Simulation support for silicon-bulk microsystems demonstrated in an inclination sensor development

Dirk Zielke

Tel.: (+49) 371 3377 260, FAX: (+49) 371 3377 272;
email: info@gemac-chemnitz.de

ABSTRACT

The design and development are supported by many simulation tools nowadays. The specific use of technology modeling and FEM-simulation for silicon bulk micromachining is contents of the paper. For this, the whole procedure between the idea and the industrial used sensor is demonstrated. The emphasis lays on the simulation of the orientation dependent etching with the simulation tool SIMODE and the interfaces to the FEM-simulation-tools. Furthermore the mechanical and thermal FEM-simulations of the sensor and of the packaging will be demonstrated. The special aspect is not the introduction of simulation models, but the demonstration of simulation runs for an industrial design of an inclination sensor and the occurred problems and founded solutions during the design.

INTRODUCTION

There are a lot of sensor concepts for 1- and 2-dimensional inclination sensors. Usually a low-g-acceleration sensor is used in microsystem applications. The most known is probably the surface-micromachined sensor of Advanced Devices [1]. But silicon-bulk-applications have the advantage of higher precision [2], [3]. The problem to realize a two dimensional inclination sensor is, that the most sensitive detection direction is perpendicular to the silicon surface. To use this sensitivity for a 2-dimensional inclination sensor it is possible to mount two sensors perpendicular to each other [3].
Amongst the optimization of the single sensors the integration to a 2-dimensional sensor produced a special demand on the simulation tools. So it is necessary to investigate a design with very low cross-sensitivity and to find a way of mounting the separate sensor-elements on a substrate with low mechanical stress.

SENSOR CONCEPT

The whole 2-dimensional sensor-system is made of two silicon-bulk-micromachined sensor-elements. A sensor-element contains a silicon spring/mass-system, which is packaged into two glass wafers by anodic bonding. The silicon is structured by 2-side and 2-step orientation dependent etch technology.

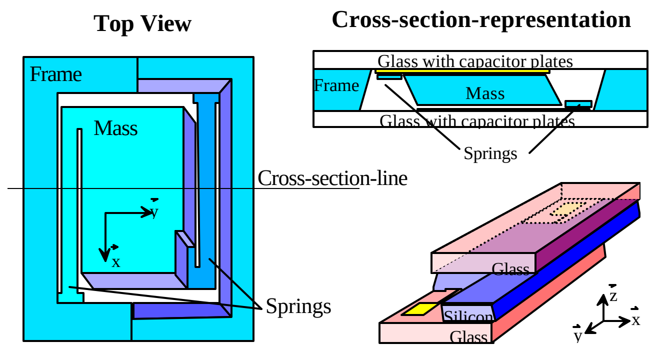


Fig. 1: Schematically view of the sensor element

The sensor-elements are mounted perpendicularly on a hybrid or PCB on which also the electronics (CV-converter) is placed. To guarantee the orthogonality of the 2-dimensional sensor-system, the sensor-elements are glued on the substrate with the help of a special device. So a misalignment below 0.1 degree can be realized.

SIMULATION OF THE ORIENTATION DEPENDENT ETCHING

For the simulation of the orientation dependent etching the simulation tools SIMODE/QSIMODE are used. Both programs base on a geometrical model [4,5]. The first task is to compensate all parts of the design, which have an etch velocity unequal zero. For that purpose on all convex mask-corners compensation structures are added. Furthermore the etch velocities of the {111}-plane and if occurs of the {110}-planes have to be taken into consideration.

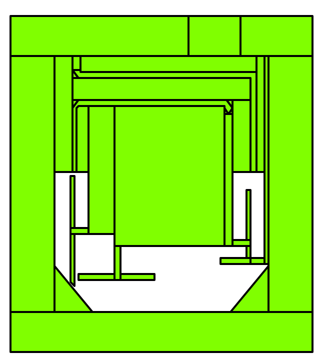
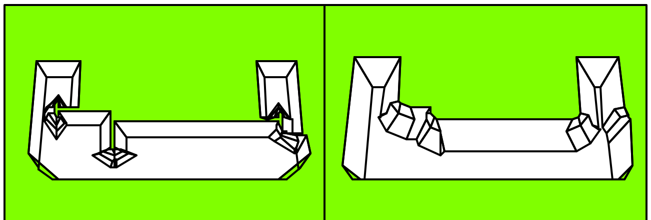


Fig. 2: Etch mask for the first etch step with beam-compensations (gray area are masked)

Amongst the support of the design, the task of the simulation is to guarantee, that all structural dimensions are reached for all variations of the technological parameters. These are for example temperature and concentration variations of the etch bath and the mask misalignment against the silicon crystal.



