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SOI-based, High Reliable Pressure Sensor with Floating Concept for High Temperature Applications

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Abstract

In this paper we present a high reliable, accurate and safe, solid state pressure sensor for high temperature applications. The sensor is based on an unique fluid-free technology using a piezoresistive SOI-based chip enclosed in a sealed metal housing. The proprietary housing concept allows a complete separation of the SOI-chip from the measured media. A thick steel membrane and an elongated member (push-rod) transfer the outside pressure into a small deflection of a silicon membrane on the SOI-chip. The thin silicon membrane is engraved by DRIE (Deep Reactive Ion Etching). The sensor is capable to measure pressures up to 1000 bar at temperature up to 400°C with an accuracy of ±0,50 %FSO. A digital correction enables a compensation of Offset and Sensitivity thermal drifts. The sensor can undergo long-term extreme working conditions without losing its performances.

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Keywords: SOI sensor; pressure sensor; high temperature sensor; plastixc estrusion; melt pressure, harsh environment; plastic molding; fluid free sensor; EN 13849-1 sensor

1. Introduction

High accuracy pressure control is a key feature in many industrial processes (e.g. plastic, ceramic, chemical or pharmaceutical industry). However, these processes often require measurements at elevated temperatures (> 150 °C), where standard silicon pressure sensors cannot withstand at direct exposure [1]. The use of mercury or oil as a coupling medium and the fact that the thin steel membrane for media separation is prone to rupture are additional drawbacks. The sensor here presented is based on an unique fluid-free technology using a piezoresistive SOI-based

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chip enclosed in a sealed metal housing [1]. The proprietary housing concept [2,3] allows a complete separation of the SOI-chip from the measured media. A thick steel membrane and an elongated member (push-rod) transfer the outside pressure directly into a very small deflection of a thin silicon membrane on the SOI-chip.

The presented technology enable additional safety features, like detection of membrane failure, not possible with the fluid-filled technology. This advantage allows the sensor to be compliant with Safety European Standard ISO EN 13849-1 (PLc - Performance Level ’c’). This requirement enable e.g. a plastic extruder to be compliant with the European Standard EN 1114-1 and thus to follow the safety requirements of the Machinery Directive 2006/42/CE.

2. Sensor concept and manufacturing technology

The SOI-chip is placed inside a squared cavity on a ceramic carrier, providing also for the electrical routing. The chip movement is avoided applying a mechanical load between silicon membrane and the external steel membrane, ensuring an optimal load transmission by the push-rod. This “floating” sensor concept avoids the use of any additional material, such as needed in common chip bonding technologies. Pressure transferring media like Hg, oil or NaK, which are hazardous (Hg non conformity to RoHS directive) or require complicated filling technology (NaK), are no longer needed. A schematic view of the sensor concept is shown in Fig. 1(a).

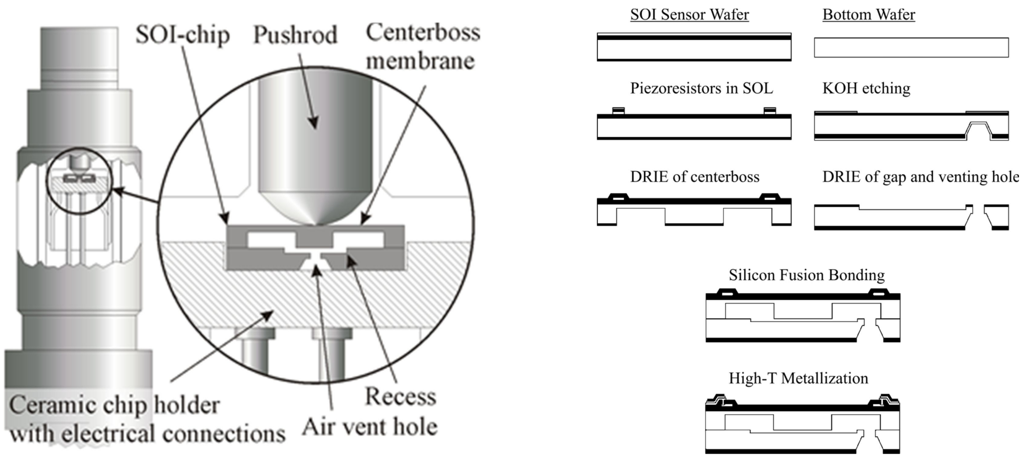

Fig. 1. (a) Schematic view on a packaged pressure sensor (left) with enlarged cross section of the packaged SOI-chip. (b) Process flow for sensor fabrication. Piezoresistors and membrane with centerboss are fabricated in SOI wafer

The silicon sensor chip consists of a circular, micromachined silicon diaphragm with a centerboss, engraved on the SOI wafer backside by DRIE (Deep Reactive Ion Etching). The induced stress due to a membrane deflection is detected with piezoresistors located on top of the membrane and connected in a Wheatstone Bridge configuration. The main advantage of using SOI material is the use of piezoresistors BOX isolation from the silicon substrate, resulting in high temperature capabilities up to 400°C. In this work the UNIBOND SOI (Smart Cut SOI® from company SOITEC) wafers were used.

