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Study of Compensation Structures for Silicon Micromachining

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ABSTRACT

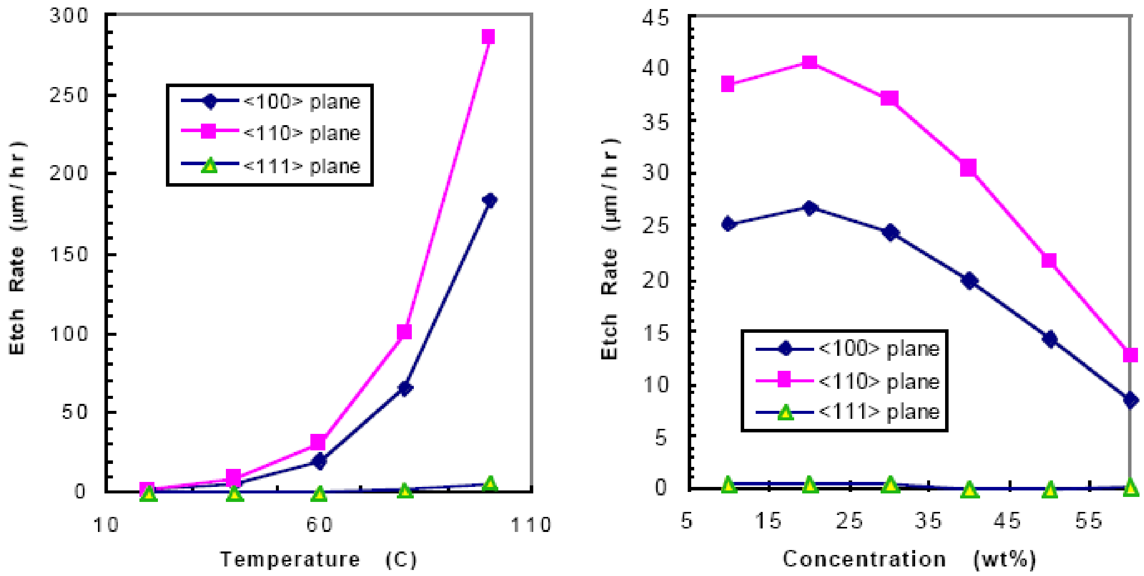
For obtaining the suspended structures, as well as for designing the necessary masks, the time evolution of etched shapes must be considered. KOH anisotropic etching is one of the basic technologies of silicon bulk micromachining. This paper deals with a study of some convex corner compensation structures for achieving the inertial mass of a micro accelerometer by using KOH anisotropic etching on (100) silicon wafer. More samples with the intermediate checking of the obtained structures during various etching times were performed.

INTRODUCTION

A silicon micro mechanical device is fabricated using a combination of lithography-based bulk and surface structuring processes carried out successively. Several constraints due to incompatibilities of materials and processes have to be considered while defining such a manufacturing sequence. A kind of constraints is the feasibility of generating the intended device geometry using the specified fabrication processes. This point is directly related to one of the major difficulties of wet chemical etching of silicon, namely to generate etch masks, which provide a correct transformation of the 2D layout into the appropriate 3D structure. The problem arises from the circumstance that convex corners of the etch mask will be under-etched due to fast etching crystal planes developing at convex mask corners. A technique widely used to obtain well-defined shapes is the application of mask compensation structures [1]. At a certain etch depth the additional mask element is completely under-etched.

Wet chemical anisotropic etching of silicon is one of the key technologies of silicon micromachining. It is also referred to as “bulk micromachining”, because in this technology the body of the silicon wafer is etched away. A square or rectangular diaphragm and other complicated 3D structures can be formed by this technique. Anisotropic etchants are also known as orientation-dependent etchants because their etching rates depend on the crystallographic directions. KOH (potassium hydroxide), EDP (ethylenediamine and pyrocatechol) and TMAH (tetramethyl ammonium hydroxide) are the commonly used orientation-dependent etchants [2]. EDP is not easy to handle. It is hazardous and its vapors are carcinogenic, necessitating the use of completely enclosed reflux condensers. TMAH is easy to use, but it reacts to a certain extent with the CO_2 in the air, so etching vessels should not be left open for a long time.

