AMS 5812 – Media compatibility of silicon pressure sensors

Pressure sensors on the basis of piezoresistive silicon measurement cells are sensitive to liquids and a number of aggressive media. This article illustrates how this can be avoided, taking AMS 5812 [1] as an example.

To understand the procedures how to avoid the media sensitivity of silicon pressure sensors, the article shall first outline the basics of piezoresistive sensing elements (pressure die).

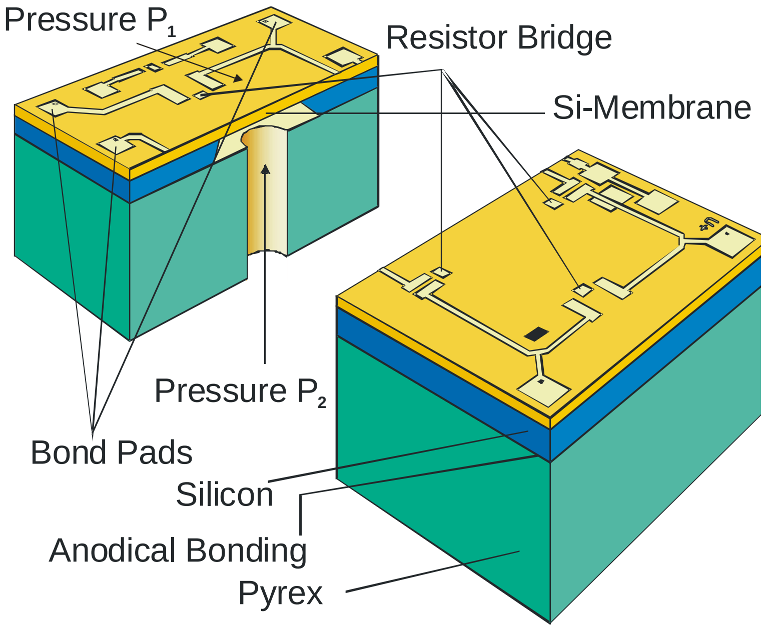

Figure 1: *Typical piezoresistive silicon sensing element (pressure die) for the measurement of relative or differential pressure*

The dimensions of the piezo-resistive sensing elements are dependent on the pressure range required and the production technology used. They range from ca. 1.5 x 1.5 x 0.5 mm³ for the standard pressure range (300 mbar to 10 bar) to 4.5 x 4.5 x 1 mm³ for the low pressure range (10 to 250 mbar). The silicon measurement cell consist of a Pyrex socle (green), a silicon substrate with the etched cavity (blue) and a membrane layer (yellow).

Micromechanical piezoresistive pressure sensing elements

As micromechanical elements based on silicon manufactured using semiconductor technology (see *Figure 1*). The measurement cells meet the high demands 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 element that is usually etched anisotropically from the silicon chip, forming a cavity. At suitable points on the membrane doped atoms are implanted in the silicon crystal using semiconductor processes, creating zones with a changed electrical conductivity that have the properties of resistors. As soon as pressure is applied to the membrane, the molecular structure of the crystal is deformed as the thin silicon membrane deflects. Particularly the implanted resistors generate

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crystalline shifts that lead to a measureable change in their resistive values (piezoresistive effect). If these integrated resistors are connected up as a bridge, on the excitation of current or voltage a pressure-dependent, differential signal in millivolts is generated that can be easily amplified and processed using a suitable electronic circuit.

Figure 2 is a schematic diagram of how the deformation of the membrane belonging to a differential pressure sensing element is to be perceived under various applications of pressure. The change in polarity in the output signal signifies nothing other than a change in the direction of the membrane deformation when the pressure conditions are altered.

The question as to whether $P_1/P_2 \geq 1$ or $P_1/P_2 \leq 1$ is effective is of prime importance to the aspect of media sensitivity with piezoresistive sensing elements and shall be dealt with later.

