Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 47 (2012) 615 – 618

Procedia Engineering

www.elsevier.com/locate/procedia

Proc. Eurosensors XXVI, September 9-12, 2012, Kraków, Poland

Wafer Level Processing of Overload-Resistant Pressure Sensors

T. Kober*, R. Werthschützky

Institute of Electromechanical Design, Technische Universität Darmstadt, 64283 Darmstadt, Germany

Abstract

The performance of industrial differential pressure sensors concerning the overload pressure, step response and measurement uncertainty covers wide application areas. We will present a novel approach of silicon differential pressure sensors with an integrated overload protection mechanism and measurement results of the processed glass wafer topology.
Thermal treated Glass wafers are processed to develop overload protected sensors at the chip level [1, 2]. By varying the process environment, the crystal growth in SCHOTT Borofloat 33® tested by x-ray crystallography and AFM analysis is reduced [3]. Without additional passivation layers the risk of chemical reactions with the glass wafer is avoided and no process steps for coating and removing are required. The glass wafers surface quality is suitable for anodic bonding.

Keywords: Differential pressure; Overload-Resistant; Deflection limiter

1. Overload-resistant differential pressure sensor with homogenous deflection limiters made of glass

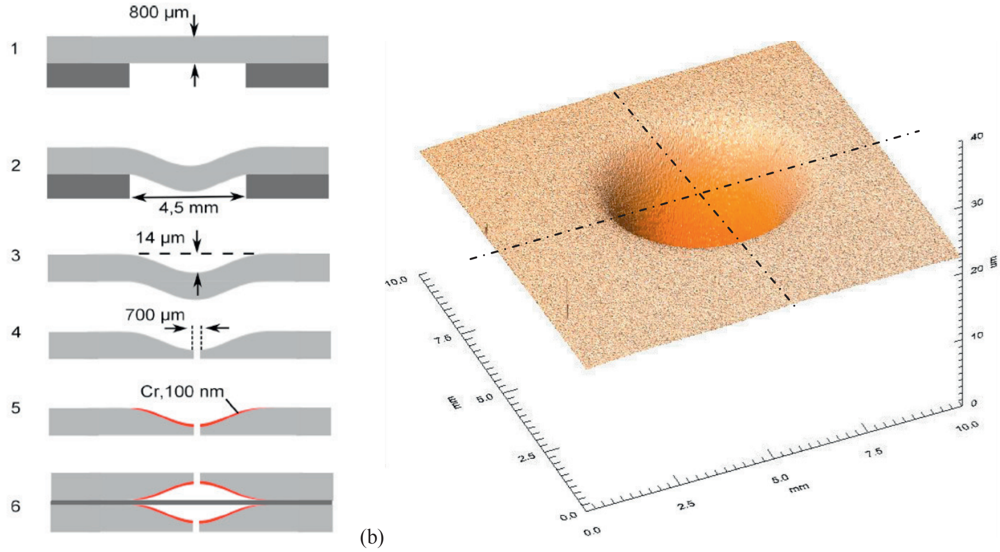
Differential pressure sensors using precision-engineered protection mechanisms provide an overload capability of at least Δp_{Max} = 160 bar at a nominal pressure range of Δp_N =10 mbar. Silicon differential pressure sensors provide good mechanical properties, due to their low hysteresis and zero point stability. Because of their basic overload capability of $p < 1$ bar at 10 mbar nominal pressure, an overload protection is required that does not affect the sensor's sensitivity. An integrated micromechanical overload protection reduces the complexity compared to state-of-the-art external overload protection made of stainless steel with defined oil filling. The presented concept of a sensor element achieves these characteristics by limiting the deflection of the diaphragm by an integrated overload protection made of structured glass (Fig. 1). The overload resistant differential pressure sensor with nominal pressure range of Δp_N = 10 mbar provides an average overload capability of Δp_{Max} = 220 bar [1].

A glass wafer is positioned on a tool wafer. Placing the wafer stack horizontally in a chamber heated up to ϑ = 750 °C produces a softening of the glass (Fig 1a). Bonding a silicon wafer and the glass wafer at ϑ = 750 °C causes a significant wafer bow. This wafer bow is avoided by using a re-usable tool, which prevents the adhesion of the glass wafer.