Another disadvantage of TMAH is the occasional formation of undesirable pyramidal hillocks at the bottom of the etched cavity. KOH is the most common and the most important etchant. It is safe, easy to handle, repeatable and etches fast. Its low cost recommends it for batch fabrication. So, KOH anisotropic etching has become one of the key technologies in silicon bulk micromachining. Figure 1 shows a graphical representation of the silicon etch rate dependence on the crystalline plane, etchant temperature and etchant concentration for KOH.



a) b)

Figure 1: Silicon etch rate as a function of temperature at fixed concentration of 40% (a), silicon etch rate as a function of concentration at fixed temperature of 60°C (b)

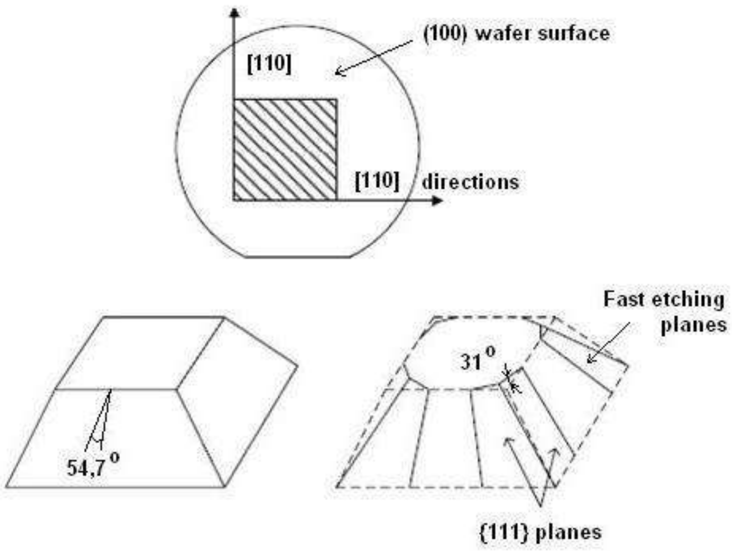


Figure 2: Drawing of the wafer, mask and etching result

THEORY

Convex corner undercutting is caused by fast etching in some planes, as is shown in Figure 2. {111} planes are etched at a rate about 400 times slower than for {100} planes in KOH solvent. Ideally, <110> mask produces structures with (111) sidewalls inclined at 54.74° relative to the (100) silicon wafer surface after KOH etching. But at the intersection line of two {111} planes, new fast etching of high-index crystal planes /(411),../ appear, so that the convex corners are etched.

There are various corner compensation structures, as we can see in Figure 3.

