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Optimization and Validation of Highly Selective Microfluidic Integrated Silicon Nanowire Chemical Sensor

Nuri. A KH Ehfaed[1,a)], Shillan A/L Bathmanathan[1,b)], Th S Dhahi[2,c)], Tijjani Adam[1,3,d)],Uda Hashim[1,e)] and N Z Noriman[4,f)]

[1]*Faculty of Technology, Universiti Malaysia Perlis (UniMAP), Kampus Uniciti Alam Sg. Chuchuh, 02100 Padang Besar (U), Perlis, Malaysia*
[2]*Physics Department, College of Science Education, Basra University,Basra, Iraq*
[3]*Institute of Nano Electronic Engineering (INEE), Universiti Malaysia Perlis (UniMAP), 01000 Kangar, Perlis, Malaysia*
[4]*Center of Excellence Geopolymer and Green Technology, School of Materials Engineering, Universiti Malaysia Perlis (UniMAP), 01007, P.O Box 77, D/A PejabatPosBesar, Kangar, Perlis, Malaysia.*

Corresponding author: [a)]nuriafeed@yahoo.com
[b)]shill1212@yahoo.com
[c)]sthkra@yahoo.com
[d)]tijjani@unimap.edu.my
[e)]uda@unimap.edu.my
[f)]niknoriman@unimap.edu.my

Abstract: The study proposed characterization and optimization of silicon nanosensor for specific detection of heavy metal. The sensor was fabricated in-house and conventional photolithography coupled with size reduction via dry etching process in an oxidation furnace. Prior to heavy metal heavy metal detection, the capability to aqueous sample was determined utilizing serial DI water at various. The sensor surface was surface modified with Organofunctional alkoxysilanes (3-aminopropyl) triethoxysilane (APTES) to create molecular binding chemistry. This has allowed interaction between heavy metals being measured and the sensor component resulting in increasing the current being measured. Due to its, excellent detection capabilities, this sensor was able to identify different group heavy metal species. The device was further integrated with sub-50µm for chemical delivery.

INTRODUCTION

Heavy metals could bring a tremendous effect to human life in particular when exposed. Most of these heavy metals have been used for thousands of year. Developing countries usually shows an alarming increase of heavy metals exposure. Heavy metals has no real definition of itself but mostly referred as specific density of more than 5 g/cm^3 .Those dangerous metals include lead, cadmium, mercury and arsenic. Cadmium occurs naturally in ores together with zinc, lead and copper. Nanotechnology is managing or altering of elements on an nano scale to perform a specific purpose which has dimension of 1 to 100 nanometers. Its application of can be considered at the lowest scale and can be used across most of relatable main fields which includes chemistry, biology, and physics. Example uses of nanotechnology are nano-foods, surface coatings, textiles, cosmetics, biological sensors, weaponry, construction material as well as miniaturization of existed devices. A nanowire is an example of nanostructure. It has an outstanding ratio of length to width that is higher than 1000. From this ratio, we could see that the nanowires are so thin until it is defined to be in one dimension which is the length. The nanowire is one of nanostructures which show high potential to be used in many applications due its high volume to length ratio that show wonderful electrical properties. There are various types of nanowire that has been developed or undergoing development stage

