PAPER • OPEN ACCESS

Design, Fabrication and Characterization of silicon Nanostructures for Lead (Pb$^+$) ion detection

View the article online for updates and enhancements.

Design, Fabrication and Characterization of silicon Nanostructures for Lead (Pb+) ion detection

Nuri A KH Ehfaed[1], Tijjani Adam[1,] Mohammed Mohammed[2], Omar S Dahham[1] and U. Hashim[3]and Nik Z. Noriman[1], Almahdi R. Rabia[4]

[1]Faculty of Engineering Technology, Kampus Uniciti Alam Sg. Chuchuh, 02100 Padang Besar, Universiti Malaysia Perlis (UniMAP)
[2]Center of Excellence Geopolymer and Green Technology, School of Materials Engineering, Universiti Malaysia Perlis, 01007, P.O. Box 77, D/A Pejabat Pos Besar, Kangar, Perlis, Malaysia
, Perlis, Malaysia
[3]Institute of Nano Electronic Engineering, Universiti Malaysia Perlis, 01000 Kangar, Perlis
[4]School of Environmental Engineering, Universiti Malaysia Perlis, Kompleks Pusat Pengajian Jejawi 3, 02600 Arau, Perlis, Malaysia

Abstract. Silicon nanostructure were prepared using cheap and in-house technique developed in INEE. Amino-functionalized Si nanowires were tested against heavy metal lead (Pb). The device was fabricated via dry oxide etching approach with control oxygen flow rate in oxidation furnace, network of uniform Si nanowires was successfully fabricated. The device was functionalized by (3-aminopropyl) triethoxysilane (APTES) to save as a sensor to heavy metal. Due to the silicon electrochemical response toward heavy metal ions, linear response to three different sources of water were observed. The results indicated, Pb can be detected with high precision. Furthermore, confirmation was demonstrated using atomic absorption spectroscopy instrument (AAS) to determine the level lead content in each water source. Three sources of water were tested: Tab water (H_2O), River (H_2O), DI (H_2O) and 0.0859mg/L, 0.0929mg/L, 0.023 mg/L with ~ 52pA, 60pA and 70pA current response respectively. Thus, with this high capability to discriminate water samples, the sensor potential to be employed for an effective heavy metals detection and can further be extended for large sensor network in water treatment plant.

1. Introduction

In the recent time, the silicon based devices in an nanoscales have attracted attention of many research communities this is because the material has shown potential prospect to broad applications in different filed, this include electronics related devices research and manufacturing, photonics related applications, the device equally shown considerable potentials in renewable energy to biomedical sensing [1,2]. Significant efforts have been employed by many researchers to used in application such as chemicals and in quest of this, new silicon nanostructures have been proposed and fabricated, this included quantum dots silicon devices device, silicon nanowires or silicon nanopores [2,3]. The silicon nanostructures such Nano-IDE, in particular, have attracted interest of the many researchers due to its good dimensional properties

which of good to its electrical and mechanical properties [1, 3]. Moreover, The properties of silicon based devices such as indirect band gap, silicon based devise can easily be explored in creating active material for functional electronics device that could use in specific application [1, 4, 5]. Decreasing dimensions to smaller pieces with 0.1 μm (100 nm) average length will not only influence the band gap, but further decrease of dimensions to even smaller pieces with average dimensions less than 10 nm will change the band gap and leads to appearance of new properties such as visible light or enough catalytic activity for a specific reaction [5,6]. These new properties are related to the "size effect," and 100 nm is approximately the border: nanostructures with dimensions lower than this amount will be affected by the size effect [7]. The reasons for the different properties of materials on the nanometric scale or their nanometric size effect have created many industrial applications of nanostructures [8]. Electrochemical sensing of heavy metal ions with inorganic, organic and bio-materials are currently occupying the mind every researching working in this field. Cui et al, have hypothesized in study that electrochemical sensor has short analytical time, low power cost, high sensitivity and easy adaptability for in-situ measurement [9]. When they were summarizing and discussing recent achievements in electrochemical sensing of heavy metal ions within organic and bio-materials using modified electrodes [10]. From their findings, they conclude that, the electrochemical measurements are the most viable method of analyzing chemical because they accurate, cheaper, simpler and easier for handheld device which could promote real time detection [9,10]. However, the device suffers a very big draw back because most researchers with these devices do only a proof-of-concept in detection of its targets [11]. They further found that, this particular sensor can be used not only for environmental monitoring but also in the clinical, safety and security fields (Cui et al, 2015). Detection of chemical pollutants in water using gold nanoparticles as sensors: This research currently occupying the mind many researchers in this area [12]have hypothesized their study that Electrochemical sensor has short analytical time, low power cost, high sensitivity and easy adaptability for in-situ measurement [13]. When they were summarizing and discussing recent achievements in Detection of chemical pollutants in water using gold nanoparticles as sensors [14]. From their findings, they conclude that, silicon-based sensors provide promising approaches for selective and sensitive analyses, and have advantages over traditional instrumental analyses, as they are usually compatible with portable devices that can be deployed in field for onsite sample screening [15]. With the advance of microfluidic sample handling units, this kind of portable device can be developed for multiplexed, quantitative and rapid analysis, and can measure unprocessed field-collected water samples with a high sensitivity. High-throughput and ultrasensitive detection technology, based on nanowires, offer effective screening methods for many environmental analyses [16-25].   However, it should be noted that a number of important issues still need to be addressed before It can become real tools for environmental monitoring [26-38]. Methods of manufacturing reliable production silicon device based a large scale, with good clone, still lacks, Especially for anisotropic particles form [39-49]. Thus, this research proposed the in-house preparation of highly though put approach, fabrication, characterization and surface modification of silicon based electrochemical sensor that could detect lead ion in water.

