# Study of UMSM Photodetectors Fabrication Technique by Silicic Acid Added in TMAH Solution

Kamonwan Suttijalern, Jirawat Prabket and Surasak Niemcharoen, *Member, IAENG*

***Abstract*—This paper presents about the U-shape metal-semiconductor-metal (UMSM) photodetectors fabrication on Al/n-Si/Al. This technique performs by using anisotropic wet etching with the depth of U-shape about 4 – 5 µm. In the experiment, 5 wt % of Tetramethylammonium hydroxide (TMAH) were mixed with 30 – 38 g/l silicic acid ($H_4SiO_4$) at 80°C. The result found that the UMSM photodetectors fabrication can increase the light detecting area about 1.73 times when compared with planar structure. Moreover, the added of silicic acid in TMAH solution were decrease Al and silicon dioxide etch rates. The effective condition is 5 wt % TMAH mixed with 34 g/l silicic acid that provided lowest Al and $SiO_2$ etch rates. For the light responsibility analysis at 25,000 Lux, the UMSM structure showed the photocurrent higher than planar structure about 2.4 times. This study found that, the optimal volume of silicic acid that added in TMAH solution can reduce the Al and $SiO_2$ etch rates. This condition should be suitable for photodetectors fabrication.**

***Keywords* —Tetramethyl ammonium hydroxide, Photodetectors, Silicic acid, Anisotropic, Random pyramid surface**

## I. Introduction

IN this present, semiconductor technology is widely popular. This technology can apply to various engineering fields i.e. photodetectors. The photodetectors structure that still interesting is metal-semiconductor-metal (MSM) structure as known as a planar structure. This planar structure has the simple process that easy to fabricate. Nevertheless, it has some limitation on the size of the electrode that affects to a light detecting area. This research presents a silicon surface etching method for photodetectors to extend the light detecting area. This technique performs by etching the planar structure to uniform U-shape metal-semiconductor-metal (UMSM) structure as shown in Fig. 1 [5].

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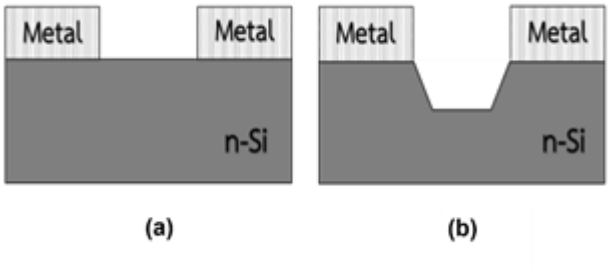


Fig. 1 The metal-semiconductor-metal (MSM) photodetectors:
(a) The planar photodetectors.
(b) The U-shape metal-semiconductor- metal (UMSM) photodetectors.

Tetramethylammonium hydroxide (TMAH) is silicon anisotropic etching solutions. This solution is most popular etchant by comparing with Potassium hydroxide (KOH) and Ethylenediamine pyrocatechol (EDP). This TMAH solution cannot produce mobile metal ion, nontoxic and no effect on the environment. It was easy to remove and compatible with CMOS fabrication process [3]. The TMAH etching obtains random pyramid on the surface of the structure and has higher silicon and silicon dioxide etch rates. This research presents about the adding of silicic acid ($H_4SiO_4$) into TMAH solution to reduce aluminum (Al) and silicon dioxide ($SiO_2$) etch rates, improves passivation quality of aluminum electrode [2] and optimizes a performance of photodetectors.

## II. Experimental

In this research used a single crystalline n-type silicon wafer (100) for the wet etching process. Each wafer has 5-10 Ω·cm resistivity and 6 inches diameter with 625 micrometers thickness. The experiment started with 2 nm aluminum layer was deposited by radio frequency sputtering (RF Sputtering) and 2.4 µm silicon dioxide layer was grown by plasma enhanced chemical vapor deposit (PECVD) process. After that, the photodetectors structure pattern was exposed with a photolithography process and removed the native oxide with 5 wt % HF solution and then, silicon chip was washed with de-ionized water to remove out the particles. In the etching process, we designed the experiment with two conditions consist of the pure 5 wt % TMAH and the mixture of 5 wt % TMAH and silicic acid. For the mixed condition, 5 wt % TMAH with different volume of silicic acid consists of 30, 32, 34, 36, 38 g/l (liter of TMAH) were mixed and pure 5 wt % TMAH at 80°C

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with the 200 rpm magnetic stirrer. The depth of aluminum and silicon dioxide layers had measured by using a profilometer. The surface of silicon chip had observed by a scanning electron (SEM) and analyzed electrical and light characteristics by 4 points probe.

