(110) 실리콘의 이방성 식각을 이용한 빗 모양 액츄에이터의 제작

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Fabrication of Electrostatically Driven Comb Actuator Using (110) Oriented Si Anisotropic Etching

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Abstract-*An electrostatically driven comb actuator with 525 ㎛ height was fabricated using (110) Si anisotropic etching in the Potassium Hydroxide(KOH) solution. The etch-rate and etch-rate ratio are strongly dependent on the weight % and temperature of KOH solution. We developed the optimal condition for the anisotropic etching on (110) wafer with varying these conditions. The force that the comb-drive actuator generates is inversely proportional to the distance of gap and proportional to the height of the comb electrodes. The electrodes must have the high aspect ratio. The (110) Si anisotropic etching is very useful to get a high aspect ratio structure.*

Introduction

The field of micro electro-mechanical systems(MEMS) is essentially developed by the progressing integrated circuit industry. Micromachining technology is a good choice to miniaturize a various three-dimensional structure. There are lots of merits - low cost and mass production by highly controllable and reproducible fabrication technology. Typical structures of MEMS are thin membrane, deep and narrow groove, cantilever and tip, etc.[1, 2]. These structures are fabricated by various micromachining technology;surface micro machining, bulk micromachining, LIGA, etc.

Si anisotropic etching technology is one of the important technologies of bulk micromachining, and has been applied to fabrication of many micro electro-mechanical systems. Anisotropic etching of (110) Si is especially important, because it can produce deep vertical grooves with high aspect ratio without using expensive equipment. This technology has been used in the fabrication of accelerometers, sensors, and micro opto mechanical devices.

In this paper, 525 ㎛ height comb electrodes were fabricated using anisotropic bulk etching of the (110) Si in the KOH solution. To obtain a high electrostatical force in comb actuator, we must fabricate high aspect ratio electrodes. To achieve the desired profile, we experimented a serial fabrication process with varying the etching condition-weight %, temperature- of KOH solution[3-6] and the spring thickness of the micro structure was controlled by a timed etching. On the other hand, it is absolutely essential to find the exact <111> crystal orientation to perform the (110) anisotropic bulk etching, so we used the alignment target mask for finding the exact <111> direction on (110) wafer and we fabricated the comb structure with aligning this pattern to <111> direction.

Etching characteristics

When a models of silicon crystal lattice are examined, it is found that the packing density of the atom is substantially greater in the <111> direction of silicon than in the <100> or <110> direction. From this, it would be expected that the (111) planes would be etched more slowly than (100) or (110) planes. Thus, if we define R as the etch rate of silicon, the etch-rate can be described as following inequality.

$$R(100)>R(110)>>R(111)$$

Using the anisotropic etching mechanism of considerably larger etch rate of (100) or (110) plane than (111) plane, we can fabricate a 3-dimensional structure we expect. The major parameters affecting the etch rate are temperature and weight % of the etching solution.

The following table shows the etch rate of (110) Si with varying the weight % and temperature of KOH solution. The etch rate is much more sensitive to the temperature than weight %. So, in case of timed etching, it is necessary to control the temperature of KOH solution exactly.

Table 1. Etch rate varying the weight % and the temperature.

	75 ℃	80 ℃	85 ℃
35%	1.42 ㎛/min	1.89 ㎛/min	2.5 ㎛/min
40%	1.3 ㎛/min	1.67 ㎛/min	2.3 ㎛/min
45%	1.09 ㎛/min	1.41 ㎛/min	1.92 ㎛/min

The Fig. 1. shows the etching profile of the square pattern as the etching is performed in KOH solution. Each time step is 35 minutes.

(a) Mask(500, 200, 100, 50, 20 ㎛) (b) after 30 min

(c) after 60 min (d) after 90 min

Fig. 1. Microphotograph of the square pattern .

The intersection of slant (111) and vertical (111) makes an angle of 30° with the surface plane of (110) wafer. The penetrated opening after sufficient etching decreased compared with the original design as shown in Fig. 2. When we perform the (110) Si anisotropic bulk etching, it is necessary to compensate this characteristic.

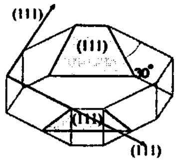
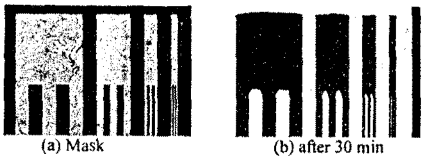
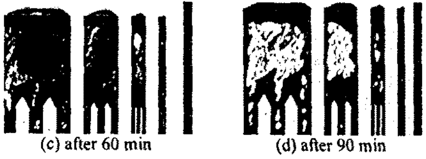


Fig. 2. 3-dimensional schematic diagram of Fig. 1 (d).

