Design and evaluation of corner compensation patterns for anisotropic etching

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ABSTRACT

This paper reports corner compensation methods for fabricating the intact mesa structure in MEMS (Micro-Electro-Mechanical System). To investigate the undercutting problem in the mesa structure, over ten corner compensation patterns are designed by computing the relations among a series of parameters, e.g. etching rates in different crystal planes, etching depth, etching times, etc. The compensation patterns are then simulated by the simulation software Anisotropic Crystalline Etch Simulation (ACES) beta 2, the 3D etching simulations are gotten. Various new compensation structures preventing the undercutting of convex corners of (100) silicon in THAH solution are redesigned and optimized based on the simulation results, the fabrication are conducted to verify the feasibility of the corner compensation patterns.

Keywords: TMAH, Corner Compensation, Wet Etching, MEMS

1. INTRODUCTION

Anisotropic wet etching has been used for microstructures fabrication, as it is easily served to fabricate small structure on a substrate. Anisotropic wet etching is also known as orientation–dependent etching because its etching rates depend on the crystallographic directions of the silicon crystal. Silicon anisotropic wet etching is one of the key manufacture techniques in MEMS fabrication and plays an indispensable role in the fabrication of microdevices.

Mesa-based structure with convex corners are often desired in various applications [1], however, during the fabrication process, the undercutting phenomenon may be caused in the convex corners due to the anisotropic etching characteristic that some planes are etched faster than others, resulting in a loss of the originally designed structure [2,3]. The phenomenon often leads to a serious problem in microsensors or microactuators applications. It is impossible to fabricate intact mesa structure without corner compensation structures. For preserving intact shapes of convex corners during anisotropic etching, an extra pattern can be added to the convex corner to prevent the undercutting on the convex corners which will be removed during the etching process. This method is called corner compensation.

Anisotropic wet etchants includes the hydroxides of alkali metals (e.g., NaOH, KOH, CsOH), simple and quaternary ammonium hydroxides (e.g., NH_4OH), ethylenediamine mixed with pyrochatechol (EDP) in water, and tetramethylammonium hydroxide (TMAH). The characteristics of each etchant are listed in [4]. Here, TMAH is chosen as the anisotropic etchant in our experiment, because it is non–toxic, non–flammable, less harmful and CMOS compatible.

2. DESIGN

The reasons of the orientation–dependent etching have been explained by screening effect from hydroxyl (OH-) [5] and bonding energy [6]. In our research, because the TMAH is used as etchant and experiments are carried out on (100) wafer, {311} planes are responsible for convex corner undercutting; while {411} planes are responsible for it, if the etchant is KOH [7]. The bevel of the {311} was observed to be approximately 25° with respect to (100) surface in the nature of the {311} crystallographic plane and the adhering surface energy, which is independent of etchant in the range of molarity or temperature [8]. As the mechanism of the TMAH undercutting on the convex corners is known, the size

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of the corner compensation can be determined by the depth of the mesa, TMAH etching rate. In our experiments, the etching depth is designed to be 300 μm for mesa, etching rate is 0.48 μm under temperature 80℃ measured by dummy wafer, the tested mesa pattern sizes are specified as 4 mm×4 mm, 2 mm×2 mm, 1 mm×1 mm, respectively. Regardless of pattern shapes, the size calculation equations for the compensation pattern can be derived as

