Analysis on Gold Nanorod Interdigitated Electrode Sensor Using Simple Photolithographic Process

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Abstract. With the higher demand of preventative healthcare in order to minimize costs and improve healthcare systems, the development and enhancement of sensor technology is vital. It is essential to develop a diagnostic device that can minimize time and lower task in testing, and can effectively reduce manufacturing and delivery costs because of portability of its designs. Here, we briefly describe the fabrication of aluminum interdigitated electrodes and deposition of gold nanorod on the fabricated microelectrode that can detect changes on the modified surface of the aluminum interdigitated electrode. Electrodes made from aluminum was employed for the fabrication because it is the most widely used electrode. Gold nanorod was deposited on the desired surface in order to enhance an enzymatic Response. The use of gold nanorod also enhances the sensitivity of detection due to the decrease of the thickness of probed zone. A simple and facile method for the deposition of gold nanorod colloid was described via a simple photolithographic technique on the interdigitated electrode (IDE). The gold nanoparticles pattern deposition on IDE was investigated by high power microscope (HPM), 3D Profilometer, and atomic force microscope (AFM).

1. Introduction
The discovery of modified electrodes is vital in creating a new device with high sensitivity and selectivity since the modifiers deliberate captivating properties that will lead to a specific recognition of analytes [1-6]. The study of modification of electrodes is important in achieving a better comprehension of the nature of charge transfer methods within the thin films [7-12]. The modification of conductive surfaces involved adsorption and covalent bond formation. Recently, gold nanorods have encouraged much interest in modifying the surface of the electrodes due to their intriguing physicochemical properties [13]. For example, gold nanorod possess exceptional electrical and catalytic properties, large surface area to volume ratio and large number of active sites which make them principally suitable for analytical purposes [14]. The properties of gold nanorod intensely depend on their sizes and shapes, therefore a procedure for their synthesis, regulating their growth and their morphologies are important and interesting [15-16]. Photolithographic technique is a simple way of fabrication and electrodeposition. This method can sometimes have some limitations on the nanomaterial dimensions and their morphologies, but it provides a lot of advantages, particularly related to the rapid synthesis...
time, the absence of chemical reductants [17]. Furthermore, when the modifier film is directly deposited on the electrode it allows a better adhesion on the surface of the IDE. The quality of biosensors is primarily recognized by the specificity of the biomolecule alongside the quality of the transducer [18]. Also the reliability in analyzing the interactions of biomolecules is essential so as to achieve the contemporary quality assurance criteria. For the detection of analytes, a biosensor must possess characteristics such as, linearity, sensitivity, selectivity, reproducibility, and stability [19]. Biosensors with a high sensitivity is capable of detecting diseases at their early states and significantly proving the chance of possibly life-saving detection and intervention [20-22].

2. Material and methods

2.1 Starting Material

The starting material used in this project is 4 inch silicon substrate. The process was started by cleaning the silicon wafer to wash away any impurity that might be present on the surface of the wafer which could eventually disrupt the process of wafer pattern transfer. The silicon wafer was washed using RCA1 and RCA2. Then, oxide layer of silicon was grown on the wafer surface. This insulating layer is to improve the final performances of the device [23].

2.2 Mask design

The purpose of designing the mask was to fabricate the microelectrode. The mask was designed using AutoCAD software. The design of the mask consists of comb like finger structure between the two electrodes to create a gap between them [24]. Figure 1 shows the mask design using AutoCAD software.

2.3 Device fabrication

This part describes the fabrication of the aluminum interdigitated electrode. Before the fabrication process starts, oxidation of silicon was conducted using an evaporator machine. Simple lithography technique was used for the fabrication of aluminum interdigitated electrode [12]. AL IDE was generated by wet etching-assisted conventional lithography, with a gap between adjacent electrodes [13]. Photolithography technique is a technique that is used to transfer designed pattern from the mask to photoresist on the wafer surface [14]. After the aluminum was pasted on the silicon wafer, then followed by spin coating for 30s at 2500rpm was carried out. Afterward, the photo resists were exposed UV light by mask aligner. The time exposure was conducted for 12 sec to pattern transfer of the IDE mask on wafer surface. Then, the substrate was developed using RD6. Next, the photoresist pattern was etched.
in aluminum etchant and photoresist was stripped off using acetone. Finally, the desired shape and size of IDE were successfully exposed. The figure 2 bellow shows the Step-by-step fabrication process of the interdigitated electrode: (a) silicon substrate; (b) oxide layer on the silicon substrate; (c) placing the mask pattern on the photoresist layer; (d) transferring the mask pattern onto the photoresist layer; (e) depositing AL via electroplating; (f) removing the photoresist.

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Figure 2. Step of fabrication of IDE.