Fig. 3 shows the residual beam profile while the wet etching is processed as to different beam width ; 20,50 and 100 ㎛.



(a) Mask (b) after 30 min



(c) after 60 min (d) after 90 min

Fig. 3. Residual beam of different width-100, 50 and 20 μm.

From these microphotograph, the beam length decreased with etching process and the decrement rate is strongly dependent on the beam width(Fig.4).

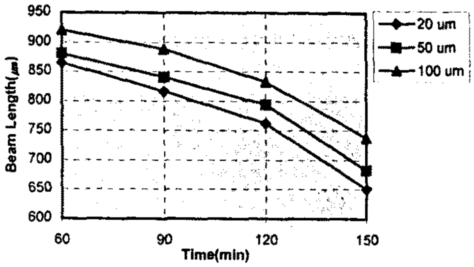


Fig. 4. Plot of residual beam length with etching process.

As a result of the previous experiments, it is very important to find the (111) orientation in order to prevent over-etching or undercutting and obtain the desired structure[7].

Alignment Target

In case of (100) or (110) wafer, it is absolutely important to align the pattern to the (111)direction before etching. So we need the indicator that prove the (111) direction; that's called alignment target[8]. In all wafers , there is primary flat, which indicates the (111) direction. But there are some errors about ± 1 degree along the true (111) direction, because this flat is only fabricated by mechanical machining. So, we must align the alignment target to the ready-made <110> direction in the wafer and etch the alignment target in order to verify the true (111) direction. After etching the alignment target, the true (111) direction can be proved by the selecting the least undercutted narrow hole. After this process, we can align the pattern to true (111) direction in order to achieve desired pattern and structure.

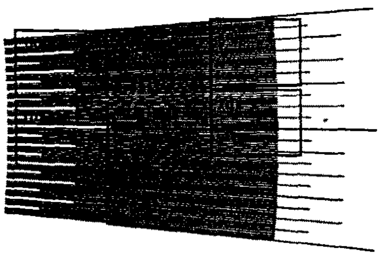


Fig. 5. Alignment target

Fig.5 shows a target mask for aligning to (111) orientation. Each narrow hole(10 μm×5 mm) makes an angle of 0.1 degree. After etching, each region of the resultant etching profile is shown in Fig. 6. Each beams have been already etched about 50 μm. The more misaligned the narrow hole is, the more the pattern is undercutted. By the experimental results in case of Fig. 6, we can prove the true <110> direction by means of selecting the least etched narrow hole, which is in the upper region in Fig. 6 (d) and has an error of ± 0.05 degree.

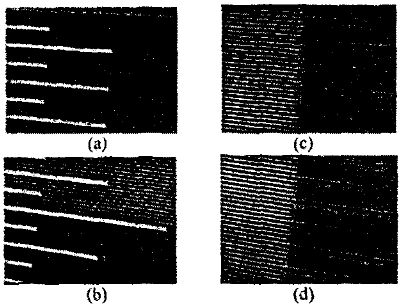


Fig. 6. Micro photograph of the alignment target after etching

Micro structures with various Actuators Design

The 3-dimensional comb structures applicable to the electrostatically driven actuator were designed and fabricated using Si anisotropic bulk etching in the basis of previous experiments. Fig. 7 and 9 show the schematic diagram of the comb actuator driven by electrostatic force. The restoring force is supplied by mechanical spring[9-12].

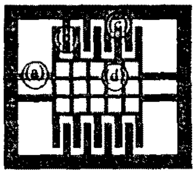


Fig. 7. Schematic view of mask

Fig. 8 shows the fabricated microstructure of Fig. 7, which has the roughness of 5-7 μm in the straight line on the mask and misaligned to (111) direction. The etching conditions are followings ; 80 ± 3 ℃, 40% KOH solution for 260 minutes. Each region of microphotograph is in Fig. 8.

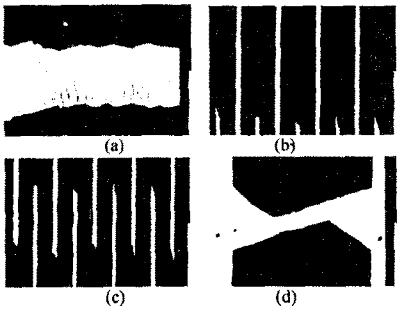


Fig. 8. Microphotograph of test pattern in Fig. 7

The width, spacing and length of comb are 100 μm, 50 μm and 3 mm respectively and the height of comb is 525 μm; thickness of wafer. The Fig. 8 (a) shows microphotograph of spring structure which has undercutting characteristics of anisotropic etching. The residual width of comb is about 50 μm shown in Fig. 8 (b) and (c) compared with the mask pattern-100 μm-. Fig. 8 (d) shows the unique (110) etching profiles. From experiment, the properties of the etched structures are influenced by the alignment to the (111) of the mask design and the roughness of the mask.

