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CANTILEVER STRUCTURES FOR MEASURING MICROSTRUCTURED SURFACES OF MACRO AND MICRO COMPONENTS

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Abstract: In this paper we present a new type of silicon micro cantilever structures with integrated tips for measuring microstructured surfaces. Results of FEM-simulation and calibration results will be discussed. Also the fabrication of the structures and the fabrication of the tips are described.

Keywords: cantilever, silicon bulk micromachining, piezoresistive strain gauge.

1. INTRODUCTION

Measuring microstructured surfaces in a range from micro to macro is still a great challenge. Systems with the ability of measuring in the nanometer range are not able to measure over long distances and/or they cannot cover larger areas in suitable times. Structures with high aspect ratios cannot be measured accurately. Conventional stylus systems for profilometry operate at too high forces for micro- and biocomponents. Optical measurements do not provide a high depth of sharpness for high aspect ratio structures or they deliver results which are hard to interpret, e.g. at the inspection of blind holes [1].

Cantilevers with lengths of a few millimeter and piezoresistive strain gauges are designed to measure in a range of several hundreds of µm at a resolution of few nanometers. With a proper manipulation system the cantilever can cover measurements of sidewall structures and drilling holes. Such a cantilever structure can also act as a portable force calibration standard [2].

We developed cantilever with piezoresistive strain gauges with different stiffnesses due to different dimensions of length, width and height. These variations are done for covering a wide area of applications for such a cantilever, e.g. as a tactile surface sensor for micromechanical or biological components or as a force and deflection sensor for stiffness calibration of some other probes like pipettes for biomedical applications.

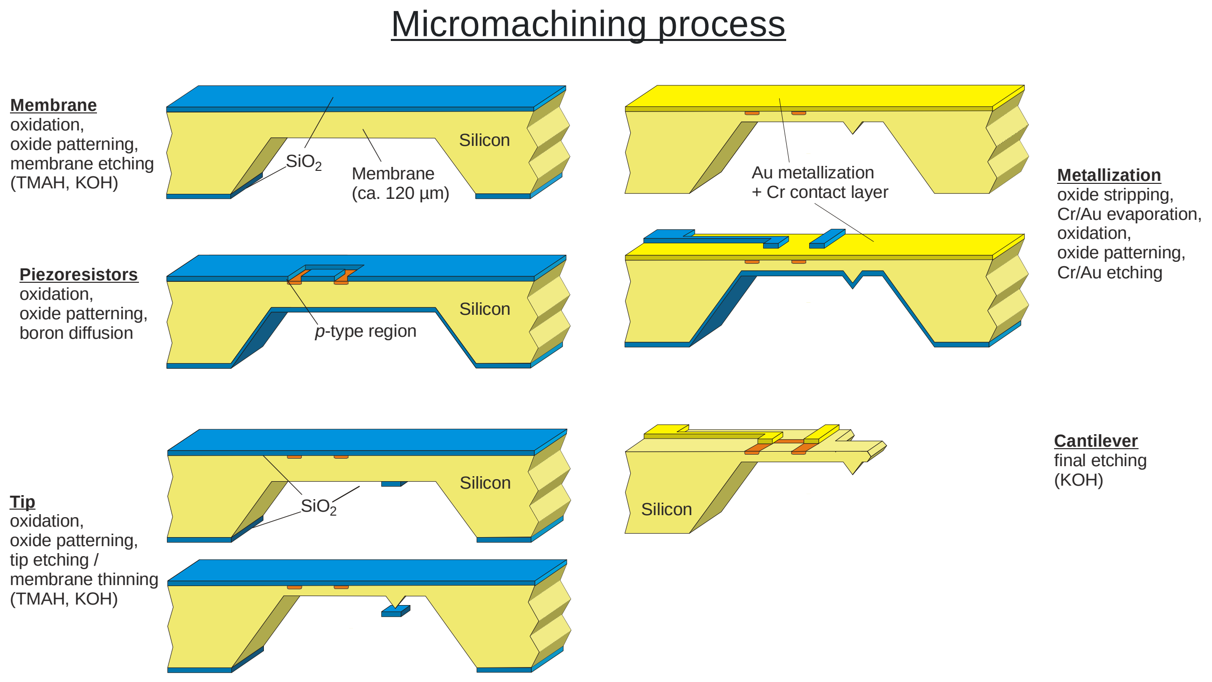

Fig. 1. Basic steps of the used micromachining process.