$$\text{Size=etching rate} \times \text{etching time} \quad (1)$$

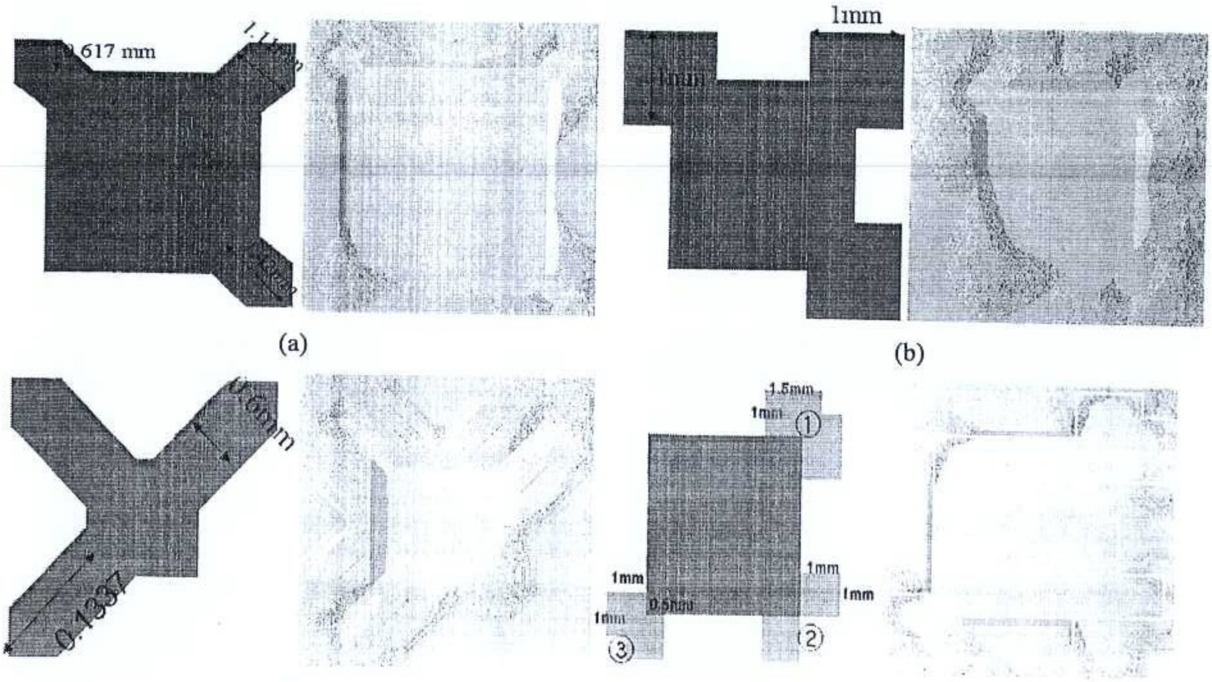
$$\text{Etching rate= etching rate (311) planes +etching rate (111) planes} \quad (2)$$

$$\text{Etching time=etching depth / etching rate (100) plane} \quad (3)$$

Here, the effect of the bevel between {311} crystallographic plane and (100) surface should be taken into account. The etching rates ratios between crystallographic planes have already known [9]. Then various patterns shapes could be designed with the sizes calculated from Equations (1-3). Square pattern, rectangular pattern, triangular pattern are basic pattern shapes that are often applied for corner compensation, by different combinations of these basic patterns, over ten patterns are proposed in our research for getting optimal patterns.

