Analysis and design of pressure sensors for micromechanical integrated pressure sensors

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Abstract. Accelerometers, pressure sensors and gyros have good prospects for the future among the wide range of micromechanical instruments that are developing most dynamically. The paper describes the modified version of the design of the pressure sensitive element created by the author with improved metrological characteristics and increased accuracy rates.

1. Introduction
The introduction of microelectronics technology and the development of micromechanical sensors of primary information on its basis allows the volume to be sharply increased and the prices for manufactured products to be reduced, at this price-quality ratio, such products go to the forefront, since monocrystalline silicon used as a structural material has high stability physical and mechanical properties.

The problem of creating a domestic electronic component base for the development of small-sized stable pressure sensors with increased metrological characteristics in the temperature range is topical.

Pressure sensors (PS) structurally consist of a sensing element (SE) that senses pressure, and converters assembled in a casing, the designs of which are very diverse.

The membrane, which is SE PS, is usually rectangular or round. It can be the same in thickness or with a rigid, non-deformable center, which has an elastic web along its contour [1].

The most important technical characteristics of micropressure sensors (MPS) include the operating range of the measurement, the sensitivity to the measured pressure, the output voltage.

All PS are characterized by error components like: nonlinearity of the characteristic, hysteresis with temperature and pressure changes, temperature drift of the initial displacement and sensitivity.

There are absolute, differential, relative and vacuum PS [2].

In the constructions of the pressure sensitive element, whose membranes have rigid centers with a thickness equal to the thickness of the original substrates, an additional monocrystalline silicon frame made using the technology of volume microprocessing is used. Monocrystalline silicon is used as the base. All silicon elements are connected by a low-melting glass, which is applied to one of the elements.

The disadvantage of using a hard center is that the pressure sensor becomes sensitive to linear and angular acceleration. In order to completely eliminate the effect of acceleration, two identical pressure sensors are performed on one plate, the second sensor being closed from pressure and reacting only to acceleration and the useful signal in the form of a difference value is extracted by means of an electronic circuit [3].

The pressure sensing element (PSE) is an assembly consisting of a strain-sensitive crystal of the integral pressure transducer (IPT) and transition parts in the form of silicon gaskets and a base.
The purpose of the research articles carried out by the authors was:
- develop and implement new technological methods to ensure the stability of the output parameters of integral pressure sensors used for monitoring, measurement, diagnostics and management systems of equipment;
- develop basic technological production processes that ensure the stability of the output parameters of the SE of integral PS;
- develop recommendations for the design of new integrated sensors and microelectromechanical systems (MEMS) based on the results of a study of the stability of the parameters of their SE;
- make prototypes of products and test them.

A particularly significant difference in the denouement values is observed in small-pressure sensors with thin membranes in which the use of the PSE design significantly reduces the temperature coefficients of sensitivity and initial imbalance of the bridge, their nonlinearity and, accordingly, increases the accuracy class of the sensors from 0.5 to 0.1 - 0.25 [4].

The output characteristics of the newly developed PSE repeat the output characteristics of the IPT crystal, which are part of the PSE. The PSE design provides denouement from the enclosure, regardless of how the bottom end of the base is fixed in a wide temperature range from -60 to +100 °C.

The design of the PSE developed by the authors is shown in figure 1.

**Table 1. Characteristics and thickness of the membrane of the crystal IPD1-0.01.**

| Notation       | The thickness of the membrane, Mkm | Upper limit of the pressure to be converted (nominal pressure) \( P_{\text{nom}} \), MPa | Change in output voltage under the influence of nominal pressure \( \Delta U_{\text{out,nom}} \), not less than, mV |
|----------------|-----------------------------------|-------------------------------------------------|-------------------------------------------------|
| HAVL.757644.001 | 28, 36                            | 0,01                                            | 45                                              |
Table 2. Characteristics and thickness of the membrane of the crystal IPT2.

