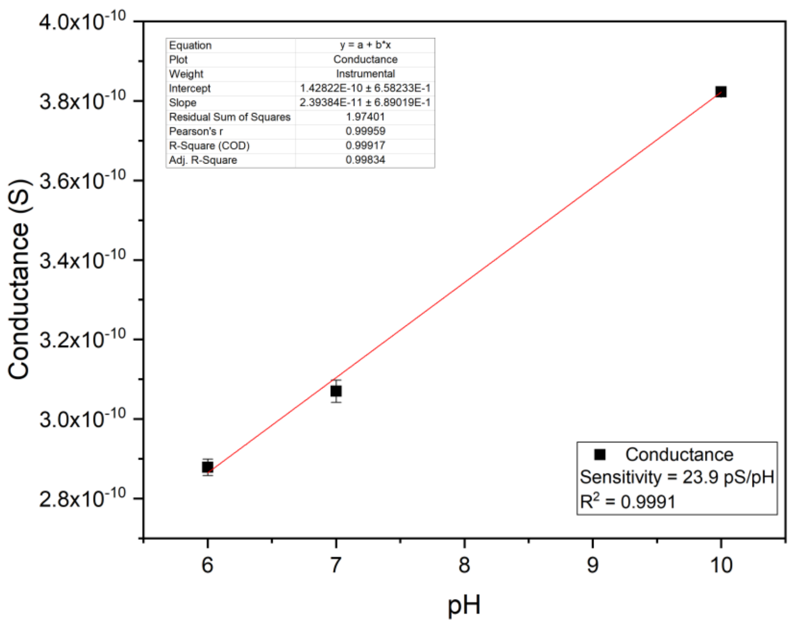

Figure 9. Average conductance value of silicon nanowire pH sensor according to pH level detection.

3.4 Performance Analysis with pH Level Detection

The silicon nanowire biosensor with the detection of different concentration interaction charge density is simulated using Silvaco Atlas. The structure of simulated silicon nanowire biosensor is viewed through TonyPlot and TonyPlot 3D. The simulated models of silicon nanowire biosensor in 3D structure are shown in Figure 10. The 2D structure as cross-sectional view along the (a) x-axis, (b) z-axis and (c) y-axis are shown in Figure 11. The parameters of simulated model of silicon nanowire biosensor are shown in Table 2. The simulated model of silicon nanowire biosensor has 4 regions, which are substrate, buried oxide layer (BOX), silicon nanowire as well as source and drain. The silicon substrate with p-type dopant low concentration of $1{\times}10^{15}$ cm^{-3} is located at the bottom. The parameter of silicon substrate with length, width and thickness of silicon (Si) substrate is 7 µm × 0.5 µm × 0.2 µm. The silicon oxide (SiO_2) buried oxide layer located on the substrate with the parameter of 7 µm × 0.5 µm × 0.08 µm. A layer of silicon as silicon nanowire with the parameter of 5.4 µm × 0.02 µm × 0.03 µm was doped with p-type concentration of 2×10^{17} cm^{-3} located on the buried oxide layer. The source and drain are made of silicon doped with concentration of $8{\times}10^{19}$ cm^{-3}. The parameter of source and drain is 0.8 µm × 0.5 µm × 0.03 µm which connected with the end of the silicon nanowire. The electrode as metal pads were made of aluminium (Al) with the parameter of 0.8 µm × 0.5 µm × 0.03 µm. There is a layer SiO_2 of 0.01 µm thickness covered around the silicon nanowire as the biomolecular interaction area.