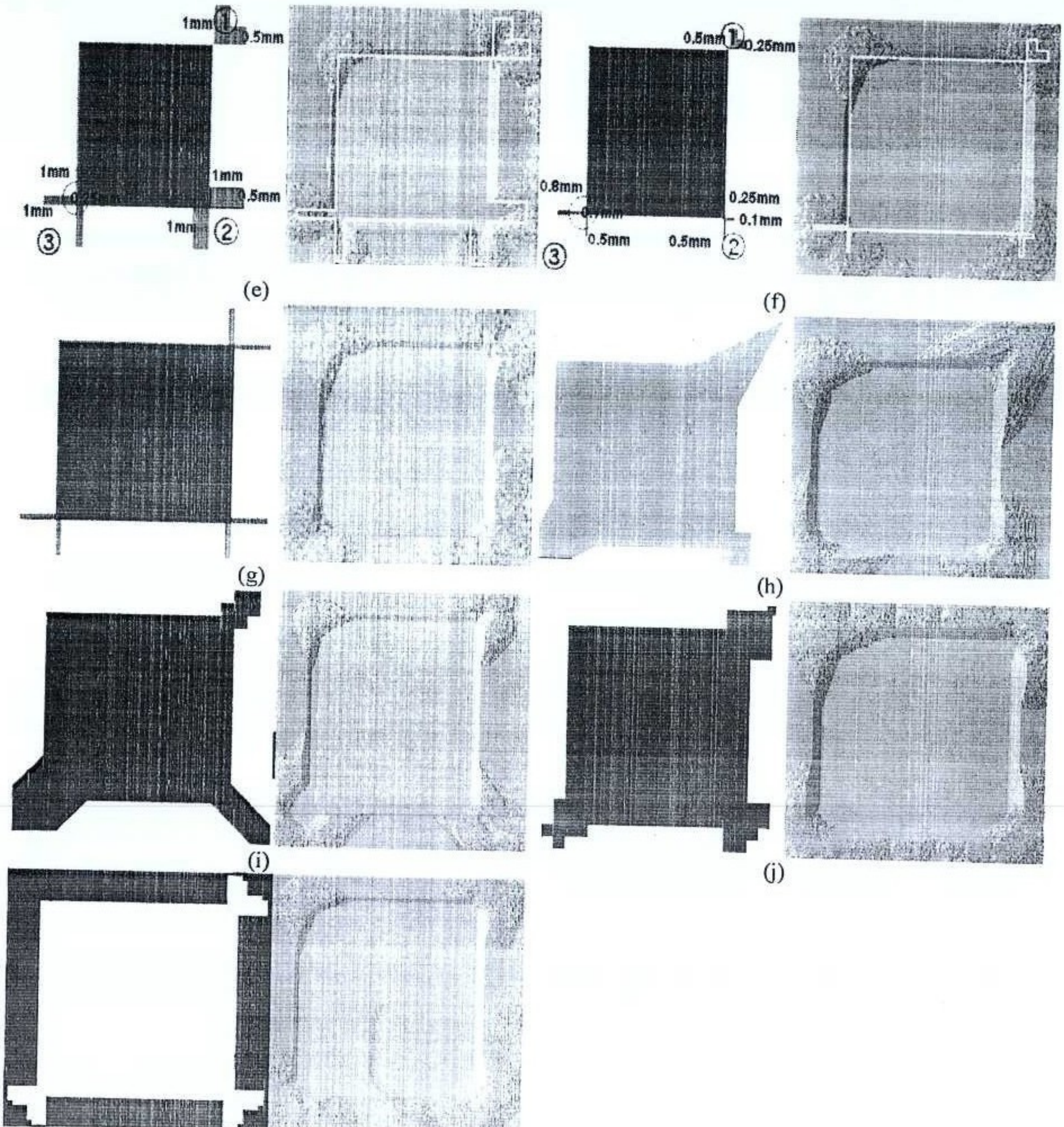
3. SIMULATION RESULTS

Due to anisotropic etching nature, it is difficult to predict or calculate the final result of silicon etching. For getting a desired structure, it needs plenty of iterations which waste time and resources. To efficiently design the corner compensation patterns, simulation software Anisotropic Crystalline Etch Simulation (ACES) beta 2 is utilized to get 3D simulation results prior to fabrications. The patterns pictures are input into the ACES as the virtual mask, the other etching parameters are then specified. Patterns which are designed by computation as introduced in above section are simulated and illustrated in Fig.1.



(a) (b)

(c) (d)



(e) (f) (g) (h) (i) (j) (k)

Fig. 1. The (a—k) types of patterns and simulation results

4. EXPERIMENTS

After the simulation, experiments are conducted on a (100) wafer. As the mask area is limited, some of the above typical patterns are chosen to be mapped on the mask. A (100) wafer is firstly oxidized on two sides for 600 μ m silicon dioxide working as protective layer in wet etching, then the patterns with corner compensation structures on the mask are transferred to the wafer by photolithography, anisotropic wet etching is then conducted, finally by removing all the silicon dioxide layer, clear etching results are shown. The fabrication process is shown in Fig.2.

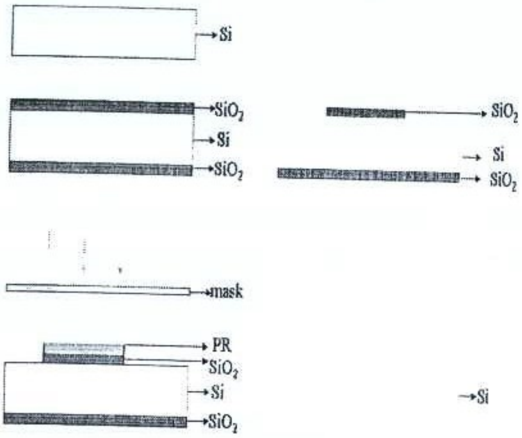
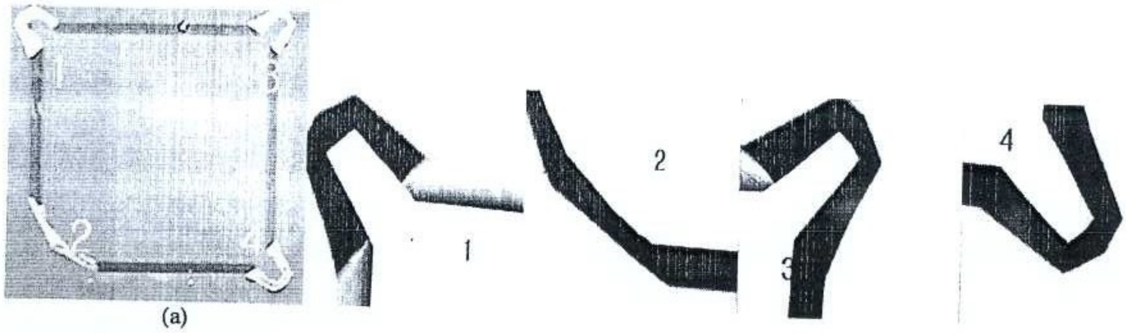
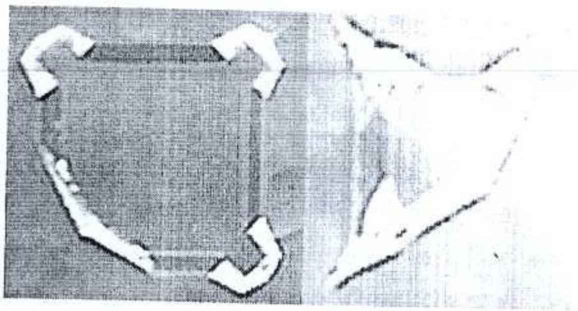


