The U-Shaped Photodetector Structure Optimization by Increase Random Pyramid Size

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

***Abstract*—This paper purpose the fabrication method of U-shape metal-semiconductor-metal structure photodetector with Al/n-Si/Al materials on anisotropic wet etching. In this paper studied on 20 wt% of potassium hydroxide (KOH) and 5 wt% of Tetramethylammonium hydroxide (TMAH: $(CH_3)_4NOH$) and mixed with 34 g/l silicic acid also heating with 80 degrees Celsius. From the experiment found the best condition for fabricating the photodetector is the experiment, which uses the mixture of TMAH solution and silicic acid because it obtained the lowest aluminum layer etch rate and no alkaline ion or contaminant on a surface that able to apply with the integrated circuit. Moreover, this mixture gave a large amount of random pyramid structure on the surface also more than fabricate with KOH solution and made the light responsibility on 25,000 lux more than KOH model about 1.3 times. This result shown the big pyramid provide the light reflection lower than small pyramid that takes many effects to light absorption and photocurrent and controls the transducing performance of a photodetector.**

***Keywords*— Random pyramid, Aluminum passivation, Wet anisotropic, Silicic acid, U-shaped photodetector**

I. Introduction

THE evolution of the electronics technology is advanced and continuous development from past to present. The semiconductor device has an influence on the daily life of human such as the communication equipment like cell phone also the computer and many of communication device. Therefore, the development has focused on the fastest data communication media. The device that can be the fastest media is a photodetector. This device has good light responsibility, fast switching and low noise on operating also compatible with the integrated circuit. The photodetector has any type such as p-n photodetector, p-i-n photodetector (PIN Diode), Avalanche photodetector and M-S photodetector. The author interested in MSM photodetector that obtains good responsibility with low light intensity.

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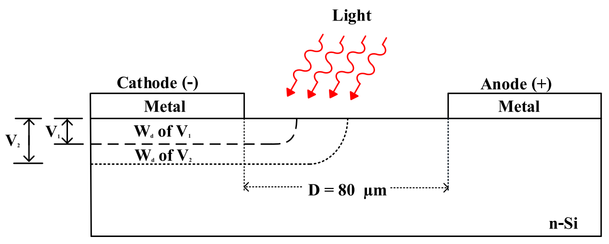
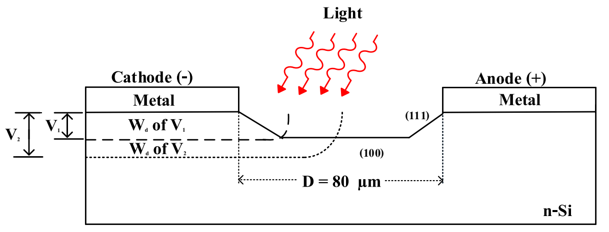


(a)



(b)

Fig. 1. The photodetectors on unilluminated and bias voltage:
(a) The planar photodetector.
(b) The U-shape metal-semiconductor- metal (UMSM) photodetector.

Normally, the MSM photodetector (planar structure) has the same process to the CMOS fabrication as shown in Fig. 1(a). However, the study found another structure that is light performance improvable, a device has a U-shape structure as shown in Fig 1(b). In this paper purpose The photodetector structure improvement by using anisotropic wet etching method to provide a U-shape structure that always uses in electrical mechanical or MEMS [3]. This method used KOH and TMAH to etching the surface of silicon and make random pyramid structure also reduce reflection on the surface and increase the light effect and the silicic acid also used because it was reduced aluminum etch rate [4] without effect to silicon etch rate on other planes. This ability uniformed a surface of silicon to be a random pyramid structure.

II. Experimental

The (100) single crystalline n-silicon substrate with 5-10 Ω·cm and 625 µm of thickness have used to study on various anisotropic wet etching methods. On preparation process growing an aluminum layer with 1.5 µm of thickness by using RF-sputtering technic then growing 2 µm thickness of the silicon dioxide layer with plasma-enhance chemical vapor deposition (PE-CVD) process after that make the texture of photodetector on a surface with photolithography process and the last step cleaning the native oxide on a surface with etching process on 5 wt% hydrofluoric acid and washing with de-ionized water (DI water).