2. Material and methods
100mm 4inch wafer, p-type silicon material was, prepared using R1 and R2 process, prior to pattern transfer, 4 wires were designed using AutoCAD and transferred to chrome mask for subsequent pattern transfer. Positive resist was prepared and spin coated using speed controllable spin coater, the coating speeds were increase from 0rpm to 3000rpm by incremental of 500rpm, this is done in order to achieve uniform coating. The resist coated samples (wafers) were place on hot plate at 110^0C temperature for 15 minutes. The samples (wafers) were taken on the hot plate and cooled for 10 minutes. With this, the samples were ready for alignment and exposure. Via mask aligner, the samples were arranged and exposed to UV light for 60miniutes. Due to the photo resist sensitive to the UV light, patterns were created and the pattern were fully revealed after washing away with resist developer. In this case, the samples were immersed in the developer for 5 minutes and removed and washed using DI (H_2O) and Hard

bake using the same hot plate at slightly different temperatures , the temperature used for the hard is 90^{0}C. This is done in order to create link with resist molecule with silicon to avoid stripping during device pattern creation and subsequent pattern trimming. With this, the sample was ready for pattern creation and subsequent residual resist removal. The silicon micro wires were first created via reaction ion etcher. To do this, the sample were arranged in the etcher chamber and set all the required gasses to their desired level, the machine was on and kept for 5 minutes and gases were on and run 2 minutes for etching and another to minutes for resist removal. These were both done within this same machine. The samples were removed and the pattern were measured both radial and longitudinal dimensions, with this, the device ready for trimming. The trimming process, was done in two steps, first, initial trimming was conducted via oxidation furnace using dry etching process and lastly the, it then trimmed nano size via the reactive ion etcher. Thus, smooth and successful nanowires were fabricated and surface modified using APTES for heavy metals detection. After the fabrication its followed by surface modification where the silicon nanowire functionalized using 3-Aminopropyl Triethoxysilane (APTES) to enhance nanowire electrochemical activities and the nanowires were immersed in 2% APTES in water. 1.5µl APTES (0.01M) was dropped on an active area of silicon nanowire. The device was drying in dry cabinet for 30 minutes until it clearly dry. After that, the device were ready for electrical measurement

3. Results and Discussion
The morphological observation and nanostructures sizes were observed and prior the measurement process, samples were prepared, series of investigated were conducted using scanning electronic microscopy (SEM) and field emission scanning electron microscopy (FESEM). FTIR spectrometer. EDX, FTIR and XRD were employed in order precise understanding of materials elemental and material composition. The silicon nanowire was fabricated using typical in-house , pattern formation and dry etching approach, Si nanowires have been successfully fabricated figure 1, the device was fabricated with minimum energy effort as does not required two many steps to achieved nanowire. This can be observed in Figure 1. The Si nanowires were highly uniform figure 1b. After patterning using the mask aligner and etching with RIE for around 5mins, the size of Si nanowires around 100nm from their cross- sectional view.
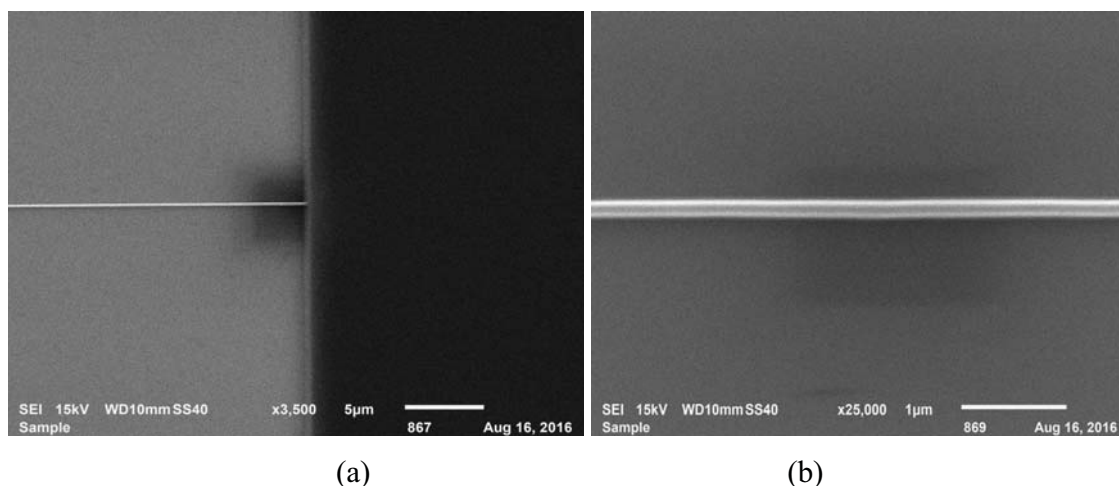

(a)   (b)

Figure 1. SEM observation forth he nanowires image with 15kV acceleration range and 3500x magnification range

