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).

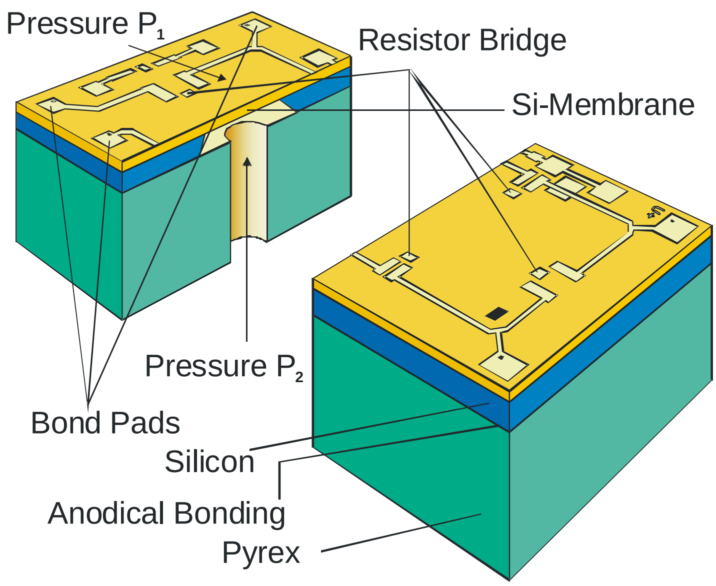

***Figure 1:** Typical silicon sensing element circuitry for a differential or relative pressure sensor*

The dimensions of the silicon sensing element (dice) depend on the applied pressure and the manufacturing technology. Typical dimensions are: 1.5 x 1.5 x 0.5 mm³ in the standard pressure range (200 mbar to 10 bar) up to 4.5 x 4.5 x 1 mm³ in the low pressure range (10 to100 mbar). The sensing elements consist of a glass base (green), a silicon structure (blue) with an etched membrane (yellow).

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 applied to the membrane, the molecular structure of the crystal is deformed as the

AMSYS GmbH & Co.KG
An der Fahrt 4
55124 Mainz
GERMANY

phone: +49 (0) 6131 469 875 0
fax: +49 (0) 6131 469 875 66
email: info@amsys-sensor.com
internet: www.amsys-sensor.com

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thin silicon membrane deflects. Particularly in the area of the resistors there are marked deformations in the crystal that leads to a measureable 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 (≈ 20 - 200mV Full Scale) is generated that can be easily logged and processed electronically using a suitable amplifier circuit.

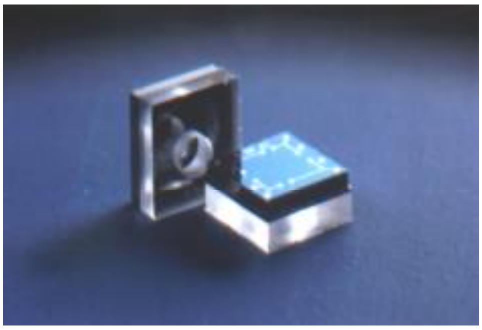

Figure 2: *Silicon sensing element*

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.

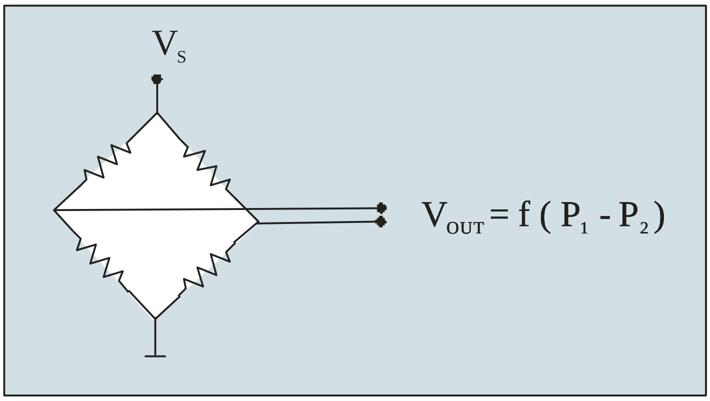

Figure 3: *Bridge circuit for piezoresistor devices*

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Uncalibrated/ uncompensated pressure sensors