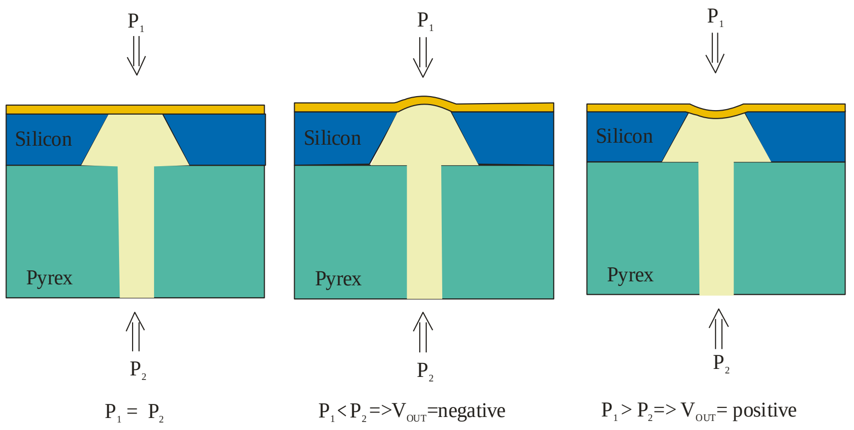

Figure 2: *How a piezoresistive sensing element functions in the measurement of differential or relative pressure*

Measuring relative pressure

Should one of the active pressures P_1 or P_2 be equal to the effective ambient pressure, we then speak of relative pressure sensing, which is a variation on differential pressure measurement.

Signal conditioning

As silicon sensing elements in a normal Wheatstone bridge circuit can generate a differential signal of typically ≤ 100 mV when pressure is applied (depending on membrane sensitivity), an instrumentation amplifier that can process the differential signal is first required for signal conditioning (*Figure 3*). This element has to amplify the signal with a minimum offset and offset drift and optimizes the signal/noise ratio. In the downstream single-ended conversion stage the differential signal is referenced to a fixed potential, usually zero. The ensuing signal conditioning process digitizes the amplified value or calibrates it with the aid of a voltage or current end stage to the required offset value in volts or milliamps. This means that with such a device without applied pressure a value of 0 V can be measured as an output signal, for example, or, in the example of the two-wire current loop application, a value of 4 mA.

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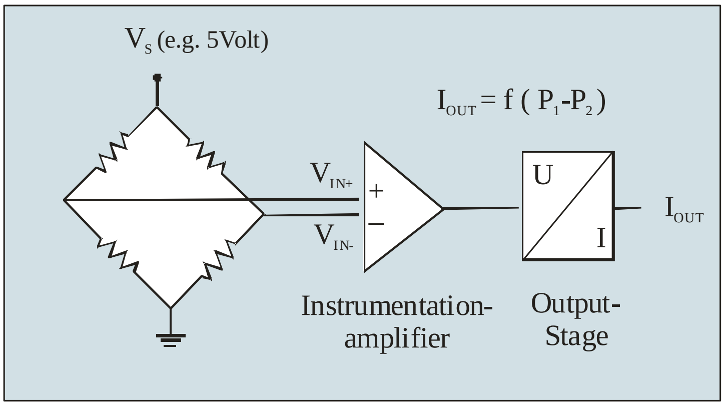

Figure 3: *Signal conditioning electronics with an analog current output stage*

If the signal amplification unit (instrumentation amplifier) is configured in such a way that it can only amplify positive input voltages, when $P_1 \geq P_2$ a positive signal is generated and the transfer characteristic is like as in *Figure 4* is illustrated.

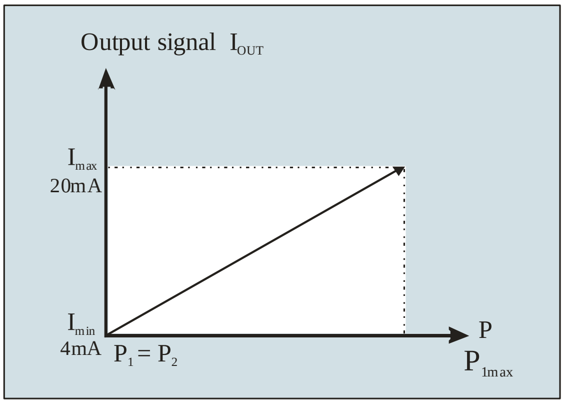

Figure 4: *Transfer characteristic with a positive input signal of $P_1/P_2 \geq 1$*

NB: In the configuration described, negative input signals where $P_1 < P_2$ are not amplified by the instrumentation amplifier. In this case, the amplifier output signal remains at zero and the sensor output signal simulates a situation where $P_1 = P_2$.