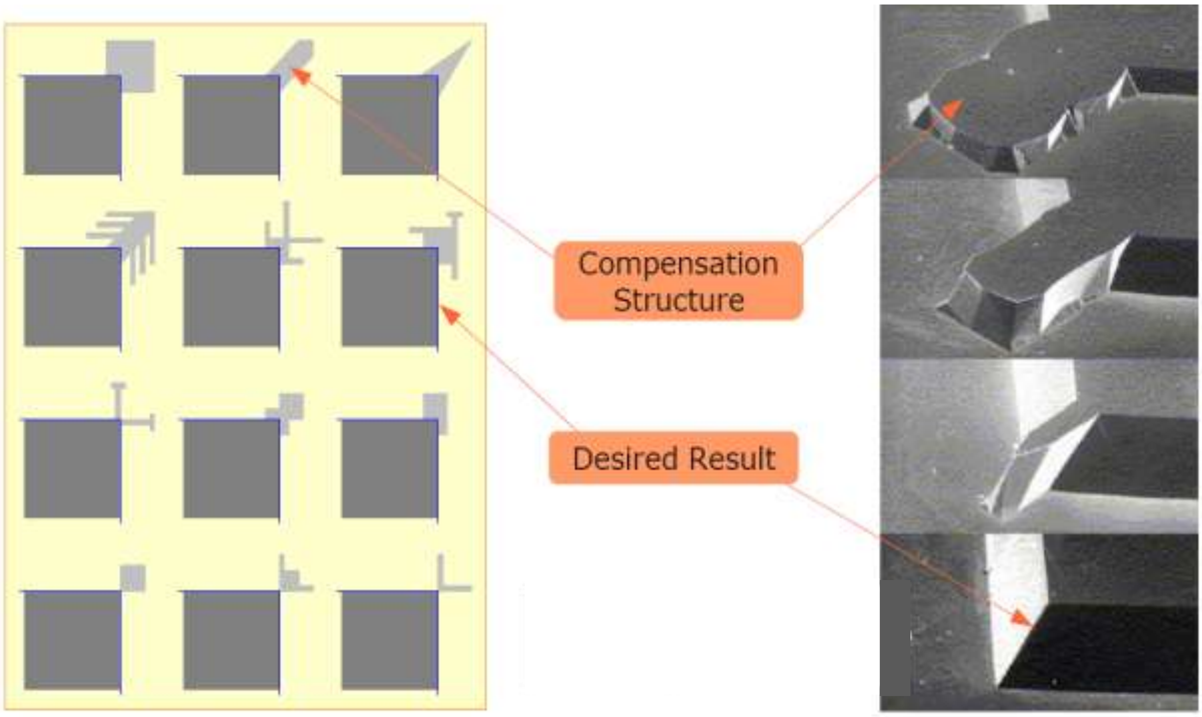


Figure 3: Compensation structures and evolution of etching results

Using aqueous KOH without any additions in a range of 15-50 wt% at temperatures of 60-100°C, the following equation, as an expression of the geometrical relationships of the etching process, can be written [3]:

$$a = \frac{H}{0.544} \tag{1}$$

where a is the characteristic size of the compensation structure (the side length of a square or the width of a beam), and H is the total etching depth.

For example, a compensation structure with two *a* × *a* squares has an evolution presented in Figure 4. According to Eq. 1, a pattern with a=690 µm can complete a convex corner when etching depth H=375 µm. This structure is often used in accelerometers, pressure sensors and other kinds of inertial sensors. In Figure 5 is given the graphical representation of Eq. 1.

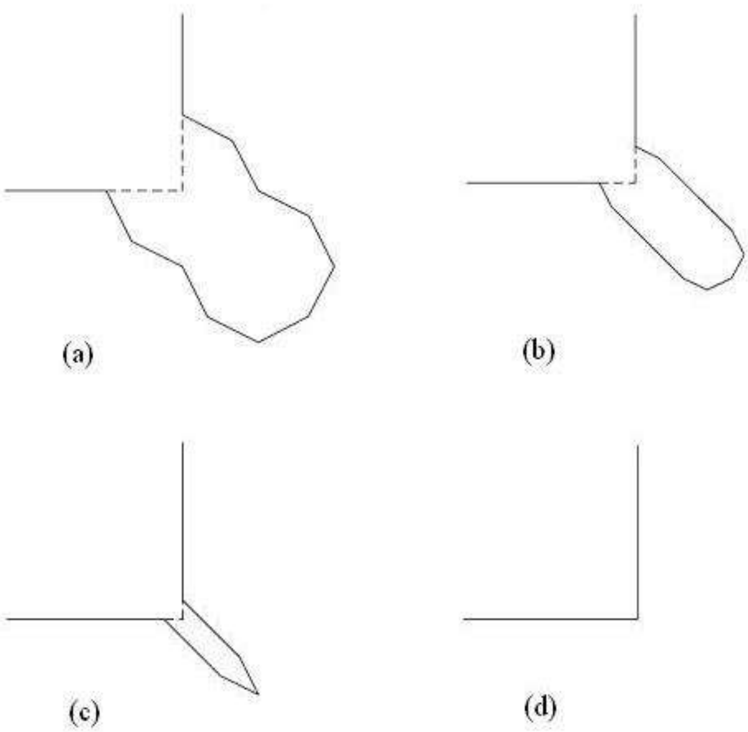


Figure 4: Convex corner structures formed by compensation at different etching depths – ~ 30%H (a), ~ 50%H (b), ~ 80%H (c) and complete convex corner at the final etching depth H (d)

