Electrical Characterization of Gold Contact on Porous Silicon Layers

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***Abstract*—Investigation on metallic contact on porous silicon (PS) layers is typically important before final integration into application devices. The electrical characterization of Au thickness of 100 nm and ~210 nm on ~3 µm and ~6 µm PS thickness on PS were studied by measuring the current-voltage (I-V) response. The PS layers of n-type oriented silicon (Si) wafer were prepared by electrochemical etching. Au was deposited on the PS layers using Q150RS automated sputter coater. Based on scanning electron microscope (SEM) images, the thickness of PS was confirmed as 3.07 µm and 6.15 µm for respective samples. The average pore diameter was determined with the aid of ImageJ and Matlab by applying image processing analysis. There were found to be 17.91 µm and 27.26 µm respectively. The I-V curve of PS with Au contact showed significant tendency of Ohmic behaviour compared to non-PS samples that shows Schottky behaviour. The higher conductivity was obtained from sample 3.07 µm of PS thickness with 100 nm Au. Based on this analysis, it can be concluded that thickness of Au and thickness of PS affect the performance of Au-PS device as the conductivity increases as the thickness of Au on PS layers was decreased.**

Keywords—Porous silicon; electrochemical etching; contact

I. INTRODUCTION

Nowadays, porous silicon (PS) is gaining scientific and technological attention as a potential applications platform in sensing and photonic devices. PS also has opened up for new alternative materials in micro and optoelectronics such as chemical sensor, temperature sensor, photodetectors sensor, light emitting diodes, passive optical filters and micromechanical components [1-7]. The extremely large surface to volume ratio of PS, the ease of its formation, control of the surface morphology through variation of the formation parameters and its compatibility to silicon (Si) IC technology leading to an amenability to the development of smart systems-on-chip sensors, have made it as a very attractive material [2].

Due to enormous advantages and potential offered by PS, the study on characterization of metallic contact on PS-based device is also needed to fulfil a good PS-based device criteria. It is important to establish good electrical contact with the volume of the PS structure for realizing the appropriate applications in the microelectronics industry. The quality of the PS-metal contact and the electrical properties of PS have attracted much attention among researchers [8]. The metallic contact must be stable enough and allows for good conduction. Therefore investigation on the type of contact created between metal and PS layers, as well as its electrical properties would be the scope in this study. The aim of this paper is to study the effect of deposited Au on PS substrate with different thickness condition by characterizing the electrical properties the fabricated Au-PS structure.

II. METHODOLOGY

A. Electrochemical Etching

The substrate used in this study was n-type phosphorus-doped Si (100) wafer with single sided-polished, thickness of 625 – 675 µm and resistivity of 0.008 – 0.018 Ω cm. After cutting the wafer into 1 cm x 1 cm substrates' size, the samples were cleaned using standard RCA (Radio Corporation of America) procedure to eliminate any surfaces contaminations and native oxide layers.

Then, Si sample underwent the electrochemically etching process in a mixture of hydrofluoric (HF) acid 49% and ethanol (C_2H_5OH) 95% electrolyte solution. The mixture ratio of HF to C_2H_5OH was 1:4 by volume. The experiment was conducted by setting the current density at ~20 mA/cm^2 and under 4 W lamp illumination. The Si substrate sample was connected as anode while platinum (Pt) wire was connected as cathode. The etching time was varied in 10 to 30 minutes range. Scanning Electron Microscope (SEM) and image processing techniques were used to study the characteristic of PS morphology. Table I summarizes the etching condition for samples used in this study.

TABLE I. ETCHING CONDITION OF THE SAMPLES

Sample	Current density, J (mA/cm^2)	Etching time, t (min)
1	21.97	30
2	19.87	30
3	20.38	30
4	19.94	20
5	20.03	10

B. Au Deposition

The Q150RS automated sputter coater was used to deposit Au layer on PS structure. It was a dry deposition process. The deposition current was set to 40 mA and deposition rate was about 30 nm/min. A physical mask using Al plate was prepared prior the Au deposition as shown on Fig. 1. The distance between the two contacts was ~2 mm. The mask was used to cover the PS surface and only that exposed area will be deposited with Au.

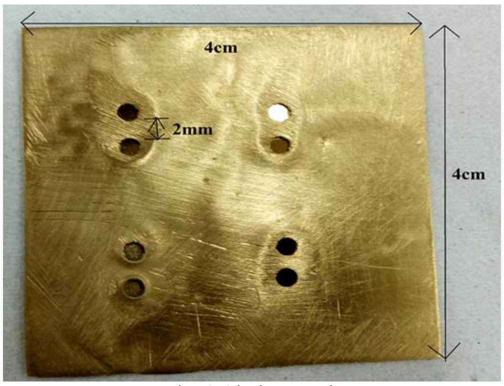

Fig. 1 Al plate mask

C. I-V Measurement Setup

The 2400 Keithley series source meter unit (SMU) with Kickstarter software were used to measure the electrical properties of the PS substrate with and without Au contact. Two points probes were used and connected to the Au contacts on PS substrate to measure the electrical properties. The schematic setup used for this measurement is shown in Fig. 2.

