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Laser bending of etched silicon microstructures

E. Gärtner, J. Frühauf, U. Löschner, H. Exner

Abstract The process of contactless laser bending using the laser induced thermal stresses that up to this moment is performed with steels and other metal alloys is firstly applied to silicon microstructural elements. One-side-fastened Si beams prepared by anisotropic wet etching were locally heated by a Nd:YAG laser. The beams were bent without additional tools towards the incident laser beam. Bending angles up to 90° are realizable. The degree of bending is strongly dependent on the used laser parameters, the position of heating and the number and distance of the laser scans.

1 Introduction

3-dimensional silicon microstructural elements are mainly prepared by anisotropic wet etching. The structures are lying inside the wafer plane. By a following plastic deformation process structures which stand out of the wafer plane are realizable. Hence new applications are expected (Frühauf et al. 1999).

One possibility to realize the plastic reshaping of silicon is to heat the whole elements to temperatures >700 °C and carry out the deformation by special reshaping tools (Frühauf et al. 1999). In the last few years a method for bending materials with a laser beam using the laser induced thermal stresses was coming up. This process becomes more and more important in macro- and microprocessing, e.g. the reshaping of sheets for the construction of prototypes in the car industry (Geiger et al. 1993) or for adjusting electromechanical, micromechanical or microoptical elements (Hanebuth and Hamann 1997; Rebhahn et al. 1994; Olowinsky et al. 1998; Widlaszewski 1997). Adjusting movements with highest precision are realizable.

Up to this moment the laser bending is mainly performed with steels and other metal alloys also in microtechnique. In this paper we will show the application of this process to silicon microstructures. The advantages of laser bending for the silicon microstructural elements are the contactless processing without tools with very high precision and the possibility of very local heating especially in cases where the heating of the whole element is not possible.

2 Plastic reshaping of silicon microstructures with tools during homogeneous heating

Microstructural elements like membranes, torsion bars and bending beams fastened at one or two sides were integrated into one silicon wafer and fabricated by wet anisotropic etching (KOH). Following the plastic reshaping which is because of the brittleness of silicon only possible at temperatures >700 °C was carried out in a testing machine equipped with a furnace in different ways:

1. loading of elements in single chips with a silica rod or special silicon tools (stamp, rest) also fabricated from silicon or
2. simultaneous loading of all elements inside the wafer with special silicon wafer tools.

Using the tools very exactly and symmetrically deformed shapes can be reached (see Figs. 1 and 2). The bend is determined by the height/depth of the tools. The detailed description of the experimental procedure and results is given in Frühauf et al. 1999.

3 Process of laser bending

The reshaping by laser can be divided into laser only and laser assisted processes. While in the first case the laser beam is the only “working tool” in the second process an additional deformation tool e.g. a stamp is used. The local heating by laser determines the region that will be plastically deformed. The reshaping without additional tools takes place by internal stresses that are created by the local heating inside the workpiece. No external force are introduced. The used principle is the restraint of the thermal expansion by the surrounding cold material.

For the laser bending several mechanisms are discussed (Vollertsen 1996; Holzer 1996; Olowinsky et al. 1998). The characteristic of the temperature-gradient-mechanism

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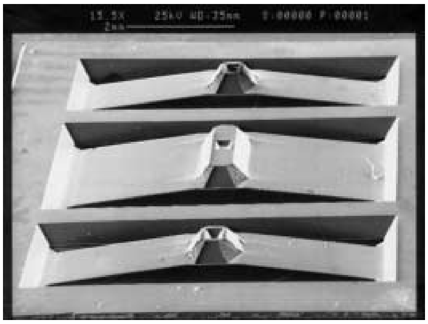

Fig. 1. Beams fastened at two sides deformed with tools to 400 µm

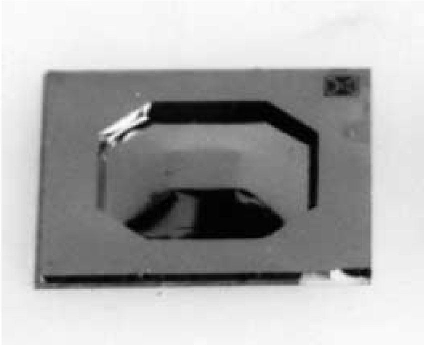

Fig. 2. Membrane deformed with a tool to 400 µm

is the great difference in temperature between the irradiated and non-irradiated region. The unsymmetrical distribution of temperature leads to a plastic compression only on the heated side of the workpiece. This causes a one-sided shortening during cooling and therefore a bending in direction to the laser beam. The degree of bending is determined by the spatial and temporal regime of irradiation, the dimensions of the workpiece and the material.

Other mechanisms are the buckling or shortening mechanism.