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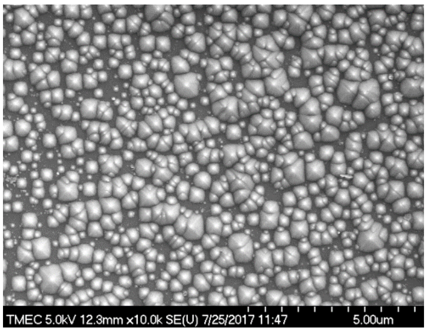
The silicon surface etching process with 20 wt% KOH, pure 5 wt% TMAH and mixture of 5 wt% TMAH and 34 g/l silicic acid with 80 degrees Celsius heating. On etching process should be stirring continuously with a magnetic stirrer with 200 rpm in the enclosure such as beaker that makes temperature steady.

In the measurement process measuring a depth of roughness on a surface of silicon with Tencor P-10 surface profilometer then analysis with scanning electron microscope (SEM) and testing the electrical and photo characteristics of a photodetector structure.

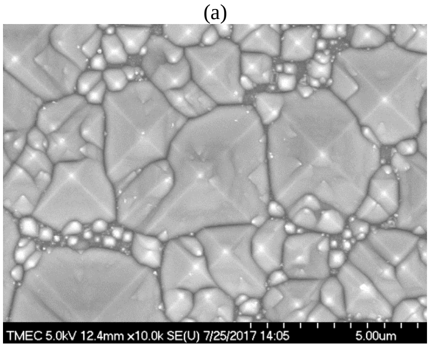
III. Result and Discussion

A. Random Pyramid Structure On Silicon Surface Analysis

In this topic, a study of the silicon surface after etched by the anisotropic wet etching process to observe pyramid structure on the surface of silicon also observe distribution pattern of the pyramid structure. The sample silicon dies has 4 µm depth from a surface by etching on 30 minutes with 20 wt% KOH, pure 5 wt% TMAH and mixture of 5 wt% TMAH and 34 g/l silicic acid. The result of this study show in figure 2 by used SEM with 10,000 times magnify.



(a)



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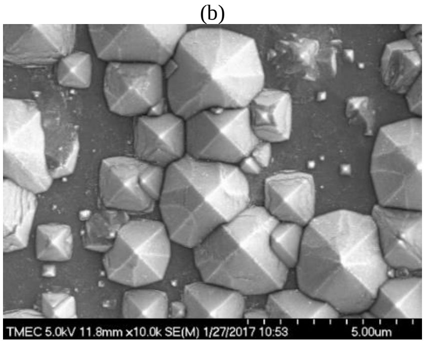

(c)

Fig. 2. The surface of (100) silicon photodetector at 80 °C SEM photograph.
(a) Pure TMAH solution
(b) Mixture of TMAH and silicic acid
(c) KOH solution

From the analysis with SEM in Fig 2(a) found size of pyramid base area, pure TMAH equal to 0.60 µm, the mixture of TMAH and silicic acid equal to 3.88 µm (54.7 degrees of angle) and KOH equal to 4.60 µm (45 degrees of angle) as shown in figure 2(c) from these result can calculate with equation (1).

$$h = \left(\frac{w}{2}\right)\tan\theta_1 \qquad (1)$$

Where h is a pyramid height
W is base of a pyramid
θ_1 is angle from anisotropic etching

From calculated found a mixture of TMAH and silicic acid provided a height of pyramid about 2.73 µm that more than KOH about 1 time. This result showed an addition of silicic acid increased the roughness on a surface of silicon also raised the density of the pyramid caused by hydrogen bubble, which produced by the dissociation of water [5].

B. Silicon Etch Rate

The analysis on the surface profilometer found the result as shown in figure 3. The pure TMAH condition provided etch rate more than the mixture of TMAH and silicic acid. In figure 4 shown the etch rate of 20 wt% KOH, which higher than TMAH solution because the silicic acid will decrease the etch rate on silicon by lowering the hydroxide ion on the solution [6] including the bond strength of silicon that makes a silicon structure difficult to separate.

