Semiconductor Nanowires Biosensors for Highly Selective and Multiplexed Detection of Biomolecules

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***Abstract*—The surface modification of Nano-structure has allowed specific and selective detection to be made on nano structures devices. Current study, a nanowire was surface engineered with the potential of silicon nanowires biosensors (SiO2) which enhance the biosensor activity especially identifying single-stranded bio-molecular such as E.coli DNA. The device's capabilities were studied based on it response n electrochemical activities of the terminal group of the surface modification agent. NH_2 -terminated APTES) to provide rigid chemistry between the DNA organic and Si inorganic link of a biomolecule single_stranded ssDNA probe and SiO_2_APTES link nanostructure. Thus, the study demonstrates that silicon nanowire sensing capability to discriminate molecular probe to that of molecule target of supra-genome 21 mers salmonella due to sensitive surface chemistries that made distinguishing the two species. The device captured the molecule precisely; the approach took the advantages of strong binding chemistry created between APTES and biomolecule. The results indicated how modifications of the nanowires provide sensing capability with strong surface chemistries that can lead to specific and selective target detection.**

***Index Terms*—APTES; DNA Biosensor; E-coli; Multiplexed Detection.**

I. INTRODUCTION

The characterization and optimization of fabricated microfluidics-based on flow profile are generally attracting serious attention, and the morphological have used a few test systems for topography and leakage test [1]. The process equally allowed to understand the effect of sensitivity and selectivity of the sensor after the integration of nanostructures and nanomaterials in one single device. This will allow comparing the performance of Lab-On-Chip through characterization and its readability of measurements [2]. Polysilicon nanowire biosensor is a promising tool in biosensor design because of their ultra-sensitivity, selectivity, and label-free and real-time detection capabilities [3-6]. The use of biosensor as screenings application options for high selectivity and sensitivity, as well as high throughput detection. By applying a nanowire biosensor as a Lab-On-Chip module, the cost of conventional methods can be reduced as well as opting for a faster detection at a very low amount of concentration [6]. The use of nanobiosensor allows for rapid identification with the possibility of within 1 hour for confirmation, in addition to multiple detections of diseases. The use of Nano biosensor has serious bring to the hope the way medical practitioners dream of making the lab to the patient bed.

Many techniques only imagined a few years ago are making remarkable progress towards becoming realities [7]. Recognizing the importance of nanotechnology, nano biochip and nano-biomaterials applicable to human health and medicinal benefits [8]. A device for detecting cancer and dengue cells at the earliest stage is being developed using various structures, among structure being produced which are nanowire, nanogap, nanoparticles, nano-thin film which have a variety of geometries and configuration [9]. The device provides powerful general platforms for the ultrasensitive direct electrical detection of biological and chemical species [10]. When that particular target is found, the sensor designed bind to complementary targets in the cells and produce electrical signal [11]. Various devices such as nanofibers, magnetic nanoparticles, gold nanoparticles and carbon nanotubes are being used in a sensor that detects proteins and DNA for usage of a specific disease. Various tests have proved these sensors accurate in detecting target molecules and results shown in less than half an hour [12]. Nowadays, these applications in medicine are undergoing rapid changes. Nanowires are defined as metallic or semiconducting particles having a high aspect ratio, with cross-sectional diameters «1 µm, and lengths as long as tens of microns. Nanoparticles and nanorods <1 µm in length are also interesting for biomolecular detection [13]. They are popular and attractive since their size is small, have high surface-to-volume ratios or electronic, optical and magnetic properties. Semiconductive nanowire-based biosensors are capable of label-free detection of biological molecules [14].

Nano-FET (field-effect transistor) biosensors exhibiting high sensitivities toward proteins, nucleic acids, and viruses have been demonstrated. Nanotechnology has often been used to amplify or transduce certain biological reactions into a proper signal. It is to estimate the concentration of a given analyte [15]. Therefore, due to improvements in

nanotechnology, the development of biosensors has been primarily advancing rapidly. Multiplexing is achieved by preparing optically distinguishable nanowires [16]. For example, by altering the sequence of different metal segments in the nanowires or by changing the diameter along metallic wires [17].

