INTERNATIONAL JOURNAL OF ENHANCED RESEARCH IN SCIENCE TECHNOLOGY & ENGINEERING

VOL. 1, ISSUE 1, OCT. 2012 ISSN NO: 2319-7463

DI Water Electrical Characteristics Monitoring Using in House Fabricated Polysilicon Nanoelectrode Based Transducer

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Abstract— Deionized water is essential to many medical, manufacturing, food processing, and other industrial applications. The research about the characterisation of nanoelectrode transducer using biomolecule detection technique has been studied to understand the important relationship between the biomolecule and the nanoelectrode. Conventional photolithography technique is applied by using polysilicon on silicon substrate to fabricate a nanoelectrode transducer and employed as an electrochemical nanoelectrode sensor to measure the DI water electrical characteristics. Physical characteristics checked optically using Single Electron Microscopy (SEM), low and high power microscopy to inspect the dimensions and the absence of particles. Then, by dropping the DI water on the nanoelectrode, electrical characteristics are measured using Dielectric Analyzer and probe station to measure the capacitance of the transducer. From the experiment, this ultra-high sensitive device is able to measure the capacitance as low as 98nF in a very low frequency. The effect on DI water is investigated and optimized for the application in DI water electrical measurement.

Keywords- DI water, Nanogap Capacitor, Nanoelectrode, pH, Polysilicon, Transducer

I. INTRODUCTION

Nanotechnology is the design, characterisation, production and application of materials, devices and systems by controlling shape and size of the nanoscale [1]. The manufacturing is also done in nanoscale and the fabricated devices are so precise that every atom has to be placed in a right place. The advantages of nanotechnology have brought miniaturization of products, novel combination of properties and universal fabrication technology [2]. One example of it is the miniaturization of mobile phone. The evolution of the technology now brings us to nanosensors. Nanosensors are any biological, chemical, or surgical sensory points used to convey information about nanoparticles to the macroscopic world. Their use mainly include various medicinal purposes and as gateways to building other nanoproducts, such as computer chips that work at the nanoscale and nanorobots[3]. These sensors are applied in construction, material sciences, precision engineering, testing and analysis fields. The applications of transducers also have been used many centuries ago, for example a canary in a cage, as used by miners to warn of gas, could be considered a transducer [4]. Many of today's transducer applications are similar, in that they use organisms which respond to toxic substances at much lower concentrations than humans can detect to warn of the presence of the toxin. Such devices can be used in environmental monitoring, trace gas detection and in water treatment facilities [5].

To understand how water behaves within nanoscale structures is critical in deciphering biological information. For example, water plays a key role in protein structure and function, cell architecture, and cell function. The author presents a unique nanoelectrode transducer that is capable of detecting changes in the structure of water and ice. Using dielectric spectroscopy inside a nanoscale cavity between two electrodes, we observe the structural changes in a network of small molecules such as water. They also demonstrate the effectiveness of a nanoelectrode transducer on detecting the changes in structure of water as it freezes under different ionic conditions [6]. Deionized water, also known as demineralized water, is water that has had its mineral ions removed, such as cations from sodium, calcium, iron, copper and anions such from chloride and bromide [7]. Deionization is done by using a specially manufactured ion exchange resins which bind to and filter out the mineral salts from water. Since the majority of water impurities are dissolved salts, deionization process will produce high purity water that is similar to distilled water. The process can be done continuously and inexpensively using electro-deionization. In semiconductor manufacturing processes DI water is very important for cleaning purposes and requires high purity so that none of the impurities can contaminate or change the electrical characteristics of the water.

