# Corner compensation mask design on (MEMS) accelerometer structure

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***Abstract*—This paper presents the analysis effect of etching temperature and KOH concentration on convex corner undercutting of (MEMS) accelerometer structure. The Intellisuite CAD simulation software was used for the simulation analysis. From the analysis it was found that the optimum etching condition for this convex corner was at 25 wt% KOH concentration and 63 °C etching temperature. Different types of compensation mask corners were designed which are corner, square and triangle in order to study the undercutting phenomena. In this case, the square corner compensation mask was chosen as it shown the most suitable compensation mask for this design of accelerometer. The etching simulation was continued with square corner compensation mask etched in the optimized temperature and KOH concentration and it indicated that the square corner compensation mask is the most suitable mask to solve the convex corner undercutting for this accelerometer structure.**

***Keywords—Convex Corner Undercutting; Accelerometer; Intellisuite CAD simulation; Compensation mask; Etching***

## I. INTRODUCTION

There are two approaches of etching techniques for bulk micromachining which are wet and dry [1]. Among both techniques, anisotropic wet etching was the popular method to fabricate MEMS accelerometer in recent technologies. Anisotropic wet etching has received much attention due it greater performance compared to dry etching. Such dry etching technique produces vertical materials removals that conform to the mask design which may include the curved features and it depends on the crystallographic alignment between the mask and the accelerometer structure. On the other hand, the wet etching was easy to use and low cost, but also can provide smooth surface [2, 3].

In wet bulk micromachining it usually carried out using anisotropic etchants like KOH (Potassium Hydroxide), TMAH (Tetra Methyl Ammonium Hydroxide) and EDP (Ethylene Diamine Pyrocatecol). Among these etchants, KOH solution has the advantages of simplicity, easy to handle, low cost and homogeneous etching rate of the (1 0 0) crystal plane[4]. KOH shows strong anisotropy, and shows large values of etch rate ratios among orientations of about (100). It means that high controllability can be expected in etched profiles, while suppressing mask undercut. KOH solutions are less toxic than other etchants, hence are easy to process[5]. These are the main reasons why KOH is widely used for fabricating silicon microstructures in the industry. Nevertheless, the critical problem normally occurred during the etching process of MEMS rectangular/square corners was the deformation of the edges due to undercutting. Corner erosion leads to deformed rectangular structures, which will subsequently influence the device performance [6].This effect consequently caused a low performance of MEMS sensors especially in the fabrication of acceleration sensors where total symmetry and perfect 90° convex corners on the proof mass are mandatory for good device prediction and specification.

From previous studies, the most compensation structures were carried out on (100) silicon substrate and various convex corner compensation structures have been develop to prevent the undercut of wet etching. However, these structures will occupy some in plane spaces especially for the case of deep silicon etching. In order to prevent the undercut issue, the compensation mask's patterns such as triangle, square and bar have been developed to protect the desired right angled corner. As a result they have become the three classical compensation methods that are still used nowadays. Nevertheless, each individual compensation structure is independent and common principle of constructing a compensation pattern is not clearly put forward [7].

Other than corner compensating by mask, the undercutting issue could also be improved by controlling etching condition such as temperature and KOH concentration. According to previous research by N. Soin, the convex corner undercutting phenomena is significantly reduced at low etching temperature and high KOH concentration respectively [8].

In this study, we demonstrate the effect of temperature and KOH concentration to the convex corner during etching and proposed MEMS accelerometer structure with different shaped appearances of corner compensation masks.

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## II. METHODOLOGY

### A. *Masks Design*

The developed design approach is modified based on the research work done by R.Mukhiya [9]. The researchers has chosen <100> square, <100> thin bar and <100> wide bar structure as their corner compensation structure. However, in this simulation, we have modified the corner compensation structure as shown in Fig. 2 respectively. Intellisuite CAD simulation software has been used for the simulation analysis in this study. The dimensions of masks design used in the process of realization of accelerometer structure are shown in Fig. 1. The structure is etched from both top and bottom directions of silicon wafer. Among various corner compensation structures, for investigation we have chosen bar, square and triangle structures. Square compensation structure is the easiest to design, analyze and most space efficient [5]. The corner compensation structures with design parameters are shown in Fig. 2.