The device has generally shown the ability to be used for both detection, and molecule germicide with optimized characteristics and the device can be integrated fabricated microfluidics with smooth flow based on passive mechanism [17]. The integration of the device with microfluidic brings several advantages such as allowing to understand the effect of sensitivity and selectivity of the sensor after the integration of nanostructures and nanomaterials in one single device. Moreover, this will equally allow comparing the performance of the chip through characterization and its readability of measurements [18]. Generally, the silicon nanowire biosensor is a great tool because of their ultra-sensitivity, selectivity, and label-free and real-time detection capabilities. It also offers several applications especially in the biosensor as screenings application options for high selectivity and sensitivity, as well as high throughput detection. Adapting the nanowire as a biosensor, the cost of medical diagnosis can be reduced as well as opting for a faster detection at a very low amount of concentration [19]. The device reduces the time of detection which allows for rapid identification within the possibility of within 1 hour for confirmation as mentioned above and can use for multiple detections [20]. Generally, the biosensors can be classified into various types according to signal transduction or biorecognition events [21].

On the basis of transducing elements, biosensors can be categorized as piezoelectric, optical or electrochemical sensors. In the arena of medical diagnostics and environmental applications, nanotechnology-based biosensors could also be used. There are 3 parts of DNA biosensors [22]. The first one is a solid surface of a transducer. Then, a single strand of DNA immobilized onto the surface which is the probe [23]. The last one is the sequence-specific single-stranded DNA which is the target. Furthermore, the core of a DNA is based on the detection of the single-stranded DNA. Escherichia Coli or known as E. coli lives in the digestive tracts of humans and animals. Mostly harmless, some pathogenic which can cause illness such as diarrhea. Escherichia coli (E. coli) O157:H7 was first discovered in 1982. It was known as the most virulent food-borne pathogenic bacteria in 1996 [24].

The sensor can be employed to detect E coli based on the DNA, the possibility of accurate detection is based assisted the microfluidic channel that has the capability to derive fluid through capillary phenomenon which could be used to drive molecular samples to reaction domain. However, the characterization of obtained real mechanism and optimization to valid the sensor data is challenging, especially fabrication of stable biosensor posed serious challenges [26, 27].

For practical applications, improved production techniques for multiplexed sensors containing a diverse range of biomolecules are needed. To characterize and optimize fabricated microfluidics morphologically using a few test system for topography and leakage test. Study the effect of sensitivity and selectivity of the sensor after the integration of nanostructures and nanomaterials in one single device. Compare the performance of Lab-On-Chip through characterization and its readability of measurements [28].

Polysilicon nanowire biosensor will be applied as a promising tool in biosensor design because of their ultra-sensitivity, selectivity, and label-free and real-time detection capabilities. The use of biosensor as screenings application options for high selectivity and sensitivity, as well as high throughput detection [29].

By applying a nanowire biosensor as a Lab-On-Chip module, the cost of conventional methods can be reduced as well as opting for a faster detection at a very low amount of concentration [30]. The use of nanobiosensor allows for rapid identification with the possibility of within 1 hour for confirmation, in addition to multiple detections of diseases [29]. The use of nanobiosensor allows for rapid identification at reduced risk for infection of laboratory personnel. The speciation part of the laboratory work can then be performed with killed bacteria or the template DNA thereof. It took days and sometimes weeks for the detection of pathogens causing a certain disease. This device will offer early detection of diseases. For both diseases, early detection is particularly important to eliminate differential diagnoses and to start the appropriate treatment as soon as possible [30].