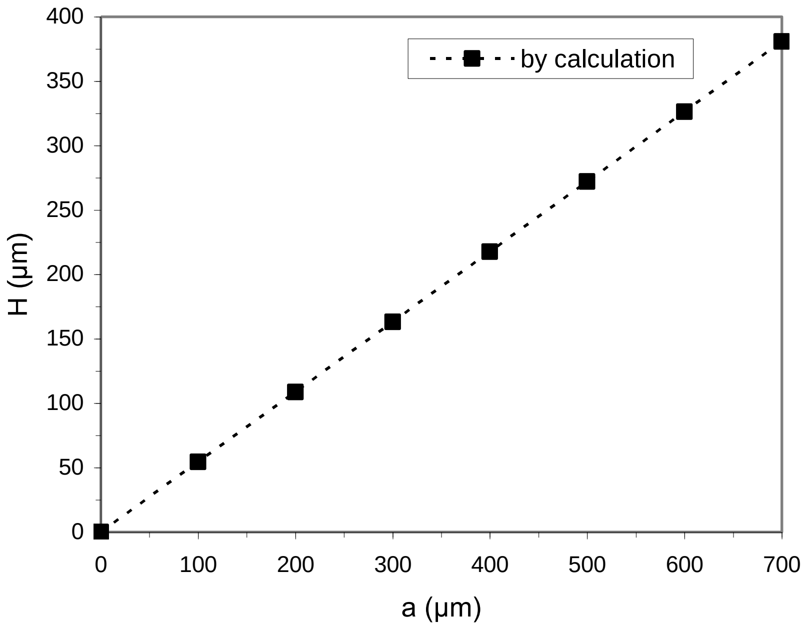


Figure 5: Computation results according to Eq. 1

EXPERIMENTS, RESULTS AND DISCUSSIONS

This paper used (100) silicon wafers in experiments. Wafer thickness is 450 µm. The masking layer is 1800 Å thermal oxide, SiO_2. The KOH solution is 25 wt% at 80°C, with an etch rate of 1.25 µm/min.

The piezoresistive micro accelerometer chip sizes are given in Figure 6 and the mask patterns used in the technological process are shown in Figure 7 [4].

The process flow is as follows:

1. Thermal oxidation on the two sides of the wafer;
2. Alignment front to back (photolithographic process and etching of front-back alignment signs by using M1A and M1B masks);
3. partial des-oxidation only on the front side (50% HF: 40%NH_4F: H_2O, 35^oC, 0.1 µm/min etch rate);
4. Piezoresistors diffusion (photolithographic process and etching for windows opening in the oxide layer on the front side of the wafer to diffuse the boron by using M2 mask, 1000^oC, 1 hr);
5. Windows opening for contacts (photolithographic process and etching for windows opening for contacts by using M3 mask);
6. Cr-Au deposition on the front side, total thickness 1150 Å (vacuum evaporation/ PVD process, p=10^{-7}torr);
7. Photolithographic process and etching for metallization tracks delimiting (M4 mask, 3HCl: 1HNO_3, 0.04 µm/min etch rate);
8. Windows opening for anisotropic etching on the front side of the wafer (photolithographic process and etching by using M5 mask);
9. Windows opening for anisotropic etching on the back side of the wafer (photolithographic process and etching by using M6 mask);
10. Front-back anisotropic etching of silicon wafer (25% KOH, 80^oC, 1.25 µm/min etch rate, H_1=40 µm);
11. Wafer front side covering by protection resin;
12. Anisotropic etching only on the back side of the wafer (KOH, H_2=410 µm) and releasing the mechanical microstructure - the inertial mass and the supporting beams;
13. Protection resin removing.

More preliminary experiments were performed to establish the necessary anisotropic etching time and to avoid the convex corners undercuts of the mesa structure (the inertial mass).

The preliminary results are presented in Figures 8 and 9, and the final structure is shown in Figure 10.

The photos were performed on an optical microscope, which gives a magnifying power of about 2000 X, corresponding to a resolution of 0.25 µm. It can be observed the real etched silicon structure relative to the SiO_2 mask.