2.4 Deposition of gold nanorod on the IDE

The deposition of gold nanoparticles on the surface of aluminum interdigitated electrodes is crucial [28], and the fundamental studies of such modified electrodes have been performed to achieve a better understanding of the nature of charge transfer inside the thin films [29]. Furthermore, Generation of hybrid nanostructures has been attested as a promising approach to develop high-performance sensing substrates [30]. Gold nanorod was deposited using conventional photolithographic process. After the device was fabricated, the surface of the IDE was covered with gold nanorod and spin coated for 20sec, after the spin coating process was done, the device was placed on a hotplate for 30min for the full deposition on the IDE to take place and the device was finally removed on the hotplate instrument after 30min. As shown in figure 3.
2.5 Device characterization

After AlIDE fabrication by a standard UV-photolithography process, HPM, SEM, AFM and 3D profilometer were used to image the AL IDE. 3D and AFM were used to image the IDE before and after coated with gold nanorod. 3D-nanoprofilometer was used for three dimensional analysis of grains between AlIDE finger electrodes as shown in figure 4 below:

![Figure 3. IDE deposited with gold nanorod.](image)

![Figure 4. Characterization of IDE.](image)

| Parameter | Type of electrode | Description |
|-----------|-------------------|-------------|
| With      | 250 μm            | Finger electrode width |
| Gap       | 20 μm             | Gap between finger electrodes |

3. Result and Discussion

Aluminum IDE was successfully fabricated and coated with gold nanorod. After the fabrication was carried out, the device was inspected by using high power microscope, scanning electron microscope, 3D Profilometer, and atomic force microscope. The surface characterization is important in examining the IDE surface[31]. The HPM and SEM images show that the aluminum electrode has been successfully fabricated without any distortion and gold nanorod was successfully deposited (figure 3). The material used for the fabrication of IDE electrode is aluminum. The fabrication was done using photolithography.
process for resist development. Figure 4a indicates the bare IDE image taken using high power microscope. As it can be clearly seen that the characterization of the bare IDE image using high power microscope was successful since no any distortion was detected. The images of an IDE sensor taken using high power microscope after being deposited with gold nanorod is shown in figure 4b, the gold nanorods were well covered on the desired surface of the IDE as it can be observed as dusky spots on the IDE surface.

Figure 4c shows the image taken using 3D Profilometer of with gold nanorod deposited on the surface of the IDE, the surface roughness of the IDE can be seen clearly with the gold nanorod evenly dispersed on the IDE. Also figure 4d shows the image of IDE taken using 3D Profilometer, as it can be seen clearly that the IDE was patterned properly. Figure 4e indicates the image taken using SEM with a gap size and finger electrode lengths. The gap of the IDE image was revealed by SEM to be 40 μm and the finger electrode lengths were 86 μm and 85 μm respectively. Figure 4f indicates the 3D image of IDE after gold nanoparticles were deposited on the surface of the IDE. AFM image uncovered gold surface. The coating of aluminum interdigitated electrode with gold nanorod was also controlled by atomic force microscope. The obtained layer is continuous, remarkably smooth, and densely uniform compared with bare IDE surface, without any error.

It is clearly shown that with the presence of gold nanorod, the surface becomes rough as in the above. The surface roughness improves the sensitivity of biomolecule detection as greater number of surface area was obtained [32]. Higher surface area to volume ratio allows higher sensitivity detection of biomolecules. It can be observed that the aluminum possesses very low surface roughness. Unlike gold nanorod, harsh surface with high porosity surface pattern formed. Basically, the rough surface provides higher surface to volume ratio that allows better sensitivity towards the biosensor devices [14]. The SEM imaging was used to analyze the morphological features of gold nanorod. Gold nanorod distinctly formed on aluminum interdigitated electrode due to the unique morphology of aluminum interdigitated electrode. The smooth surface of silicon wafer does not incite the formation rock-like structures. The aluminum interdigitated electrode grown via photolithography shows a unique irregularly spaced structure with rippled surfaces that cause the gold nanorod to self-assemble into rod-like structure. Table 1 shows the measurement IDE gap and finger electrode lengths. As it can be clearly seen that the gap is 40 μm and the finger electrode lengths of 86 and 85 μm. Based on the morphological characterizations conducted, we can conclude that the fabrication and deposition of gold nanorod were successful.

4. Conclusion
The advantages of using gold nanorod for surface modification is that, they have electrochemically active surface areas and the better accessibility of the analyte to the surface of the electrode. Fabrication of IDE and coating of gold nanorod were described based on photolithographic method. The method serves as a coating for a conductive surface to develop an electrochemical sensor with an actively modified sensing surface. This method is simpler and cheaper than other modification techniques. The bond of the coating is better and gold nanorod are already adhered to the IDE surface without the application of any supplementary chemical that might inhibit subsequent sensing materials. Nevertheless, this method produces a low amount of material on the electrode surface, making the characterization more complex. Hence, further optimization is needed for the fabrication of submicron of IDEs in order to improve the sensitivity.

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