II. METHODS

The process is as follows; the 0.5 microlid (uL) of GNP 15nm was added onto the bare device and waited for 30 minutes to let the solution evaporate. The GNP 15nm is a pinkish liquid. This process needs to be done at Laminar Flow Cabinet. The cabinet is an enclosed bench designed to prevent contamination of semiconductor wafers, biological samples or any particle sensitive devices. It is also can be used for UV curing. After 30 minutes, measure the IV characteristic. Bare + GNP 15nm + APTES. After that, add 0.5 microlid (uL) of APTES onto the device and wait for another 30 minutes. As shown in Figure 1

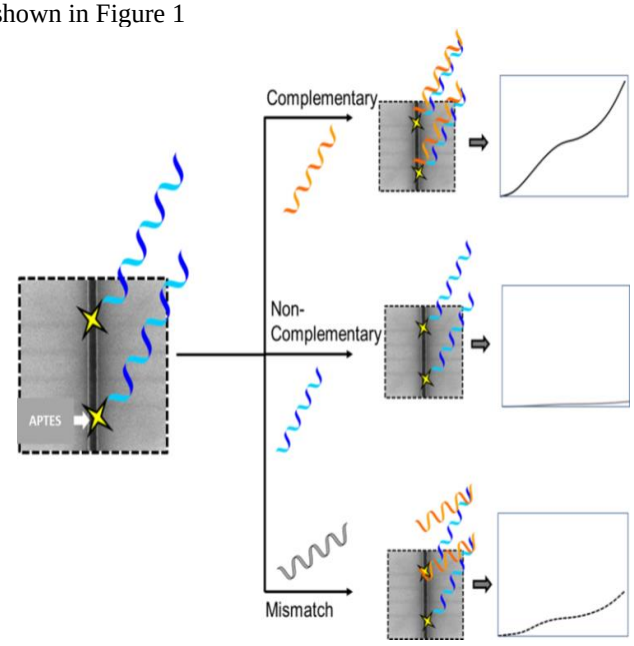

Figure 1: Scheme for the surface modification, immobilization, and hybridization

APTES is to provide contact between the organic & inorganic surfaces of a single-stranded DNA probe & SiO2 nanoparticles while maintaining the sensing system's physical characteristics. Measure the IV characteristic after 30 minutes. Bare + GNP 15nm + APTES + Probe. Add 0.5 microlid (uL) of the probe onto the device and wait for 30 minutes. The probe is a single strand of DNA immobilized

onto the surface. Measure the IV characteristic after 30 minutes. Bare + GNP 15nm + APTES + Probe + Target. Lastly, add 0.5 microlid (uL) of the target which is the DNA of E. coli and wait for 30 minutes, the typical APTES peak is shown in Figure 2. The device selectivity was further analyzed by hybridizing 3 different targets independently. The other targets are a non-complement target, mismatch DNA, and DI water.

III. Results And Discussions

To examine response of the devices barred IDE (ide3-1) configuration was prepared, the black traced curved with ~ 200pA is recorded prior to surface modification, the modification could allow and enhance the IDE electrical properties by allowing the polarized charged molecules attached to the sensor surface, the modified IDE device was tested in solutions with putting gold Nano particles, the red curve in Figure 3 indicated the range of the electrical response of the IDE (ide3-1/gnp) , it exhibited increases in conductance, in turn, allow more electrons to jump the ide barriers electrode , this is repressed in red curves with ~1nA. The highest curve with blue indicating highest current values recorded, this wonderful behavior was seen with APTEs dropped on gnp treated IDE, minimum curve In black indicating the minimum current recorded according to with the barred device. To observe the behavior of charged molecules, present in the sensor surface, from the series of the modification step, the device electrical profile continues to alter as at any time when the device is subjected surface treatment.