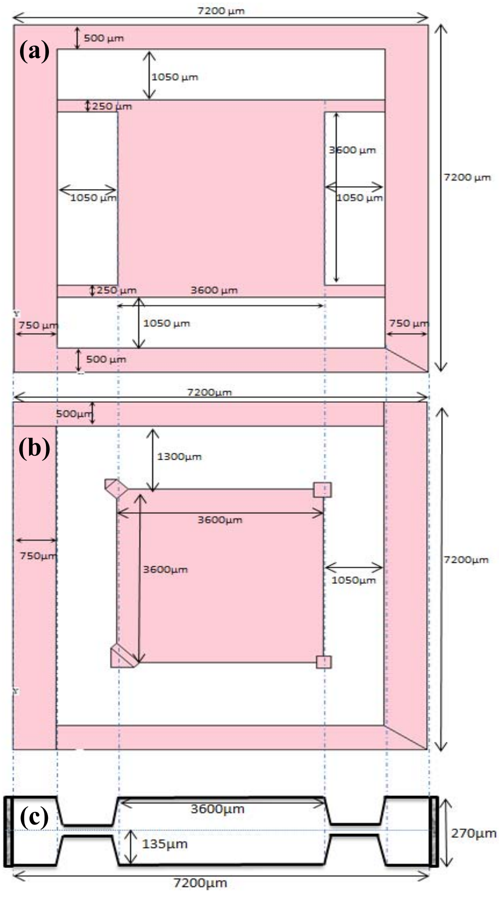


Fig. 1. (a) Top mask (b) Bottom mask (c) cross section view of complete accelerometer structure

### B. *Wet Etching Simulation Process*

The wet etching simulation was carried out using KOH etchant of <100> silicon wafer. During the simulation, the final etching time was 4.5 hours in order to achieve nearly perfect 90° of convex corners. Etching rate is very temperature dependent. In this simulation, the range of the KOH concentration and the etching temperature was chosen to be from 10 wt% to 45 wt% and 30ºC to 85 ºC respectively.

## III. SIMULATION RESULTS AND ANALYSIS

### A. *Determination of optimum KOH temperature on undercutting convex corner*

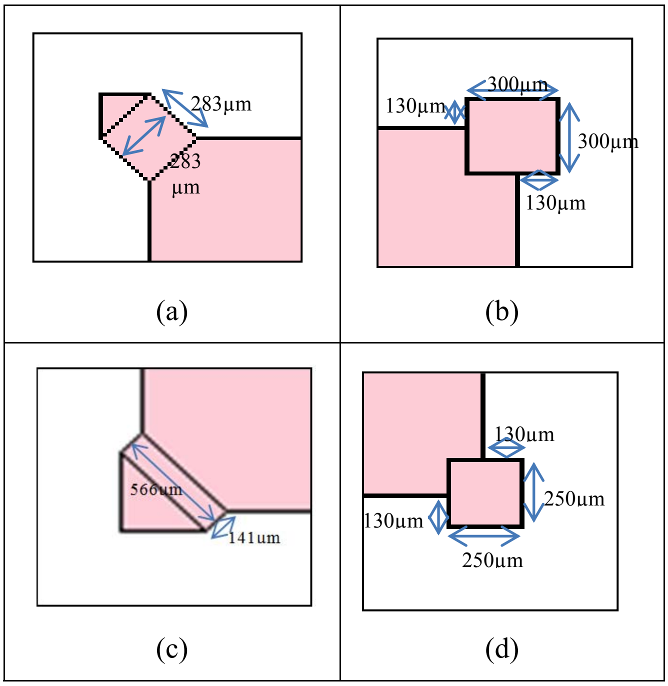


Fig. 2. Corner compensation structures (a) corner (b) square 1 (c) triangle (d) square 2.

The variation of etching temperature and etching rates as a function of etching depth is shown in Table I. As can be seen in Fig. 3 the etching temperature increased with the increased of etching rate. However, both trends were only seen in the crystal plane (100) and (110) meanwhile there is no significant increment in etching depth for crystal plane in (111). At the beginning of the temperature until 50 ºC the etching depth was slightly increased. The etching depth was noticeable increased sharply at 50 ºC onwards. The major increment was seen at 80 ºC.

