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Relative media pressure compensation technique using rectangular diaphragms

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Abstract

A novel compensation design that significantly improves the accuracy of O-ring packaged silicon MEMS differential pressure sensors, is presented. The work focusses on eliminating the overall relative media pressure dependency of O-ring packaged MEMS pressure sensors. The presented sensor is based on a rectangular micromachined diaphragm with piezoresistive elements implanted near the diaphragm edges and center. The resistors are interconnected in a Wheatstone bridge configuration with each quadrant consisting of series connected resistors from the diaphragm center and edge. Using this simple approach, the relative media pressure dependency of O-ring packaged MEMS pressure sensors are reduced from maximum 1.5% to maximum 0.4% of the overall sensor output. This shows the significant improvement in differential pressure sensor accuracy using the developed sensor. Furthermore, the temperature dependency and various application aspects of the sensor design is presented and analyzed in detail. All through the work the findings are supported by 3D FE stress analysis.

Keywords: Relative media pressure; Compensation; Rectangular diaphragm; O-ring; Packaging; Wheatstone; MEMS; Silicon; Piezoresistive; FE; Stress

1. Introduction

The output signal from O-ring packaged piezoresistive MEMS pressure sensors mainly depends on the difference between the media pressure on each side of the diaphragm—the so called differential (media) pressure. Recent studies have shown that the output signal also depends slightly on the difference between the media pressure and the atmospheric pressure surrounding the external edges of the sensor system—the so called relative (media) pressure [1,2]. In this paper we present a novel compensation technique, which significantly reduces the relative media pressure dependency of O-ring packaged differential MEMS pressure sensors and thereby increases the overall sensor accuracy.

The compensation technique is based on a rectangular micromachined diaphragm with eight piezoresistive elements implanted in the diaphragm region—four near the edges and four near the center. Edge and center resistors of opposite orientations are interconnected in pairs to form four quadrants of a full Wheatstone bridge configuration. This simple but powerful coupling method cancels out the overall relative media pressure dependency of the device.

Fig. 1 shows a cross-section of an O-ring packaged silicon MEMS pressure sensor including a definition of the absolute media pressures $P_{a,high}$ and P_a and atmospheric pressure P_{atm} acting on the chip and O-ring surfaces. From this the differential pressure is defined as $P_d = P_{a,high} - P_a$ and the relative media pressure as $P_r = P_a - P_{atm}$. Over a span of 9 bar in relative media pressure ($\Delta P_r = 9$ bar) and a span of 2 bar in differential pressure ($\Delta P_d = 2$ bar), the relative media pressure dependency of MEMS pressure sensors with square shaped diaphragms contributes with maximum 1.5% FS (Full Scale) of the sensor output [1,2].

The presented compensation technique places all interconnected piezoresistors on a rectangular shaped diaphragm in regions having a high stress sensitivity to changes in differential pressure across the membrane. The presented design therefore does not reduce the differential pressure sensitivity of the device. This may be compared with other compensation designs found in literature aiming at packaging stress and temperature compen-

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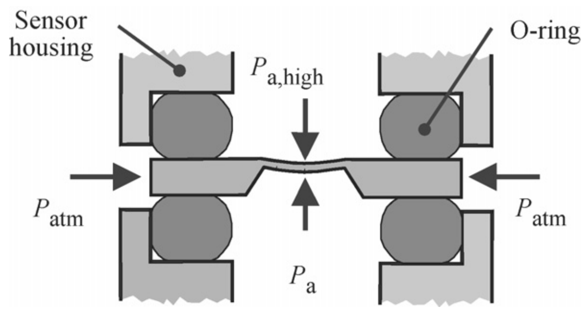

Fig. 1. A sketch of an O-ring packaged MEMS pressure sensor including a definition of media pressures.

sation [3,4]. These compensation designs uses compensation resistors placed on the substrate and thereby introduce large resistors passive to changes in the differential pressure. This eventually results in a significant reduction in differential pressure sensitivity of the device. Furthermore, in contrast to the present work, the conventional designs using substrate compensation resistors does not aim at a passive relative media pressure compensation for varying media pressures on both sides of the diaphragm.