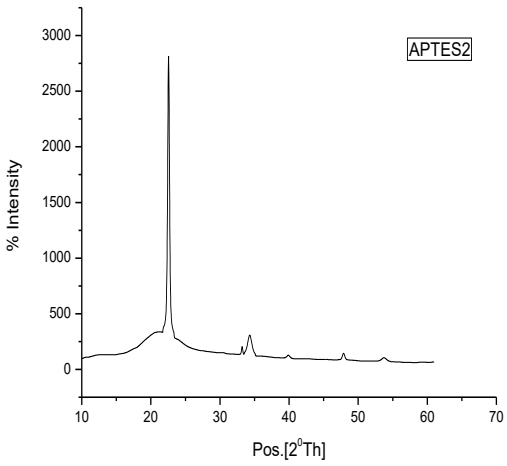

Figure 2: XRD image of APTES

This behavior is resultant from the presence of two distinct polarized charges groups that are promoted to come closer with each other as results of minimizing the distance of each electrode. Thus the band energy gap is reduced thereby higher electrons exchanges occurred, the exchange is further becoming higher with modification elements are in aqueous form, this claim can be observed from figure where the aptes application, aptes is normally in aqueous and upon drop in, it was subject to test before fully dried and this has allowed a higher current to be recorded with aptes, the reason is simple to be at the aqueous the charge accumulation increase becomes eligible to jump from one electrode to another resulting in higher negative charge on the idle surface. The increase in ion charge enhances the charge accumulation on each electrode and this behavior consistent with many results of a similar experiment performed which is equally shown in [30], which can be further explained by DLVO theory. A high concentration of ions in the medium restricts the ion transfer and leads to more charge accumulation since electrostatic interactions are stronger than the attractive van der Waals forces.

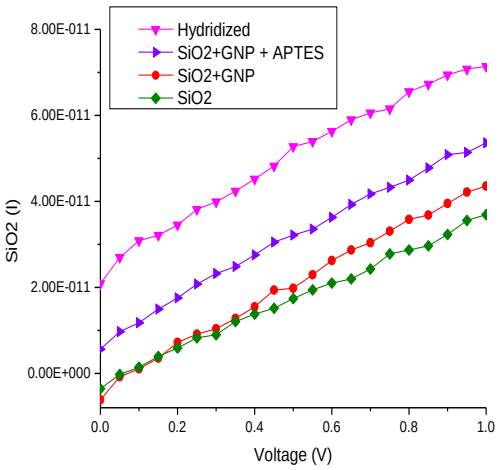

Figure 3: Device response to surface modification, probe immobilization and hybridization

In creating a DNA sensor, it is especially imperative to self-assemble a monolayer to present a contact layer with oligomer DNA. Under atmospheric conditions, the SiO2 metal oxide was ended by the hydroxyl gather (OH), which permits the connection of particles through a condensation reaction. Along these lines, APTES was utilized for a salinization procedure. The hydroxyl group gatherings were hydrolysed and bonds (SiOSi) with APTES. The current for SiO2 marginally changes when APTES was basically dropped on the created sensor. After immobilization prepare, the present esteem unexpectedly increments as per the expansion in surface charge thickness from the contrarily charged DNA spine Figure 3.

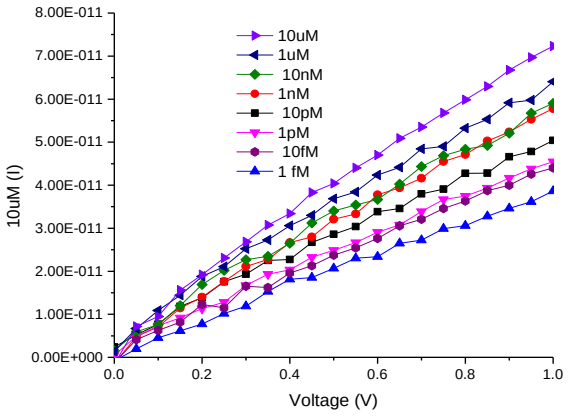

Figure 4: Device response to various concentrations

DNA discovery was further performed by checking the concentration-dependent resistance change upon hybridization to complementary target DNA. The relative

change in resistance was extricated from the I V. An undeniable resistance change was acquired when 10 μM concentration of corresponding target DNA was hybridized to the immobilized DNA probe. Then, the resistance change diminished when 10 nM, 10 pM and 10 fM concentration of complementary target DNA were utilized as shown in Figure 4. From these outcomes, it can be presumed that the higher concentration of the target DNA was hybridized, the more negative charges included the silicon nanowires surface which prompts to a collection of more positive charges carrier, bringing about the expanding of the relative change in resistance as watched. Maximizing the immobilization process of the DNA sensor's surface

IV. CONCLUSION

The study demonstrates that silicon nanowire sensing capability to discriminate molecular probe to that of molecule target of supra-genome 21 mers salmonella due to sensitive surface chemistries that made distinguishing the two species. The device captured the molecule precisely; the approach took the advantages of strong binding chemistry created between APTES and biomolecule. The results indicated how modifications of the nanowires provide sensing capability with strong surface chemistries that can lead to specific and selective target detection.