4 Laser beam bending of silicon microstructures

4.1 Experimental

The experiments were carried out with silicon bending beams fastened at one side (Fig. 3), prepared by anisotropic wet etching in KOH 30% at 80 °C. The resulting thickness of the bending beams was 50 µm.

For the local heating a Nd:YAG-laser with a wave length of 1064 nm in the continuous mode was used. The experimental setup is shown in Fig. 4.

The heating was done rectangular to the width of the Si beams. The position of heating (positions A and B in Fig. 3), the number and distance of the laser scans were varied. The bend is the out-of-plane deflection of the beams and was measured microscopically at the end of the beams.

Following investigations were carried out with the laser-bent structures:

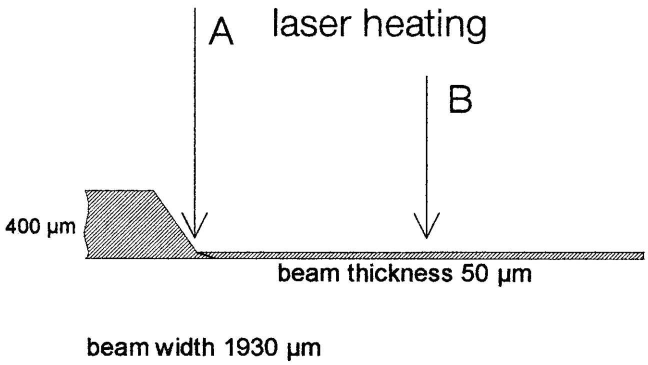

Fig. 3. Schematic cross view of the beams used for the laser bending experiments

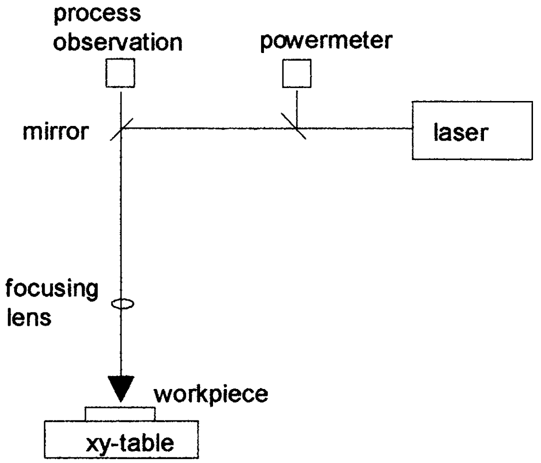

Fig. 4. Schematic set up of the laser device

- analysis of slip lines and dislocations created in the nearly dislocation free material during deformation (etch pit technique)
- profile measurements (UBM, DEKTAK)
- investigation of the symmetry of bending.

4.2 Results

Table 1 shows some of the results of the laser experiments with silicon beams.

As can be seen from the Table 1 and Fig. 5 the bending of silicon microstructural elements in consequence of laser induced heating is possible. The beams are bent in direction towards the incident laser beam. The degree

Table 1. Parameters and results of laser bending of silicon beams

Laser treatment	Position of bending	Bend (µm)	Bending angle
$P_{cw} = 5$ W 6 scans (distance 20 µm)	A	None	–
$P_{cw} = 5$ W 6×10 scans	A	1500	13°
$P_{cw} = 5$ W $6 \times 10 \times 5$ scans	A	1930	16.5°
$P_{cw} = 2$ W $6 \times 10 \times 5$ scans	B	1050	22°

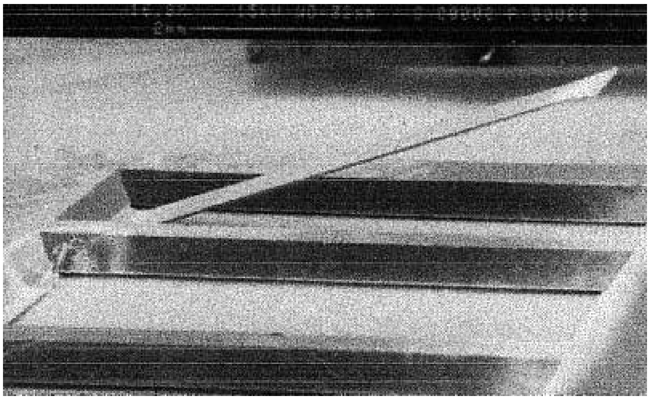

Fig. 5. Beam fastened at one side, bent by laser heating at position A

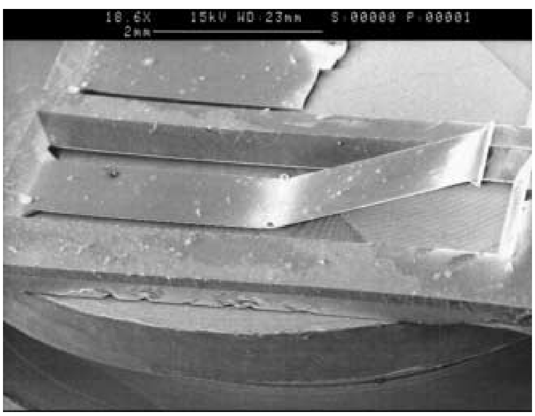

Fig. 6. Beam fastened at one side, bent by laser heating at position B

of bending is strongly dependent on the used laser parameters, the position of heating and the number and distance of the scans. Bending angles up to 90° can be realized.