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which includes superconducting, metallic, semiconducting, insulating and molecular nanowires which are divided into two categories which are organic or inorganic. To ensure for the safety of end user to consume or use water from unknown water sources, a simple, effective, versatile device that is multifunctional needed to be created, thus enabling the people themselves to test at the testing site without having to wait for prolonging lab tests. This could make ease to test the toxicity of any water sources and save the cost to test as well as lessen the lab and labor costings. In these recent days, water being consumed by end user has no guaranty of its safety. Water could contain heavy metals that could be harmful to consumers. Heavy metal could be related as metal or metalloid mostly found in environmental surroundings that has its potential toxicity. Examples of heavy metals that could be harmful to living context include arsenic, lead, mercury as well as cadmium. This has been proven as series of testing done using living mice. These elements exist naturally on earth. Heavy metals has the property to coagulate together to form a higher concentration lump. Those heavy metals become coagulated due to activities caused by human. Plantations, animals, or any form of living things including human could be affected when those toxics enter or interfere important functioning organs. To overcome this problem, an easy way of testing water supplies need to be implemented, thus creating a device that could analyze water samples and differentiate the heavy metal concentrations would be essential. Nanowire provides a better option for the device base as nanowires are extremely sensitive to even a small electrical spike when their specific chemical complementation are met. For general understanding silicon is a metalloid most abundant in the Earth's crust with a relative atomic mass of 28.085 and atomic number of 14 which makes this element half insulator as well as half conductor. More than 90 percent silicon on Earth are isotope 28, less than 5 percent are isotope 29, and about 3 percentile is isotope 30, while the rest might be unstable or radioactive isotopes. A semiconductor nanowire is a strong pole with a width under 100–200 nm made out of one or a few semiconductor materials. A lower point of confinement is difficult to characterize – wires of 5 nm in distance across are reasonable alternatives for this innovation. Nanowire wire can be grown in various ways such as vapor-liquid-solid (VLS) growth mechanism and vapor-solid-solid (VSS) mechanism. Nanowires can likewise be developed without a metal seed, for instance within the sight of an oxide or by masking a substrate. In order to produce nanowires, molecular or chemical beam epitaxy, vapor phase epitaxy or chemical vapor deposition, and ion implantation. Crucial parameters for the electrical execution of nanowire gadgets are the bearer focus, characterized by the doping level, transporter portability, and bandgap. Since these parameters can emphatically rely on upon subtle elements of the nanowire development, coordinate criticism between electrical portrayal and development enhancement is important. The versatility can then be evaluated in light of how the nanowire conductance changes with the back-door voltage. In parallel, μ-photoluminescence can likewise address singular wires and, specifically, uncover the bandgap. The intrinsic band structure and thickness of conditions of nanowires depend straightforwardly on the basic plan and quality, specifically on the event of development related imperfections (separations, stacking deficiencies, and so forth.). Thus, these must be explored and comprehended before the electronic properties can be improved. The crystalline nanowire structure might be very not the same as that of mass materials or other semiconductor heterostructures (superlattices, quantum dots) on account of surface unwinding impacts or active confinements. For instance, longitudinal or pivotal InAs/InP nanowire heterostructures developed on InAs(111) have a hexagonal, while both of these materials are cubic in the mass. The thermal spending accessible for nanowire development restrains the materials that can be utilized. Plainly, this limit condition and the sullying issues said above rely on upon where in the process usage is to be considered. In FEOL, high temperatures are utilized for dopant actuation streak anneal to 1100°C, while the substitution of Co by nickel silicide limits consequent process temperatures to underneath 450°C for steadiness reasons. Low-k materials utilized as a part of BEOL normally get to be distinctly shaky in the vicinity of 400°C and 450°C. This plainly restrains the greatest temperature for development of nanowires proposed to convey extra usefulness to existing CMOS. Be that as it may, nanowire development has been accounted for at reliably bring down temperatures, which demonstrates that usage might be conceivable inside the thermal requirements of the procedure. Nanowire is technology of manipulating extremely sensitive one dimensional conductor which has a wide applications field. Example of these applications includes energy field in solar cell that uses graphene coated with zinc oxide nanowires because the nanowire has special ability to concentrated sunlight. Sensors that powered by nanowire piezoelectric allows the least amount of mechanized movements to be manipulated. Recent researches reveal that nanowire able to reduce the cost to manufacture solar panels. Amount of power storage in a lithium ion battery could be greatly improved by using silicon nanowires on the anode rods as well as avoiding from silicon cracking due to excessive swelling during absorption of ions. In environment field polluted water could be treated by using silver chloride nanowires as photo catalysis to break down unwanted coagulated particles such as in oil spill situation. Silver nanowires, carbon nanotubes and cotton could be used to purify water from microorganism. Another field that uses nanowires widely is electronics field. Nanowires such as silver nanowire makes it possible to produce a thinner and flexible display screens due to its relatively small space consuming and easy to be manipulated its dimensions. All the electronics device are possible to miniaturize to a smaller version and avoid power dissipation as nanowires gives option to build transistors without its p-n junction. Zinc oxide nanowires are used to sense a vast range of chemicals. Different type of heavy metal species with its own toxicity properties has different type of harm to human. Based on the studies done heavy metals became harmful to human as human activities that alters chemical composition in the environment by both regular and anthropogenic means to become dense in some areas. Since the 90s cadmium usage has been greatly reduced due to better batteries has been introduced compared to Ni-Cd batteries. Leaking or flows of the fertilizer or sewage sludge into running water might increase the probability of water contamination. Mercury was known as white lead in ancient Greece where it was used as a cosmetic substances as well as in medical field to cure syphilis. Aside from the already said utilization of mercury as a cure for syphilis, mercury mixes have additionally been utilized as diuretics , and mercury amalgam is as yet utilized for filling teeth. Thermometers, barometers and instruments used to measure blood pressure uses mercury as its level indicators. Inorganic mercury is changed over to natural mixes, for example, methyl mercury, which is extremely steady and coogulate in the food chain. Until the 1970s, methyl mercury was regularly utilized for control of parasites on seed grain. Amid the most recent century, lead emanations to surrounding air have additionally contaminated our condition, more than half of lead discharges starting from petrol. Occupational introduction to inorganic lead happens in mines and smelters and in addition welding of lead painted metal, and in battery plants. Low or direct exposure may occur in the glass business. Abnormal amounts of air discharges may contaminate ranges close lead mines and smelters. Airborne lead can be stored on soil and water, hence achieving people by means of the natural pecking order. Tetramethyl lead and tetraethyl lead penetrate the skin easily. These compounds may also cross the blood–brain barrier in adults, and thus adults may suffer from lead encephalopathy related to acute poisoning by organic lead compounds. Arsenic is a generally circulated metalloid, happening in rock, soil, water and air. Inorganic arsenic is available in groundwater utilized for savoring a few nations everywhere throughout the world, while natural arsenic mixes, for example, arsenobetaine are essentially found in fish, which in this manner may offer ascent to human All inclusive community exposure to arsenic is mostly by means of admission of nourishment and drinking water. Nourishment is the most essential source, yet in a few territories, arsenic in drinking water is a critical wellspring of presentation to inorganic arsenic. Tainted soils, for example, mine-tailings are additionally a potential wellspring of arsenic exposure. Ingesting or drinking anything that has a high concentration of cadmium might expose to higher probability of kidney damage and formation of kidney stone due to peaking of calcium exraction in urine as result of tubular damage. Longer period of exposure might cause skeletal damage, combination of asteomalacia and osteoporosis. Bones tends to become brittle and prone to break and face difucullity to bear own body weight. Cadmium has been related with prostate cancer, yet both positive and negative reviews have been distributed. Early information demonstrated a relationship between cadmium introduction and kidney cancer. Mercury exposure may offer ascent to lung harm. Ceaseless harming is described by neurological and mental side effects, for example, tremor, changes in person physiological behavior, fretfulness, uneasiness, rest unsettling influence and depression. Metallic mercury is an allergen, which may bring about contact skin inflammation, and mercury from amalgam fillings may offer ascent to oral lichen.