* Corresponding author. Tel.: +49-6151-165496; fax: +49-6151-164096.
E-mail address: t.kober@emk.tu-darmstadt.de.

doi:10.1016/j.proeng.2012.09.222

Because of its own weight, the glass sinks slightly into a structured tool. Using ultrasonic drilling, a capillary tube with diameter smaller than Ø = 700 µm is processed into the glass wafer, to ensure pressure equilibrium. Vacuum deposition of a 100 nm thin chrome layer is needed to realize selective anodic bonding. Prior to the overload test, a silicon diaphragm is bonded by anodic bonding. Simultaneous processing of 24 devices at one 100 mm wafer is possible.

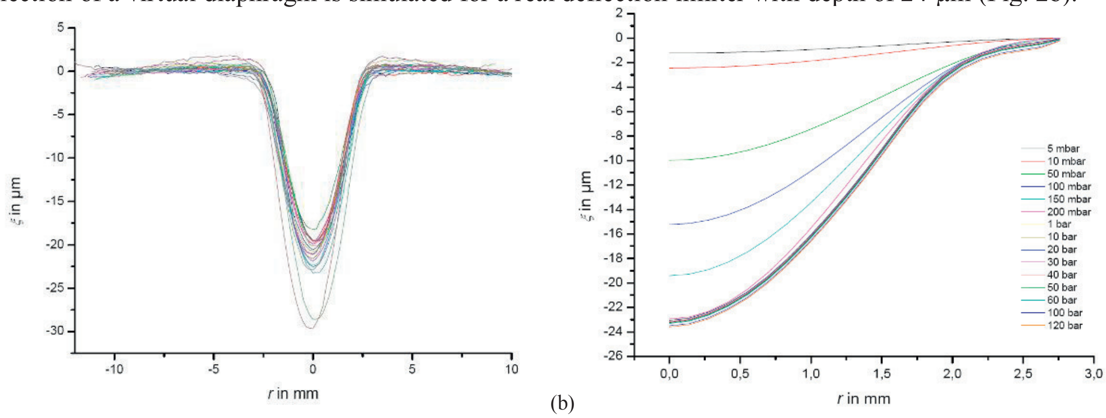


(a) (b)

Fig. 1: Process steps for wafer level processing of overload resistant differential pressure sensors: *(a) Process steps with a re-useable tool for thermal treated glass deflection limiters, 1) Alignment of the glass wafer and tool wafer, 2) Forming the deflection limiter at ϑ = 750 °C, t =5 h, 3) Separating the glass wafer from the tool wafer, 4) Levelling the rear side and processing of the capillary tube, 5) Vacuum deposition of a local chrome layer, 6) Joining of the glass wafers with a silicon diaphragm and dicing the sensor elements; (b) Analysis of the structured deflection limiter, at the wafers surface with chromatic interference measuring.*

2. Surface analysis of the deflection limiters

Because of the specified nominal pressure range of Δp_N = 10 mbar, the deflection limiter´s aspect ratio width to depth is 300. To locate these structures at the surface of the transparent wafer, a high resolution out of plane measurement is required. With an optical distance measurement sensor with a nominal measuring range of 300 µm and a maximum depth-resolution of 3 nm, the measurement of the deflection limiters shapes is possible (Fig. 2a). The deflection of a virtual diaphragm is simulated for a real deflection limiter with depth of 24 µm (Fig. 2b).



(a) (b)

Fig. 2: Aspheric deflection limiters made of structured glass: *(a) Experimental measurement of 24 deflection limiters; (b) FEM simulation of diaphragm deflection with a real deflection limiter.*

The simulation shows a free movement of the diaphragm within the nominal pressure range. If the pressure increases, the deflection is still limited to 24 µm and the structured deflection limiter provides an adapted, aspheric shape that prevents destruction of the diaphragm.

The thermal treatment of the glass wafer results in a surface, which can be visualized, preferably by chromatic distance measurement (Fig. 3a). The typical distribution of the depth of the deflection limiter shows an inclined plane (Fig. 3b).