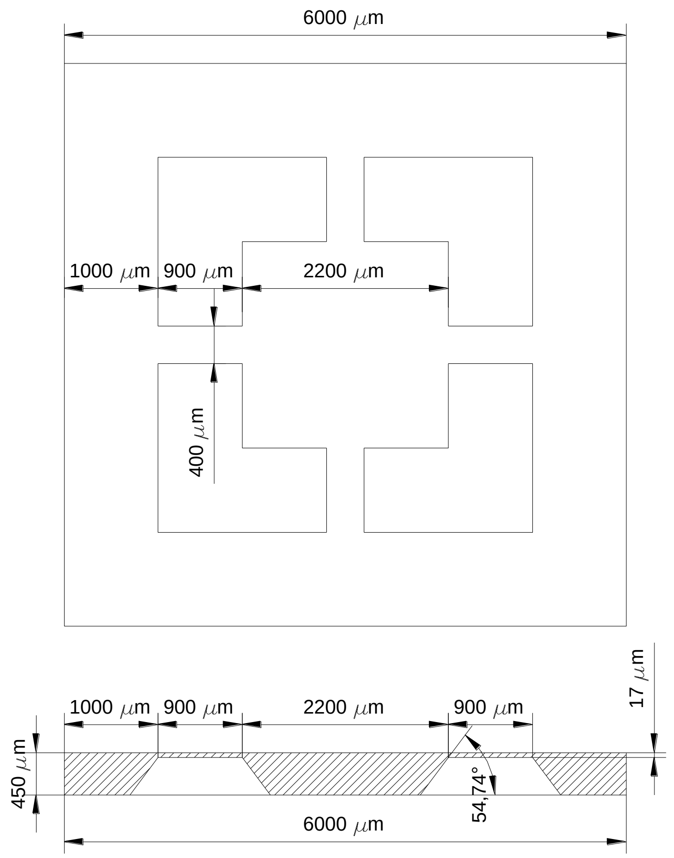
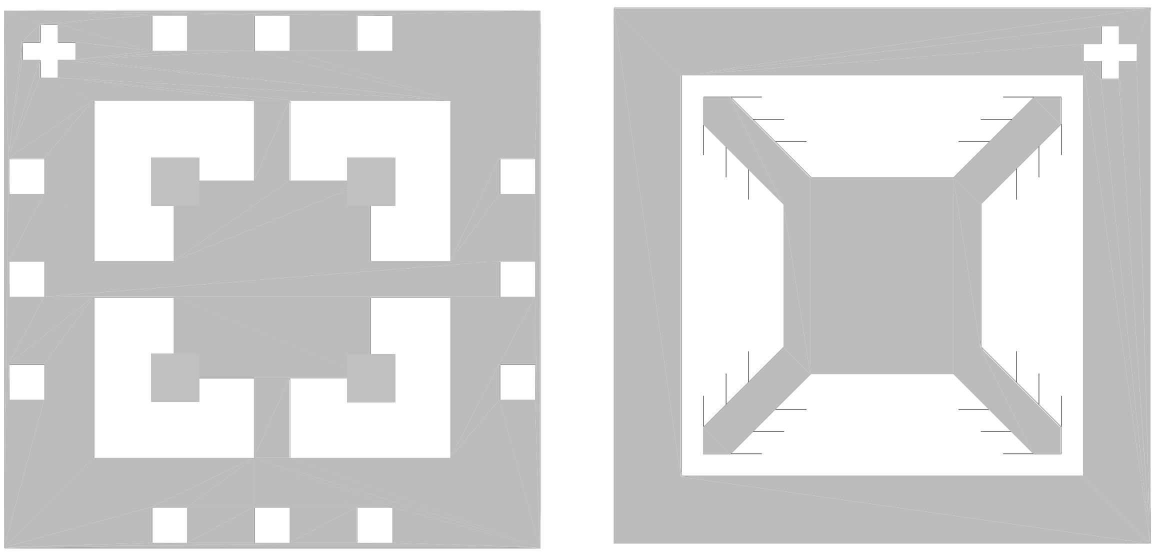