Figure 2, show the SEM images of the fabricated nanowires full length. The nanowire were uniformly and highly straight through out the nanostructure. From highly magnified SEM image shown in Fig. 2, it can be further confirmed that it the structure is approximately 100nm.
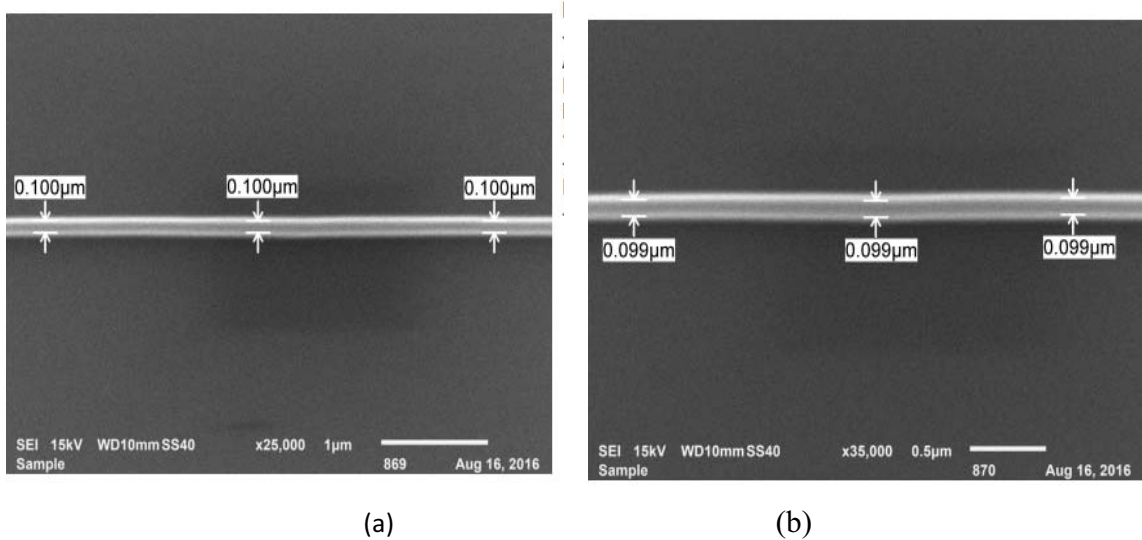

(a)   (b)

Figure 2. The observation of the nanowires SEM monograph

The silicon nanowires were fabricated as explained above by a simple, cheap and yet reproducible . figure 2a above the devices are entirely composed of silicon material and nanowires with lengths up to several thousand of micrometres. The typical diameters shown in both SEM AND FESEM of the nanowires are in the range of 90-00 nm fgire 2b, this will allow high surface-to-volume ratios.
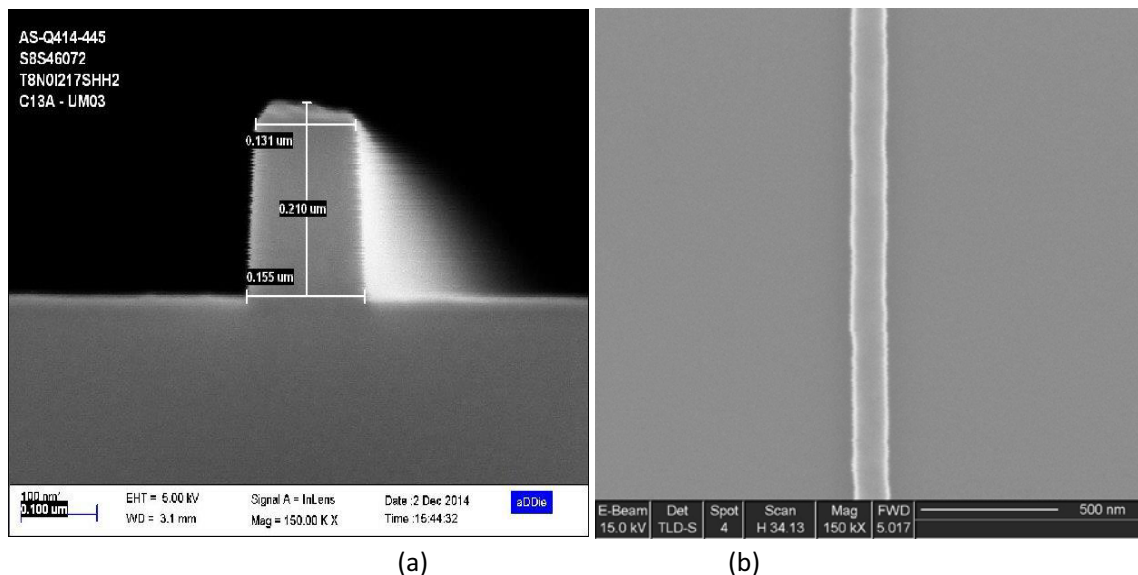

(a)   (b)

