Techniques for micromachining multilayered structures in silicon

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Abstract - The effects of wet anisotropic etching of (100) silicon were studied with mask edges aligned 45^0 to the primary wafer flat. Samples were etched in aqueous KOH solution with the addition of isopropyl alcohol (IPA). The addition of IPA caused a change from formation of vertical {100} walls to sloping {110} walls only for solutions below a critical concentration and temperature. The dependence on concentration was then applied to produce a new multilayer structure with {110} walls fabricated on top of {100} walls.

A. Introduction

Micromachining of three-dimensional structures in crystalline silicon has been used in many optical applications such as waveguides, switches, gratings, modulators, and resonators [1]. The technique of anisotropic etching is of particular interest since in (100) silicon it can produce smooth walls in useful direction for mirror surfaces. The three possible structure types, shown in figure 1 are: vertical {100} walls [2], {110} walls inclined 45^0 to the surface, or {111} walls inclined at 54^0 [3]. Both the {100} and {110} walls have many possibilities for use in optics since they may be used to create 90^0 bends or to couple light out of the plane of the substrate [4,5]. To achieve either {100} or {110} walls the pattern edges must be in the <100> direction, 45^0 from the prime wafer flat [3].

The selection between {100} and {110} walls depends on their relative etch rates R_{100} and R_{110}. The plane forming a sidewall is always the one with the slowest etch rate aligned to the mask edge [6]. In Pure KOH $R_{100} < R_{110}$ but the rates can be reversed with addition of isopropyl alcohol (IPA) [3], allowing the formation of {110} walls. Addition of IPA has also been shown to improve surface smoothness [7,8], so to be able to also produce vertical walls with IPA added would be an advantage.

It is possible exploit the anisotropy of KOH etching to create three-dimensional structures with multiple layers [5,9]. This may be done with careful selection of multiple masking steps, or in some cases maskless etching [10,11].

B. Experimental Details

The etching solution used was aqueous KOH with IPA added. The influence of KOH concentration and temperature on the etching anisotropy was investigated. 75 samples were patterned with rectangular shapes aligned visually to the <100> direction (45^0 from the cleaved sample edges) and etched in different solutions. A 150nm thermal oxide was used for the masking layer, which was patterned using a positive photoresist. The solutions were held in a Teflon beaker and agitated with a magnetic stirrer. The samples were held above the stirrer by a Teflon disk with small holes drilled through it to allow fluid flow. The beaker was housed in a temperature-controlled water bath.

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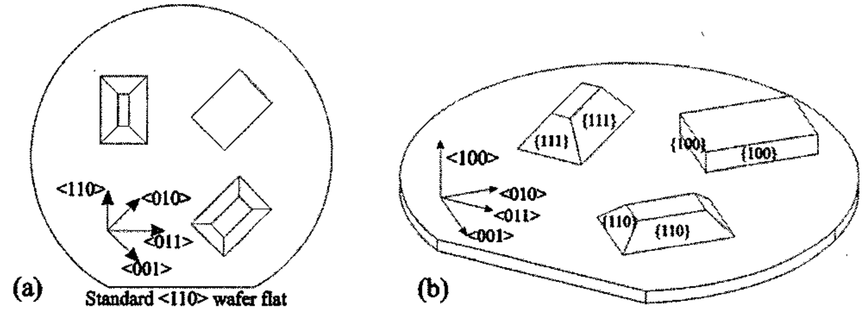

Figure 1. Structure types producible on a (100) wafer in plan and isometric views

The solutions were made by dissolving KOH pellets in water and then adding IPA. The water and KOH concentrations were measured to within $\pm 5\%$. The majority of the IPA floated as a second layer on top, the amount actually dissolved in solution is known to be less than 5% by weight [12], and depends on the KOH concentration. A water cooled condenser was installed above the beaker to minimize evaporation of the top layer.

An investigation into fabrication of multilayer structures was made, using the same mask for successive lithography steps. The aim was to show that a 45^0 sloping {110} wall could be produced on top of a vertical {100} wall by exploiting the dependence of anisotropy on KOH concentration.

C. Results

C1. Concentration dependence

It was found that vertical sidewalls were produced in KOH+IPA solutions with a high enough KOH concentration and temperature. The difference between structures produced at KOH concentrations of 50% and 35% by weight may be compared in figure 2. The formation of vertical walls in KOH+IPA has only recently been reported [13] but it was claimed to be of no practical use because of the low etch rate and irregularity in the selection of the planes. Neither of these issues were found to be a problem in this experiment. Etch rates of 700nm per minute were achieved for KOH+IPA solutions with KOH concentrations of 50% and temperature of 80^0C, with reliable selection between the two planes.

C2. Application to two layer structure

The intended structure was to be in the shape of a house. The sloping *roof* would be made from {110} planes and the vertical *walls* would be flush with the edge of the roof. Examples of the final structure are shown in figure 3, with the associated fabrication steps in figure 4. The roof was fabricated with a simple rectangular mask and KOH+IPA solution of low concentration. Structure heights from 10 μm to 50 μm were easily produced.