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Media compatibility

For the purpose of substrate bonding the upper membrane surface of the silicon sensing element has several small metal surfaces (bonding pads) made of refined aluminum (see *Figures 1* and *5*) that are not corrosion resistant. After the gold wires (wire bonding) have been attached, these contact pads are covered with soft silicone gel for protection. There are gels that provide a good level of protection against e.g. water, or oils or alcohol, but there is no gel that guarantees full universal protection against mixed media. The protective cover must thus be adapted to suit the application on hand.

Another disadvantage of the gel material is its hygroscopic behavior. Through direct contact with liquids or through condensation moisture is stored in the gel that in time can seep through to the silicon layer. When it does, it not only causes corrosion but also a high impedance between the wires connected at various potentials, can modify the measurement values.

In low pressure sensing elements the gel cover also has a considerable influence on the sensitivity and temperature coefficients of the sensing element.

For the reasons given above, sensing elements without a gel protection can only be used to measure dry, non-aggressive gases, such as air, for example.

The obvious disadvantages of the silicon sensing element can be avoided to achieve the required media compatibility by either mounting the sensing element in a oil filled capsule (generating considerable extra cost) or applying the pressure encumbered by media to the non-sensitive underside of the sensing element (underside pressure).

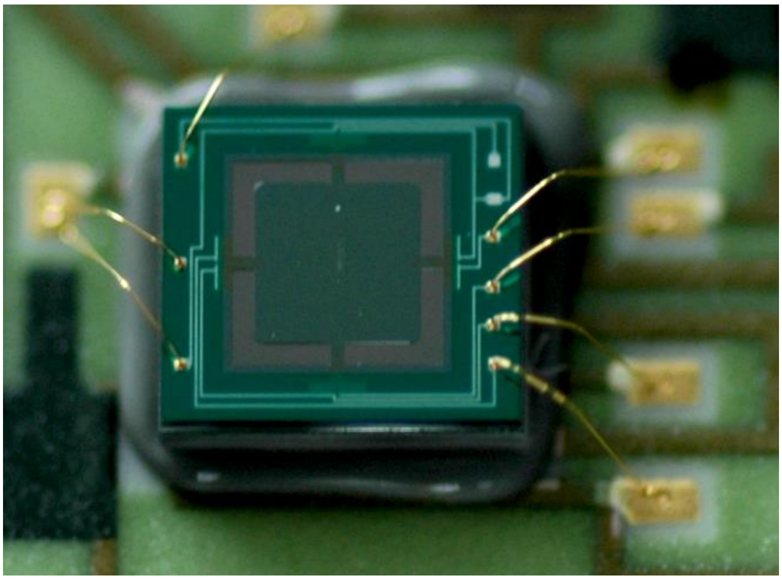

Figure 5: *Gold wire bonded low pressure dice*

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Underside pressure

The underside of the silicon sensing element (*Figure 1*) provides much better media protection as unlike the topside, it has no bonding pads. The only materials to come into contact with the measurement media are silicon oxide, Pyrex glass, ceramic and silicone or epoxy adhesive in a narrow joining gap. Thus if in the case of critical media pressure is applied to the underside, neither does corrosion occur nor are high impedance connections made.

For the sensing element, applying pressure to the underside means that the effective (higher) pressure is P_2 (*Figures 1* and *6)*. The condition $P_1/P_2 \geq 1$ thus changes to $P_2/P_1 \geq 1$, resulting in the membrane deformation being reversed and the differential bridge signal polarity changing. At the negative input of the instrumentation amplifier there would then be a higher value present than at the positive input, meaning the amplifier has a negative input signal. However, negative input signals are not recognized by the standard version of the instrumentation amplifier. In this case, the output signal of the instrumentation amplifier would remain at zero.

If we were to reverse the polarity of the amplifier input, however, if $P_2/P_1 \geq 1$ the instrumentation amplifier would detect a positive signal and then amplify it in the given manner.

