Enhancement Efficiency of UMSM Photodetectors by Doping AP and IPA in TMAH Solutions for Fabrication Process

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Abstract— **This paper presents electrical characteristics and finds the conditions in UMSM photodetectors fabrication by chemical wet etching process. Isopropyl alcohol (IPA) and ammonium peroxodisulfate (AP) technique was doped into tetramethyl ammonium hydroxide (TMAH) solutions. Using n-type silicon wafers these have resistivity as 5-10 ohm-cm. It was found that doping 7 gm/l AP with 5wt% TMAH, surface of silicon was etched smoother than adding 30 %vol IPA into 25 wt% TMAH solutions approximately 5 times. Then measure the electrical characteristics of UMSM photodetectors to determine dark current and photocurrent. UMSM photodetectors was fabricated by 5%wt TMAH solutions 7 gm/l AP added technique with leakage current and photocurrent are 7 µA and 57.7 µA, respectively. And UMSM photodetectors was fabricated by 25 %wt TMAH solutions 30 %vol IPA added technique with dark current and photocurrent are 8.9 µA and 46.1 µA, respectively. According to this study found that TMAH solutions with AP added is suitable for design photodetector in further research.**

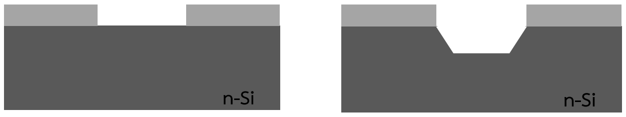
Index Terms— **photodetector, TMAH, chemical wet etching, smooth surface**

I. INTRODUCTION

A photodetectors is a device that measures the intensity of light that can be converted to electrical characteristics by absorbing the energy of photons to stimulate the release of free carriers[1]. In this research, we are studied the MSM (metal-semiconductor-metal)photodetectors structure. MSM photodetectors is a photodetector device containing two schottky contacts. MSM structure's characteristics are low capacitance, good stability, high sensitivity, planar devices, simple fabrication process and most importantly, it can be easily integrated circuit[2].For these characteristics, research has been conducted to improve the efficiency of the MSM photodetectors.

From the previous research, MSM photodetectors had a simple fabrication process and not too complicated which, we called that planar structure. However, planar structure has only sensor area depending on the spacing of the electrodes. In this work, sensor area of the photodetectors is increased without increasing the spacing of the electrodes by the etching process of the surface of the sensor area (figure 1) [3]. Etching process is divided into two types are wet etching and dry etching. In this research, wet etching is used in the fabrication process. It has the advantage that it is harmless and no complicated equipment preparation [4].

In this experiment, Tetramethyl ammonium hydroxide (TMAH) was used in the experiments where TMAH solutions had no toxicity problems, thus providing greater safety than other chemicals. TMAH solutions is anisotropic etching, which makes the surface of the photodetectors look like a U-shaped [3]. We call these fabrication processes that the process of fabrication a U-shaped MSM (UMSM) photodetectors. Comparison of isopropanol alcohols (IPA) [6] and ammonium peroxodisulfate (AP; $(NH_4)_2S_2O_8$) [5] was doped into TMAH solutions to reduce the surface roughness to be smooth. The roughness will have the least effect on the electrical characteristics of the UMSM photodetectors.



(a) (b)

Fig 1. Cross section of planar MSM (a) and U-shaped MSM (b) photodetectors.

II. EXPERIMENTAL

N-type (resistivity 5-10 Ω-cm) single crystal (100) silicon wafer were used for fabrication process of UMSM photodetectors. Initially, an aluminum metal layer of thickness around 2 µm was deposited by RF magnetron sputtering process and a silicon dioxide layer of thickness around 2.4 µm was grown by PECVD process. Square electrode windows of UMSM photodetectors were opened at the front side of the wafer by photolithography process. Then, some areas of silicon dioxide layer, aluminum layer and native oxide were removed using BOE, special aluminum etchant and HF 5%, respectively. By process flow was described in Figure 2. Finally put the samples into the next etching process.

Etching solutions were prepared by adding IPA into TMAH solutions and mixing AP into TMAH solutions. Experimental process is divided into two parts. First part,

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etching studies with 25wt% TMAH solutions and adding IPA 10 vol%, 20vol% and 30vol%, respectively. Second part, etching studies with 5wt% TMAH solutions and doping AP 5, 6, 7 and 8 gm/l, respectively. A temperature of 80˚C and 200 rpm of magnetic stirring are defined for use in the etching process.

