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GOLD NANOPARTICLES EMBEDDED SILICON CHANNEL BIOSENSOR FOR IMPROVED SENSITIVITY

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ABSTRACT

This paper presents the fabrication steps of a biosensor device on p-type silicon-on-insulator (SOI). The gold nanoparticles (GNPs) are used to enhance the sensitivity of the device. Conventional photolithography technique is used to fabricate the device. Optical and electrical characterization of the fabricated device are carried out using optical microscope and source meter. Surface morphology of the fabricated device is captured using scanning electron microscope (SEM) and atomic force microscope (AFM). Source meter is used to plot the I-V graph and to characterize the electrical behaviour of the fabricated device with or without GNPs. By incorporating the GNPs, higher current can be expected compared with the device without GNPs. Hence, with the addition of GNPs, it boost up the signal and enhance the sensitivity of the device.

Keywords: gold nanoparticles, silicon-on-insulator, sensitivity, surface immobilization, DNA hybridization.

INTRODUCTION

The completion of human genome study has encouraged the development of sensors for DNA diagnostics and forensic medicine. For example, with the biological properties, detection of cancer can be identified by the genetic changes during tumorigenesist. Moreover, infectious disease which is the first cause of death worldwide is detectable by genetic means. The changing of gene in DNA can be sensed. With the discovery of DNA, number of cases of illness, disability and death are significantly reduced (M. E. Ali, S. Mustafa, U. Hashim, Y. B. Che Man, 2012). A biosensor is a device used to measure biologically relevant information. Biosensor device is made up of two components which are biological component and electronic component. Figure 1 illustrates the principle of biosensor.

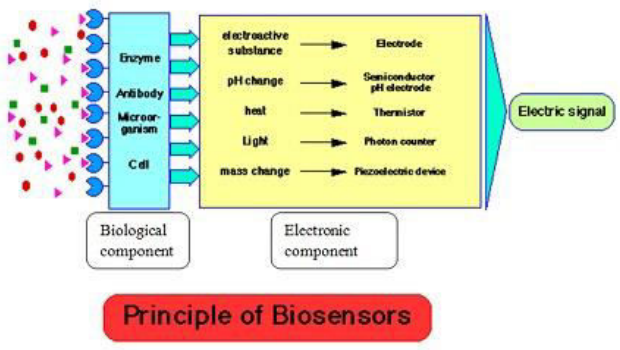

Figure-1. Principle of Biosensor (YOKOYAMA, 2014).

This paper discusses on the previous work done regarding the methods that have been used to fabricate biosensor. This includes the functionalization of the silicon channel (surface modification), the study of immobilization and hybridization of the DNA, and the use of the gold nanoparticles on the functionalized surface. The study of DNA detection and the technologies use to fabricate the devices are discussed.

GOLD NANOPARTICLES (GNPs)

Gold has always been the one precious and noble material. As a result of extensive research and continuous development, it has been discovered that gold can be used successfully for scientific purposes as well. One of these special uses of gold refers to what is called 'nanogold', 'colloidal gold' or 'GNPs' (Admin, n.d.). The use of GNPs is not recent, and the existence of these special gold particles has been known since ancient times, yet it was in 1850s that scientists focused their full attention on them. The main reasons behind this interest for GNPs are their extraordinary optical, electronic and molecular-recognition properties. These properties allow GNPs to be utilized in various fields of applications, including electron microscopy, electronics, nanotechnology and materials science (Admin, n.d.).

In earlier years, studies had proved that GNPs can be used to detect breast cancer. Due to the material properties, GNPs is believed can easily associated with the bio-receptors. Thus, GNPs are evolving in increase the sensitivity of biosensor.

According to Liu *et al.* (Liu, Tang, & Jiang, 2004), nanogold modification of the sensor surface in addition to the nanogold amplifier, DNA detection sensitivity was higher than 10-16 mol/L can be obtained in a quartz crystal microbalance (QCM) system, much higher than the ordinary QCM sensor without surface modification by nanogold. In the research carried out, a method known as the "nanogold amplifier method", where DNA-capped gold nanoparticles are used as an amplifier. This method has shown a great advantage in its improvement of the detection limit. The highest detection sensitivity obtained was 10-14 mol/L DNA. Although the sensitivity of DNA sensors have been greatly improved by this "nanogold amplifier method" and the effect increases as the particle size increases, but when the size of gold

amplifier further increases, the detection limitation still decreases after a certain size is reached (12 nm). In order to overcome this difficulty and to understand the nature of this phenomenon, this study investigated nanogold surface modification. Anyhow, the statement already proved that the present of GNPs will greatly boost up the sensitivity of a device.