## III. Result and Discussion

### A. *Physical Characteristics of U-shape groove photodetectors Al / n-Si / Al structure.*

The etch rates of aluminum and $SiO_2$ in pure 5 wt % TMAH and 5 wt % TMAH with different concentration of silicic acid. The Fig. 2 shown etch rates of pure 5 wt % TMAH, the etch rates that affected to Al and $SiO_2$ at 116.50 µm/h and 221.66 µm/h respectively. The mixture of 5 wt % TMAH with 34 g/l silicic acid, the etch rates of Al and $SiO_2$ at 0.136 µm/h and 0.407 µm/h respectively. The result found that a mixture of TMAH with the appropriate amount of silicic acid could dramatically decrease etch rates because ion hydroxide in the solution reacts with silicic acid [1].

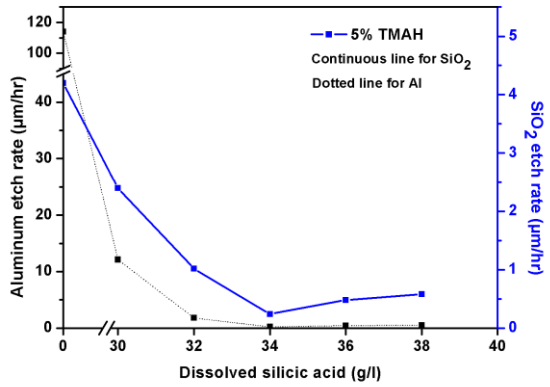


Fig. 2. Variation of the aluminum and silicon dioxide etch rates with silicic acid at a concentration of 5 wt % TMAH at 80 °C.

In the etching process, the reaction took place on aluminum shown as follows:

$$2Al + 2SiO_3^{2-} \rightarrow Al_2(SiO_3)_3 + 2e \qquad (1)$$

From the chemical equation about the adding of silicic acid into TMAH solution, the silicic acid molecular structure is $H_4SiO_4$ and a combination of TMAH solution will be produced $SiO_3$ to decrease the aluminum etch rates and obtained $Al_2(SiO_3)_3$. This product cannot react seem to TMAH. Therefore, $Al_2(SiO_3)_3$ become a thick coat on the aluminum surface. Moreover, the silicon dioxide etches rate has reduced [3].

The depth of aluminum and silicon dioxide with various etching times as shown in Fig. 3. The depth trend of Al and shown slightly increased whereas the etch rates of Al shown lower than $SiO_2$. The photodetectors structure was fabricated by the wet etching method using the mixture of 5 wt % TMAH and 34 g/l silicic acid at 80 ºC.

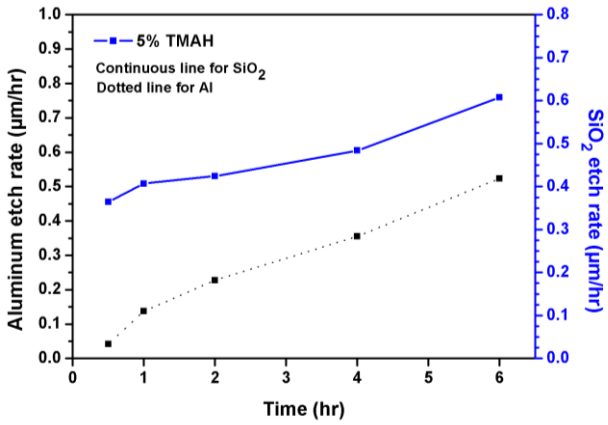


Fig. 3 Variation of the aluminum and silicon dioxide depth with time etching of 5 wt % TMAH and 34 g/l silicic acid added at 80 °C.

