The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

In pressure sensing technology a wide range of products, from the silicon sensing element to the pressure transmitter, sold under the general term "sensor". This article deals with the various types of sensors and what the user should look out for.

The following studies the various types of pressure sensors from the simple sensing element mounted on a substrate to the amplified, compensated and calibrated sensing element packaged in a suitable housing and with the relevant electronics as a ready-to-use sensor with normed output signals (transmitter).

Piezoresistive, micromechanical pressure sensing elements of silicon

The micromechanical measurement cells based on silicon are manufactured using semiconductor technology (see Figures 1 and 2). Therefore they meet the high requirement of reliability and economy that are the trademarks of integrated circuits (ICs). All micromechanical pressure sensing elements made of silicon have a thin membrane as their pressure-sensitive structure that is normally etched from the silicon chip anisotropically, forming a cavity. At suitable points in the membrane atoms are locally implanted into the silicon crystal using the semiconductor process so that zones with an altered electrical conductivity are formed that have the characteristics of resistors. As soon as pressure is...
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

applied to the membrane, the molecular structure of the crystal is deformed as the thin silicon membrane deflects. Particularly in the area of the resistors there are marked deformations in the crystal that leads to a measurable change in their resistive values (the piezoresistive effect). Typically these integrated resistors are connected up as a bridge (Figure 3). By the excitation of voltage or current a pressure dependant, differential output signal ($\approx 20 - 200$mV Full Scale) is generated that can be easily logged and processed electronically using a suitable amplifier circuit.

For manufacturing a pressure sensor with a silicon sensing elements (dice) a clean room is imperative, also the necessary semiconductor equipment. Assembling and packaging processes have a great influence at the performance of the future sensor. Each process from the die separation to the covering with a protective gel must be carefully done and well controlled.

Application notes:

*It is obvious that it only makes sense to make the necessary investment in silicon processing for large-volume projects. The bare silicon sensing element is thus not a suitable component for most users or for small quantity projects.*
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

Uncalibrated/ uncompensated pressure sensors

*Figure 4*: Typical device of a silicon pressure sensing element mounted on a ceramic substrate without a plastic cap

*Figure 5*: Typical device of a silicon pressure sensing element mounted on a ceramic substrate with a plastic cap

In the field of sensor technology, trimming means the adjustment of the transfer function to a fixed offset and span, the linearization thereof and the correction of disturbance variables, such as temperature dependency, for example.

Pressure sensors that are adjusted to match fixed outputs in the offset and span are termed as being "calibrated". Sensors with corrected temperature behavior are "compensated for".

Uncalibrated/ uncompensated pressure sensors consist of a silicon pressure element that due to temperature matching requirements is in most cases mounted on a ceramic substrate (Al₂O₃) and protected by a plastic or metal cover (*Figures 4 and 5*). The pressure sensing element itself is often covered with a layer of silicone gel to stop it corroding in contact with water or other liquids. This form of assembly enables the sensor to be treated just like an electronic component in production.

Depending on the range of pressure, the uncalibrated/ uncompensated pressure sensors generate a full-scale signal in the region of 20 to 200 mV maximum. Because of the strong temperature dependency of the output signal, the temperature behavior must be individually compensated. Additionally the output signal has to be amplified and calibrated to the normal values.

This means that in addition to the sensing element the user needs suitable signal electronics with adjustment possibilities, a calibration algorithm and a calibration setup (measurement area with a stable and adjustable oven and pressure calibrators).
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

Application notes:
With uncalibrated/ uncompensated pressure sensors the user has to carry out the elaborate sensor adjustment process himself. As the sensing elements are strongly dependent on temperature and their output values individually fluctuate, they must be individually compensated for/calibrated on all accounts. To this end the user needs an adjustable evaluation circuit with a calibration structure, a calibration setup and a calibration algorithm.
The lower the pressure, the higher the demand for accuracy and the wider the range of temperature, the more elaborate the time and effort required for calibration/compensation.