| Notation | The thickness of the membrane, Mkm | Upper limit of the pressure to be converted (nominal pressure) \( P_{\text{nom}} \), MPa | Change in output voltage under the influence of nominal pressure \( \Delta U_{\text{out}_{\text{nom}}} \), not less than, mV |
|----------|-------------------------------|---------------------------------|---------------------------------|
| E.757644.003 | 30 not less than 37 no more | 0,10 | 70 |
| -01 | 88 98 | 1,0 | 100 |
| -02 | 140 154 | 2,5 | 100 |

The parameters of the IPT2 crystal are clearly estimated by the value of the exponent of the construction of the \( I^* \). According to the formula:

\[
\Delta U_{\text{out}} = \frac{I^*_s}{d_m} \cdot P_n \cdot U_b
\]

where \( I^*_s \) – crystal sensitivity index, \( d_m \) - membrane thickness, \( P_n \) - nominal pressure, \( U_b \) - stress on strain gage, \( \Delta U_{\text{out}} \) – range of output voltage variation.

In IPT1 crystal structure and crystal IPT2 each arm of the Wheatstone bridge consisting of a single strain gauge, is arranged on separate straightforward thin diaphragm portion on one respective groove, the longitudinal axis of which is parallel to the longitudinal axis of the respective strain gage. The rectilinear thin area on the other side of the membrane has a width of 5 to 100 μm and a length of at least 0.7 times the length of the strain gage. The longitudinal boundaries of said thin portion of the membrane parallel to strain gages, and in the intervals between the thin portions of the membrane there are three rigid centers. Width of the rectangular area of the membrane substantially doubles the mechanical stress on the membrane in the region between faces due to the addition of stresses arising in the individual hard center region. A further increase in width results in a decrease in sensitivity. If the width is less than 5 μm, the sensitivity also decreases, as the strain gage appears on the thick part of the membrane. The length of the thin section of the membrane ensures the same mechanical stresses along the resistor, which is necessary for the linearity of the conversion characteristic [5, 6].

Test sample of the sensitive element of excess pressure PSE1-I-0.01

Test sample of the gauge pressure sensor PSE2-I

Figure 2. Test sample of the sensing element integrated pressure sensor.
The technical characteristics of the sensing elements are determined in the test samples. The test samples of the pressure sensing elements PSE1-I-0.01 and PSE2-I (Pnom = 0.1, 1.0, 2.5 MPa) are mounted in a metal-glass case for research.

The body of the test sample is not sealed. Tightness is provided in the part of the separation of the measured and surrounding environments.

2. Conclusion
In the course of the work, the scientific and technical and patent literature on the most important technical characteristics and error components (static and dynamic) were analyzed, on the basis of which implemented the analysis of PSE construction and a modified version of the PSE design was developed with improved metrological characteristics and increased accuracy. Test samples were developed.

Two designs of IPT have been developed: IPT1 with a size (6.2×6.2) mm for nominal pressure 0.01 MPa and IPT2 with a size (4.0×4.0) for nominal values pressure 0.1 MPa; 1.0 MPa; 2.5 MPa. Width of the rectangular portion of the membrane substantially doubles the mechanical stress on the membrane in the region between edges due to the addition of stresses arising in the individual hard center region. A further increase in width results in a decrease in sensitivity. If the width is less than 5 μm, the sensitivity also decreases, as the strain gage appears on the thick part of the membrane. The length of the thin section of the membrane ensures the same mechanical stresses along the resistor, which is necessary for the linearity of the conversion characteristic.

The development was carried out on the basis of the strain-sensitive crystal of the integral converter (overall dimensions, the range of the measured pressure, the allowable pressure, the supply voltage, the nominal output signal, the nonlinearity of the output signal, the initial unbalance of the bridge from the output signal, the operating temperature range, the temperature coefficient), which made it possible to obtain a membrane sensitivity with improved metrological characteristics.

For experimental studies, test samples were developed in which values such as membrane thickness, the upper limit of the converted pressure, the change in the output voltage under the influence of the nominal pressure varied.

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