2. SIMULATION AND FABRICATION

2.1. *Simulation*

For the simulation of the mechanical behaviour of the cantilever structure, the commercially available program ANSYS 8.1 is used. We worked with the element type SOLID 187 on a PC with 1 GB RAM.

The results of the simulations of different geometries of the models are displayed in Table 1. The listed results under an applied force of 500 µN include calculated deflections and calculated stiffnesses of the used cantilever models.

The simulation results deliver the mechanical background of the cantilever to be fabricated.

Table 1. Simulation results.

Cantilever l, w, h [µm]	**F_{appl} [µN]**	**Deflection [µm]**	**Stiffness [N/m]**
5000, 200, 50	500	50.5	9.9
3000, 100, 25	500	202	2.48
1500, 30, 25	500	53.4	9.36

2.2. *Fabrication*

The fabrication of the cantilever is done with the methods of silicon bulk micromachining. The base techniques are lithography, thermal oxidation, metallization, thermal diffusion, and wet etch processes (Fig. 1). We use standard-<100>-oriented n-silicon wafer, for doping of the strain gauge areas we use a boron spin-on source for thermal diffusion at elevated temperatures.

Due to the aim of fabricating very small and narrow cantilevers with high lengths we develop a double side wet etch process in KOH. With this etch process, the excess width of the cantilever by the trapezoidal cross section shape can be reduced by 25% compared to the standard one side etch process (Fig. 2). In Fig. 3 a first approach of this etch process is shown. In Fig. 4 it can be seen, that with a certain over-etching further reduction of width and a nearly rectangular cross section can be achieved.

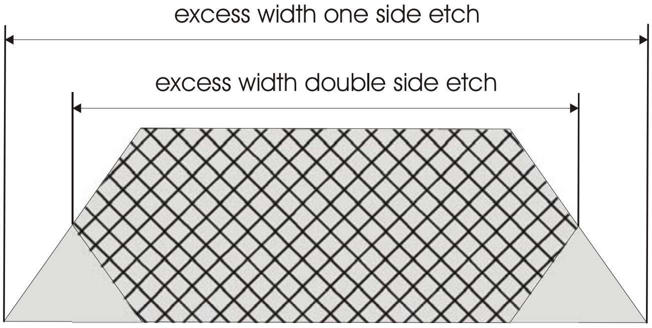

Fig. 2. Schematic of the excess widths with one and double side etch process.

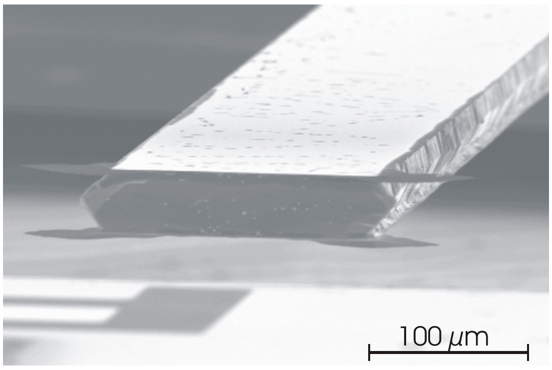

Fig. 3. Double side etched cantilever. At the corners the remaining mask oxide can be seen.

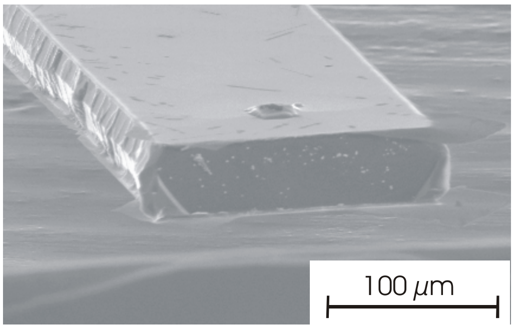

Fig. 4. Double side etched cantilever. A nearly rectangular type cross section is achieved.

