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Redundant Pressure Sensor Based on Steel and Ultra-Thin Glass Strain Gauges

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Summary:

A pressure sensor with the goal of enhanced reliability and built-in redundancy is developed using the possibilities offered by highly sensitive and high temperature stable thin films. The sensors show promising results with potential application for high temperature applications and incorporate a modular approach using an ultra-thin glass based strain gauge with redundant Wheatstone bridges joined to a monolithic stainless steel membrane by glass soldering.

Keywords: pressure sensor, reliability, glass, thin film, strain gauge

Background, Motivation and Objective

In many applications, pressure sensors are important devices to control the pressure in fluids and gases. This is often done to realize closed-loop controls or for safety reasons. In case the pressure is relevant to security, two separate sensors are installed to allow a conformity check of the redundant pressure signals. This entails not only higher costs, but also increases complexity, overall size and requires multiple pressure connectors. To counteract this, we developed a sensor with built-in redundancy and high flexibility utilizing some advantages our highly sensitive thin-films provide, with the primary goal of enhanced reliability and long-term stability. The concept is based on a monolithic sensor design; i.e. the steel body is one-piece without any welding connection. We chose a modular approach for more flexibility regarding different pressure ranges and various mechanical connectors.

Description

The modular approach resulted in the development of a universal strain gauge design, which can be joined to various mechanical variants of a monolithic steel pressure membrane. The sensor body is designed with an internal screw thread, allowing it to be paired with male stud couplings common in industry. This allows the use of widely available, mass produced parts and therefore a cost-efficient possibility to offer a variety of pressure connectors without the need for welding while still keeping the overall design compact.

The strain gauge carrier consists of highly temperature resistant ultra-thin glass, cut in circular geometry by means of a laser. The glass carrier greatly reduces cross-sensitivity from moisture, which especially can be a challenge with foil strain gauges. A glass soldering process is adapted for joining the strain gauge to the steel pressure membrane. As a further advantage, the membrane's surface need not to be sanded and polished as would be necessary if an insulating layer like SiO2 is to be sputtered. The ultra-thin glass already has a smooth surface with less than 1 nm RMS.

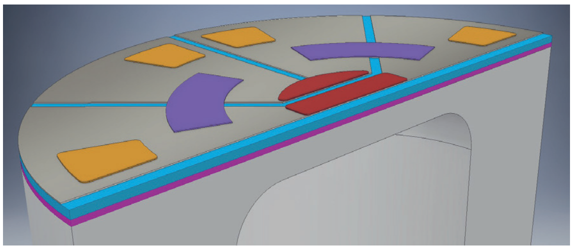

Fig. 1. Half-section of a sensor showing one of two Wheatstone bridges that are laser-structured into a thin film (grey color) on ultra-thin glass substrate (blue). The glass is joined to the steel membrane by means of a glass solder (magenta). Yellow markings indicate the zones for electrical contacts.

In addition to a strong bond, the glass soldering process results in a compressive stress state of the glass carrying strain gauge, if the different thermal expansion coefficients are chosen in a way that the steel membrane has the highest and the glass has the lowest coefficient. This helps to avoid tensile stress states in the glass substrate, susceptible for crack formation [1].

Thus, even under applied pressure the glass circumference ideally remains free of tensile stress, allowing for a non-perfect glass cutting quality.

The thin film material allows the sensor to not only endure the necessary soldering temperature of over 450 °C but also enable the appropriate, simultaneous thermal conditioning of the thin film strain gauge [2][3]. By adjusting the heating and cooling ramps, the thin film may be modified in order to reduce the sensors overall temperature sensitivity.

The design comprises two electrically independent Wheatstone bridges on the midway divided pressure membrane. After the joining process, a contact PCB is glued to the sensor and the bridges can be contacted electrically by a bonding process as shown in Fig. 1. This concludes the manufacturing process and the sensor bridges are then calibrated simultaneously.

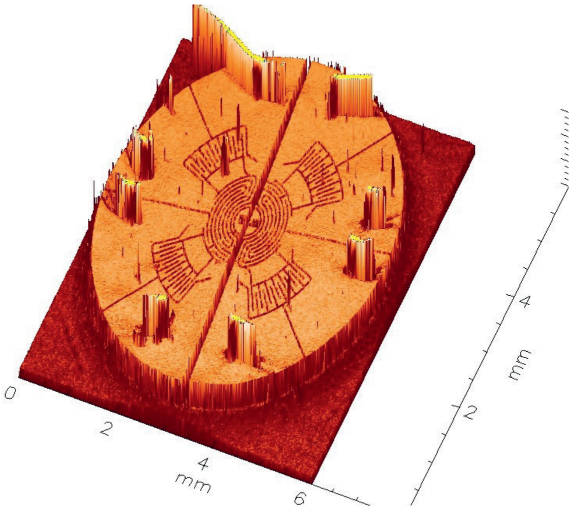

Fig. 1. 3D optical scan of a glass strain gauge surface showing the structure of the dual bridge design with resistors and the foot marks of eight bonds.

Results

The sensors show promising results despite the novel usage of the pressure membrane area. As hoped for, the individual bridges display similar, but not identical behavior. For instance, identical bridge signal drifts would cancel the advantage of multiple signals in detecting long-term run-away. Because of this, mechanical asymmetries due to tolerances, positioning offsets and even inhomogeneity in the thin film can actually be a benefit. Non-identical bridge behavior can also be induced on purpose by using different strain gauge layouts for bridge A versus bridge B. Table 1 shows a prototype with identical layouts for both bridges, but different sensitivities likely due to a strain gauge misalignment of around 0.2 mm.

Tab. 1: Exemplary characteristics of one prototype with a nominal pressure of 200 bar

	Temp. °C	Sensitivity mV/V	Hysteresis % full scale
Bridge A	30	7.404	0.053
	80	7.512	0.054
	125	7.611	0.046
Bridge B	30	6.433	0.055
	80	6.524	0.063
	125	6.607	0.046

The split-membrane approach has shown potential and has the advantage of allowing a simpler mechanical design compared to available redundant pressure sensors with dual membranes, as only one pressure channel and membrane are required. Thus, lathe turning the sensor body without additional reworking is an option.

An operating temperature of up to 125 °C was the original goal of development, but measurements indicate potential for higher temperature applications, as rising temperatures do not seem to have negative effects on measurements within the temperature range. Fig. 2 shows a creep measurement at 125 °C for 180 min. Similar errors have also been measured for much longer exposure times of several days.

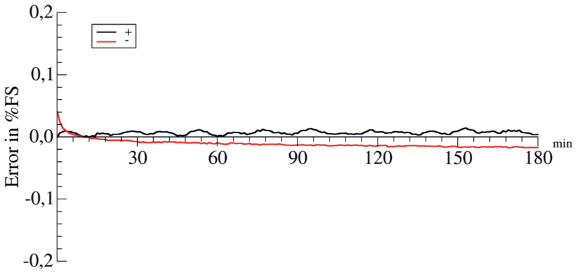

Fig. 2. Typical creep measurement of a 200 bar sensor at 125 °C for 180 min. The ripples in the pressurized state (black) result from closed-loop pressure regulation and do not appear when the pressure is relieved (red).

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