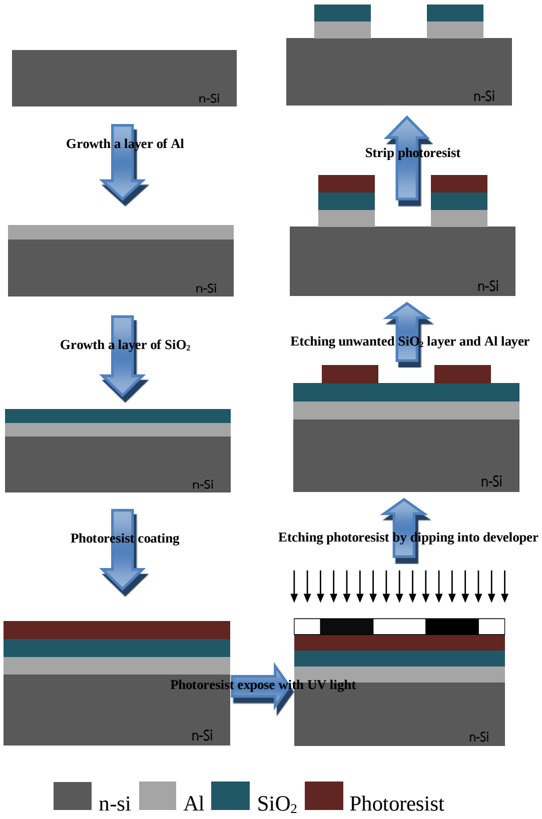


Fig 2.Fabrication process of MSM photodetectors fabrication

The etched samples (figure 3) were analyzed using a tencor p-10 surface profilometer and the etch rates were calculated using the step data obtained from the profilometer. Surface roughness of silicon was observed using scanning electron microscope (SEM).Electrical characteristics was performed by Cascade Microtech M150 probe station, uses a halogen lamp to control the workpiece exposure. The values are as follows: 5,000 10,000 15,000 20,000 25,000 lux and bias voltage from -10 V to 10 V

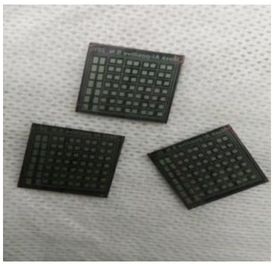
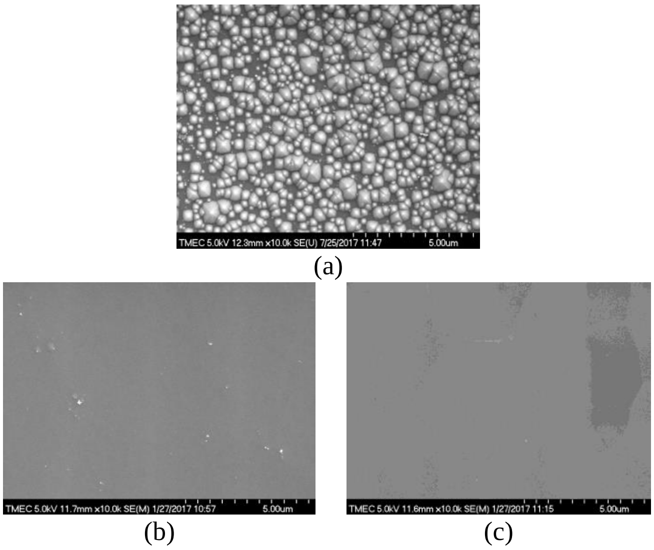


Fig 3.Front view of the etched samples

III. RESULTS AND DISCUSSIONS

A. The etched surface morphology of UMSM photodetectors and etching rate of Si (100)

From Figure 4, the etched surface morphology of silicon was etched by both conditions. It found that the surface of the silicon is quite smooth. Surface roughness may be caused by the amount of hydrogen bubbles that are generated at the surface of the silicon during the etching process, which is the regenerative reaction of the chemical solution. Thus, the addition of IPA and AP results in a reduction in the amount of hydrogen bubbles [5], [6]. However, the chemical reaction of IPA and AP are different. As shown in Figures 5 and 6, respectively.



(a)

(b) (c)

Fig 4.SEM microphotograph of silicon (100) after etching in (a) pure 5 wt% TMAH (b) TMAH 25%wt+ IPA 30%vol at 80˚C and (c) TMAH 5%wt+AP 7 g/l at 80˚C.