II. METHODOLOGY

A. *Starting Material*

The research has been conducted in our Nano-biochip Laboratory at UniMAP. The following points are considered and the details of the fabrication steps are explained. The starting material used in this project is N-type, 100 mm in diameter (4 inch wafer) Silicon substrate and silicon-on-insulator (SOI) wafer as shown in fig. 1. Silicon on insulator (SOI) wafer is used to reduce parasitic device capacitance and thus improve the final device performance. Prior to fabrication process, the Si & SOI wafers are prepared as follows:

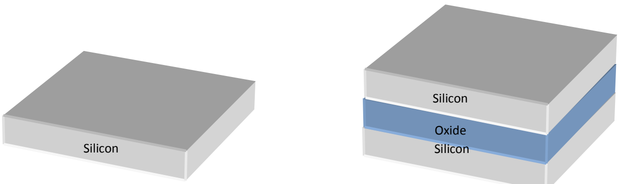


Figure 1: (a) Silicon Wafer (b) SOI Wafer

The first process is to check the wafer type from its specification, measure wafer thickness (Si thickness), measure the sheet resistance. After doing this, the backside of each wafer lightly scribed and the top surface is protected using provided scribe tool. The wafer is marked gently and making it visible and scribed wafer placed in container. Wafer is cleaned before each process. Then, the SOI wafer is doped with boron on the silicon layer using spin on dopant technique. Concentration and sheet resistant is checked again to make sure the doping process gives effect to the structure [8].

B. Mask Design

In this research, two photo masks are employed to fabricate the nanoelectrode using conventional photolithography technique. Commercial Chrome mask is expected to be used in this research for better photo masking process. In this study, we have used p-type; 100 mm in diameter (4 inch wafer) silicon substrate wafer to fabricate the nanoelectrode structure. For the fabrication of the polysilicon nanoelectrode with Aluminum (Al), first we have designed two masks and gently applied on silicon (Si) substrate following the process flow to accomplish the required task [9]. During the process flow, dry etching RIE is used to form the polysilicon nanoelectrode and wet etching for the Al electrode structure. Anisotropy of RIE is modeled and the etching profiles are simulated.

Fig.2 is showing the first mask for nanoelectrode electrode formation with length and width of 5000µm and 2500µm respectively, and the actual arrangement of device design on chrome mask. It consists of 160 dies with 6 different designs as shown in Fig. 3. The proposed angle length of the end electrode is taken sixth scale start from 100µm until 1100µm increase by 100µm for each Sd length. This is simply to check the best angle for the best nanoelectrode formation after etching process [9]. The symbol Sd refers to the dimension of the side angle for the nanoelectrode design formation. It shows that when Sd is large the nanoelectrode becomes very sharp and less sharp with smaller dimension of Sd. The photomask is designed using AutoCAD and then printed onto a chrome glass surface. Fig.4 is showing a schematic design of mask 2 with 1500µm length and 1500µm width. The distance between two squares is 3500µm, also the schematic of mask on chrome glass is shown in fig 5.

Figure 2: Schematic design of the actual mask on chrome glass.

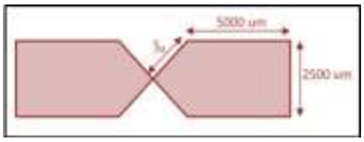


Figure 3: Design specification of the first mask

Figure 4: Schematic design of mask 2 on chrome glass

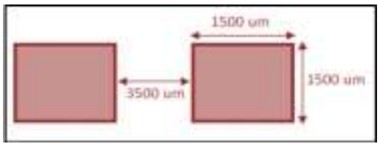


Figure 5: Design specification for mask 2

*C. Nanostructure Fabrication*The process steps of the polysilicon microgap with Al pads are described here in brief. A clean Si wafer is deposited with 150nm SiO2 using LPCVD process as in fig. 6 (a). In a next step 600nm polysilicon layer is deposited using a LPCVD process before evaporating 135nm of the Al as in fig. 6 (b&c) using a resistive heating process (the Al layer used as a hard mask) to avoid damage of the polysilicon layer during the etching/ RIE process [8]. Next, in the photolithography process, a 1200nm layer of positive photoresist is first applied on to the Al surface, and then exposed to ultraviolet light through mask 1 as in fig. 6(d). After resist development, only the unexposed resist will remain and then wet etching process of Al layer is done before removing the resist as in fig. 6 (e). After that, a dry etching process is applied on the polysilicon layer to fabricate the microgap for the micro structure as in fig. 6(f). Then a layer of 135nm Al is deposited before the resist coating process, fig.6 (g). After exposing mask 2 the layer of the resist is developed as in, and then wet etching process of Al substrate is performed before removing the resist [8]. Finally a structure with the Al contact electrode polysilicon nanogap electrode is obtained as shown in fig 6 (h).