Figure 3. Nanowire crosesction few with FESEM

The figure 3 results obtained from the FESEM also indicated, the profile of the the fibricated nanoires are straight and uniform with total surace intergrity with ~ 200nm height and 100nm width
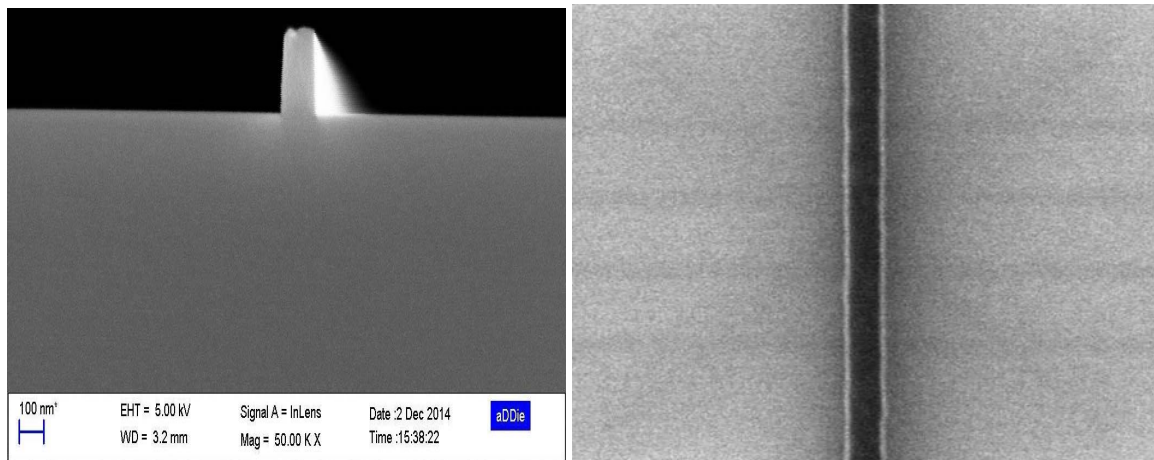
Figure 4. The cross section view based of field emission scanning electron microscope showinf the fabricated nanowires

Moreover, based on the above figure 4, the nanonire is more or less ractagular with cylinder curve end, however, the original wire dimension after the pattern was between 1µm and height was before the oxidation etched was about 10µm. After the thermal oxidation with removal from RIE etching of the layer at 1000° C for 30 minutes, and process consumed part silicon and some thickness converted to SiO2, this has lead for the microwire to reduce to height of about 200 nm and with of 100nm figure 4a. Thus, a pattern-size reduction by about more that $10\times$ times has been achieved. The process produce uniform and straight wire   figure 4b. The precise control of nanostructure dimensions is a crucial point for a reproducible fabrication and for good electrical behaviour.
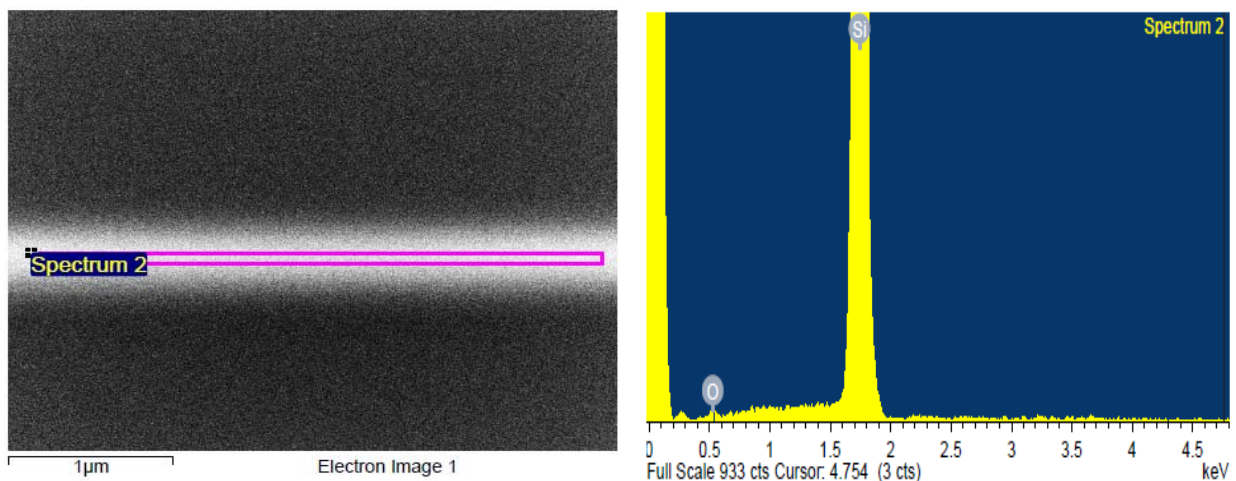
(a)   (b)

Figure 5. Show the Energy Dispersive X-ray (EDX) Spectroscopy which confirms the presence of Si and O on the nanowire.
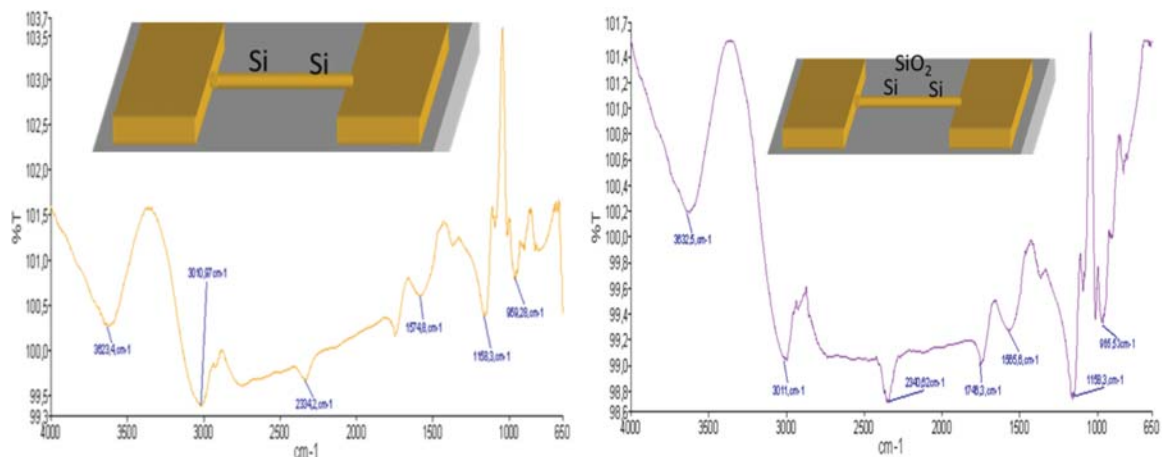
Figure 6. FTIR spectra of barred silicon nanowire and oxide functionalized Si Nanowires