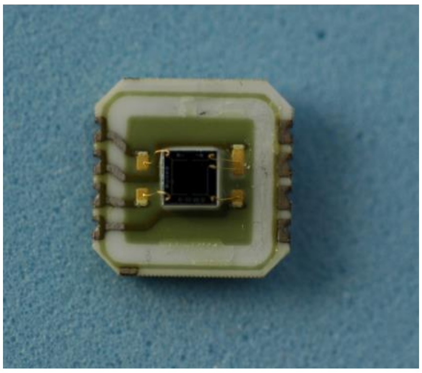

Figure 4: *Typical device of a silicon pressure sensing element mounted on a ceramic substrate without a plastic cap*

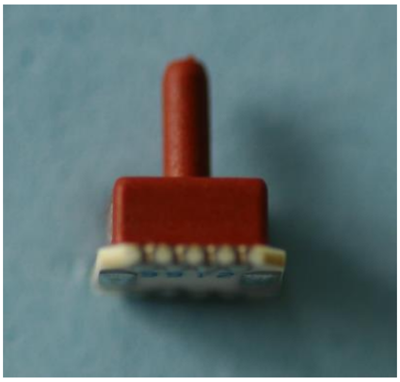

Figure 5: *Typical device of a silicon pressure sensing element mounted on a ceramic substrate with a plastic cap*

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 (Al_2O_3) 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).

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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

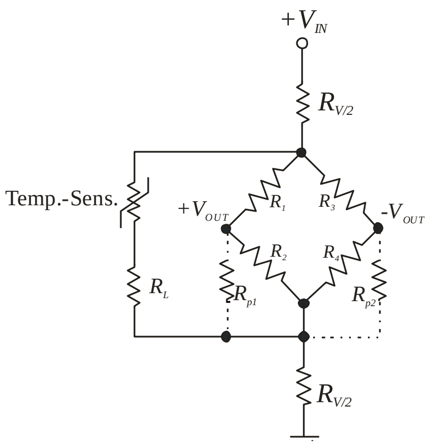

Figure 6: *Schematic circuit diagram of a resistive adjustment network*

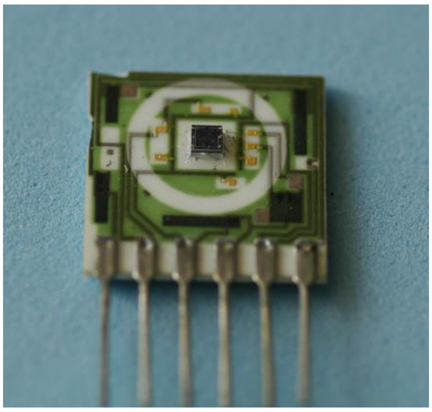

Figure 7: *Typical circuit for a calibrated/ compensated, (unamplified) sensor*

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 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.

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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)

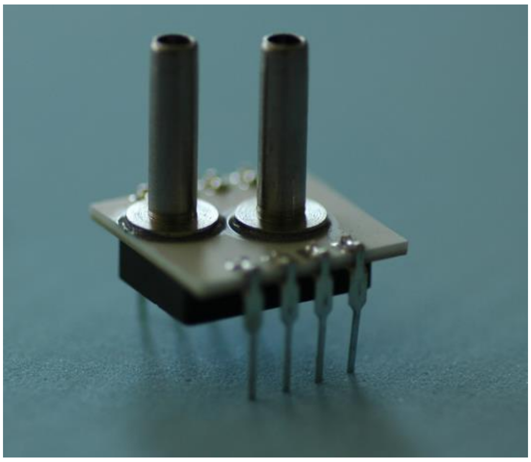

Figure 8: *Typical calibrated, compensated and amplified OEM-pressure sensor (e.g.: AMS 5812 [1])*

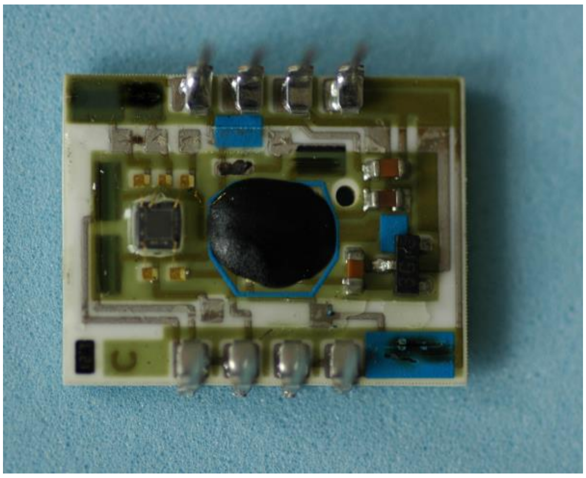

Figure 9: *Top view of a ceramic substrate with the sensing element and the integrated electronics (ASIC) protected by a glob top layer*

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 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.