Calibrated/compensated (unamplified) pressure sensors

The output signal of a silicon pressure sensing elements demonstrates a strong temperature dependency, so that the sensors have to be temperature compensated. Depending on the required level of accuracy the sensor must be characterized at two or more temperatures. This means that the output characteristic of the sensor has to be recorded at various temperatures and pressures. The correction coefficients for the relevant temperature effects (TCO and TCS) are then calculated and the measurement values can be corrected to the required setpoints. This is done by using a resistive network (Figures 6 and 7) or suitable electronics.
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

The temperature compensation is carried out during production by the manufacturer so that the user does not have to make any corrections. These sensors are also usually calibrated to a uniform value by the manufacturer.

With unamplified, calibrated and compensated sensors the user then has to add his specific signal electronics that, if specified, convert the sensor output voltage into the required output values (such as 4–20 mA, 0 – 10V, I²C, SPI or others for example).

Application notes:
Calibrated/compensated sensors are suitable for users who do not wish to carry out temperature compensation themselves but who have adjustable evaluation electronics at their disposal (the ability to set offset, span and linearity) or who have special requirements regarding output characteristics as compared to standard outputs.

Amplified (OEM) pressure sensors (calibrated and compensated for)

Figure 8: Typical calibrated, compensated and amplified OEM-pressure sensor (e.g.: AMS 5812 [1])

Figure 9: Top view of a ceramic substrate with the sensing element and the integrated electronics (ASIC) protected by a glob top layer

Calibrated, compensated and amplified (OEM-) pressure sensors have a standard output signal (voltage, current or a digital signal) but no housing or package in the usual sense. They are designed for mounting onto printed circuit boards and consist of a ceramic substrate onto which the sensing element and electronic circuit (ASIC) are mounted (Figure 9). The pressure
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

to be measured is applied via two tiny tubes (Figure 8). Such OEM-sensors are recommended when the pressure sensor has to be inserted into a larger electronic network, such as e.g. a control unit.

The AMS 5812 by AMSYS [1]) covers pressure ranges from 0 - 5mbar up to 0 - 7bar full scale and can be used to measure absolute pressure, relative pressure and differential pressure. AMSYS has also recently launched sensors for the measurement of bidirectional differential pressure that can determine both positive and negative pressure.

Application notes:

*With such amplified OEM-pressure sensors the user does not need to carry out any additional tasks – with the exception of soldering the sensor onto the circuit board. They are thus suitable for users who do not want to have to bother with the further processing of the sensor and its signal generation but who prefer to use their own package or mount the sensor onto their own printed circuit boards.*

Pressure transmitters

*Figure 9: Pressure sensor in a metal casing (transmitter), example: precision sensor U5100 [2]*

*Figure 10: Pressure sensor in a plastic casing (transmitter), example: AMS 4712 [3]*

Pressure transmitters are amplified, calibrated and compensated sensors mounted in a stable housing. They are calibrated to standard output values (such as 0–10 V and 4–20 mA, SPI, I²C, etc.) using the relevant electronics and compensated in a wide temperature range. They can be used without the need for any further processing as soon as the wires have been connected up.
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

The most transmitters (e.g. the U5100 [2]) have been designed for general applications and optimized in their design for this purpose.

In the past 'classic' transmitters used in industrial applications normally were sold in a metal housing, with a multitude of connectors and thread types on the pressure side of the device. On the output side various possibilities are provided by a number of different connectors, such as the Bendix bayonet-, DIN- or Packard connector. For less robust applications more and more transmitters are being marketed in plastic packages for reasons of economy. Figure 10 shows with the AMS 4712 [3] and the AMS 4711 [4] for example, the new transmitter series by AMSYS. These fully amplified, calibrated and compensated transmitters in a rugged plastic package are protected according to IP67 and can be used within a temperature range of -25 to 85°C.

Application notes:

These sensors (transmitters) are ready to use directly in the most industrial facilities and do not require any further processing.
The various versions of pressure sensors – from the silicon sensing element to the pressure transmitter

Summary

<table>
<thead>
<tr>
<th>Specific variants</th>
<th>Pressure sensing elements</th>
<th>Pressure sensing elements with casing</th>
<th>Compensated, unamplified pressure sensors</th>
<th>Calibrated/compensated and amplified pressure sensors</th>
<th>Transmitters</th>
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<tr>
<td>User input</td>
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<td>Average</td>
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<td>None</td>
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* Total error

Table 1: Comparison of various sensor types


For further information, please visit www.amsys.de