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REFERENCES

[1] Guo-Jun Zhang and Yong Ning (2012). Silicon nanowire biosensor and its applications in disease diagnostics: A review.Analytical Chemical Acta 749 pp 1–15

[2] Guo-Jun Zhang, Li Zhang, Min Joon Huang, Zhan Hong Henry Luo, Guang Kai Ignatius Tay, Eu-Jin Andy Lim, Tae Goo Kang, Yu Chen (2010) Silicon nanowire biosensor for highly sensitive and rapid detection of Dengue virus, Sensors and Actuators B: Chemical Vol. 146 (1), pp138–144

[3] J, L., Y, Z., S, T., L, Y., & Y, S. (2011). Effect of nanowire number, diameter, and doping density on nano-FET biosensor sensitivity. ACS Nano , 1-8.

[4] Katz E, Willner I. Biomolecule-functionalized carbon nanotubes: applications in nanobioelectronics. ChemPhyschem. 2004;5 : 1084-1104

[5] Kuan-I Chena, Bor-Ran Lia, Yit-Tsong Chen (2012) Silicon nanowire field-effect transistor-based biosensors for biomedical diagnosis and cellular recording investigation, Nano Today. Vol 6(2) pp 131–154

[6] L. De Vico, L. Iversen, M.H. Sorensen, M. Brandbyge, J. Nygard, K.L. Martinez et al. (2011). Predicting and rationalizing the effect of surface charge distribution and orientation on nano-wire based FET bio-sensors, Nanoscale.3, pp.3635–3640

[7] Li Y, Afrasiabi R, Fathi F, Wang N, Xiang C, Love R, et al. Impedance based detection of pathogenic E. coli O157:H7 using a ferrocene-antimicrobial peptide modified biosensor. 2014. p. 193–9. View Article PubMed/NCBI Google Scholar

[8] Li Y, Cheng P, Gong J, Fang L, Deng J, Liang W, et al. Amperometric immunosensor for the detection of Escherichia coli O157:H7 in food specimens. Analytical Biochemistry. 2012;421 (1):227–33. doi: 10.1016/j.ab.2011.10.049. pmid:22119072 View Article PubMed/NCBI Google Scholar

[9] Lin Y-H, Chen S-H, Chuang Y-C, Lu Y-C, Shen TY, Chang CA, et al. Disposable amperometric immunosensing strips fabricated by Au nanoparticles- modified screen?printed carbon electrodes for the detection of foodborne pathogen Escherichia coli O157:H7. Biosensors and Bioelectronics. 2008;23 (12):1832–7. doi: 10.1016/j.bios.2008.02.030. pmid:18424027 View Article PubMed/NCBI Google Scholar

[10] Tijjna Adam U. Hashim and Th S. Dhahi, Silicon nanowire formed via shallow anisotropic etching, Si-ash-trimming for specific DNA and electrochemical detection, Chinese Physics B Vol. 24, No. 6 (2015) 06810

[11] Tijjani Adam, U Hashim, Highly sensitive silicon nanowire biosensor with novel liquid gate control for detection of specific single-stranded DNA molecules, Biosensors and Bioelectronics. 67(2015) 656–661

[12] Md. Eaqub Ali, Th.S. Dhahi, Rasel Das, U. Hashim, DNA hybridization detection using less than 10-nm gap silicon nanogap structure, Sensors and Actuators A 199 (2013) 304–309.