Figure 6: Sizes of the analysed structure of micro accelerometer



a) b)

Figure 7: The front side (a) and the back side (b) mask configurations (M5 and, respectively, M6) and compensation structures for inertial mass of the micro accelerometer

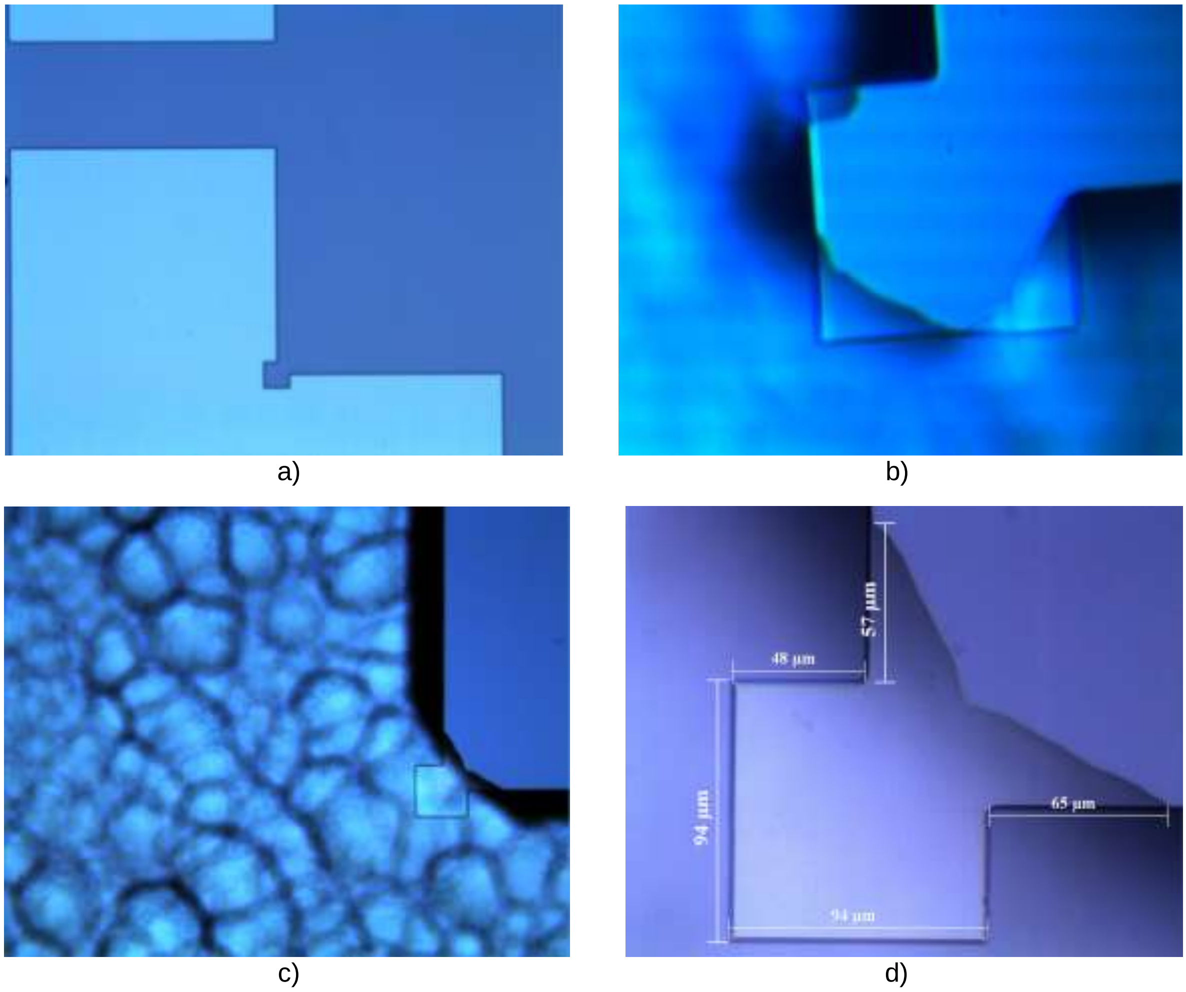


Figure 8: Photos presenting the front side compensation structure mask (a), and the wafer after t_{etch}=20 min (b) and t_{etch}=60 min (c, d)