The barred silicon have ability to response to the heavy metal ion, however, in order to enhance the response and complete absorption of ion, the silicon nanowire was surface treated, this will aloow the Si nanowires toward to sensitive heavy metal ion. The present of the amino(–NH2) in surface modification agent (APTES), functionalization process was conducted. The process was first started with barred wire was observed with FTIR as shown in figure above, Their schematic processes for the oxide deposition was presented in figure above are.. In Figure above the FT-IR spectrums barred silicon and oxide deposited device, the confirmed the EDX spectra explained prior this section.
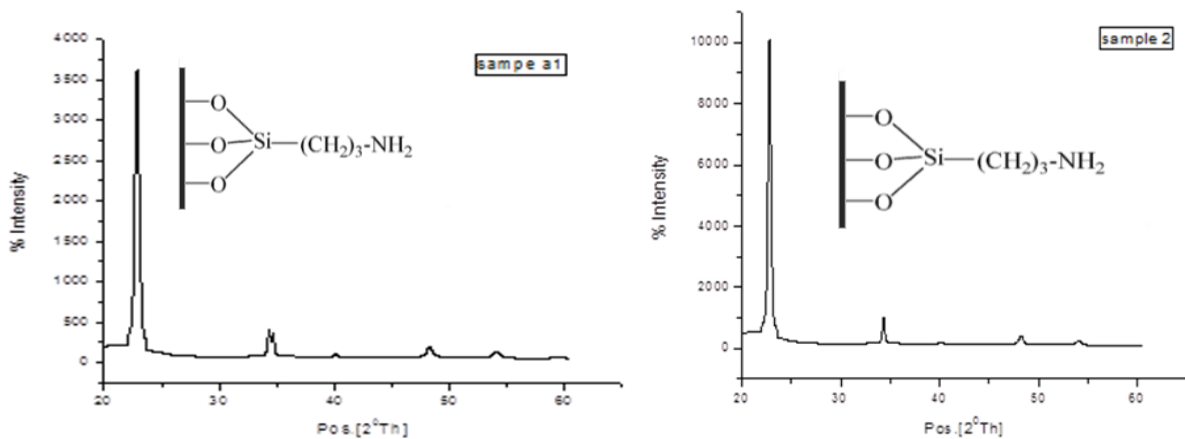

Figure 7. Aptes spectra

After the oxide deposition, aptes was droped without further treatment, from the figure above in both samples it can be observed two major peaks one in each sample where the band with 3500 and 10000 % intensity with 20 to 30° and another minor peaks appears with the range of 30 to 40°, this minor peak within thin this band is ascribed to vibrating band of amino group of the aptes on surface of –silicon nano wire NH2, For the other element such CH-R component of the aptes on-Si nanowires produce lower peaks, this might be due lack enough chemical activities and fully anchored limiting vibrations tendency. However, in amino -NH$_2$

groups. On Si nanowires, can be obviously seen have reveal vibration characteristic that have tendency to participant during heavy metal detection process, the CH-R component is indeed weak, however, it produced some vibration tendency that could enhance some reaction activities. Moreover, it can clearly seen and that can be concluded that aptes is exist on Si nanowires and are successfully grafted with functional groups of -NH_2. From the EDX, spectra, the above results of weak peaks also can be ascribed to present of the other element such oxide of silicon are present and a stiff silicon peak besides the peaks of oxygen is appeared for the Si nanowires due to the formation of a very thin film of SiO_2. Other peaks of very low intensity as moving from left to right   arises as a result of residual of gasses element during the etched process in fabricating the nano structures.
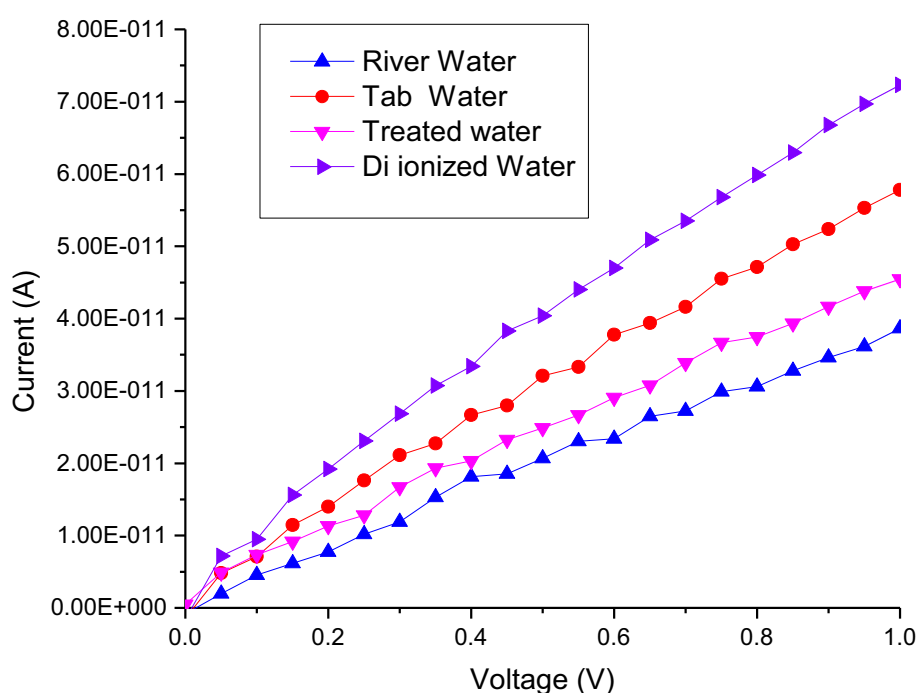