Table 2 Parameters of simulated model of silicon nanowire biosensor

Region	Material	Dopant Concentration (cm^{-3})	Length (µm)	Width (µm)	Thickness (µm)
Substrate	Silicon	p-type, $1{\times}10^{15}$	7.00	0.50	0.20
Buried Oxide (BOx)	SiO_2	-	7.00	0.50	0.08
Silicon Nanowire (SiNW)	Silicon	p-type, $2{\times}10^{17}$	5.40	0.02	0.03
Source and Drain	Silicon	p-type, $8{\times}10^{19}$	0.80	0.50	0.03
Electrode	Aluminium	-	0.80	0.50	0.03

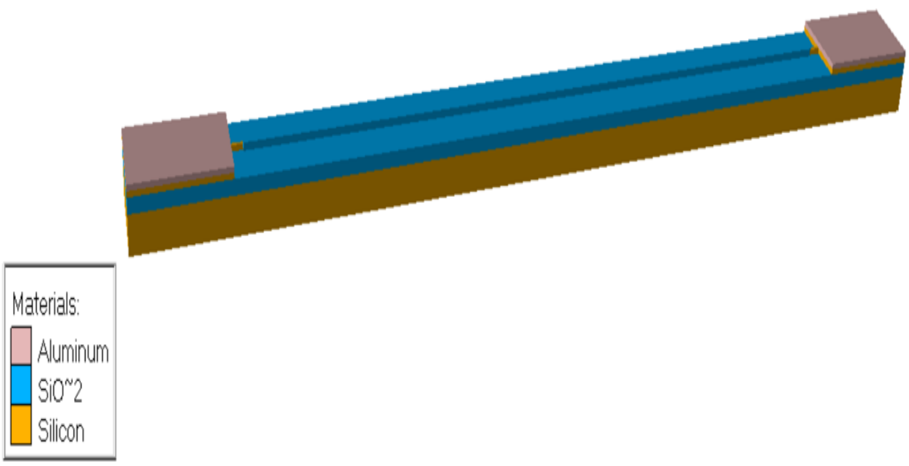

Figure 10. Simulated model of silicon nanowire biosensor in 3D view.