This solution reacted with (100) silicon orientation to etch the silicon surface from planar to U-shape that contain random pyramid. This result was analyzed with scanning electron microscope (5.0 kV power and 10,000x magnification).

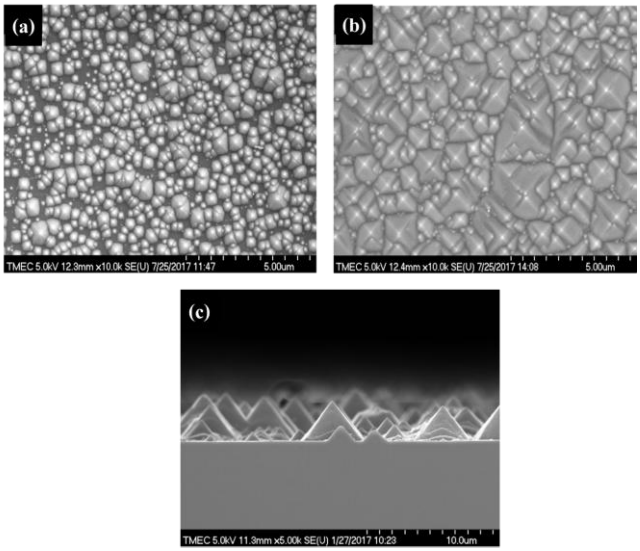


Fig. 4 SEM microphotograph of silicon (100) after etched with: (a) 5 wt % TMAH solution; (b) 5 wt % TMAH and 34 g/l silicic acid added; and (c) cross-sectional images of SEM 5 wt % TMAH and 34 g/l silicic acid added at 80° C.

The analyzed result found pure 5 wt % TMAH and mixtures conditions, the surface of silicon in light detecting area shown the random pyramid structure because the non-directional etching reaction of TMAH was produced hydrogen ion on the silicon surface [6].

The Fig. 4 shows the pure 5 wt % TMAH could obtain random pyramid structure on the surface higher than mixture because the decreasing of the silicon etch rates also decrease the amount of random pyramid. In Fig. 3(c) shown a cross-section of photodetectors from SEM in case of the mixture, this solution could etch on (100) better than (111) [5].

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### *B. Characteristics of current and voltage of photodetectors during non-illuminated*

The electrical characteristics of photodetectors were measure with Cascade Microntech M150 Probe station by using -10 to 10 DC voltage. For the leakage testing, in case of non-illuminated with forward bias, the depletion region of photodetectors was increased and made the electron that moved from metal across the Schottky barrier to semiconductor and given a leakage current [4].

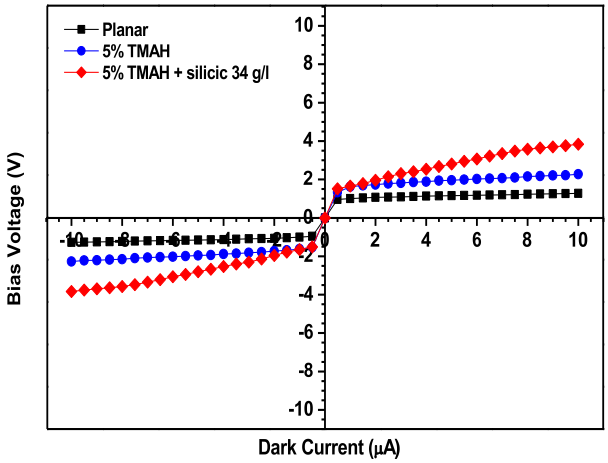


Fig. 5 Current and voltage characteristic of UMSM photodetectors and planar photodetectors during non-illuminated.

In Fig. 5 after biased at 10 volts, the leakage current of planar photodetectors equal to 1.28 μA whereas UMSM photodetectors with pure 5 wt % TMAH and mixtures were obtained the leakage current 2.27 μA and 3.84 μA respectively. From the result found the leakage current of planar structure lower than UMSM structure, pure 5 wt % about 1.77 times and mixture about 3 times.