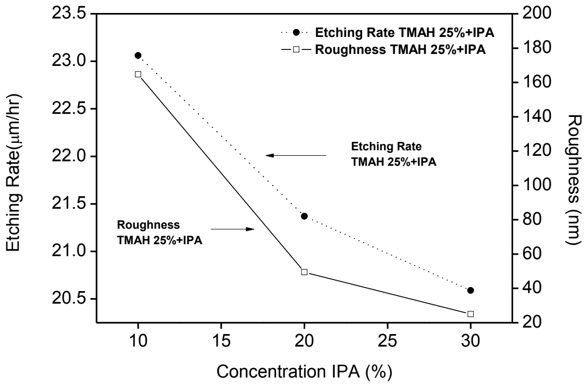


Fig 5.Etch rates and surface roughness of Si (100) with 25 wt% TMAH solutions and adding IPA concentrations at 80˚C.

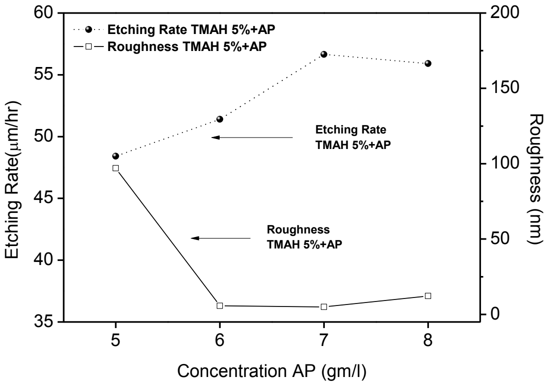


Fig 6.Etch rates and surface roughness of Si (100) with 25 wt% TMAH solutions and doping AP concentrations at 80˚C.

In the present study, when added to the IPA solutions with 25 wt% TMAH, the etched silicon surface becomes smoother than pure 25 wt% TMAH solutions because IPA is a surfactant. As a result, a large bubble of hydrogen gas at silicon surface decrease with the surface tension of the solution decreased, so that the surface of the silicon is quite smooth[6]. It was found that when the IPA increased, the rate of etching decreased (figure 5). Due to IPA was the surfactant of the solution, the addition of IPA to TMAH solutions resulted in a slower chemical reaction. However, the surface of silicon has the least roughness of 25 nm when was etched by adding 30 vol% IPA concentrations into 25 wt% TMAH solutions.

In Figure 6, it was found that when the higher AP concentration resulted in surface of silicon was smooth. Surface roughness was eliminated by the oxidation agents of AP, which reduces the roughness of the silicon surface [7]. The surface of silicon has the least roughness of 5 nm when was etched by doping 7 gm/l AP concentration into 5 wt% TMAH solutions.

B. Electrical characteristics of UMSM photodetectors

In designing the UMSM photodetectors structure, it is important to consider depletion region as the first condition because depletion region is the same as sensor area. When lights was detected by sensor area, electrons gain sufficient light energy to move from valence band to conduction band and electrons are generated in conduction band and holes are generated in valence band becomes electron-hole pairs at depletion region. So, photocurrent of UMSM photodetectors increase with depletion region of UMSM photodetectors increased. Depletion region was calculated from equation 1.

$$W = \sqrt{\frac{2\varepsilon_S\left(V_{bi} - V_A\right)}{qN_D}} \qquad (1)$$

where W is the depletion region width, ε_S is the permittivity of the semiconductor, V_{bi} is the built-in voltage, V_A is the applied bias, q is the charge of an electron and N_D is the concentration of donor atoms.

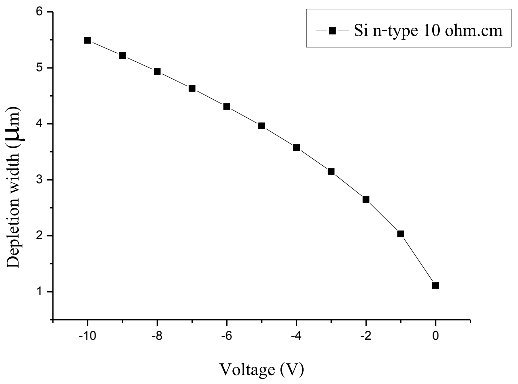


Fig 7. Depletion region width of UMSM photodetectors at different the applied bias.

When applying the bias voltage to -5 V and -10 V, depletion region is extended to 4μm and 5.5μm, respectively (figure 7). The expanded depletion region is used to calculate the appropriate depth of structure for UMSM photodetectors.

In this experiment, UMSM photodetectors will be tested in the absence of light. The voltage is generated from -10 V to 10 V, which results in the expansion of the depletion region, causing an electron to move across the potential barrier, become Dark current (leakage current) of the UMSM photodetectors (figure 8) [2].