The etching simulation performed in this simulation has shown that most efficient etching temperature might occur from 62 ºC to 64 ºC. In order to study the optimum etching temperature, four type of corner compensation mask was designed and tested in the etching parameter study as shown in Fig. 5. It can be seen that at temperature of 62 ºC, the convex corner started to etch nearly complete. As the temperature reached at 63 °C, the convex corner was shown completely etched.

The temperature was continually increased and it has been seen that the convex corner started to undercut and deformed. Hence from structure analysis it can be concluded that the optimum temperature was at 63 ºC.

TABLE. I VARIATION OF ETCHING TEMPERATURE AS FUNCTION OF ETCHING DEPTH

| Etching Temp.(°C) | Etching Rate (µm/hour) | | | Etching depth | | |
|---|---|---|---|---|---|---|
| | {100} | {110} | {111} | {100} | {110} | {111} |
| 30 | 3.33 | 5 | 0.04 | 14.985 | 22.5 | 0.18 |
| 35 | 5.12 | 7.705 | 0.07 | 23.04 | 34.673 | 0.315 |
| 40 | 6.91 | 10.41 | 0.1 | 31.095 | 46.845 | 0.45 |
| 45 | 10.29 | 15.57 | 0.16 | 46.305 | 70.065 | 0.72 |
| 50 | 13.67 | 20.73 | 0.22 | 61.515 | 93.285 | 0.99 |
| 55 | 19.825 | 30.165 | 0.355 | 89.2125 | 135.765 | 1.598 |
| 60 | 25.98 | 39.6 | 0.49 | 116.91 | 198.2 | 2.205 |
| 65 | 36.765 | 56.23 | 0.765 | 165.443 | 253.035 | 3.443 |
| 70 | 47.55 | 72.86 | 1.04 | 213.975 | 327.87 | 4.68 |
| 75 | 65.83 | 101.175 | 1.575 | 292.235 | 455.288 | 7.088 |
| 80 | 84.11 | 129.49 | 2.11 | 378.495 | 582.705 | 9.495 |
| 85 | 114.14 | 176.22 | 3.11 | 513.63 | 792.99 | 13.995 |

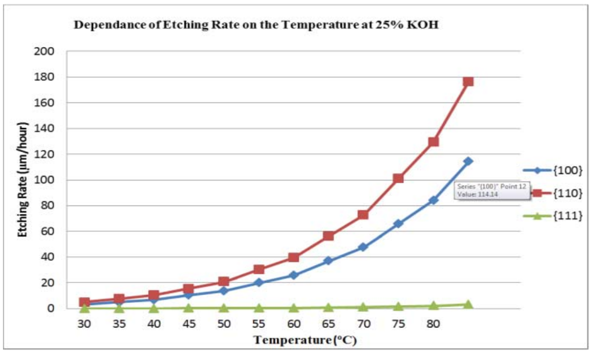


Fig. 3. Dependence of etching rate with temperature at 25 wt% KOH concentration

### *B. Determination of optimum KOH concentration on undercutting convex corner*

The variation of etching concentration as function of etching rate is shown in Table II. The temperature has been set at 63 °C as the previous simulation shown 63 ºC is the optimum temperature. The dependence of etching rate on the KOH concentration is presented in Fig. 5.

The analysis indicates that the most efficient KOH concentration might occur at KOH concentration from 20 to 30 wt%. Therefore in order to confirm that, the analysis was extended with concentration from 20 to 30 wt% to etch four types of corner compensation masks. The description of convex corner undercutting dependence on KOH concentration was illustrated in Fig. 6. Four different masks corner have been etched at three different KOH concentrations for about 4.5 hours.