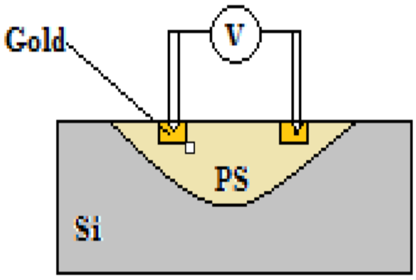

Fig. 2 Schematic of measurement setup

III. RESULTS AND DISCUSSION

A. Morphological Characterization of PS

A simple early test on PS luminescent ability has been conducted by exposing the fabricated PS under ultra-violet light as shown in Fig. 3. It was reported [1-2] that PS might able to emit light under ultra-violet radiation if its luminescent property was good. From the test, all samples fabricated in this study did not emit any red-brownish or red-orange color as predicted. The possible reason of no emission obtained for these samples was the Si-H_2 bond in the PS structures that keep PS layers fluorescence intensity and wavelength stability [9]. Besides, the factor of porosity of PS also might affects the luminescent properties. However, the actual porosity of the fabricated PS was not evaluated yet in this study. As reported in [10], it was claimed that any PS sample with below than 55% porosity will not produce any PL properties. Therefore, it was predicted the porosity of fabricated PS in this study probably below than 55%.

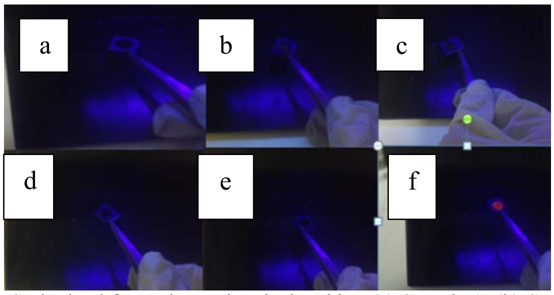

Fig. 3 PS obtained from electrochemical etching (a) Sample 1, (b) Sample 2, (c) Sample 3, (d) Sample 4, (e) Sample 5, (f) Reference sample that emit red-orange color (fabricated at different etching condition)

The combination of equipment and tools such as SEM, image processing technique and Matlab were used to characterize the morphology (surface, pore size and thickness) of the fabricated PS before deposition of Au. Due to technical constraints and limitation (such excessive cracks found on samples), only two best samples were chosen for SEM characterization. The top view surfaces of PS samples are shown in Fig. 4 and Fig. 5 respectively.

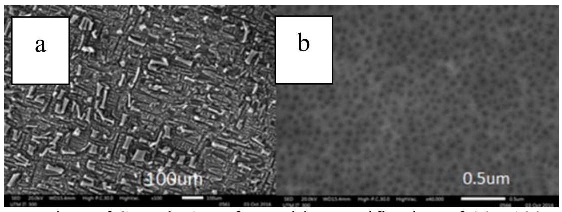

Fig. 4 Top view of Sample 1 surface with magnification of (a) x100, and (b) x40000

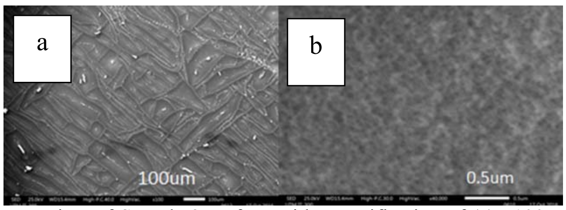

Fig. 5 Top view of Sample 2 surface with magnification of (a) x100, and (b) x40000

From the SEM images, it was found that PS existed in both Sample 1 and 2 although they did not emit light in previous early testing. Pores were randomly distributed in almost uniform density. By using image processing tools, pore size was determined. The software used was ImageJ. From the SEM image, the threshold pixel value was optimized to differentiate the background and foreground of the image. Then, by applying closing process to the image, the noise of the image was reduced and pores image became clearer. Next, process of segmentation was applied to the image to count the pore distributions. From the segmented image, several data such as perimeter, area and dimensions were extracted. Fig. 6 shows the overall process involved for image processing.

Next, the data extracted from ImageJ software was transferred into Matlab to plot the pore size distribution as shown in Fig. 7. From the analysis, the pore size of Sample 1 was distributed between 20 to 30 µm range with average pore diameter of 27.26 µm. On the other hand, Sample 2 had the average pore diameter of 17.91µm and pore mostly distributed in 0 to 20 µm range.