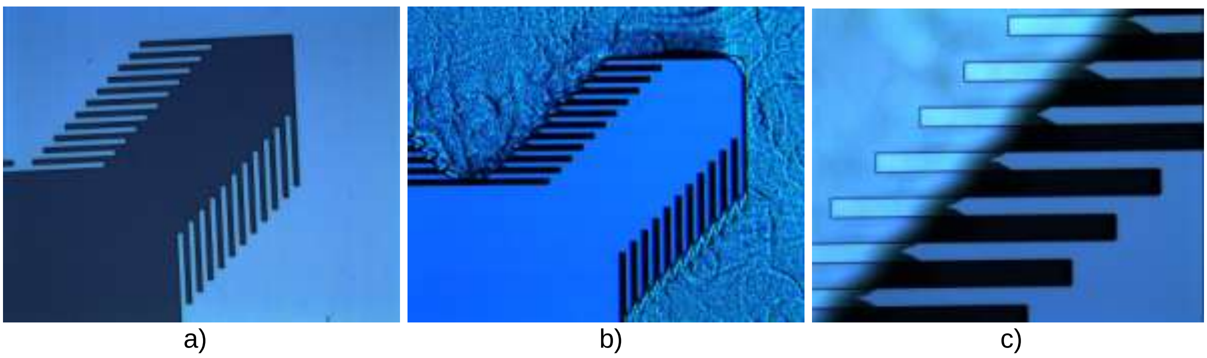
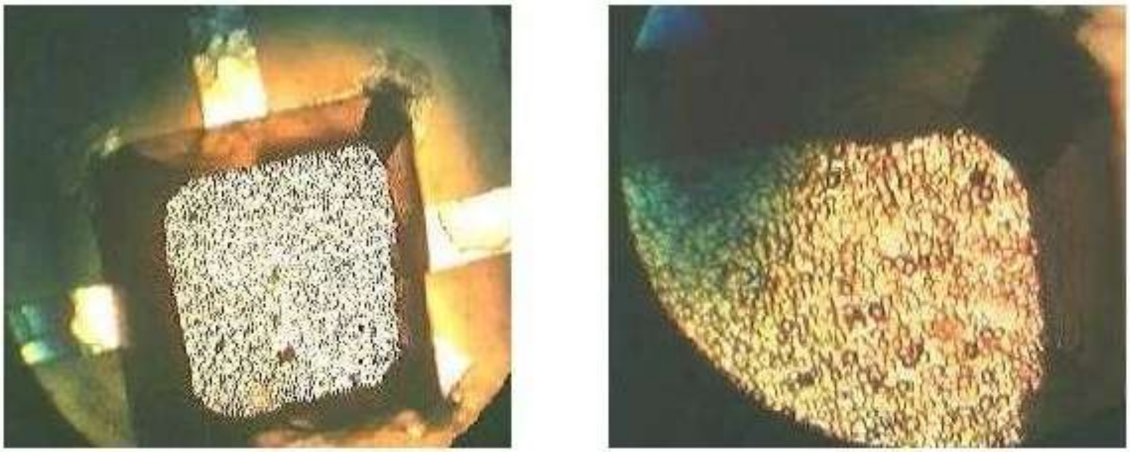


Figure 9: Photos of the back side compensation structure mask (a), and the wafer after t_{etch}=40 min (b, c)



a) b)

Figure 10: Photos of the micro accelerometer final structure – the inertial mass (a) with detailed corner (b)

CONCLUSIONS

Due to the lateral anisotropic etching, an accentuated undercutting can be observed at the convex corners. Test masks with well-known shapes are useful to determine, generally, the material behavior and to establish the compensate pattern adequate in a particular case. In this paper, some convex corner compensation structures are studied for achieving the inertial mass of a micro accelerometer by using KOH anisotropic etching on (100) silicon wafer. More samples with the intermediate checking of the obtained structures during various etching times were performed.

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