Fig. 10 shows the fabricated microstructure of Fig. 9 which has the roughness of 2-5 μm in the straight line on the mask and aligned to (111) direction. The etching conditions are followings;80 ± 3 ℃, 45% KOH solution for 260 minutes. Each region of microphotograph is in Fig. 10.

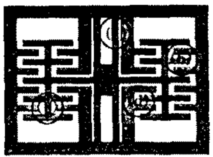
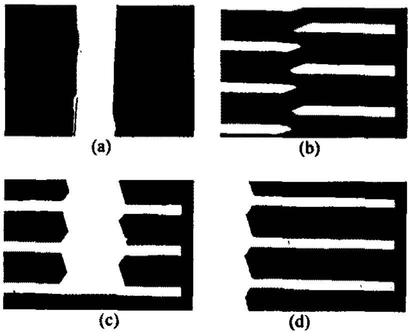


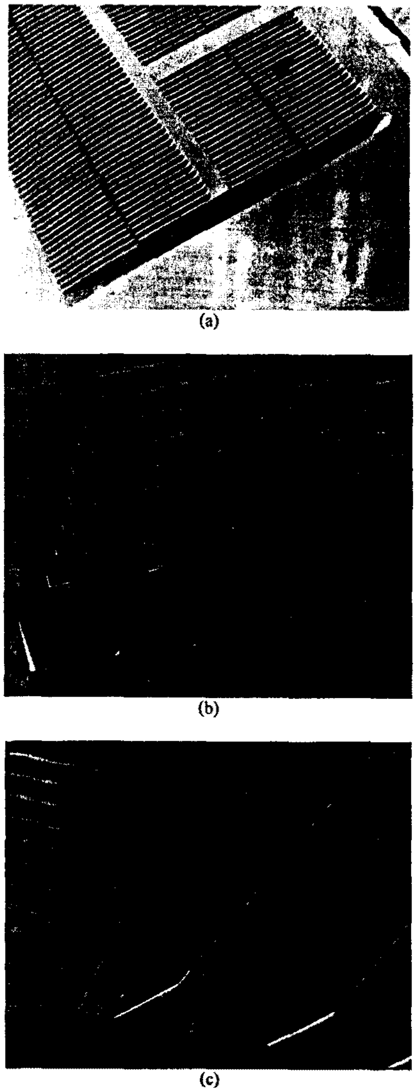
Fig. 9. Schematic view of mask


(a) (b)

(c) (d)

Fig. 10. Microphotograph of test pattern in Fig.9

The width of comb is 100 ㎛, the spacing of comb is 50 ㎛, the length is 3 ㎜ and the height of comb is 525 ㎛; thickness of wafer. The Fig. 10 (a) shows the region of spring structure which has undercutting characteristics of anisotropic etching. The residual width of comb is about 80 ㎛ shown in Fig. 10 (b), (c) and (d) compared with the mask pattern-100 ㎛.


(a)

(b)

(c)

Fig. 11. SEM photograph of the comb structure.
(The comb width is about 80 ㎛, spacing about 70 ㎛ , height 525 ㎛)

Fig. 11 (a) and (b) are the SEM photograph of the comb electrode and Fig. 11 (c) is the spring structure in Fig. 10.
Even if the mask was aligned to the (111) direction, there are so much undercutted area. Because the mask of pattern is rough and every surfaces of the structures converge to (111) planes after sufficient etching.

Fig. 12 shows these dependence of mask properties. It is the results of fabrication etched upto 100 ㎛ depth in case of aligned to (111) and very straight line mask.

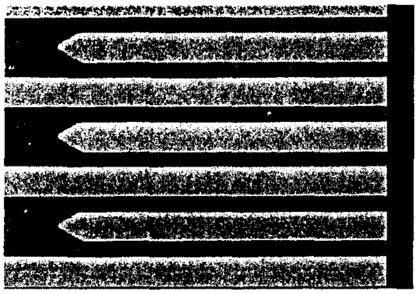


Fig. 12. Microphotograph of the result of 100 ㎛ etching.

Conclusion

In this paper, (110) Si anisotropic etching is performed to fabricate the electrostatically driven comb actuator. Using the alignment target, we find the true (111) direction in the (110) wafer. From the various test pattern, we obtain the anisotropic etching characteristics.
The comb electrodes were successfully fabricated by the anisotropic etching, but there are some problems to produce a expected spring structure perpendicular to the lateral direction of comb electrodes. Because spring structure was manufactured by the timed etching, it is very difficult to control the undercutted area ; the cross-section of spring and the joint of spring with mass. Consequently, we will consider a new micro structure that can make precise spring system with comb structures at the same time.

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