RESULTS AND DISCUSSION

The elemental composition for the first spectrum of the first Si nanowire was figured out using EDX mapping and is shown in figure 1. EDX mapping confirms the presence of silicon and oxygen. The quantitative EDX analysis shows the silicon weight percentage of around 46.74% and the weight percentage of oxygen to be about 53.26%. The silicon peak is due to substrate background which results in 100% compound percentage of silicon.

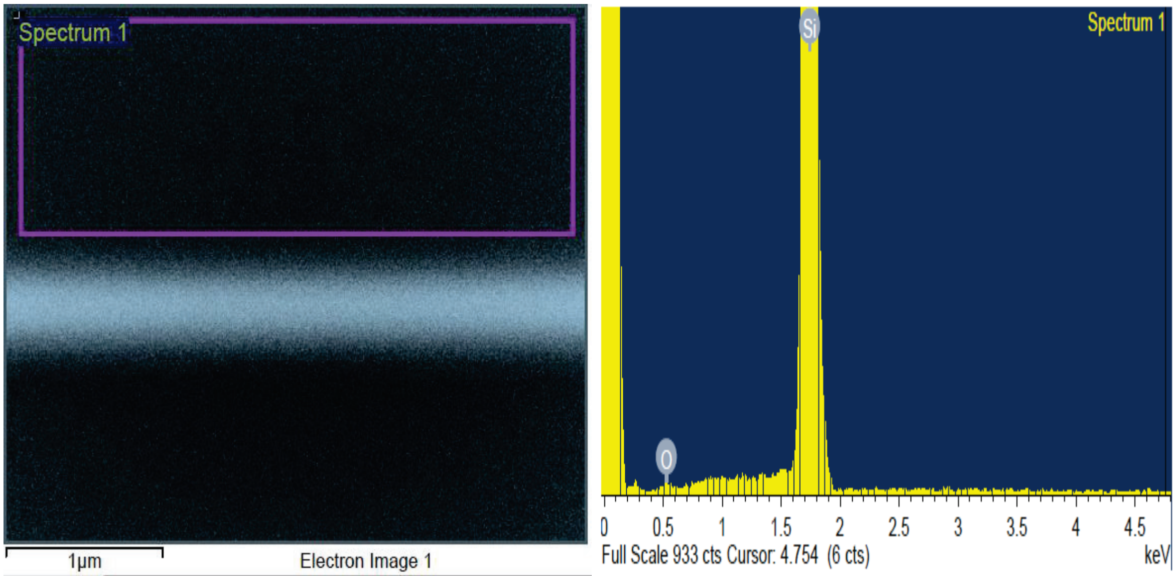

FIGURE 1

Figure 2. shows XRD spectrum of silicon nano structure, Thus, there are 4 mains peaks that indicate the presents of silicon and oxide. Those peaks are located at 3434, 1629.90, 1270.82, 875.97 and 555.11 cm^{-1}. The peak at 555 cm^{-1} indicates the siliconc and Oxide. The peak at 1270 cm^{-1} is belongs to silicon materila. While the presence of oxide at 3434 cm^{-1}. Thus, from XRD results concludes that siliconc and oxide are main composition if the sample