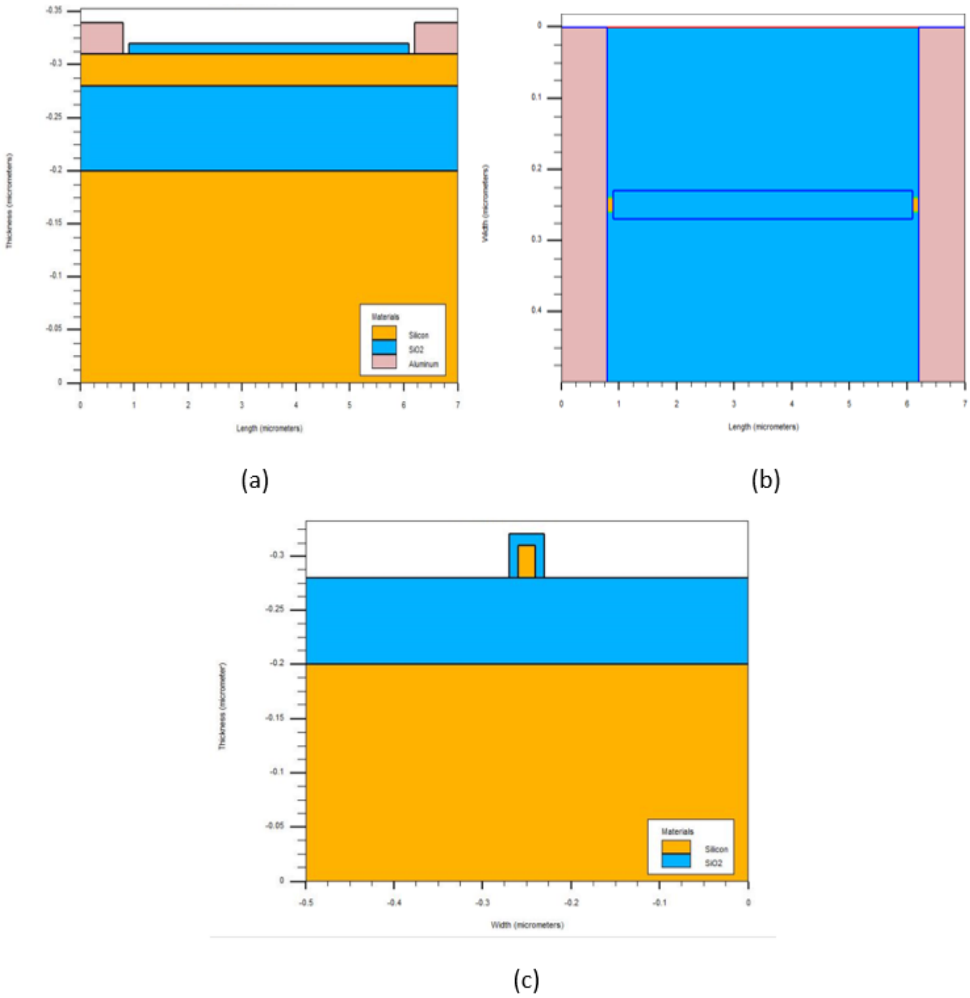

Figure 11. Simulated model of silicon nanowire biosensor in 2D views with cross-sectional along (a) x-axis, (b) z-axis and (c) y-axis.

The V_{ds} in range from -2 V to 0 V with 0.1 V step are used in the simulation to determine the I-V characteristic of simulated silicon nanowire biosensor. The biomolecular Q_F as negative charge of target biomolecules are applied on the surface of silicon nanowire is 0×10^{10} cm^{-2}, -6×10^{10} cm^{-2}, -7×10^{10} cm^{-2}, -8×10^{10} cm^{-2}, -9×10^{10} cm^{-2}. It can represent as the biomolecules analyte such as RBP4. Figure 12 shows the I-V characteristic of simulated silicon nanowire biosensor according to different concentration of interface charge density. As the channel of silicon nanowire is doped with the p-type dopant, the channel is majority of hole charge carrier. The more negative Q_F applied on the surface of silicon nanowire, the more current flow through silicon nanowire from drain to source. Therefore, the Q_F of -9×10^{10} cm^{-2} has strong current flow as it has lowest negative I_{ds} while the Q_F of -0×10^{10} cm^{-2} has weak current flow as it has highest negative I_{ds}. In theoretical, the Q_F of -0×10^{10} cm^{-2} as bare silicon nanowire biosensor which has same I-V characteristic with the MOS transistor [15]. In V_{ds} = -2 V, the I_{ds} of Q_F with concentration of 0×10^{10} cm^{-2}, -6×10^{10} cm^{-2}, -7×10^{10} cm^{-2}, -8×10^{10} cm^{-2}, -9×10^{10} cm^{-2} are -17.28 nA, -36.91 nA, -38.81 nA, -40.83 nA and -44.92 nA, respectively.