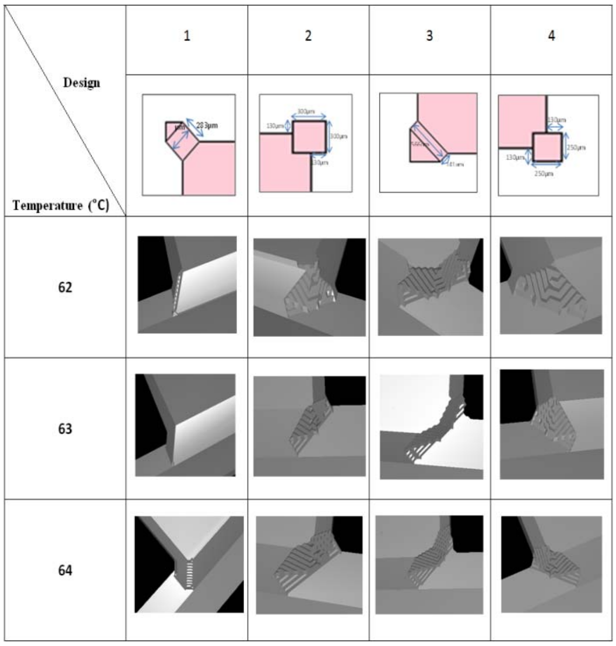


Fig. 4 Etched morphology of convex structure at 4.5 hours etching time at different etching temperature.

As the concentration reached at 20 wt%, the convex corner was nearly complete been etched. Finally at concentration 30 wt%, it can been seen that the structure deformed due to undercutting issue. Thus, it can be conclude that the most optimum concentration was at 25 wt%. The previous study performed by N. Soin also shown that the most ideal KOH concentration was around 30 wt% and slightly greater than our result [8].

TABLE II. VARIATION OF ETCHING CONCENTRATION AS FUNCTION OF ETCHING DEPTH

| KOH Conc. (%wt) | Etching Rate (µm/hour) | | | Etching depth | | |
|---|---|---|---|---|---|---|
| | {100} | {110} | {111} | {100} | {110} | {111} |
| 10 | 31.58 | 48.248 | 0.639 | 142.11 | 217.125 | 2.88 |
| 15 | 33.25 | 50.801 | 0.671 | 149.625 | 228.6 | 3.015 |
| 20 | 33.39 | 51.016 | 0.678 | 150.255 | 229.59 | 3.06 |
| 25 | 32.451 | 49.578 | 0.655 | 146.025 | 223.11 | 2.97 |
| 30 | 30.566 | 46.696 | 0.616 | 137.565 | 210.15 | 2.79 |
| 35 | 27.93 | 42.767 | 0.564 | 125.685 | 192.465 | 2.52 |
| 40 | 24.908 | 38.056 | 0.506 | 112.095 | 171.27 | 2.295 |
| 45 | 21.458 | 32.784 | 0.438 | 96.57 | 147.51 | 1.98 |

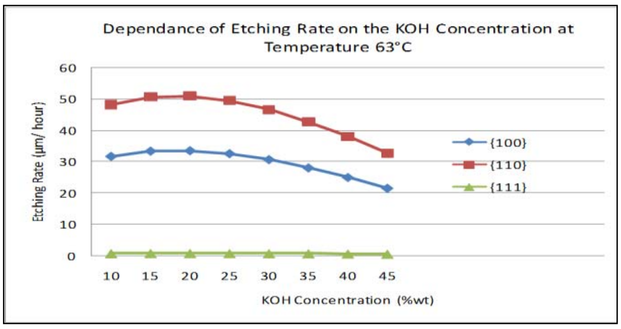


Fig. 5. Dependence of etching rate on KOH concentration at temperature 63 °C.