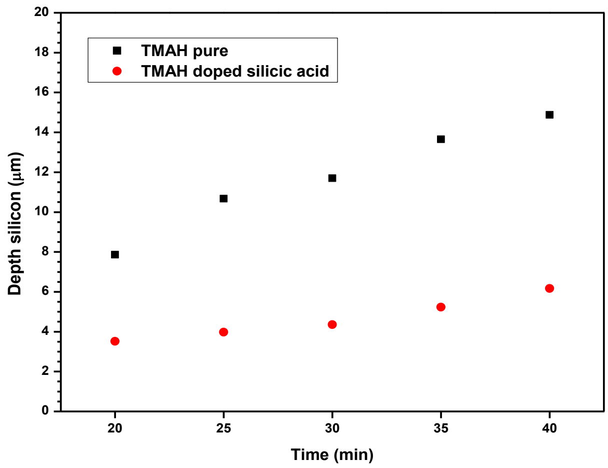

Fig. 3. The relationship between a depth of silicon and time after etch by 5 wt% TMAH and mixture.

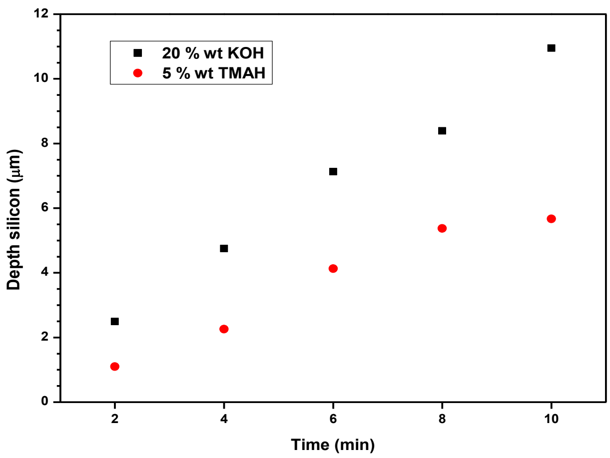

Fig. 4. The relationship between a depth of silicon and time after etch by 20 wt% KOH and 5 wt% TMAH.

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C. Aluminum Etching Analysis

From considered in figure 5 found the aluminum layer that etched with KOH and pure TMAH in 30 minutes and the mixture of TMAH and silicic acid in 1 hour, provided the aluminum etch rate 2.6 µm/min, 1.9 µm/min and 0.0023 µm/min respectively.

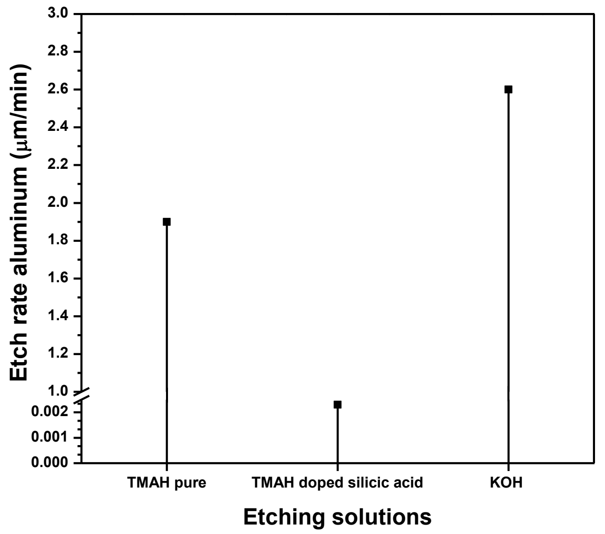

Fig. 5. The relationship between aluminum etch rate and etchant.

From the experiment found the mixture has the lowest etch rate than pure TMAH about 800 times because of the silicic is acid, in case of a combine with hydroxide of TMAH, there would be decrease hydroxide ion and lowering alkaline in TMAH and falling the aluminum etch rate to less than pure TMAH and KOH that has pH >13 [7,8].

TABLE I
THE COMPARISON OF PHYSICALS AND CONDITIONS

Etchant	Silicon etch rate (µm/min):	Aluminum etch rate (µm/min):	Silicon roughness (µm):	CMOS Comp:
TMAH pure	0.68	1.9	0.42	Yes
TMAH doped silicic acid	0.15	0.0023	2.73	Yes
KOH	1.18	2.6	2.34	No

In table 1 found the pure TMAH was not left alkaline ion or contaminate that different to KOH, this solution left the potassium ion (positive ion) [9] on the surface on material even though it has no effect to etching but the ion of potassium decrease the electrical performance that no need on the integrated circuit fabrication process.