Figure 8. SiNW response to various water collected from 4 different sources

The device designed as sensor, it current response it determines its ability to response to other electrochemical activities which its response defined as the ratio of voltage to resistance. The voltages were swept from 0V to 1V using semiconductor analyser with input signal (0 V D.C Offset).Reference plane is full calibrated to reference plane and probing station was fully vacuum. Below is typical nanowire measurement at 100 nm. Primary current model for the three target analytes source of H_2O value shown in the graph for tab (H_2O), river (H_2O) and lake (H_2O with 0.0859mg/L, 0.0929mg/L, 0.1104 mg/L with ~ 52pA, 60pA and 70pA current response respectively. As shown in figure above , the response by barred nanowire, deionized water, lower than other three source of water, that might lack of the electrochemical activities contributed by the two afore mentioned samples. The factors that ultimately determine the present of the ions in the heavy metals. The river and the lake water normally full of heavy metals cations, which include Pb^{2+}, The existing of this metals ions are reveal by the sensors response from the figure above indicating the, ability of the sensor to response, different ions and when observed closely , even the

treated water have still contain certain ion present and this is due to the alkaline and alkaline earth metal cations commonly, possess weaker coordination bonding with functional amino groups, whereas heavy metal ions exhibit a much stronger bonding with amino ligands, this has resulted in a remarkable selectivity, the claimed equally reported (Wei et al, 2014). The APTES anino group (NH_2) are receiving serious attention in the enhancing sensors to recognize heavy metals ions due to its specific and selective recognition of heavy metals ions, the interaction between heavy metals amino group happen as a results of electrochemical activities in which the animo acid react with ions of the metals which supported by the Pearson theory where the amino heavy strong affinities to ionic soft base and generally, heavy metals such Lead (Pb^+), Silver (Ag^+), Mercury (Hg^{2+}) etc . These ions are grouped according soft base ions tend react with animo group. The lead is generally classied as the both hard and soft based ion that can easily be react with the donor atoms. As shown table above the water sample contain some degree of lead ions present, this results result was obtained from the atomic absorption spectroscopy (AAS). The The selective of the sensor to the heavy metals ions as a result of membranes, electrochemical interferences creating potentiometric effect across the sensor surface, that will lead to heavy metal detection
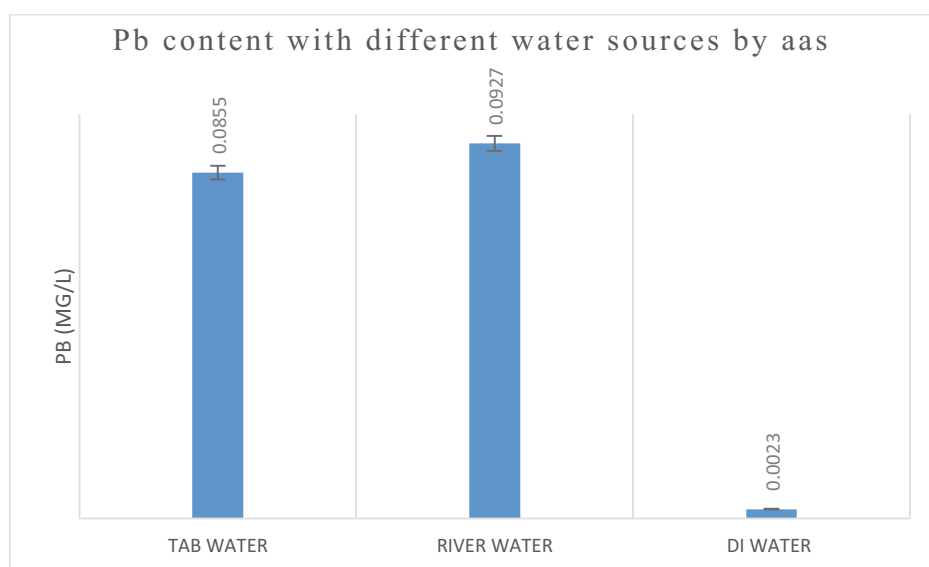

Pb content with different water sources by aas

Figure 9. Show comparison of Barred SiNW with 4 different waters collected in 4 different

Generally, the traces amount of metals are common in water, however, it quite harmful, if exceed beyond the standard limits. Especially lead because is a highly toxic metal whose widespread use has caused extensive environmental contamination and health problems, the contamination of lean to environment and ground water highly cmmmon compared to other heavy metals because lead is found every aspect industrial activities, lead used in battery, cosmetics. That why the traces of the lead are always high. For example, the table above is the measurements contacted on three water samples namely Di. Water, tap water and river water, both river water and tab water.