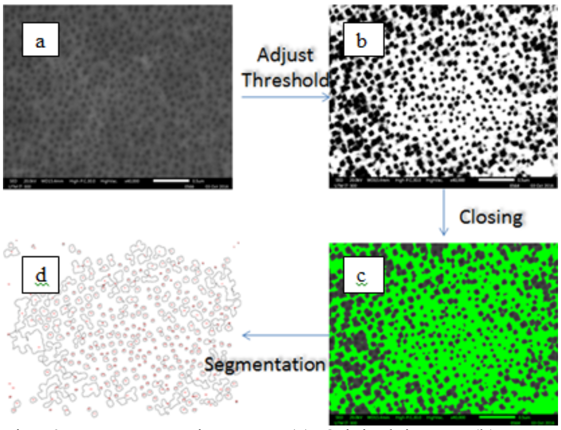

Fig. 6 Image processing steps (a) Original image. (b) Image output after adjusting the threshold. (c) Output of closing image. (d) Output of segmentation step.

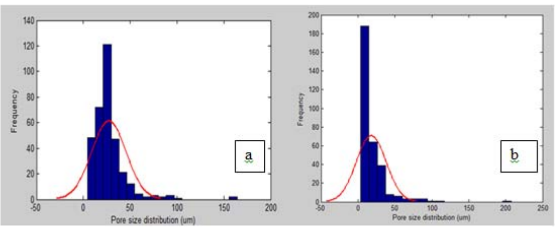

Fig. 7 Pore size distribution using Matlab for (a) Sample 1 and (b) Sample 2.

Besides pore size distribution analysis, the thickness of PS also had been confirmed by observing the cross sectional view using SEM. It had been confirmed that the PS thickness of 3.07 µm and 6.15 µm were obtained for respective Sample 1 and 2.

B. Electrical Characterization

Subsequently, the Sample 1 was cut into two pieces as well as Sample 2 to deposit each pieces with different thickness of Au. The thickness of deposited Au on PS substrate were 100 nm and 210 nm. Current-voltage (I-V) response was measured and recorded as shown in Fig. 10 and Fig. 11.

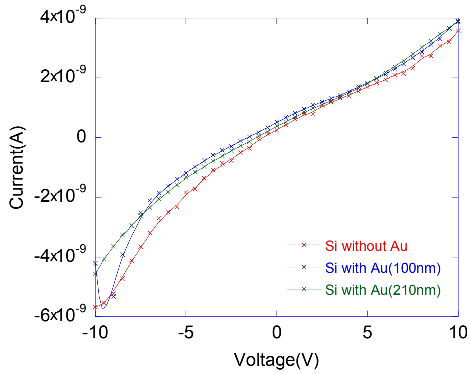

Fig. 10 Si (non-porous sample) electrical characteristics

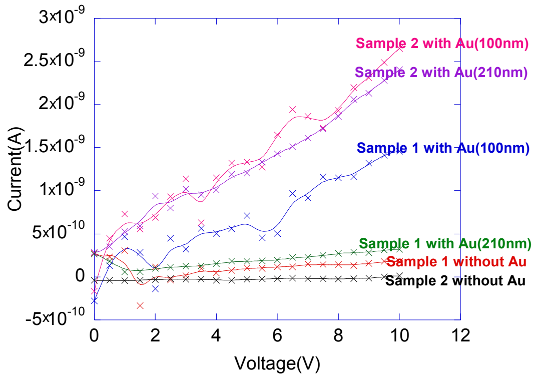

Fig. 11 Electrical characteristics of PS

From Fig. 10 and Fig. 11, it can be seen that I-V characteristics of the sample is strongly related with the formation of the pores and Au deposition. Thickness of PS and Au thus affect the I-V characteristics. The slope of curve represents the conductivity of the samples [12]. The conductivity is increasing as the slope of curve increases. Based on the slope, the non-porous samples shows generally the Schottky-like properties while PS samples show Ohmic properties as the linear-like curve was observed. With that, it suggested that combination of Au-Ps could be possible as good contact in PS-based devices. By neglecting the PS thickness, there were significant changes in conductivity basically observed for PS with Au compared to without Au. However, PS with higher thickness (Sample 2) had shown better compared to Sample 1. Moreover, Sample 2 with 100 nm of Au shows better conductivity than with 210 nm of Au. It also demonstrates the highest current conductivity from other PS samples. In contrast, Sample 1 with 210 nm of Au shows better conductivity than with 100 nm of Au. The results suggests that behavior of Au/PS interfaced were relying on the suitable thickness combination of metal and substrate. Further optimization is required to clarify this behavior.

IV. CONCLUSION

PS structures were successfully fabricated by electrochemical etching by varying several parameters conditions. The effects of parameters were physically observed in general. Variation of PS thickness was obtained from varying the etching time. The study of PS morphology was done using SEM, and image processing analysis with the aid of Matlab and ImageJ. The morphology of PS was dependent on the etching circumstances. The electrical properties of the PS and Au-PS samples were studied by evaluating the I-V characteristics on each PS with and without Au contacts. The results showed that thickness of Au and thickness of PS affect the performance of Au-PS device. The best conductivity of the results was obtained for PS sample with thickness of 3.07 μm (Sample 1) and 100 nm thickness of Au contact in this study.

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