D. I-V characteristics of photodetectors during non-illuminated

This experiment has biased the photodetector with -10 V to 10 V (DC) to provide the I-V characteristics of photodetectors. From the results found the planar (MSM) structure and UMSM structure with 10 V biased as shown in figure 6. The lowest dark current was (MSM) and UMSM etched with KOH gave highest, which more than etched by mixture (TMAH+silicic acid) about 1.1 times. The dark current of KOH came with the potassium ion on the surface of silicon after done etch process.

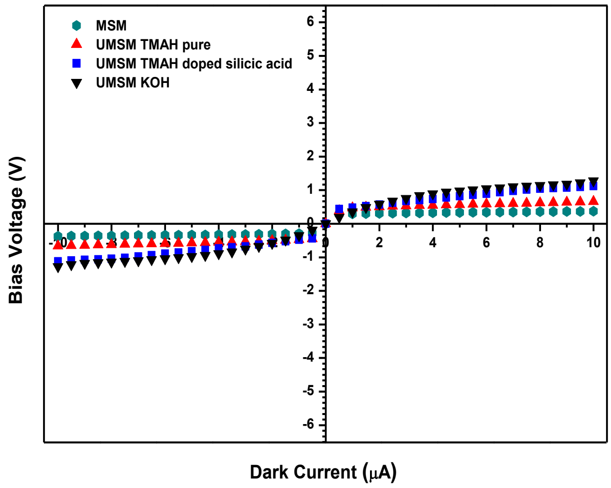

Fig. 6. The electrical characteristics of planar and UMSM photodetectors on non-illuminated.

E. I-V characteristics of photodetectors during illuminated

In this experiment present the light responsibility of photodetectors by illuminate the structure with 25,000 lux and biased with 0 V to 10 V (DC) as shown in figure 7. The results found the planar (MSM) provide a photocurrent equal to 23.9 µA and UMSM structure, which etched by pure TMAH, KOH and mixture obtained 42.5 µA, 50.8 µA and 64.1 µA respectively. The photocurrent of photodetector that etched with mixture more than etched with KOH because the density of random pyramid and surface roughness of silicon improve the light detecting area of a photodetector. This result shown the big pyramid provide the light reflection lower than small pyramid that takes many effects to light absorption and photocurrent and controls the transducing performance of a photodetector.

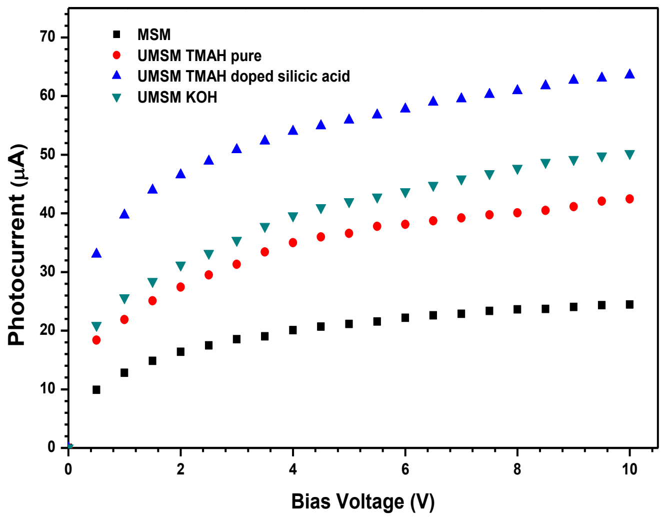

Fig. 7. I-V of planar and UMSM photodetector on illuminated with 25,000 lux.

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IV. Conclusion

This paper purpose the silicon surface etching to provide the biggest random pyramid structure and studies on the aluminum layer etching also silicon etch rate to fabricate the UMSM photodetector on Al/n-Si/Al by using potassium hydroxide (KOH) Tetramethylammonium hydroxide (TMAH) with additional of silicic acid. The results found on 5 wt% TMAH with 34 g/l silicic acid obtained the roughness height about 2.73 µm and aluminum etch rate about 0.0023 µm/min. The highest silicon etch rate about 1.18 µm/min by etched with 20 wt% KOH. From the results of electrical characteristics on unilluminated, the dark current was high and illuminated the photocurrent varied with the light intensity that shown the fabricated photodetector can response the light. This paper was the starting point for research and development also optimized performance of the photodetector in the future.

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