4. Conclusion
The study demonstrated, aptes modified silicon nanowires sensors for electrochemical detection of Pb^+ ions, this does not only enhanced the silicon nanowires but also successfully discriminate the three samples with different electrical behavior. In conclusion, Silicon nanostructure were prepared using cheap

and in house technique developed in INEE. Amino-functionalized Si nanowires were tested against heavy metal lead (Pb). The device was fabricated via dry oxide etching approach with control oxygen flow rate in oxidation furnace, network of uniform Si nanowires were successfully fabricated. The device was functionalized by (3-aminopropyl)triethoxysilane (APTES) to save as a sensor to heavy metal. Due to the silicon electrochemical response toward heavy metal ions, linear response to three different source of water were observed . The results indicated, Pb can be detected with high precision. Furthermore, confirmation were demostarted using atomic absorption spectroscopy instrument (AAS) to determine the level lead content in each water source. Three sources of water were tested: Tab water (H_2O), River (H_2O), DI(H_2O) and 0.0859mg/L, 0.0929mg/L, 0.0023 mg/L with ~ 52pA, 60pA and 70pA current response respectively. Thus, with this high capability to discriminate water samples, the sensor potential to be employed for an effective heavy metals detection and can further be extended for large sensor network in water treatment plant.

5. Acknowledgement

Reference

[1]. Abdul Rashid, J. I., Abdullah, J., Yusof, N. A., Hajian, R., Abdul Rashid, J. I., Abdullah, J., … Hajian, R. (2013). The Development of Silicon Nanowire as Sensing Material and Its Applications. *Journal of Nanomaterials*, *2013*, 1–16. https://doi.org/10.1155/2013/328093

[2]. Ahmed, R. A., & Fekry, A. M. (2013). Preparation and characterization of a nanoparticles modified chitosan sensor and its application for the determination of heavy metals from different aqueous media. *International Journal of Electrochemical Science*, *8*(5), 6692–6708.

[3]. Boken, J., & Kumar, D. (2014). Detection of Toxic Metal Ions in Water Using SiO 2 @ Ag Core-Shell Nanoparticles, *4*(4), 303–308.

[4]. Chen, K. I., Li, B. R., & Chen, Y. T. (2011). Silicon nanowire field-effect transistor-based biosensors for biomedical diagnosis and cellular recording investigation. *Nano Today*. Elsevier Ltd. https://doi.org/10.1016/j.nantod.2011.02.001

[5]. Chua, J. H., Chee, R. E., Agarwal, A., She, M. W., & Zhang, G. J. (2009). Label-free electrical detection of cardiac biomarker with complementary metal-oxide semiconductor-compatible silicon nanowire sensor arrays. *Analytical Chemistry*, *81*(15), 6266–6271. https://doi.org/10.1021/ac901157x

[6]. Cui, L., Wu, J., & Ju, H. (2015). Electrochemical sensing of heavy metal ions with inorganic, organic and bio-materials. *Biosensors and Bioelectronics*, *63*, 276–286.

[7]. Cui, Y., Wei, Q., Park, H., & Lieber, C. (2001). Nanowire Nanosensors for Highly Sensitive and Selective Detection of Biological and Chemical Species. *Science*, *293*(5533), 1289–1292.

[8]. Cui, Y., Zhong, Z., Wang, D., Wang, W. U., & Lieber, C. M. (2003). High performance silicon nanowire field effect transistors. *Nano Letters*, *3*(2), 149–152. https://doi.org/10.1021/nl0258751

[9]. Dhahi, T. S., Hashim, U., & Ahmed, N. M. (2011). Fabrication and Characterization of 50 nm Silicon Nano-Gap Structures. *Science of Advanced Materials*, *3*(2), 233–238. https://doi.org/10.1166/sam.2011.1155

[10]. Dielacher, B. K. (2015). A Combined Electrical , Plasmonic and Fluidic Measurement System for Metal Nanostructure based Ion Sensing, (22493). https://doi.org/10.3929/ethz-a-010414691

[11]. Eshkeiti, A., Narakathu, B. B., Reddy, A. S. G., Rebrosova, E., Rebros, M., Joyce, M., & Atashbar, M. Z. (2012). A Novel Fully Gravure Printed Flexible Surface Enhanced Raman Spectroscopy (SERS) Substrate for the Detection of Toxic Heavy Metals, 1479–1482. h

[12]. Mohammad Razif Bin Mustafa, Tijjani Adam, U. Hashi, N. Azizah (2017) Specific and Selective Target Detection of Supra-genome 21 Mers Salmonella via Silicon Nanowires Biosensor, IConGDM2017-177, AIP Conference Proceedings ISSN: 1551-7616

[13]. B. Basri, Tijjani Adam and U.Hashim (2017) Synthesis of zinc oxide thin films prepared by sol-gel for specific bioactivity, IConGDM2017-178, AIP Conference Proceedings ISSN: 1551-7616

[14]. Mohammed Mohammed A.R Rozyanty Tijjani Adam, Bashir O. Betar (2017) Study of the Weathering Effect in a Natural Environment on the Hybrid Kenaf Bast /Glass Fibre-Filled Unsaturated Polyester Composite, ConGDM2017-181, AIP Conference Proceedings ISSN: 1551-7616

[15]. Neesyan A/L David Rajah, Tijjani Adam Uda Hashim (2017) Lattices Parameter Dependent Of Effective Atomic Interactive Coefficient For Unstressed And Stressed 1nm Nanostructure, ConGDM2017-198, AIP Conference Proceedings ISSN: 1551-7616

[16]. Mohamed Jamal Bin Amanullah, Tijjani Adam, Uda Hashim, (2017)Calculation of the Band Structure Parameter in Silicon Nanowires Using first Principle Analytical Method, AIP Conference Proceedings ISSN: 1551-7616

[17]. Mohammed Mohammed A.R Rozyanty, Tijjani Adam, Bashir O. Betar (2017)ZnO Characterization, UV and Photocatalysis Mechanism for Water Repellent Phenomena in Polymer Poly Composite, IConGDM2017-211, AIP Conference Proceedings ISSN: 1551-7616