### *C. Characteristics of current and voltage of photodetectors during illuminated*

In case of illuminated, halogen lamp had used for measuring a current of photodetectors with 5,000 15,000 and 25,000 Lux by bias 0 to 10 DC voltage on the planar structure and UMSM structure. In Fig. 6 the U-shape photodetectors provided the current that directly increased with bias voltage and light intensity. The structure that etched by mixture gave current more than pure 5 wt % TMAH structure because the silicic acid could decrease aluminum etch rates and got an effective aluminum electrode.

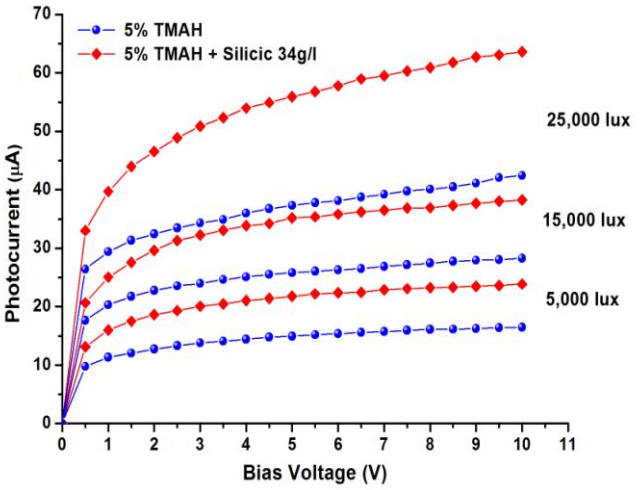


Fig. 6 Current and voltage characteristics of UMSM photodetectors during illuminance at 5000, 15000 and 25000 lux.

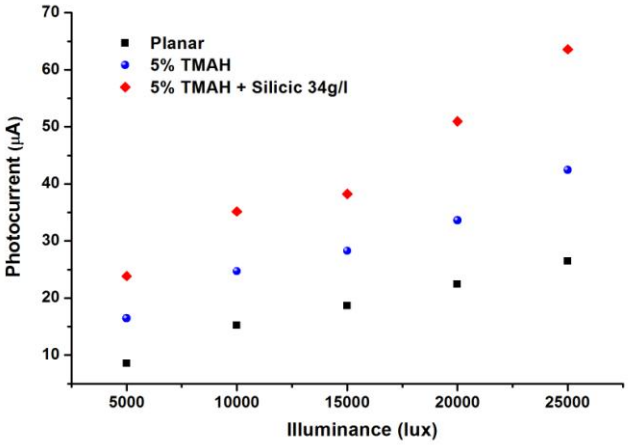


Fig. 7 Relationship between current and illuminance of planar and UMSM photodetectors at 5 wt % TMAH solution and 5 wt % TMAH and 34 g/l silicic acid added during illuminated.

In Fig. 7 shown that photocurrent was increase by the light intensity that caused the electron-hole pair to obtain the photocurrent. From the result of the photocurrent of planar structure and UMSM structure had directly increasing trend (linear). On 10 V biasing with 25,000 Lux, the UMSM structure was etched with mixture gave the highest photocurrent about 63.6 μA that higher than planar structure (about 26.45 μA) at 2.4 times due to extended of the light detecting area on U-shape and random pyramid surface can be afforded an effective light responsibility of photodetectors.

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## IV. Conclusion

This research studies about the photodetectors with Al/n-Si/Al planar and U-Shape structure fabrication with Tetramethylammonium hydroxide (TMAH) and silicic acid. The result found that 34 g/l of silicic acid had obtained aluminum and silicon dioxide etch rates equal to 0.137 µm/h and 0.407 µm/h respectively. For electrical characteristics of U-Shape photodetectors in case of 5 wt % TMAH with silicic acid, the leakage current and photocurrent equal to 3.84 µA and 63.6 µA respectively which more than planar structure about three times. The study of photodetectors fabrication found the effective light responsibility. This finding is the beginning of photodetectors development in the future.

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