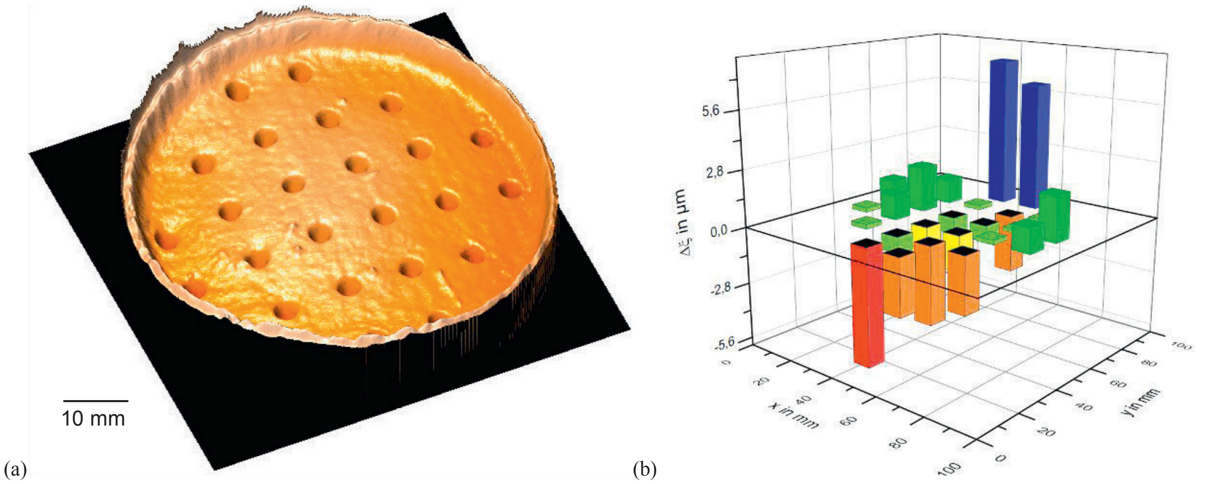


Fig. 3: Surface analysis of thermal threated glass wafers: *(a) Wafer surface of a glass wafer Ø = 100 mm, measured with white light interference; (b) Deflection limiter depth distribution of an example wafer* $\xi = \xi_{Mean} + \Delta\xi$ *with* ξ_{Mean} = 22,79 µm.

3. Electrodes for the capacitive working principle

An analytical model based on discrete capacitor summation is developed to calculate the capacity for the ideal diaphragm deflection (Fig. 4a). An insulation circle is required to avoid a permanent electrical contact to the silicon diaphragm. Assuming the boundary condition $R_2 \ll R$ a nominal capacity of $\Delta C(\Delta p_N)$ = 100 pF can be achieved. A first approach with an external capacitive sensor for dynamic pressure calibration is built up to prove the deflection of the silicon diaphragm (Fig. 4b).

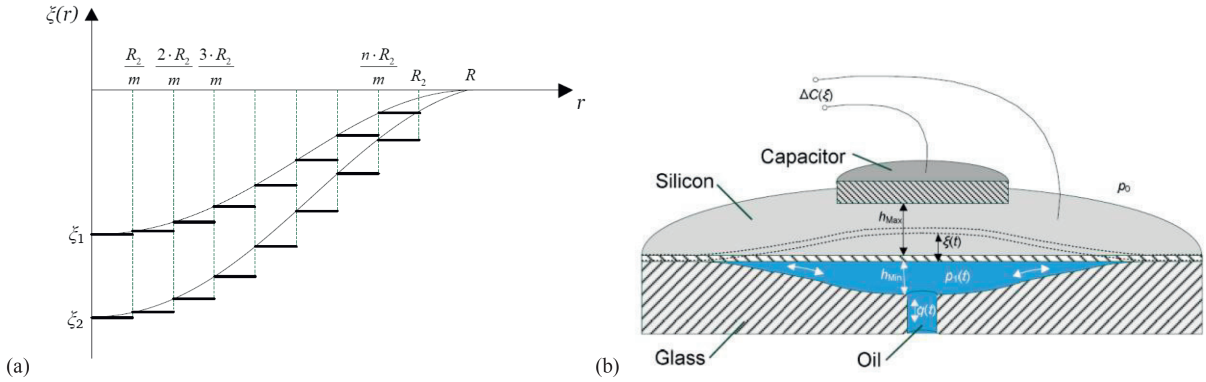


Fig. 4: Capacitive working principle: *(a) Analytical approach of the achievable internal electrical capacity; (b) Measurement setup for dynamic pressure calibration with external capacitive sensor.*