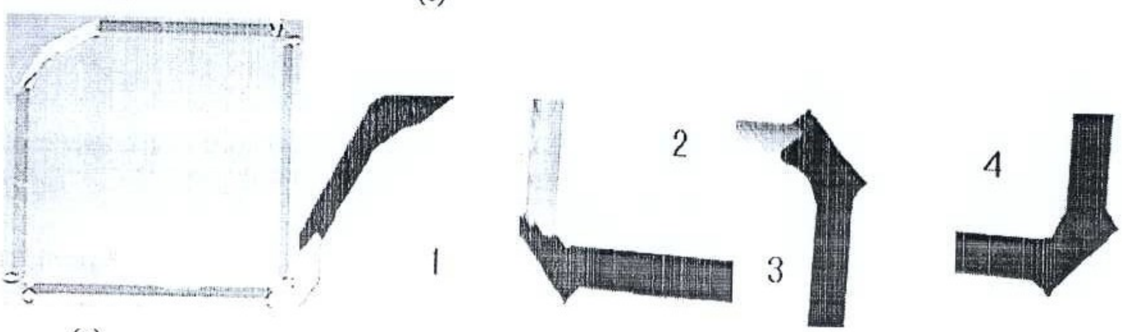
Fig. 2. Fabrication process



(a)



(b) (c)



(g)