Representation:	40° tilt	Representation:	40° tilt
Wafer:	{100}-Silicon	Wafer:	{100}-Silicon
Etchant:	KOH 30% 80°C	Etchant:	KOH 30% 80°C
Etch time:	232 min	Etch time:	439 min
Etch depth:	256 µm	Etch depth:	483 µm

Fig. 3: Example for the simulation of the orientation dependent etching with SIMODE.

Points of special interest can be detailed simulated. So the cross-section through the springs and the flatness of the etch ground are separately simulated by QSIMODE. Fig. 4 shows the realized spring/mass-structure on the silicon wafer.

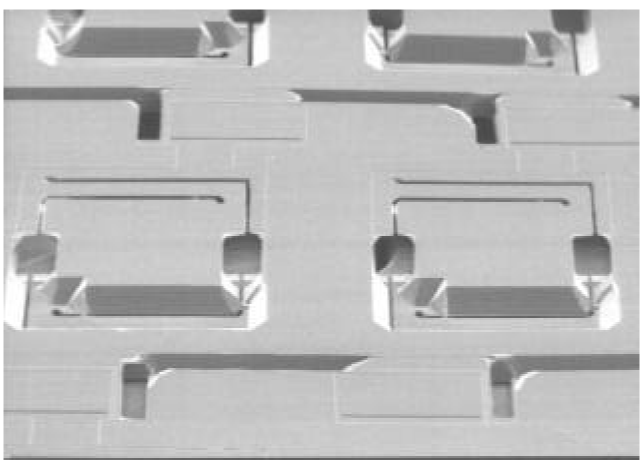


Fig. 4: Spring/Mass-system of an inclination sensor produced by orientation dependent etching

After simulation of the 3-dimensional structuring of the silicon it is possible to export the body into FEM-programs [6]. To avoid the handling of a very large amount of data, only the most interesting parts of the simulated structure are transferred into the FEM-program. These parts are combined with simple geometrical bodies to generate a useful FEM-model of the sensor.

SIMULATION OF THE SENSOR-BEHAVIOR

To simulate the mechanical and thermal behaviors of the sensor-system the FEM-program 'EuroFem' was used.
First of all the mechanical parameters are determined. But it was a step by step process to optimize the mechanical parameters considering the technological possibilities of the orientation dependent etch process. This fact demands also a comfortable interface between the technological- and FEM-simulation tools. As mechanical parameters are determined the static movement of the spring/mass-system, the behavior of the sensor during overload, the cross-sensitivity and the characteristically frequencies.

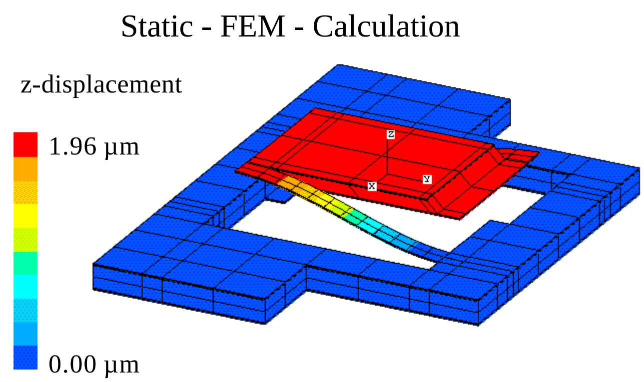


Fig. 5: Displacement of the spring/mass-system of the inclination sensor for 1 g acceleration in z-direction

The temperature drift of the sensor, based on the different Young-modules of silicon and glass, are calculated and optimized by static-thermal FEM-runs.
Two other critical thermal steps are the anodic bonding and the assembly of the sensor-elements on the substrate. At the first case a temperature difference of over 300 K (Bond temperature of about 350...400K) arise. This temperature difference lead to a high stress at the glass/silicon/glass-sandwich and probably to a offset for the sensor signal.
Fig. 6 shows that the mass is 2.5 µm tilt out of the plane, but there is no parallel displacement in the z-direction. The rotation does not give any offset, because of the use of a differential capacitive measurement principle. But it has an influence on the non-linearity and on the minimal possible capacitor gap.