Due to this double side etch process the protection of the tip has to be improved. In the standard process step the tip can be covered by wax, but in the new double side process, we need to perform another lithography step on the backside of the sample, i.e. the side of the tip, where wax is not suitable. We used thick photoresist with a thickness of about 14 µm for covering the tip and for defining the cantilever structure on the backside for lithography. The process step is as follows: A tip is etched, followed by the lithography process with thick resist, and afterwards the standard etching process for the cantilever structure is done. In Fig. 5 the result is shown. The tip is not attacked during the cantilever etching in 30 % KOH at 60 °C for 30 minutes.

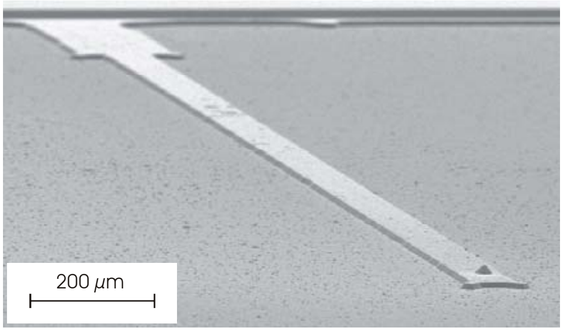

Fig. 5. First results of the tip protection for the double side etch process.

For the wide area of applications for the cantilever type tactile sensor special tip geometries in addition to the cantilever geometries are needed.

We developed several tip geometries which are shown in Fig. 6. Some of these geometries are still under investigation. The tips are fabricated by using wet etch processes based on TMAH- and KOH-solutions. Beside the type of the solution itself, different tip types can be etched under variations of etch bath temperature and concentration [4], [5].

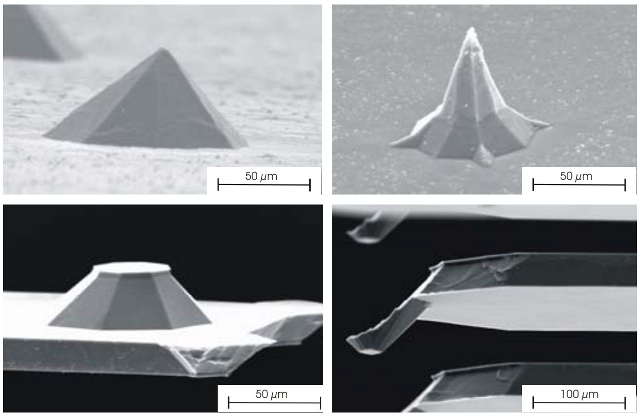

Fig. 6. Variation of tip geometries.

To adjust the type of the tip, the etch rates of the silicon facettes which are building up the tip in combination with the conditions of the etch bath have to be known. Some publications have dealt with this topic, e.g. [4 - 8], but investigations are still necessary, because of some unknown influences like the etch bath size and the question of either bath circulation or sample rotation.

The tip etching process is time controlled. With known etch rates and tip mask sizes the time for building a sharp tip can be calculated. In Fig. 7 a field of tips of about 1 cm^2 is etched parallel and it can be seen that approximately 95 % of all tips are finished.

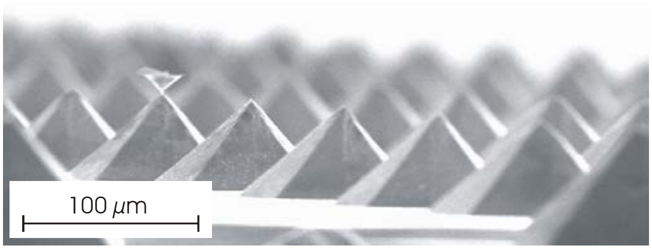

Fig. 7. A field of parallel etched tips.

In Fig. 8 a size comparison with cantilevers of old and new contact pad design is shown. Both have a cantilever length of 5000 µm and a width of 200 µm. On the right side two cantilevers with lengths of 3000 and 5000 µm, and widths of 100 µm and 200 µm, respectively, can be seen.