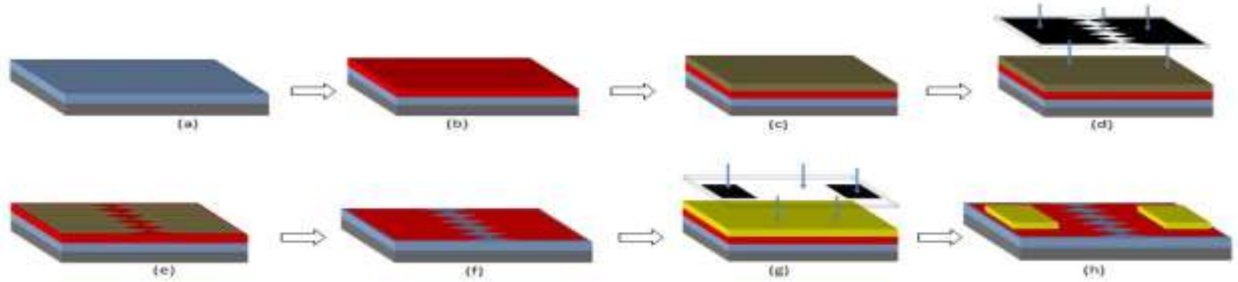
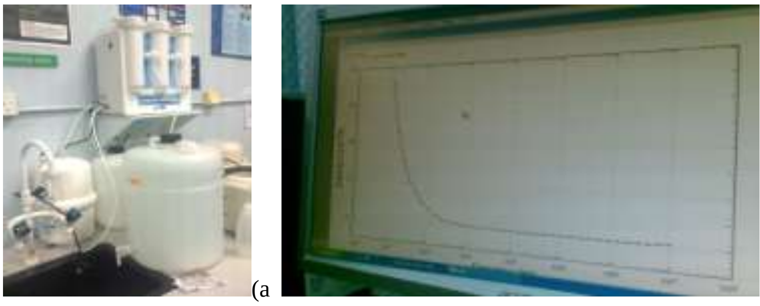


Figure 6: The process flow for the fabrication of Aluminium electrode polysilicon nanoelectrode structure.

D. Nanoelectrode Measurement and Characterization

The fabricated nanoelectrode structures are characterized by low power microscopy (LPM), high power microscopy (HPM) and a scanning electron microscope (SEM). The images are taken to compare the gap sizes and its sensitivity. Fig. 7 shows the final device structures used for the electrical characterization using a Dielectric Analyzer. The transducer will thus act as a capacitor between two polysilicon nanoelectrodes which is connected to aluminum pads [10]. The DI water is obtained from the installed Low Range RO Series Water Purification System in the laboratory which was purchased from SASTEC Laboratory Equipments. The capacitance is measured by dropping DI water in between the nanoelectrodes. Then a graph is plotted for capacitance versus the voltage frequency of the analyzer as in fig.8.

Figure 7: Characterization of nanoelectrode transducer



(a (b)

Figure 8: (a) Low Range RO Series Water Purification System in the laboratory. (b) The results are obtained in form of graph according to the voltage frequency.

The final device will be connected to the analyzing equipment for measurement set-up. Probing is done to the aluminum pads on the device as shown in fig.9. At each measurement, the device is tested in the cleanroom environment to standardize the condition of test. The raw data obtained will be recorded and discussed in the final report and thesis.

Figure 9: Capacitance measurement set up with a dielectric analyzer

E. Detection and Measurements

Before starting the measurements using the prepared nanoelectrode, the nanoelectrode is cleaned using de-ionized water followed by dry spinning and then soft baking in less than 100º C for few minutes [10]. After that the DI water is dropped wise across the nanoelectrode structure and the change in the capacitance is measured.