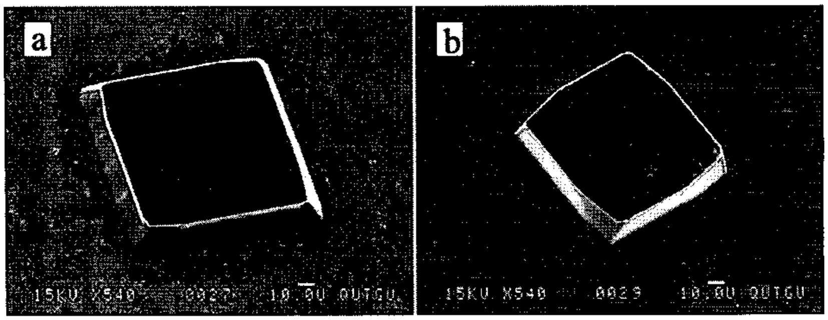

Figure 2. Structures etched in KOH+IPA at 34% and 51% KOH concentration (by weight)

For the second step the lateral dimensions of the roof needed to be less than the mask, to allow for under etching in the formation of the walls. (As the vertical walls are formed the silicon is etched laterally and vertically at the same rate. For example to make a vertical $10\,\mu m$ high wall the mask edge must initially extend $10\,\mu m$ from the edges of the roof.) Only one mask pattern was available and so the roof had to be made smaller by an intermediate step, this was done by maskless etching. It was found that by using KOH+IPA at high KOH concentration the roof structure etched inwards without change in the overall height or slope.

As an additional bonus, the maskless step made a novel corner compensation technique. The rounded corners which had been caused by high order planes undercutting the mask (shown in figure 2) disappeared after 15 minutes of maskless etching. The cost of the intermediate step was an increase in surface texturing, which can be seen by comparing figures 3(a) and (b) with (c) which was made without the intermediate step. (The mask was offset to allow the structure to form correctly on only two sides).

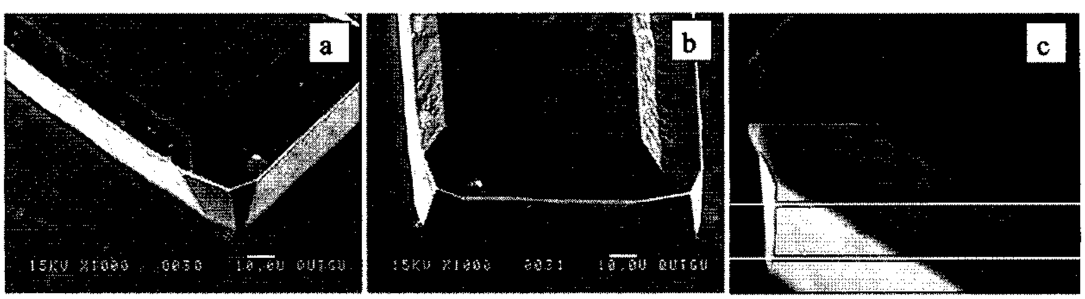

Figure 3. Microhouses, (a) and (b) using the maskless step, (c) smoother surface without maskless step

Figure 4. Structures after each processing step: 1. Photoresist and SiO_2 mask, 2. Etching 45^0 walls, 3. Maskless etching, 4. Repeated mask (extended beyond roof), 5. Etching vertical walls

Considerable difficulty was found with the application of photo resist for the second lithography step. The photo resist did not adhere to the top edges of the roof structure. This problem has been reported for many large silicon structures and has been attributed to high surface tension at the edges [14]. The solution was to use an artists air brush to spray on the photo resist while spinning the sample at low speed. The sprayed layer was very thick and so required exposure times of more than five minutes but good coverage was achieved at the corners.

Conclusion

It has been shown that KOH solution with IPA added can be used in micromachining of three dimensional structures in (100) silicon with the flexibility of revealing the {100} planes or {110} planes depending on the KOH concentration. A two level structure was demonstrated with the top half bounded by {110} walls and the bottom half bounded by {100} walls.

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References

[1] P.P. Deimel, J. Micromech. and Microeng. **1** (1991) 199-222.

[2] H. Seidel, in "Integrated micro motion systems: Micromachining, control and applications", ed. F. Harashima, Elseiver, (1990) 956-59.

[3] H. Sidel, L.C. A. Heuberger, and H. Baumgartel, J. Electrochem. Soc. **137** (1990) 3612-26.

[4] L. Rosengren, Y. Bäcklund, and L. Smith, J. Micromech. and Microeng. **2** (1991) 75-79.

[5] M. Vangbo and Y. Bäcklund, J. Microelectromech. Syst., **6** (1996) 42-45.

[6] D.B. Lee, J. Appl. Phys. **40** (1967) 4569-74.

[7] I. Zubel and I. Barycka, Sens. Actuators A **70** (1998) 259-68.

[8] A. Merlos, M. Acero, M. H. Bao, J. Bausells, and J. Esteve, Sens. Actuators A 37-38 (1993) 737-43.

[9] I.B. Kang, M.R. Haskard, and N.D. Samaan, Sens. Actuators A **62** (1997) 646-51.

[10] X.Li, M. Bao, and S. Shen, Sens. Actuators A **57** (1996) 47-52.

[11] M. Bao, X. Li, S. Shen, and H. Chen, Sens. Actuators A **63** (1996) 217-21.

[12] J.B. Price, in "Semiconductor Silicon 1973", Princeton NJ, Electrochem. Soc. (1973) 339-53.

[13] I. Zubel, Sens. Actuators A **84** (2000) 118-25.

[14] V.G. Kutchoukov, J.R. Mollinger, and A. Bossche, Sens. Actuators A **85** (2000) 377-83.