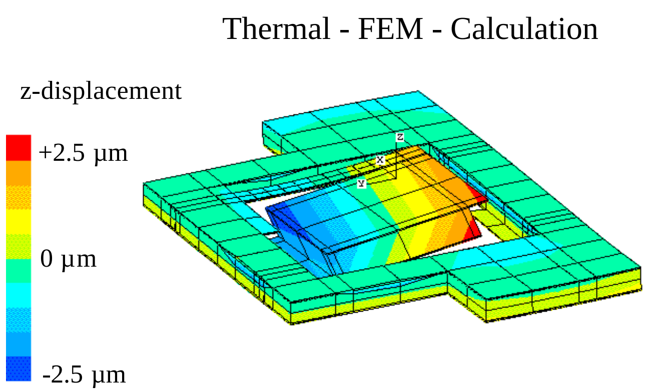


Fig. 6: Displacement of the spring/mass-system in z-direction based on the mechanical stress produced during the anodic bonding process. (only the silicon part is represented)

The second case is the thermal glue of the sensors on a substrate. The temperature difference is not so high for this step (around 100K) but the differences of the Young-modules of the sensor-element and the substrate are much higher.

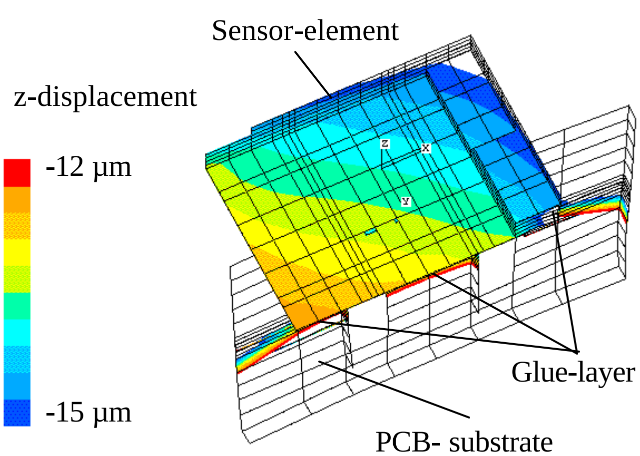


Fig. 7: Thermal FEM-Simulation of the sensor behavior during the mounting process on PCB.

The simulation showed a bend of the substrate and a slight influence on the sensor-element. If the stresses would be to high, the glue does not stand and the electrical contact will be worsen. The shown finger-structure of the PCB was finally not used, because of the calculated stresses on normal substrates, which are low enough.

CONCLUSION

With the help of the sensor-elements a family of 2-dimensional inclination sensors are produced, which are in the position to determine inclination over a wide angle range (60°) with an maximal error of 0.5 degree. The sensors can be used in a temperature range of -25 to 85 °C.

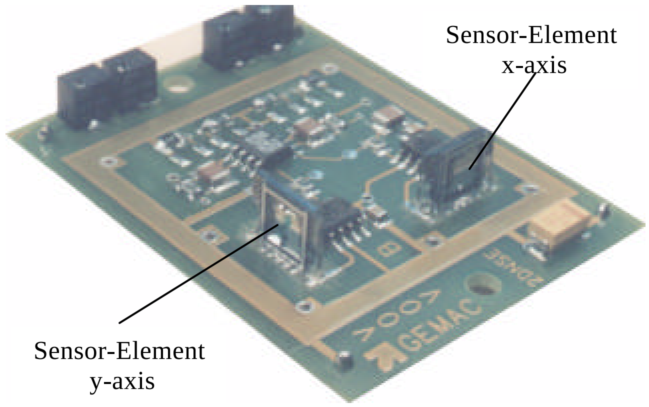


Fig. 8: Mounting of the sensor-elements on PCB

With the help of the concentrated use of simulation tools it was possible to design a inclination sensor system in a very short time. Very important were the interfaces between the separate simulation tools for it.
Furthermore it was possible to use standard materials, like PCB, for the assembly. This was only possible by FEM-simulation of the whole sensor-system.

ACKNOWLEDGMENT

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