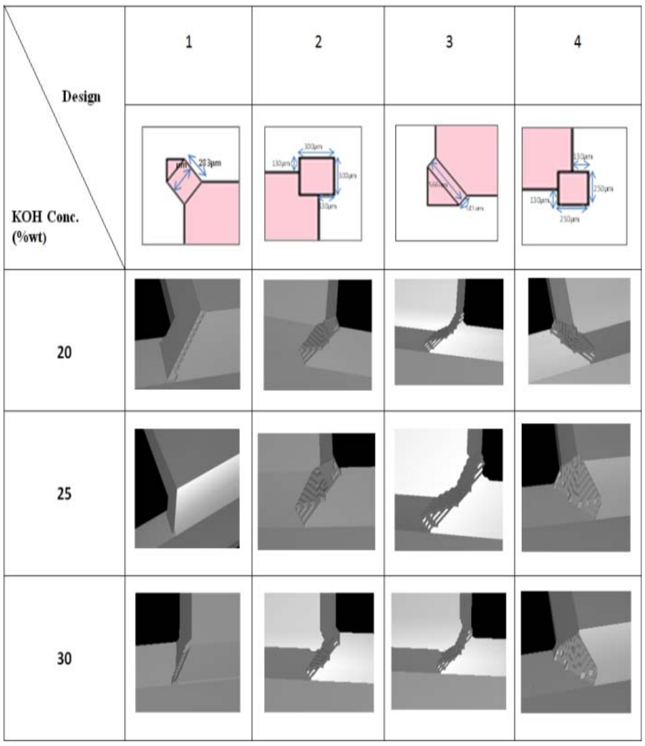


Fig. 6. Etched morphology of convex corner structure at 4.5 hours etching time at difference KOH concentration.

### *C. Determination of the best shape of compensation mask*

Early data was interpreted in this study and it was identified that the suitable etching temperature was at 63 °C and 25 wt% KOH concentration. Based on four types of convex corner compensation mask, it was found that the best design was the square corner. Therefore, the simulation was extended to etch the accelerometer structure with the square corner compensation mask. The result was displayed in Fig. 7. The compensation mask had covered the accelerometer structure successfully at etching temperature 63 °C in 25 wt% KOH concentration.

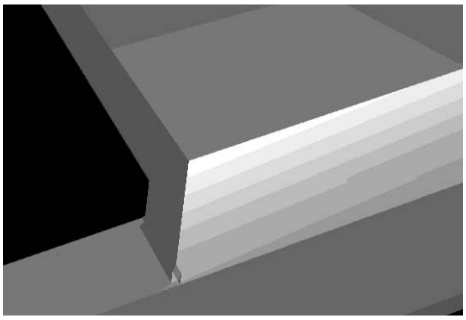

Fig. 7. Etched accelerometer structure with square corner compensation mask

## IV. CONCLUSION

Etching simulations of convex corner of accelerometer structure by KOH anisotropic etching have been performed. It was observed that the etching parameter such as temperature and concentration of KOH solution have influenced the corner undercutting phenomena. The simulation result was identified that the optimum etching temperature was at 63 °C and the KOH concentration at 25 wt%. Based on the optimum etching parameter applied to different type of compensation mask, it was shown that the suitable corner compensation mask was square corner pattern.

## ACKNOWLEDGEMENT

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## REFERENCES

[1] J. Judy, “Microelectromechanical systems (MEMS): fabrication, design and applications,” Smart Mater. Struct., vol. 10, no. 6, pp. 1115, 2001.

[2] M.A. Hines , “In search of perfection: understanding the highly defect selective chemistry of anisotropic etching,” Annu. Rev. Phys. Chem. Vol. 54, pp. 29 – 56, 2003.

[3] G.S. Higashi , Y.J. Chabal , G.W. Trucks , K. Raghavachari , Ideal hydrogen termination of the Si (111) surface , Appl. Phys. Lett. Vol. 56, 656 – 5818, 1990.

[4] J. Han, S. Lu, Q. Li, X. Li, and J. Wang, “Anisotropic wet etching silicon tips of small opening angle in KOH solution with the additions of I2/KI,” Sensors Actuators A Phys., vol. 152, no. 1, pp. 75–79, May 2009.

[5] J.-B. Waldner, Nanocomputers and Swarm Intelligence. John Wiley & Sons, 2013.

[6] X.-P. Wu and W. H. Ko, “Compensating corner undercutting in anisotropic etching of (100) silicon,” Sensors and Actuators, vol. 18, no. 2, pp. 207–215, Jun. 1989.

[7] Fan W, Zhang D.A simple approach to convex corner compensation in anisotropic KOH etching on (100) silicon wafer. J. Micromech Microeng, 2006, 16:1951.

[8] N. Soin, B.Y. Majlis, "Development of perfect silicon corrugated diaphragm using anisotropic etching," Microelectronic Eng., vol.83, pp. 1438-1441, 2006.

[9] R. Mukhiya, a. Bagolini, T. K. Bhattacharyya, L.Lorenzelli, and M. Zen, “Experimental study and analysis of corner compensation structures for CMOS compatible bulk micromachining using 25wt% TMAH,” Microelectronics J., vol. 42, no. 1, pp. 127–134, Jan. 2011.