In this paper, we first review the effects causing the relative media pressure dependency of O-ring packaged MEMS pressure sensors. Then, we introduce some basic design considerations followed by a presentation of the developed sensor concept. This is followed by a presentation of a series of FE simulations carried out on the developed sensor and a presentation of experimental data obtained from manufactured components. Finally, a discussion of relevant sensor topics is presented.

2. The relative media pressure dependency

Fig. 2 illustrates the two main contributors to the relative media pressure dependency of O-ring packaged MEMS pressure sensors. Fig. 2a illustrates how a high relative media pressure P_r acting on the etched sidewalls on the backside of the chip compresses the substrate and thereby stretches the diaphragm. Similarly, Fig. 2b shows how a large increase in the relative media pressure (ΔP_r) increases the O-ring contact pressure on the chip surface. The two effects in Fig. 2 contributes with about 60–95% of the overall relative media pressure dependency [1,2].

In addition to the main effects in Fig. 2, a third but minor contribution to the relative media pressure dependency has been found [5]. This third effect is believed to result from stress stiffening in the diaphragm. In agreement with this hypothesis, the third effect is found to be highly dependent on the aspect ratio of the diaphragm and the resistor position on the surface of the diaphragm. For square shaped diaphragms with dimensions on the order of $1000\ \mu m \times 1000\ \mu m \times 20\ \mu m$ and resistors placed at the diaphragm edges, stress stiffening contributes with about 5–40% of the relative pressure dependency, depending on the differential pressure. However, for the rectangular shaped diaphragms implemented in this work, stress stiffening only contributes with maximum 5–10% of the overall relative media pressure dependency for pressure spans of $\Delta P_r = 9$ bar and $\Delta P_d = 2$ bar. For the sake of simplicity, the rest of this work therefore only considers the two dominating effects illustrated in Fig. 2.

3. Design considerations

The ratio of a diaphragm sidelengths (the aspect ratio) has a dramatic effect on how a diaphragm is deformed, when subjected to a high relative media pressure on the sloped sidewalls on the backside of the chip. This important observation serves as the key element in the compensation design presented in this work. In general, the deformation of the diaphragms in MEMS pressure sensors is very complex, when subjected to both differential and relative media pressure. An accurate description of the diaphragm deformations can therefore only be found by numerical simulations. However, a lot of useful information about the

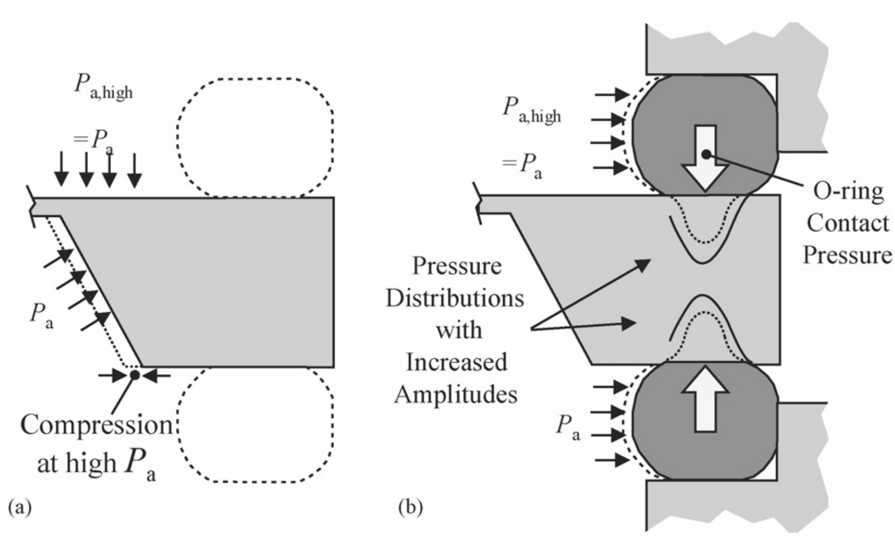

Fig. 2. Sketch of the main effects contributing to the relative media pressure dependency of O-ring packaged MEMS pressure sensors: (a) compression of the substrate region and stretch of the diaphragm; (b) media pressure induced increase in the O-ring contact pressure on the surfaces of the chip.