Effect of temperature on etch rate and undercutting of (100) silicon using 25% TMAH

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Abstract

Silicon etching using aqueous Tetra-Methyl Ammonium Hydroxide (TMAH) provides a simple and cost effective technique for the fabrication of diaphragms. The etching of {111} planes leads to undercutting, causing a deviation in the designed size of diaphragm. This induces variation in the designed characteristics of the device. It is necessary to estimate and minimize this deviation. In the present work, the etch rates in the {100} and {111} planes for 25% wt TMAH have been empirically estimated at different temperatures. Based on these results the undercut was estimated and a relationship has been established between the etch rate ratio for the two planes. These findings are extremely useful in the fabrication of silicon diaphragms with precise dimensions.

Keywords: TMAH etching, Piezoresistive pressure sensor, temperature dependence, undercutting.

Introduction

A Piezoresistive pressure sensor consists of a diaphragm with Piezoresistors as shown in Fig 1. The diaphragm deflects on the application of pressure, giving rise to stress in the diaphragm. The placement of the Piezoresistor at the maximum stress regions is an important part of the design of a pressure sensor [1]. While fabricating the diaphragm using aq. TMAH etching, the expected position of the Piezoresistors may shift due to etching in {111} planes. In order to minimize this deviation in existing mask sets and to estimate the sizes of the masks in future, a study of etch rates in {100} and {111} plane at different temperatures have been carried out.

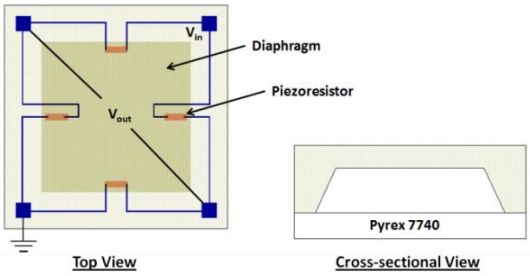


Fig 1: A Piezoresistive pressure sensor

The etch profile while performing etching using TMAH in (100) silicon substrate is depicted in Fig. 2. The figure clearly shows the anisotropic nature of etching and undercutting due to etching in {111} planes.

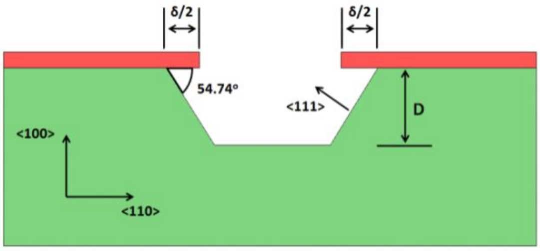


Fig 2: TMAH etch profile

The etch rate (ER) in the <100> direction can be estimated by finding the depth of etching (D). The etch rate in <111> is found by measuring the undercutting (δ) and using appropriate formula as shown below.

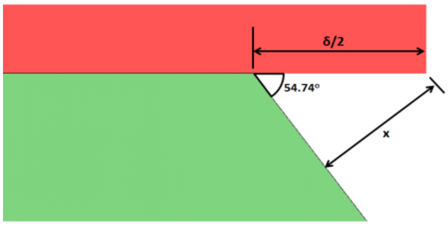


Fig 3: Etching in (111) plane

$$\boxed{\frac{x}{\delta/2} = \sin 54.74 = \frac{\sqrt{2}}{\sqrt{3}}}\ , \quad \boxed{\delta = \sqrt{6}x}$$

$$ER\ of\ \{111\}\ planes: \boxed{\frac{x}{t} = \frac{\delta}{\sqrt{6}t}}\ , \qquad t = etch\ time$$

$$Undercut\ per\ unit\ depth: \boxed{\frac{\delta/2}{D}}$$

Experimental details

For determining the characteristics of (100) Si etching in aq. TMAH at different temperatures, n-type (100) silicon wafers having a resistivity of 5-7 Ω-cm and a thickness of 525-530 μm were chosen. A 1 μm thick thermally grown SiO_2 layer was used for masking.

The first level mask to be used for the fabrication of pressure sensors was used to obtain the required diaphragms, which were analyzed to obtain etch rates in the (100) and (111) planes. The TMAH etching of different samples was performed at different temperatures with an error of ± 1^0C. In order to maintain the concentration of the TMAH solution, DI water was added after each experiment [2]. The etching was performed for 5 hours for each temperature.

The etch depth of the diaphragm at different temperatures was measured using the Dektak 3M profiler. The measured value was divided by the total time to get the etch rate in <100> direction. To find the etch rate in <111> direction (at different temperatures), the final size of the square alignment mark was compared with the size before etching. The initial width is 104.8 µm and the final width was measured from SEM images after etching the masking oxide. The undercut (δ) so obtained was used to calculate the etch rate in the <111> direction.

Results and discussion

The representative SEM images of the alignment mark, the complete diaphragm and the hanging oxide are shown in figure 4 and 5 respectively.

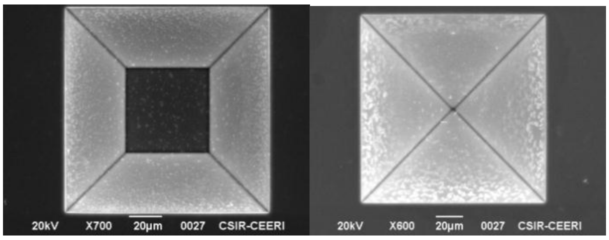
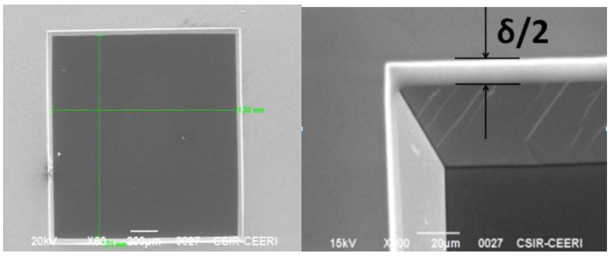


Fig 4: SEM image of alignment marks (used for calculating undercutting)



(a) (b)

Fig 5: (a) SEM image of a diaphragm (b) Hanging oxide after TMAH etching

The experiment was carried out at six different temperatures. The calculated etch rates in <100> and <111> directions are listed in Table 1.

Table 1: Etch rates of Si in TMAH

Soln. Temp. (in ^{0}C)	Etch rate <100> (µm/hr)	Etch rate <111> (µm/hr)	Etch rate ratio <100>/<111>	Undercut per unit depth
63	10.02	1.73	5.79	0.141
68	13.8	1.93	7.15	0.114
73	17.98	2.10	8.56	0.095
78	21.62	2.59	8.34	0.098
83	30.38	2.83	10.73	0.076
88	38.9	3.01	12.92	0.063

It is clearly visible from the table that the etch rates in both the <100> and <111> direction increase with increase in temperature [3]. Also, the etch rate ratio increases with increase in temperature. In other words, for the same amount of etching in <100> direction, lower undercutting is observed at higher temperatures. A small deviation from the increasing trend is observed at 73^{o}C and 78 ^{o}C. This may be attributed to some error due to temperature variation in the TMAH solution or in the measurement of the diaphragm from SEM images.

Conclusions

In this work, the variation of etch rate in <100> and <111> direction is calculated at different temperatures. For 25% wt TMAH, it was found that the silicon etch rate increases with temperature in both these directions. Also the etch rate ratio <100>/<111> increases with temperature and the undercut per unit depth of etching in <100> direction, decreases with temperature. This study provides an important guideline towards making silicon diaphragms with precise dimensional control.

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