High temperature resistant metallization enables accurate and reliable pressure measurements. The measuring dies are composed of two wafers connected by wafer direct bonding. Additionally, the bottom wafer acts as an overpressure safety feature limiting the maximum membrane deflection by mean of the centerboss. An air venting hole allows pressure balancing. The process flow is shown in Fig. 1(b).

The SOI chip wire bonded in the ceramic carrier is then assembled in a metal housing, constituted by different sections optimized for compensation of CTE mismatches. The assembly procedure consists of subsequent welding steps between the different machined parts. The measuring cell is then welded in a tubular shaft housing, providing for a ½ 20 UNF threated process connection and for the signal cables, high-temperature insulated. The cables are connected to a remotely placed electronic module providing for power supply, sensor calibration and thermal drifts compensation.

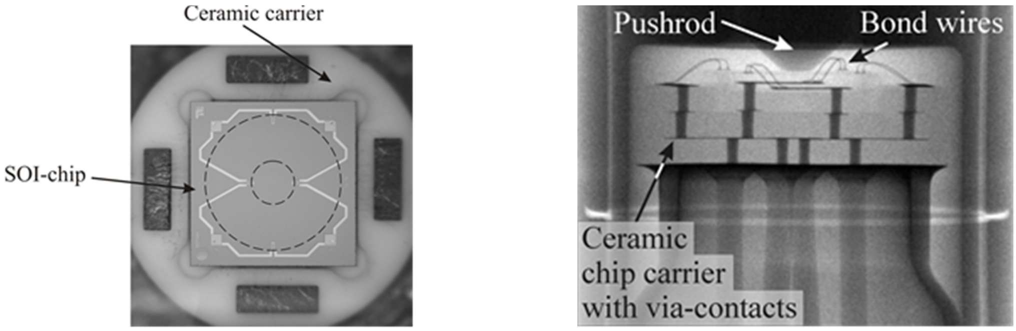

Fig. 2. (a) Top view of SOI-pressure sensor chip placed in a ceramic carrier cavity; (b) X-ray photograph of the packaged sensor.

Fig. 3. Advanced SOI-based sensor system from Gefran for use in harsh environments.

3. Measurement and characterization

The manufactured sensor system has been exhaustively tested in a test bench provided with heated and pressurized manifolds. An hydraulic balance have been used to precisely generate the desired pressure. Long-term high temperature stability tests have been performed in a heated non-pressurized manifold.

The sensors output have been measured at various pressures and temperatures up to 400°C, in a constant current supply mode, 1 mA. Some relevant data are shown in Figure 4(a) and Table 1. Extended metrology characterization give e.g. at 200°C non-linearity is as low as 0,2% FSO (end points), pressure hysteresis as low as 0,4% FSO and negligible repeatability.