Additionally to the laser heating at position A and therefore bending of the whole beam a deformation of a part of the beams also succeeded (Fig. 6). Therefore multiple bendings become possible. Because of the different heights of the surrounding material and therefore different heat deduction variing bendings compared to position A can be reached by using the same laser parameters.

4.3 Slip lines and dislocations

As a result of the laser beam induced stresses causing the deformation slip lines can be observed on the upper and lower sides of the beams mainly perpendicular to their longitudinal direction in the regions the heating was done, Fig. 7a. The number of slip lines is higher at the upper side. A few slip lines run in the longitudinal direction, too. The dislocation etch pits are situated on all slip lines and in the regions between them. The greatest number is found in the region of deformation (Fig. 7b). It decreases in direction to the end of the beam and to the sidewall.

4.4 Profile measurements

The measured profiles of the deformed structures confirm the optically measured bendings and reveal a slight curvature in longitudinal direction of the bend parts of the beams. At some specimens a small distortion of the beams (0.6°) compared to the chip frame can be observed.

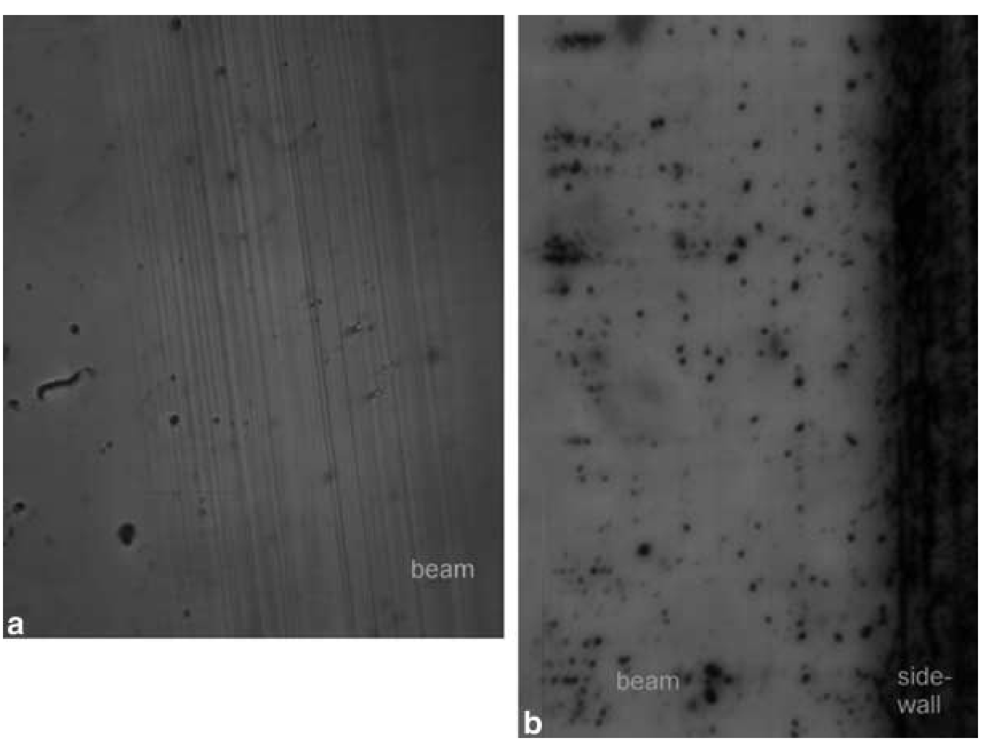

Fig. 7 **a** Slip lines at the bottom side of the laser deformed beam. **b** Dislocation etch pits

5 Conclusions

The process of laser bending can also be applied to silicon microstructures. The variation of the bending angle between 0 and 90° allows the application of the method as well for adjusting as for reshaping. The deformations can be realized with highest precision. Multiple bendings and the forming of continuous contours are possible. The experiments performed up to this time indicate a high symmetry of deformation. The bending of the beams towards the incident laser beam and the shape of the slip lines and dislocations confirm the model of the compressed surface zone on the irradiated side (temperature gradient mechanism).

The method of contactless laser bending offers a very good completion to the reshaping process of silicon microstructural elements performed with tools in a furnace.

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