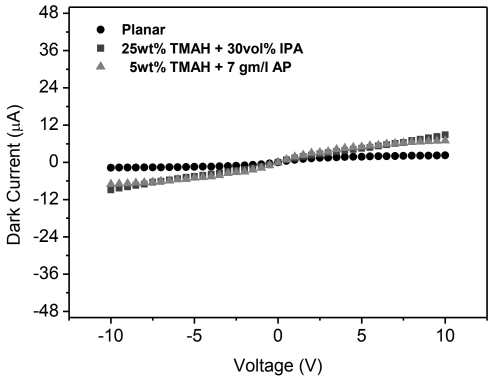


Fig 8. Dark current of planar MSM photodetectors, UMSM photodetectors was fabricated by adding 30 vol% IPA concentrations into 25 wt% TMAH solutions and doping 7 gm/l AP concentration into 5 wt% TMAH solutions.

From Figure.8 the results have shown dark current of planar MSM photodetectors is lower than that of UMSM photodetectors. In the process of fabrication an UMSM photodetectors, chemicals are used in the etching process, whereby these chemicals may cause the discharge of the charge on etched surface. However, an UMSM photodetectors was fabricated by doping 7 gm/l AP concentration into 5 wt% TMAH solutions with a dark current of less than by adding 30 vol% IPA concentrations into 25 wt% TMAH solutions.

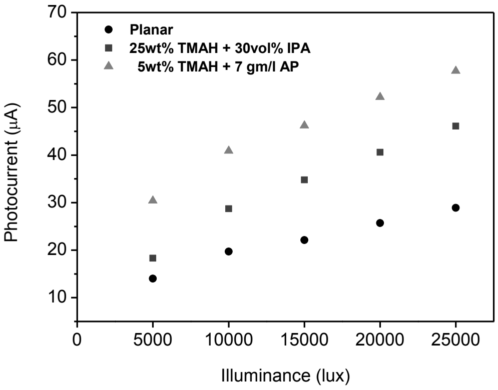


Fig 9. Photocurrent of planar MSM photodetectors, UMSM photodetectors was fabricated by adding 30 vol% IPA concentrations into 25 wt% TMAH solutions and doping 7 gm/l AP concentration into 5 wt% TMAH solutions at bias voltage 10 V with illuminance 5,000, 15,000, 20,000 and 25,000 lux, respectively.

From the concept, planar MSM photodetectors has only sensor area depending on the spacing of the electrodes. It has been added sensor area by etching surface to make a U-shaped MSM photodetectors. And to design the conditions used in the fabrication process to require that sensor areas have the least rough surface, surface roughness will not affect to electrical characteristics. Then study current and voltage of UMSM photodetectors. Light is affected by illuminance at 5,000, 15,000, 20,000 and 25,000 lux, respectively, as shown in figure 9.

From Figure.9, it was found that photocurrent at illuminance 25,000 lux of UMSM photodetectors was higher than that of planar MSM photodetectors, increase a sensor area by using etching processes. And photocurrent of UMSM photodetectors by doping 7 gm/l AP concentration into 5 wt% TMAH solutions was higher than that by adding 30 vol% IPA concentrations into 25 wt% TMAH solutions, due to the smooth surface, resulting in more photocurrent. As shown in Table 1.

TABLE I
SHOW THE SURFACE ROUGHNESS, DARK CURRENT AND PHOTOCURRENT OF THE UMSM PHOTODETECTOR USING VARIOUS CONDITIONS IN FABRICATION.

Conditions	Surface Roughness (nm)	Dark current (µA)	Photocurrent (µA)
25wt% TMAH + 30vol% IPA	25	8.9	46.1
5wt% TMAH + 7 gm/l AP	5	7	57.7

IV. CONCLUSION

This article has been used to fabricate UMSM photodetectors by adding 30 vol% IPA concentrations into 25 wt% TMAH solutions and doping 7 gm/l AP concentration into 5 wt% TMAH solutions. From the concept, planar MSM photodetectors has only sensor area depending on the spacing of the electrodes. It has been added sensor area by etching surface to make a U-shaped MSM photodetectors. It was found that the process of fabrication an UMSM photodetectors using 5% wt TMAH+7 gm/l AP conditions was optimized for use as an UMSM photodetectors because of its surface roughness of about 5 nm, we can control the roughness of the surface smooth, so we can fabricate a repeatable work. This is different from the rough surface. Photocurrent was 7 and 57.7 µA, respectively. It is important to reduce the amount of the TMAH solutions so that it does not waste. In the future, we will improve the structure of the UMSM photodetectors to measure responsivity and quantum efficiency.

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