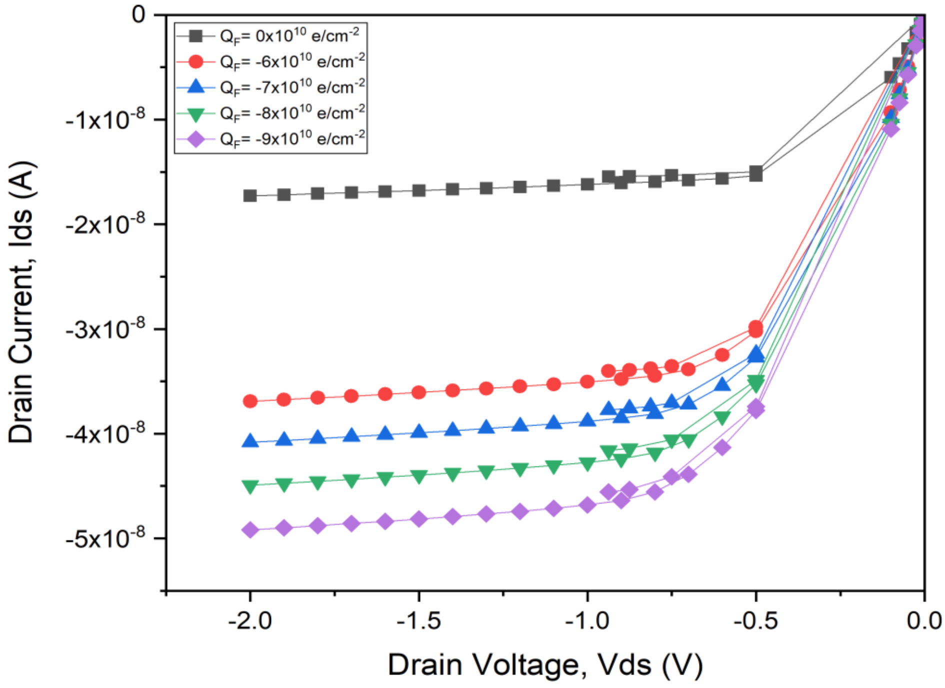

Figure 12. The I-V characteristic of simulated silicon nanowire biosensor according to different concentration of interface charge density, Q_F.

3.5 Performance Analysis with pH Level Detection

The resistance, conductance and sensitivity are study from the I-V characteristic of simulated silicon nanowire biosensor. From the Table 3, it shows the resistance and conductance with different concentration of negative Q_F at -1 V of V_{ds}. The resistance of simulated silicon nanowire biosensor according with different concentration of Q_F is shown in Figure 13. The inverse relationship of resistance versus concentration of negative Q_F shows the higher concentration of negative Q_F conducts the lower resistance of silicon nanowire biosensor.

Table 3 Resistance and conductance with different concentration of negative interface charge density, Q_F at -1V of drain voltage, V_{ds}

Negative Interface Charge Density (x10^{10} e/cm^{-2})	Drain Current, I_{ds} (A)	Drain Voltage, V_{ds} (V)	Resistance (Ohm)	Conductance (S)
6	-3.505×10^{-8}	-1.000	2.853×10^{-7}	3.505×10^{-8}
7	-3.881×10^{-8}	-1.000	2.577×10^{-7}	3.881×10^{-8}
8	-4.274×10^{-8}	-1.000	$2.339\times10^{-}$	4.274×10^{-8}
9	-4.680×10^{-8}	-1.000	2.137×10^{-7}	4.680×10^{-8}

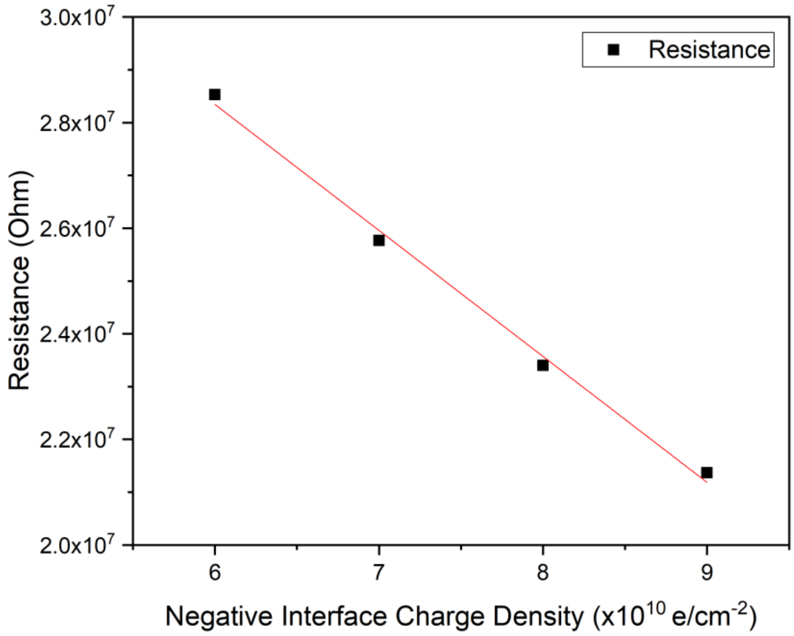

Figure 13. The resistance of simulated silicon nanowire biosensor according with different concentration of interface charge density, Q_F.