To form the GNPs on the prepared silicon/polysilicon channel, there are two ways, either by using RF-sputtering or by using GNPs solution. Ang et al. reported, GNPs solution was prepared and the electrodes were immersed into the solution for 30 seconds (Ang *et al.* 2014). A hot plate with 150 °C was used to dry the electrodes for 20 minutes. The steps were repeated three times to enhance the reaction between 3-Aminopropyl triethoxysilane (APTES) and GNPs. RF sputtering is another method to embedded GNPs on the channel. The 4 nm Au wetting layer was physically deposited by RF sputter with the condition of 60 W RF-power at 1 mTorr pressure with 10 sccm gas flow rate for 4 s. As a consequence, Au grains were not fully connected together and, thus, started to become agglomerated and separated through the post-annealing process (Ryu *et al.* 2010). This method have a weakness where during the RF-sputtering, GNPs were deposited not only on the channel but also on the pad and substrate. The GNPs on the pad and substrate region could make the device "short" and reduced the sensitivity of the device. Figure-2 shows the image of GNPs embedded silicon nanowire (SiNW) device.

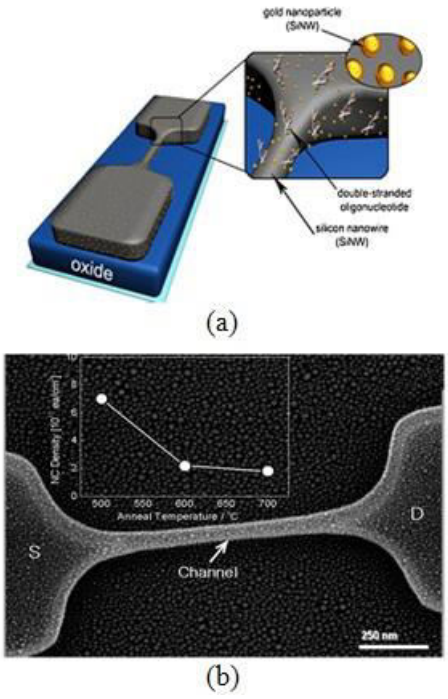

Figure-2. GNPs embedded SiNW (a) 3D-view and (b) SEM image(Ryu *et al.* 2010).

SURFACE FUNCTIONALIZATION

In recent years, many methods have been meticulously researched and created for the synthesis of functionalized surface of various materials, made it able to manipulate their biomedical properties, in particular, hemocompatibility (Alekhin *et al.* 2010). Organic functionalization produces a stable structure, lower bond polarity to silicon surface and present versatile application functional group such as alkyl, acid, amine, ester and others (Y. M. Ang *et al.* 2014).

In surface modification, there are two type of methods which by using APTES ("(3-Aminopropyl)triethoxysilane (APTES)," n.d.) or by using thiol-group. APTES is a solution which forms aminopropyl derivative of glass, which is an absorbent for affinity chromatography. It is commonly used to prepare positively charged slides suitable for use with various immunohistochemical and in situ hybridization procedures ("(3-Aminopropyl)triethoxysilane (APTES)," n.d.). These materials are coated on the surface of silicon or Poly-Si to functionalize the surface. The introduction of APTES is to improve the sensitivity of the silicon or polysilicon channel.

Another surface functionalization method is by using thiol-group, which is charged particle such as GNPs. GNPs have grown into significant interest because of their unique characteristics, such as out of ordinary optical and electronic properties, high stability and biological compatibility, controllable morphology and size dispersion, and easy surface functionalization [9,10]. Figure 3 shows the thiol-group structure.

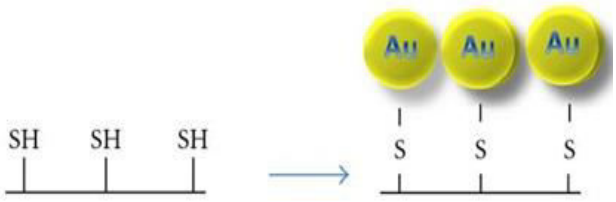

Figure-3. Thiol-group structure.