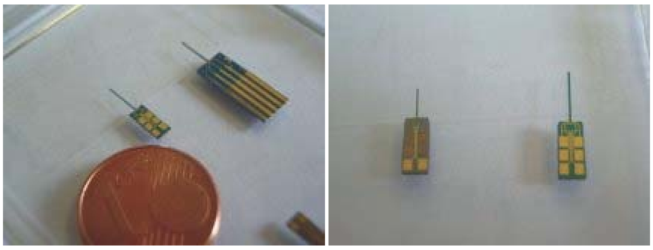

Fig. 8. Old and new design (left); different cantilever lengths of the new design (right).

2.3. Calibration

Calibration measurements are done at the Physikalisch-Technische Bundesanstalt (PTB), the national german metrology institute. We use a fine positioning device (PIFOC) by which the cantilever is driven against a compensation balance [2]. Force and deflection as well as the output voltage of the strain gauge are recorded (Fig. 9 and 10).

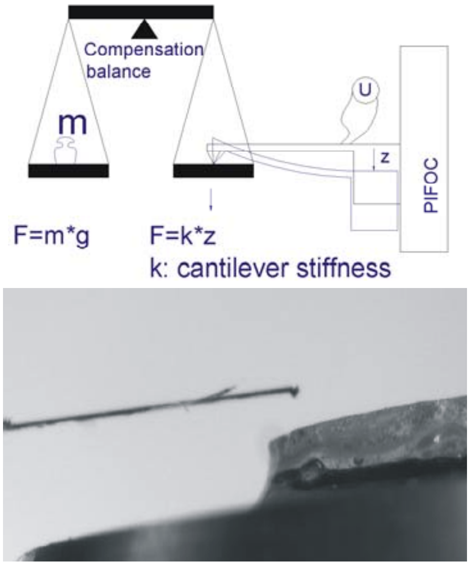

Fig. 9. Schematic of calibration set-up (upper part); close-up of a cantilever approaching the weighing pan of a compensation balance (lower part).

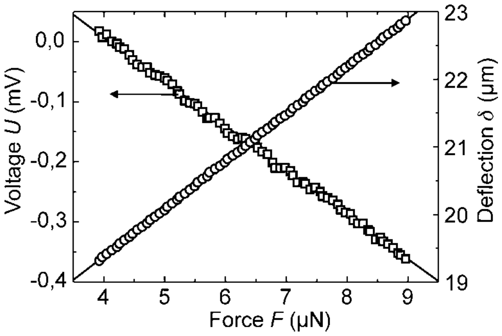

Fig. 10. Calibration result of a cantilever

In Fig. 11 the measurement set-up for measuring the resistances as well as test structures for sheet and contact resistances is shown. With the measurement of the resistances of the piezoresistive strain gauge elements the strain gauge bridge can be characterized. We use to fabricate the resistances in the range of some kOhm and an offset voltage of the Wheatstone bridge of less than 15 mV.

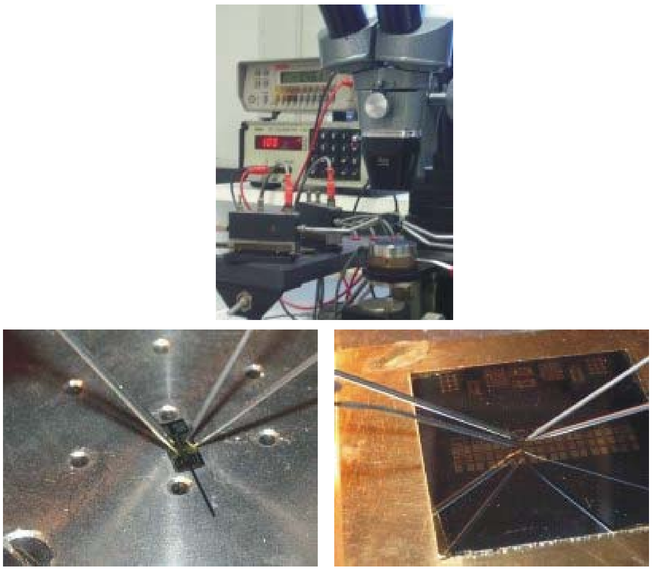

Fig. 11. Measurement set-up for probing the resistances of the piezoresistive elements.