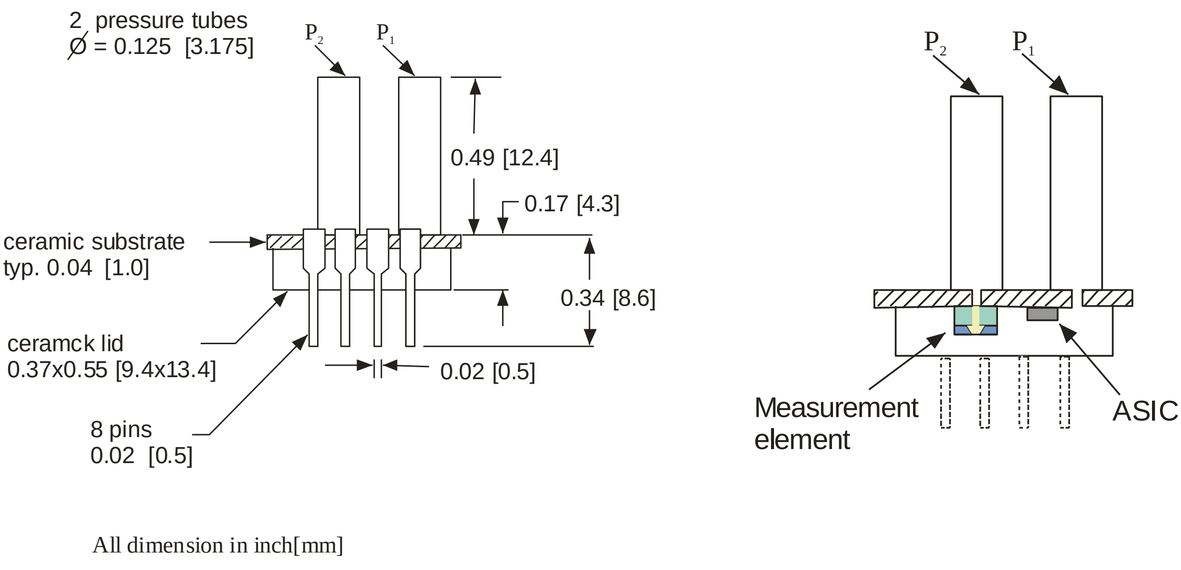

Figure 6: *Construction of the AMS 5812*

The disadvantage of the method described above is that higher pressure P_2 antagonizes the adhesive joint used. The Pyrex - substrate and the Pyrex - silicon conjunctions (see *Figure 1*) must thus be securely joined using suitable adhesives. With modern adhesives, this is a question of material preparation and the time and effort required for qualification. AMSYS uses some adhesives in its pressure sensors that permit an admission of pressure of well over 60 bar within a temperature range of -45 to 125°C.

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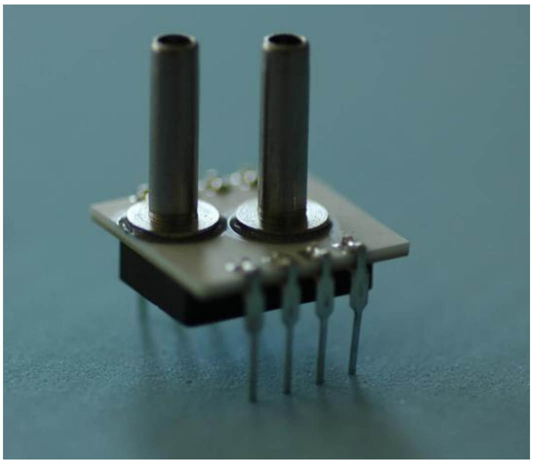

Figure 7: *AMS 5812 circuitry*

The aforementioned modification of the instrumentation amplifier electronics (reverse polarity) can be carried out during the production of the AMS 5812 at the customer's request for all pressure ranges, making AMS 5812 [1] almost completely media resistant e.g. for level measurement in liquid tanks.

The AMS has an analog and a digital output (I^2C-bus-interface with individual addressing).

In contrast, the AMS 5915 series [2] has a digital output and the AMS 5105 series [3] has two independent programmable switching outputs and one analogue output.

These sensors are used in a wide range of applications from breath control to HVAC and level measurement.

Summary

Modern silicon pressure sensors can be largely protected against aggressive gases and a multitude of liquids by applying pressure to the underside of the measurement silicon cells and reversing the polarity of the instrumentation amplifier input. This enables pressure sensors with silicon sensing elements to be used e.g. for level measurement in liquids and pressure control in wet gas systems.

With the modification described above, inexpensive, media-protected pressure sensors can be manufactured for nearly all measurement tasks in the field of differential and relative pressure sensing technology.

Further information

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

[2] Product information AMS 5915: https://www.amsys-sensor.com/products/pressure-sensor/ams5915-digital-pressure-sensor-5mbar-to-10-bar/

[3] Product information AMS 5105: https://www.amsys-sensor.com/products/pressure-sensor/ams5105-pressure-sensor-with-switching-output/

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