III. RESULT AND DISCUSSIONS

A. Optical Characterization

The nanostructure is first inspected by using LPM, HPM and SEM. The smallest gap sizes are chosen for the characterization process. When the distance between plates is decreased, the capacitance will be increased. Fig.12 below is the images of the biosensor taken with low power microscopy;

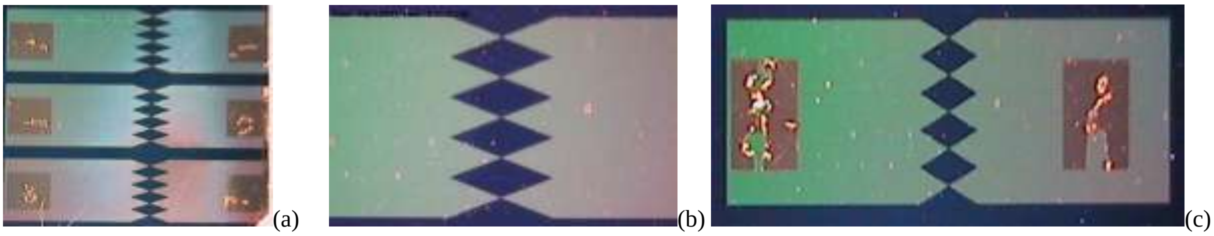

(a) (b) (c)

Figure 10: The images are taken using low power microscopy. (a) the nanoelectrode biosensor on the Si wafer; (b) close view on the gaps; (c) image of the whole device.

The images of the nanostructures are again taken with high power microscopy as in Fig.13 to inspect the presence of particles or impurities. It is important so that, the measurements are not affected during the characterization process. The dimensions and alignments also inspected for a good nanoelectrode.

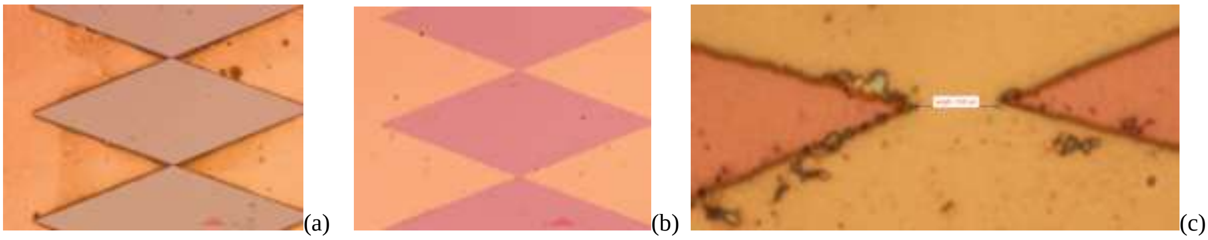
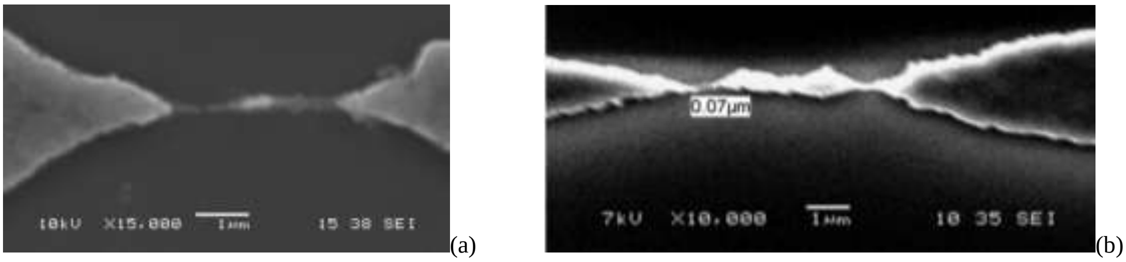
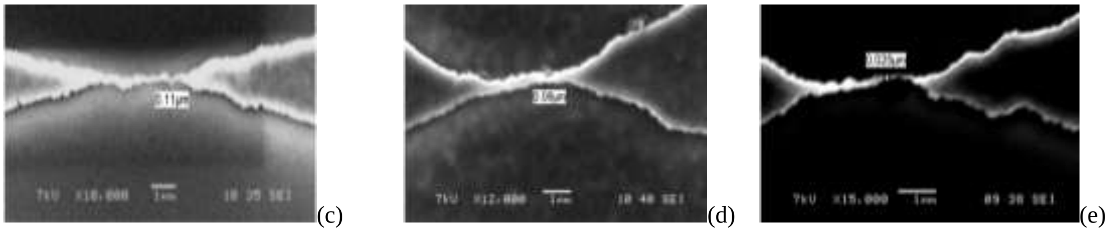