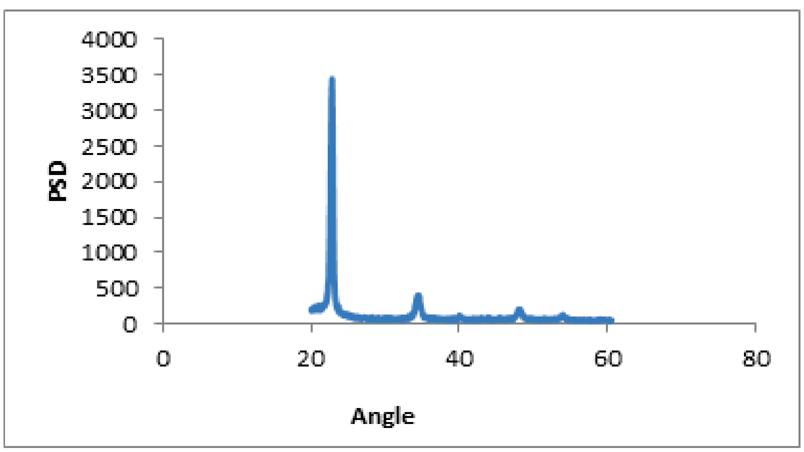

FIGURE 2. shows XRD spectrum of silicon nanowire

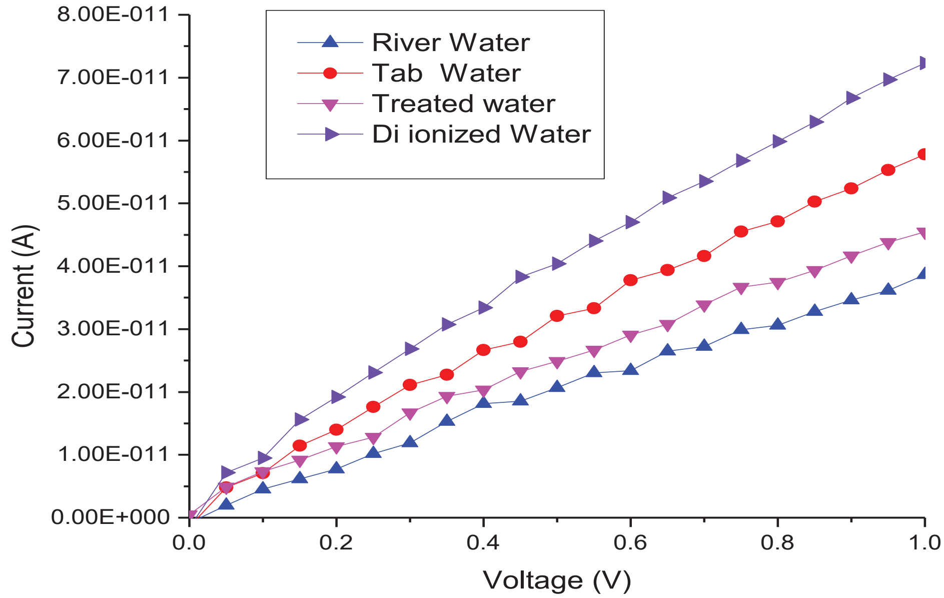

FIGURE 3. Nanowires Response to different water sources

To examine response of the devices 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 above 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 nanostructure, minimum curve In black indicating the minimum current recorded according with the barred device. Figure : I-V curves of surface modification with gnp/APTES, immobilization and hybridization To observed the behavior of charged molecules present in the sensor surface, from the series of the modification step, the device electrical profile are continue to altered as at any time when device is subjected surface treatment. 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 distance of each electrode, thus the band energy gap is reduced there by higher electrons exchanges occurred, the exchange is further becomes higher with modification elements are in aqueous form, this claim can be observed form 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 be at the aqueous the charge accumulation increase becomes eligible to jump from one electrode to another resulting in higher negative charge on the ide surface. The increase in ion charge enhance the charge accumulation on each electrode and this behavior consistent with many results of a similar experiment performed by Tijjani Adam and U. Hashim(2014), which can be further explained by DLVO theory (Adamczyk and Weronski, 1999). 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 (Adamczyk and Weronski, 1999)

CONCLUSION

In this study, silicon nanowire sensor was fabricated which can transduce high-performance sensing for bio-recognition. This surface chemically functionalized and gold solution was spotted to capture the heavy metals on this surface duplex formation and mis-match analyses were carried out. A clear complementation was found with the sensitivity and the simplicity of sensing domain makes it feasible to miniaturize for the development of point-of-care kits, facilitating its use in both clinical and non-clinical environments. With its novel electric response and potential for mass commercial fabrication, silicon based biosensor can be developed to become a portable biosensor for both field and diagnostic application

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