The conductance of silicon nanowire biosensor according with different concentration of Q_F is shown in Figure 14. The linear line shows the more negative concentration of Q_F, the higher conductance value of silicon nanowire biosensor. The more negative charge attached the surface of silicon nanowire is accumulate the charge carrier resulting in change of conductance and lead the increasing of current flow. The sensitivity can be determined from the slope of linear regression line for conductance versus different concentration of Q_F. From the Figure 14, it can be observed the conductance increased linearly with concentration of negative Q_F from -6×10^{10} cm^{-2} to -9×10^{10} cm^{-2} with the sensitivity of 3.91 nS/e.cm^2.

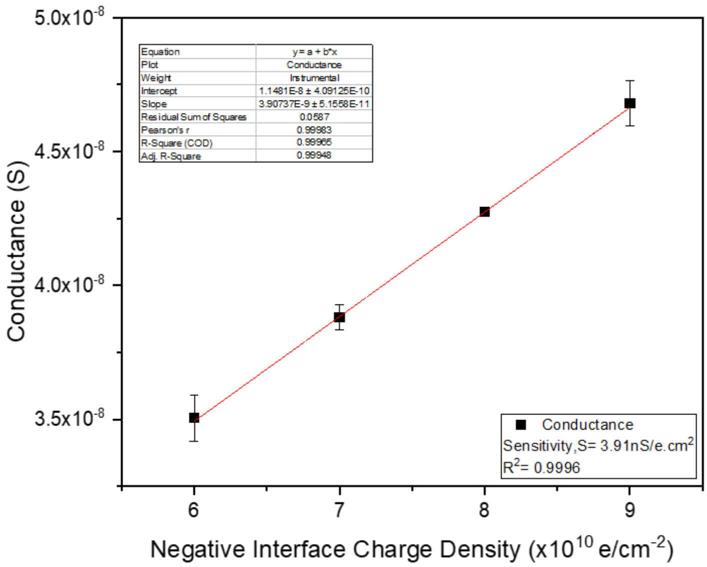

Figure 14. The conductance of silicon nanowire biosensor according with different concentration of interface charge density, Q_F.

4. CONCLUSION

This research is presented the fabrication and simulation of Silicon Nanowire pH Sensor as preliminary study for DM detection. In the fabrication process, the 100 nm silicon nanowire is fabricated on the SOI wafer using top-down conventional lithography technology, anisotropic etching and metallization process. The structure of silicon nanowire is inspected by HPM after development process and the RIE process. The electrical performance of fabricated silicon nanowire as a pH sensor is investigated. The DI water, pH6, pH7 and pH10 as the analytes are used for the detection of the pH sensor. The sensitivity of silicon nanowire pH sensor is 23.9 pS/pH. The trend of I-V characteristics for silicon nanowire pH sensor shows it function well according with pH level detection. As the more negative concentration of the pH solution attached the surface of silicon nanowire, the more current are accumulated to flow through the silicon nanowire resulting of the highest sensitivity of the silicon nanowire pH sensor. In the simulation, the silicon nanowire with 5.40 μm in length, 20 nm in width and 30 nm in height and doped p-type with concentration of 2×10^{17} is simulated by Silvaco ATLAS device simulator. The simulated silicon nanowire biosensor is designed by 5 regions which are silicon substrate, SiO_2 buried oxide layer, source and drain, silicon nanowire and the top layer is electrode. The dimension of whole silicon nanowire biosensor is 7 μm in length, 0.50 μm in width and 0.34 μm in height. The structure simulated silicon nanowire biosensor of 3D view and 2D view along with x-axis, y-axis and z-axis are viewed in TonyPlot. The sensitivity of silicon nanowire biosensor is 3.91 nS/e.cm^2. The concentration of biomolecular interface charges is represented RBP4 in simulation. The trend of I-V characteristics for silicon nanowire biosensor shows it functions well according with different concentration of interface charges. As the more negative concentration of interface charge density attached the surface of silicon nanowire, the more current are accumulated to flow through the silicon nanowire resulting of the highest sensitivity of the silicon nanowire biosensor.

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