(a) (b) (c)

Figure 11: Images taken with high power microscopy. (a) nanoelectrode area are contaminated; (b) good nanoelectrode structure; (c) the distance between gaps are measured.



(a) (b)



(c) (d) (e)

Figure 12: These images are taken using Single Electron Microscopy (SEM). (a) nanoelectrode image at 1micron; (b) gap size of 70nm; (c) gap size of 110nm; (d) gap size of 60nm; (e) the smallest gap size of 25nm.

B. *Electrical Characterization*

DI water is commonly used for lab purposes. It is used for cleaning and dilution for solutions. To characterize the DI water, we had exposed it onto the nanoelectrode structure to read its electrical characteristics. By using Dielectric Analyzer in probe station, the data for capacitance of DI water is taken and plotted against the voltage frequency in table 1. For comparison, DI water and air characteristics plotted in the same chart as in fig. 13.

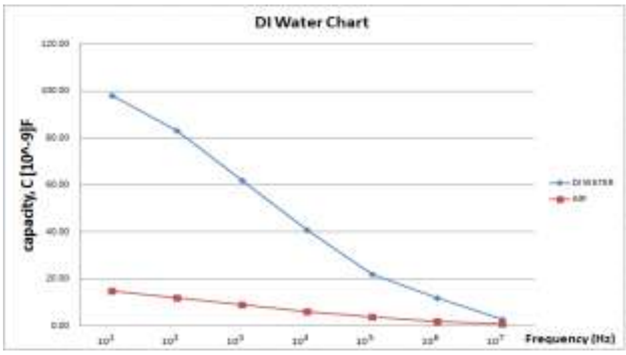


Figure 13: DI water characterisation chart for capacitance test.

TABLE 1: LIST OF DATA ACQUIRED FOR DI WATER CAPACITANCE MEASUREMENT.

	Voltage Frequency (Hz)						
Dielectric Medium	10^1	10^2	10^3	10^4	10^5	10^6	10^7
Di Water (C, nF)	98.00	83.00	62.00	41.00	22.00	12.00	3.00
Air (C, nF)	15.00	12.00	9.00	6.00	4.00	2.00	1.00

To discuss the characteristics of the DI water, the dielectric analyzer reads the amount of electron passes between both nanoelectrodes and therefore the chances of the electron moves across nanogap increases when the frequency voltage is low. The device shows high sensitivity when exposed to DI water during voltage frequency of 10Hz. Thus, this device can operate in very low power and showing ultra-sensitive results at the same time. Besides that, when the gap between the electrode reduces, the capacitance (1) of the device will increase [11].

$$Capacitance, C = \frac{\varepsilon A}{d} \tag{1}$$

Based on the capacitance value of DI water, the capacitance value can be determined since the transducer behaves as a capacitor and the solution dropped in between behaves as the dielectric material.

III. CONCLUSIONS

The DI water detection technique has been successfully demonstrated as a DI water transducer. By applying simple conventional lithographic method we have fabricated the proposed polysilicon nanoelectrodes for DI water sensing. The capacitance is measured when the nanoelectrode sensor was exposed to DI water sample. Our results present a potential development towards future practical application of our proposed fabricated nanoelectrode electrodes for the bio-molecule detections.

ACKNOWLEDGEMENT

Author Sharma Rao thankfully acknowledges collaborators at the Institute of Nano Electronic Engineering (INEE) at University Malaysia Perlis (UniMAP). This work was supported by INEE at (UniMAP), through the Nanotechnology project. The views expressed in this publication are those of the authors and do not necessarily reflect the official view of the funding agencies on the subject.

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