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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.

With a suitable arrangement, the pressure can also be measured in liquids. This is achieved by a media-compatible design of the sensor [2].

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 10: *Pressure sensor in a metal casing (transmitter), example: precision sensor D5100 [3]*

Figure 11: *Pressure sensor in a plastic casing (transmitter), example: AMS 4712 [4]*

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.

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The most transmitters (e.g. the D5100 [3]) have been designed for general applications and were 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 11 shows with the AMS 4712 [4] and the AMS 4711 [5] 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. They are suitable for all types of pressure such as absolute pressure, relative and differential pressure and cover a wide pressure range (5 mbar to 2 bar). The same applies to the robust version of this series made of metal, the AMS 3011 [6] which can be used for pressure ranges up to 10 bar both indoors and outdoors and can withstand high system pressure. Besides the fact that such sensors are very convenient for the industry and represent a low maintenance, they should also be RoHs and REACH compliant*, which is playing an increasingly important role today.

Application notes:

These sensors (transmitters) are ready to use directly in the most industrial facilities and do not require any further processing.

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Summary

Specific variants	Pressure sensing elements	Pressure sensing elements with casing	Compensated, unamplified pressure sensors	Calibrated/ compensated and amplified pressure sensors	Transmitters
User input	Very large	Large	Average	None	None
Specific processing requirements	Clean room	Clean industrial environment	Clean industrial environment	None	None
General requirements	Semiconductor expertise	Electronics experience	Electronics experience	None	None
External components	Many	Many	Average	None	None
Media sensitivity	Very large	Large	Average	Low	Very low
Accuracy*	Low	Low	Average	Very good	Very good
Elec. protective circuits	No	No	No	Yes	Yes
Standard output	No	No	No	Yes	Yes
Negative pressure < 100 mbar	Yes	Yes	Yes	Yes	No
Positive pressure > 30 bar	No	No	No	No	Yes
Pressure connectors	None	Nipple, O-ring	Nipple, O-ring	Nipple, O-ring	Thread
Electrical connectors	Bonding pads	Solder pads	Solder contacts	Pins, wires	Pins, wires
Ready to mount	No	No	No	Yes	Yes
External assembly	No	No	No	Yes	Yes
IP67 protection	No	No	No	No	Yes
Dimensions	Very small	Very small	Small	Average	Average/Large
Costs	Very low	Low	Average	Average	High

* Total error

***Table 1:** Comparison of various sensor types*

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Further information

[1] AMS 5812 pressure sensor: https://www.amsys-sensor.com/products/pressure-sensor/ams5812-pressure-sensor-with-analog-and-digital-output/

[2] Application note media compatibility: https://www.amsys-sensor.com/downloads/notes/ams5812-media-compatibility-of-silicon-pressure-sensors-amsys-508e.pdf

[3] D5100 pressure transmitter: https://www.amsys-sensor.com/products/pressure-sensor/d5100-wet-wet-differential-pressure-transmitter/

[4] AMS 4712 pressure transmitter: https://www.amsys-sensor.com/products/pressure-sensor/ams4712-analog-pressure-transmitter-4-20ma-output/

[5] AMS 4711 pressure transmitter: https://www.amsys-sensor.com/products/pressure-sensor/ams4711-analog-pressure-transmitter-5v-output/

[6] AMS 3011 pressure transmitter: https://www.amsys-sensor.com/products/pressure-sensor/ams3011-pressure-transducer-5v-in-metal-housing/

Contact

AMSYS GmbH & Co. KG
An der Fahrt 4
55124 Mainz
GERMANY

phone: +49 (0) 6131/469 875 0
fax: +49 (0) 6131/469 875 66
email: info@amsys-sensor.com
internet: www.amsys-sensor.com