[13] Chen, X., Guo, Z., Yang, G.-M., Li, J., Li, M.-Q., Liu, J.-H., & Huang, X.-J. (2010). Electrical nanogap devices for biosensing. Materials Today, 13(11), 28-41. doi

[14] M Wesam Al-Mufti, U Hashim, M Rahman, Tijjani Adam, M Arshad, Studying Effect Dimensions of Design and Simulation Silicon Nanowire Filed Effect Biosensor, Applied Mechanics and Materials 754, 854-858, 2015.

[15] Yi, M., Jeong, K.-H., & Lee, L. P. (2005). Theoretical and experimental study towards a nanogap dielectric biosensor. Biosensors and Bioelectronics, 20(7), 1320-1326

[16] Uda Hashim, N. T., Thikra S. Dhahi, Azizullah Saifullah. (2011). Polysilicon nanogap structure development using size expansion technique. Microelectronics International, 28(3), 24-30

[17] Wang, C., Huang, J., Wang, J., Gu, C., Wang, J., Zhang, B., & Liu, J. (2009). Fabrication of the nanogapped gold nanoparticles film for direct electrical detection of DNA and EcoRI endonuclease. Colloids and Surfaces B: Biointerfaces, 69(1), 99-104

[18] Yexian Wu, T. A., Sebastian Gautsch, Nico De Rooij. (2011). Development of passivated Heteregeneous metal nanogaps using E-Beam Overlay Technique. Paper presented at the Proc. Eurosensors XXV, Anthens, Greece.

[19] Francois Beguin, E. F. (Ed.). (2013). Supercapacitors, Materials,Systems, and Applications (Vol. 4). Germany: Wiley-VCH Verlag GmbH & Co.

[20] Dimitrios P.Nikolelis, T. V., Arzum Erdem, Georgia-Paraskevi Nikoleli (Ed.). (2014). Portable biosensing of food toxicants and environmental pollutants (Vol. 1). New York: CRC Press.

[21] Tijjani Adam, U Hashim, Design and fabrication of micro-mixer with short turns angles for self-generated turbulent structures, Microsystem Technologies, 1-8, 2015

[22] T Adam, U Hashim, TS Dhahi, KN Khor, PS Chee, PL Leow, ELECTROCHEMICAL ETCHING: An Ultrasonic Enhance Method of Silicon Nano Porous Fabrication, Wulfenia Journal 20 (1), 45-55, 2013

[23] U Hashim, T Adam, J Lung, P Ling, Fabrication of Microchannel and Micro Chamber for Microfluidic Lab-on-Chip.Australian Journal of Basic & Applied Sciences 7 (1)2013

[24] T Adam and U. Hashim Light Observation in Polymer: A Study of Silicon-Based Organic Polymer Using Visible Spectroscopy, Australian Journal of Basic and Applied Sciences 7 (1), 76-80, 2013.

[25] U Hashim, MW Al-Mufti, T Adam, Silicon Nanowire Geometry: Investigation of Interaction Site Potential in Semiconductor-DNA Interaction, Australian Journal of Basic and Applied Sciences 7 (5), 242-245, 2013

[26] MW Al-Mufti, U Hashim, T Adam, Simulation of Nano lab on chip devices by using COMSOL MultiphysicsJournal of Applied Sciences Research 9 (2), 1056-1061, 2013

[27] T Adam, U Hashim, KL Foo, TS Dhahi, T Nazwa, Technology development for nano structure formation: Fabrication and characterization, Advanced Science Letters 19 (1), 132-137, 2013

[28] T Adam, U Hashim, PL Leow, KL Foo, PS Chee, Selection of optimal parameters in fabrication of poly (dimethylsiloxane) microfluidics using taguchi method, Advanced Science Letters 19 (1), 32-36,2013

[29] T Adam, U Hashim, KL Foo, Microfluidics design and fabrication for life sciences application, Advanced Science Letters 19 (1), 48-53, 2013

[30] T Adam, U Hashim, ME Ali, PL Leow, The electroosmosis mechanism for fluid delivery in PDMS multi-layer microchannel, Advanced Science Letters 19 (1), 12-15, 2013