4. Cristobalite growth at the glass wafers surface

The necessary process temperature enables cristobalite growth at the glass wafers surface (Fig. 5). To prevent the expansion of micro cracks, the crystal growth during the estimated process time of t = 5 h at $\vartheta = 750$ °C has to be reduced. It is proved that the crystal growth of cristobalite in SCHOTT BOROFLOAT® 33 can be reduced by vacuum processing (p_V=10^{-5} mbar). For an atmosphere of air as well as for nitrogen, cristobalite growth takes place over a period of t = 5 h. If the process time is increases up to t = 12 h the crystallization of cristobalite can be registered again at the wafers surface [3].

To restrict the possible surrounding conditions it is useful to enable the processing of deflection limiters without passivation layers. Vacuum processing is a suitable method to integrate the protection against crystallization into the existing process steps. The glass wafers surface quality is suitable for anodic bonding which is the next process step.

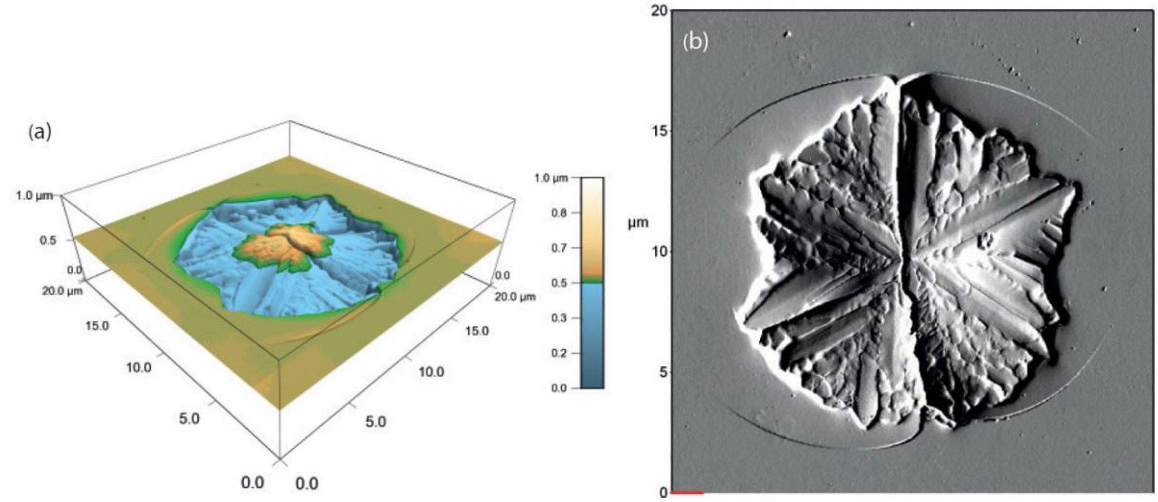


Fig. 5: Temperature treatment of the glass wafer: *(a) Crystal growth at the wafers surface [3]; (b) Mechanical stress dissolves in cracks beginning at the crystal edges [3].*

Outlook

This sensor concept will be characterized for the nominal pressure range of Δp_N = 10 mbar. The symmetrical layout with double-sided overload protection will be tested for static and dynamic pressure overload.

References

[1] Kober T., Werthschützky R, Overload-Resistant Pressure Sensors in the Nominal Range of 10 mbar (1 kPa). In: Eurosensors XXV Conference, September 4-7, Athens, Greece, Proc. Eurosensors XXV, 2011.

[2] Kober, T., Werthschützky, R., Überlastfeste Silizium-Differenzdrucksensoren mit thermisch strukturierten Gegenlagern aus Glas, Sensoren und Messsysteme, Nürnberg, VDE Verlag, Germany, 2012.

[3] Hildebrandt, S., Alff, L., Kristobalitbildung (SiO2) im Herstellungsprozess überlastfester Differenzdrucksensoren, Sensoren und Messsysteme, Nürnberg, VDE Verlag, Germany, 2012