SURFACE IMMOBILIZATION

Surface immobilization is a process of implanting the probes (known as bio-receptor) on the fabricated device after surface modification using APTES. With the advent of latest technologies, it is possible to immobilize DNA probes with various methods. One of the methods is immobilizing the 2.5 µl of 10 µmol/L of probe DNA in phosphate-buffered saline (PBS) (pH 6.8, 50 mmol/L NaCl). Then, it is dropped on the modified electrodes surface to form gold-thiolate bond. 2.5 µl of ruthenium complex was added right after the probe DNA. After the DNA probe is dropped, the electrodes were then incubated at room temperature for 5 hours for the probes to implant on the modified surface (Y M Ang, Arshad, Foo, Noor, & Hashim, 2014).

Another method is by immersed the devices into deionized (DI) water solution containing thiolated DNA. This method is valid for the surface functionalization by using GNPs. A solution with 10 µM of thiolated-probe oligonucleotides for 2 hours and then rinsed with DI

water. The co-adsorption of the pre-immobilized DNA oligonucleotide layers on the GNPs was performed by 100 M mercaptohexanol (Sigma-Aldrich) for 30 min to displace such unwanted oligonucleotides probe which were not adsorbed through the thiol end group and to put the fallen oligonucleotide probe back up (Ryu *et al.* 2010).The current always have an increment after immobilization with the target probes. Figure-4 illustrated the process steps of immobilization and hybridization.

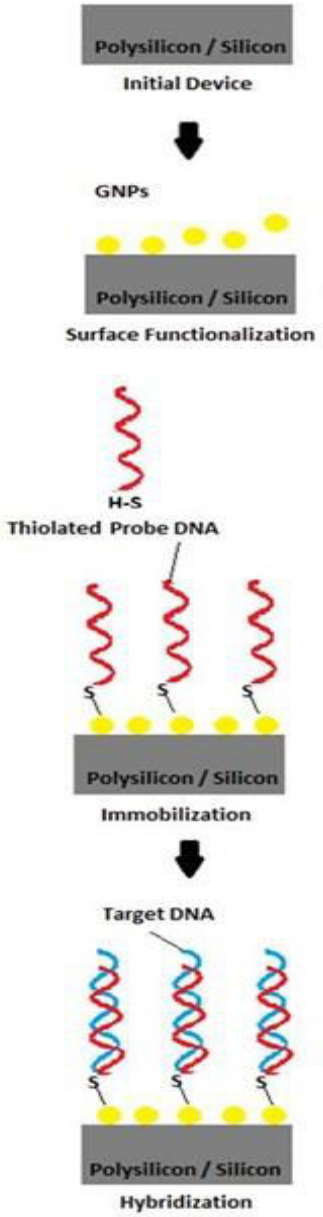

Figure-4. Process steps of immobilization and hybridization.

DNA hybridization is integration between optical and fluidic surface chemistry. After immobilization, the target DNA is dropped on the device. The immobilization of the probe and hybridization with the complementary target DNA were monitored by measuring the change in the electrical characteristics of the GNPs embedded SiNW device. According to Ryu *et al.* [6], I-V characteristics were measured by semiconductor parameter analyzer (Agilent, HP4156C) and a probe station in air environment, i.e., dried atmosphere. The drain voltage was swept from 0-5 V with the source grounded.

Figure-5 shows the result of hybridization. The electric current flow between two terminals, a source and a drain electrode, is measured to sense the immobilization of oligonucleotides probe and their hybridization with oligonucleotides target.

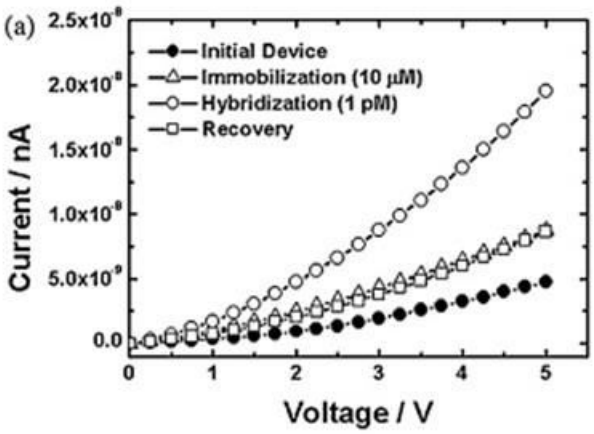

Figure-5. I-V characteristics of the GNPs embedded SiNW devices change without any adsorbate (filled-circle), with the probe oligonucleotides of 10 M (hollow-triangle), and the complementary target oligonucleotides of 1 pM (hollow-circle), and after recovery treatment (hollow-square) (Ryu *et al.* 2010).

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