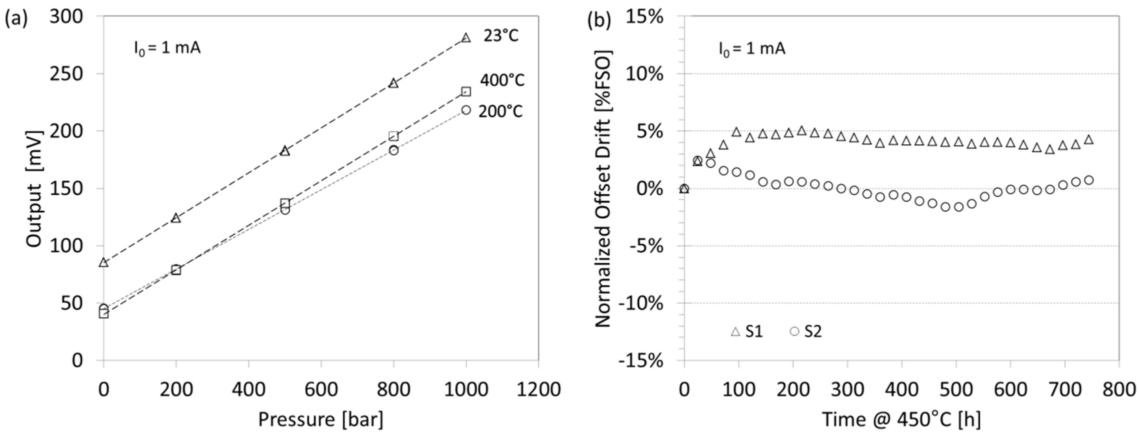

Fig. 4. (a) Sensor characteristics measured at 23°C, 200°C and 400°C, 1 mA supply. (b) Sensor output over time of two packaged sensors in an accelerated long-term stability test, 450 °C. FSO = 1000 bar.

Tuning the external steel membrane thickness makes possible to manufacture pressure sensors with desired measuring ranges and sensitivities, from 10 bar FSO to 1000 bar FSO. Precise digital compensation of the residual thermal drift of both Zero and Sensitivity allows to reach ±0,50 %FSO drift in the whole temperature and pressure range. Fig. 5 shows the effect of compensation of thermal drift on the offset and sensitivity. Normalized data are shown (100 % = FSO). All sensors have shown very stable and repeatable behavior.

Table 1. Typical performances of packaged sensor elements at different temperatures. (FSO = 1000 bar, I = 1 mA). Not compensated sensors.

Temperature	Non-Linearity EPL	Pressure Hysteresis	Repeatability	TCR	TCO	TCS
°C	%FSO	%FSO	%FSO	ppm/°C	%FSO/°C	%FSO/°C
23	0.06	0.53	0.02	-	-0.17	-0.12
200	0.21	0.38	0.06	1280	-0.04	+0.01
400	0.43	0.17	0.15	1410	+0.02	+0.07

Accelerated long term stability tests have been performed at 450°C in static conditions. After over 700 h testing at 450°C the maximum Zero drift is within ±5%FSO, as shown in Figure 4(b). From an Arrhenius calculation, not reported here, we estimate that this corresponds to roughly 6000 h of continuous exposure to 400°C. This Zero drift can be digitally corrected by users with a “Autozero” function.

The sensors have been subjected to repeated creep cycles at 400°C, 1000 bar to evaluate the mechanical stability of the metal package. After 62h testing the sensitivity and offset are practically unaffected.

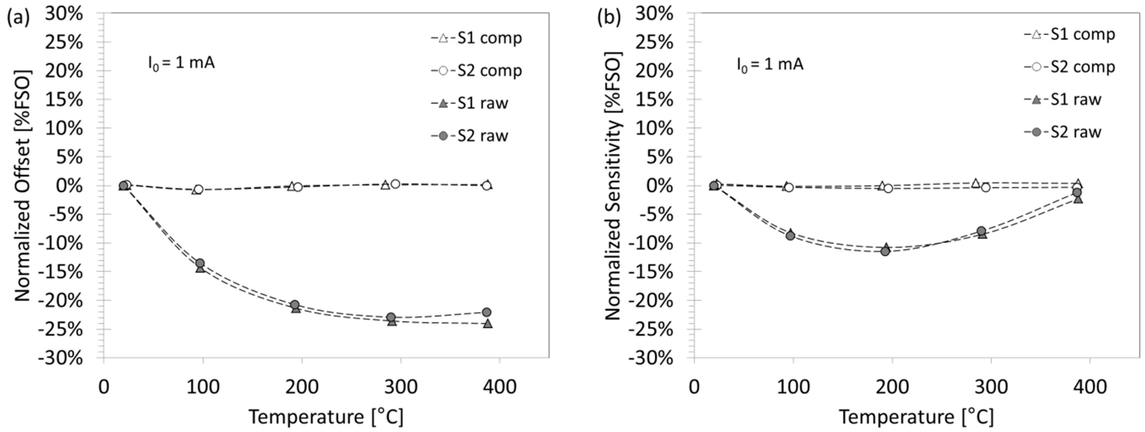

Fig. 5. (a) Offset drift over temperature of two packaged sensors with and without compensation (b) Sensitivity drift over temperature of two packaged sensors with and without compensation. FSO = 1000 bar.

4. Conclusions

We presented our SOI-based pressure sensor system using a floating concept. The sensor offers accurate and stable pressure measurement up to 400°C, 1000 bar with an accuracy of ±0,50 %FSO. A digital correction enables a very accurate compensation of offset and sensitivity thermal drifts, in the range 23°C-400°C. Due to its rugged steel package the sensor can undergo long-term extreme working conditions without losing its performances.

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