In recent process evaluations we measured the dependence of resistances on the doping process temperature for a better understanding of the possibilities to adjust the resistances of the strain gauge elements. Some other aspects came into account, too, like the number and the temperatures of following oxidation processes, but in this step we kept these variables constant. In Fig. 12 the bridge resistances in dependence of the temperature variations of the first boron diffusion step are shown. Also the offset voltages of the bridges are displayed.

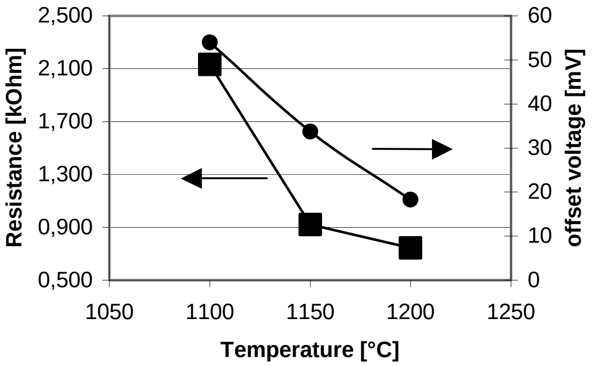

Fig. 12. Effect of temperature variation in the first boron diffusion process on the resistance of the single piezoresistive elements and on the offset voltage of the bridge with constant geometries. The second boron diffusion process was performed at 1250 °C, for the values at 1200 °C it was performed at 1300 °C.

In addition to process uncertainties the relatively high values of the offset voltages are possibly due to some geometric non-conformity in the lithography mask. The offset voltage is decreasing with increasing diffusion temperatures, but also the bridge resistances are decreasing. For the aim of resistances of about 2 kOhm and offset voltages of less than 15 mV, we have to improve our design of the bridge itself and of the lines from the contact pads to the bridge, which are of both Gold and Boron diffused areas.

3. APPLICATIONS

Application fields are high aspect ratio structures, drilling micro holes, blind holes, surfaces of micromechanical and biological samples, force and deflection sensors, among others.

Cantilever with a tip-plateau can be used as a calibration standard or a force sensor. The cantilever with the protruding tip can measure surfaces into the edges of, e.g., blind holes (Fig. 13).

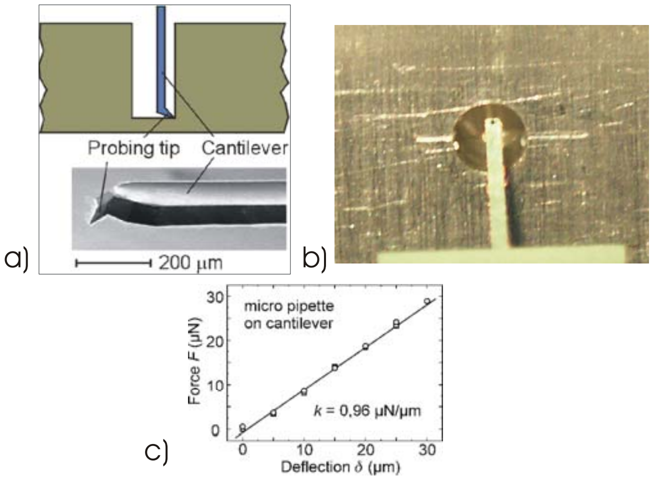

Fig. 13. a) Schematic of measuring a blind hole with a protruding tip; b) drilling hole measurement; c) stiffness calibration of a glass pipette on a cantilever.

4. CONCLUSION

In this study the developments of different piezoresistive silicon microcantilever structures with integrated probing tip are described. Various tip geometries are realized as required for different applications. Simulation results with finite-element-methods are given. Further results of the improvement of the fabrication processes as well as of the calibration procedures and electrical measurements are presented.

5. ACKNOWLEDGMENTS

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