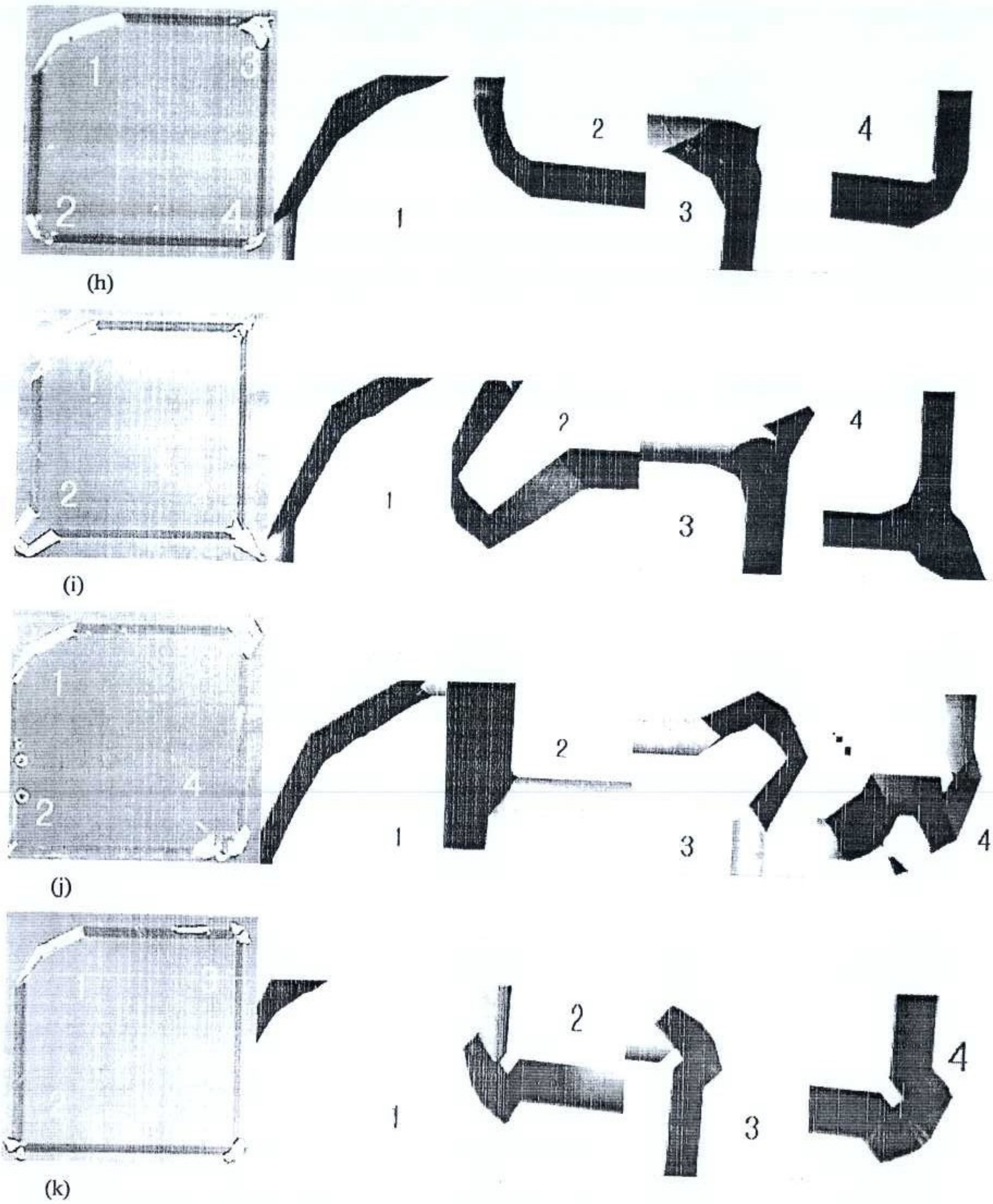


Fig. 3. The experimental results (the notations correspond to the ones in Fig.2)

The final experimental results are observed by optical microscope and demonstrated in Fig.3. Compared with the simulation results shown in Fig.2, the experimental results are in agreement with them.

5. CONCLUSIONS

From above theoretical analysis, simulation and experimental results, all the corner compensation patterns are compared and analyzed. The single square pattern, rectangular pattern or triangular pattern occupy a big area and can not obtain a desired corner compensation results, as their shapes don't fit the etching geometry, as shown in pattern b.Thin or wide bar corner compensation structure with the design equation [7] can not achieve the nice results and leave the extra corner compensation pattern after final etching, as demonstrated in pattern a and c. By combining the {311} crystallographic planes structure and the characteristics of TMAH anisotropic wet etching, we find two same structures which are located symmetrically and perpendicular to the two sides at the convex corners are capable to get good compensation results, because this structure can compensate the convex corners from two sides around the corners, after the etching, they will be completely etching without undercutting as shown in patterns g, j (2) and k. For perfect corner compensation, additional geometry correction factor for design equation will be considered in the future research.

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REFERENCES

1. Shen, F. ; Lu, P. ; O'Shea, S.J. ; Lee, K.H, "Frequency coupling and energy trapping in mesa-shaped multichannel quartz crystal microbalances," Sensors and actuators. A, Physical, v.111 no.2/3, 2004, pp.180-187
2. Chu, Huai-Yuan ; Fang, Weileun, "A novel convex corner compensation for wet anisotropic etching on (100) silicon wafer," Micro Electro Mechanical Systems, 2004. 17th IEEE International Conference on. (MEMS), 2004, 2004, pp.253-256
3. Wilke, N ; Morrissey, A, "Silicon microneedle formation using modified mask designs based on convex corner undercut," Journal of micromechanics and microengineering, v.17 no.2, 2007, pp.238-244
4. Nadim Maluf, Kirt Williams, An Introduction to Microelectromechanical Systems Engineering, Second Edition, Artech House, 2004
5. Aleksandrov, O. V, "Influence of the Screening Effect on Passivation of p-Type Silicon by Hydrogen," Semiconductors, Volume 36, Issue 1, January 2002, pp.21-25
6. Moldovan, C. Iosub, R. Nechifor, G. Dascalu, D. Craciunnoiu, F. Serban, B, "The mechanism of anisotropic etching of silicon in a complexantalkaline system," Semiconductor Conference, 1998. CAS '98 Proceedings. 1998 International, Volume: 2, On page(s): 353-356 vol.2
7. MUKHIYA R; BAGOLINI A ; MARGESIN B ; ZEN M ; KAL S, "<100> bar corner compensation for CMOS compatible anisotropic TMAH etching," J. Micromech. Microeng, 2006, vol. 16 , pp. 2458-2462
8. Drago Resnik, Danilo Vrtacnik and Slavko Amon, "Morphological study of {311} crystal planes anisotropically etched in (100) silicon: role of etchants and etching parameters," J. Micromech. Microeng. 10 (2000) 430–439
9. Tokoro, K. Uchikawa, D. Shikida, M. Sato, K, "Anisotropic etching properties of silicon in KOH and TMAH solutions," Micromechatronics and Human Science, 1998. MHS '98. Proceedings of the 1998 International Symposium on, On page(s): 65-70