[18]. Shillan A/L Bathmanathan , Tijjani Adam, Uda Hashim (2017) Optimization and Validation of Highly Selective Microfluidic Integrated Silicon Nanowire Chemical Sensor, IConGDM2017-212, AIP Conference Proceedings ISSN: 1551-7616

[19]. G. Ozin, A. Arsenault, L. C. (2009). Nano chemistry, 0–3.Guo, Z., Seol, M., Gao, C., Kim, M., Ahn, J., Choi, Y., & Huang, X. (2016). Electrochimica Acta Functionalized porous Si nanowires for selective and simultaneous electrochemical detection of Cd (II) and Pb (II) ions. *Electrochimica Acta*, *211*, 998–1005. https://doi.org/10.1016/j.electacta.2016.06.141

[20]. Harrison, B. S. (2008). Applications of Nanotechnology. In *Principles of Regenerative Medicine* (pp. 554–561). https://doi.org/10.1016/B978-012369410-2.50033-4

[21]. Joyner, J. J., & V., D. K. (2015). Nanosensors and Their Applications in Food Analysis : A Review. *International Journal Of Science & Technoledge*, *3*(4), 80–90.

[22]. Korent Urek, Š., Frančič, N., Turel, M., & Lobnik, A. (2013). Sensing heavy metals using mesoporous-based optical chemical sensors. *Journal of Nanomaterials*, *2013*. https://doi.org/10.1155/2013/501320

[23]. Li, Z., Chen, J., Guo, H., Fan, X., Wen, Z., Yeh, M. H., … Wang, Z. L. (2016). Triboelectrification-Enabled Self-Powered Detection and Removal of Heavy Metal Ions in Wastewater. *Adv Mater*, 2983–2991. https://doi.org/10.1002/adma.201504356

[24]. Long, F., Zhu, A., & Shi, H. (2013). Recent advances in optical biosensors for environmental monitoring and early warning. *Sensors (Basel, Switzerland)*, *13*(10), 13928–13948. https://doi.org/10.3390/s131013928

[25]. Luo, L., Jie, J., Zhang, W., He, Z., Wang, J., Yuan, G., … Lee, S. T. (2009). Silicon nanowire sensors for Hg2+ and Cd2+ ions. *Applied Physics Letters*, *94*(19). https://doi.org/10.1063/1.3120281

[26]. Ly, N. H., & Joo, S. W. (2015). Silver nanoparticle-enhanced resonance raman sensor of chromium(iii) in seawater samples. *Sensors (Switzerland)*, *15*(5), 10088–10099. https://doi.org/10.3390/s150510088

[27]. March, G., Nguyen, T., & Piro, B. (2015). Modified Electrodes Used for Electrochemical Detection of Metal Ions in Environmental Analysis. *Biosensors*, *5*(2), 241–275. https://doi.org/10.3390/bios5020241

[28]. Melde, B. J., Johnson, B. J., & Charles, P. T. (2008). Mesoporous Silicate Materials in Sensing. *Sensors*, *8*(8), 5202–5228. https://doi.org/10.3390/s8085202

[29]. Park, W., Zheng, G., Jiang, X., Tian, B., & Lieber, C. M. (2008). Controlled synthesis of millimeter-long silicon nanowires with uniform electronic properties. *Nano Letters*, *8*(9), 3004–3009. https://doi.org/10.1021/nl802063q

[30]. Paul, B., & Tiwari, A. (2015). A Brief Review on the Application of Gold Nanoparticles as Sensors in Multi Dimensional Aspects, 1–7.

[31]. Screen, S. N., & Carbon, P. (2016). Sensory Measurement of Mercury and Cadmium Ions in Water Using, *28*(7), 1429–1434.

[32]. Tarasov, A. (2012). Silicon Nanowire FET for Sensing Applications. *Thesis*.

[33]. Tsang, C. H. a, Liu, Y., Kang, Z., Ma, D. D. D., Wong, N.-B., & Lee, S.-T. (2009). Metal (Cu, Au)-modified silicon nanowires for high-selectivity solvent-free hydrocarbon oxidation in air. *Chemical Communications (Cambridge, England)*, (39), 5829–31. https://doi.org/10.1039/b912341e

[34]. Wang, C., & Yu, C. (2013). Detection of chemical pollutants in water using gold nanoparticles as sensors: A review. *Reviews in Analytical Chemistry*, *32*(1), 1–14. https://doi.org/10.1515/revac-2012-0023

[35]. Yang, S. I. (n.d.). Nanomaterial based Environmental Sensing What is Nanotechnology ?

[36]. Zeng, S., Yong, K.-T., Roy, I., Dinh, X.-Q., Yu, X., & Luan, F. (2011). AuNP138-A Review on Functionalized Gold Nanoparticles for Biosensing Applications. *Plasmonics*, *6*(3), 491–506. https://doi.org/10.1007/s11468-011-9228-1

[37]. Zhang, L., & Fang, M. (2010). Nanomaterials in pollution trace detection and environmental improvement. *Nano Today*. Elsevier Ltd. https://doi.org/10.1016/j.nantod.2010.03.002

[38]. Tijjani 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

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

[40]. 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

[41]. Tijjani Adam, H Uda, M Eaqub, PL Leow, The electroosmosis mechanism for fluid delivery in PDMS multi-layer microchannels, American Scientific Publishers All rights reserved.2013

[42]. 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

[43]. 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.

[44]. 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

[45]. 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

[46]. 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

[47]. 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

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

[49]. 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