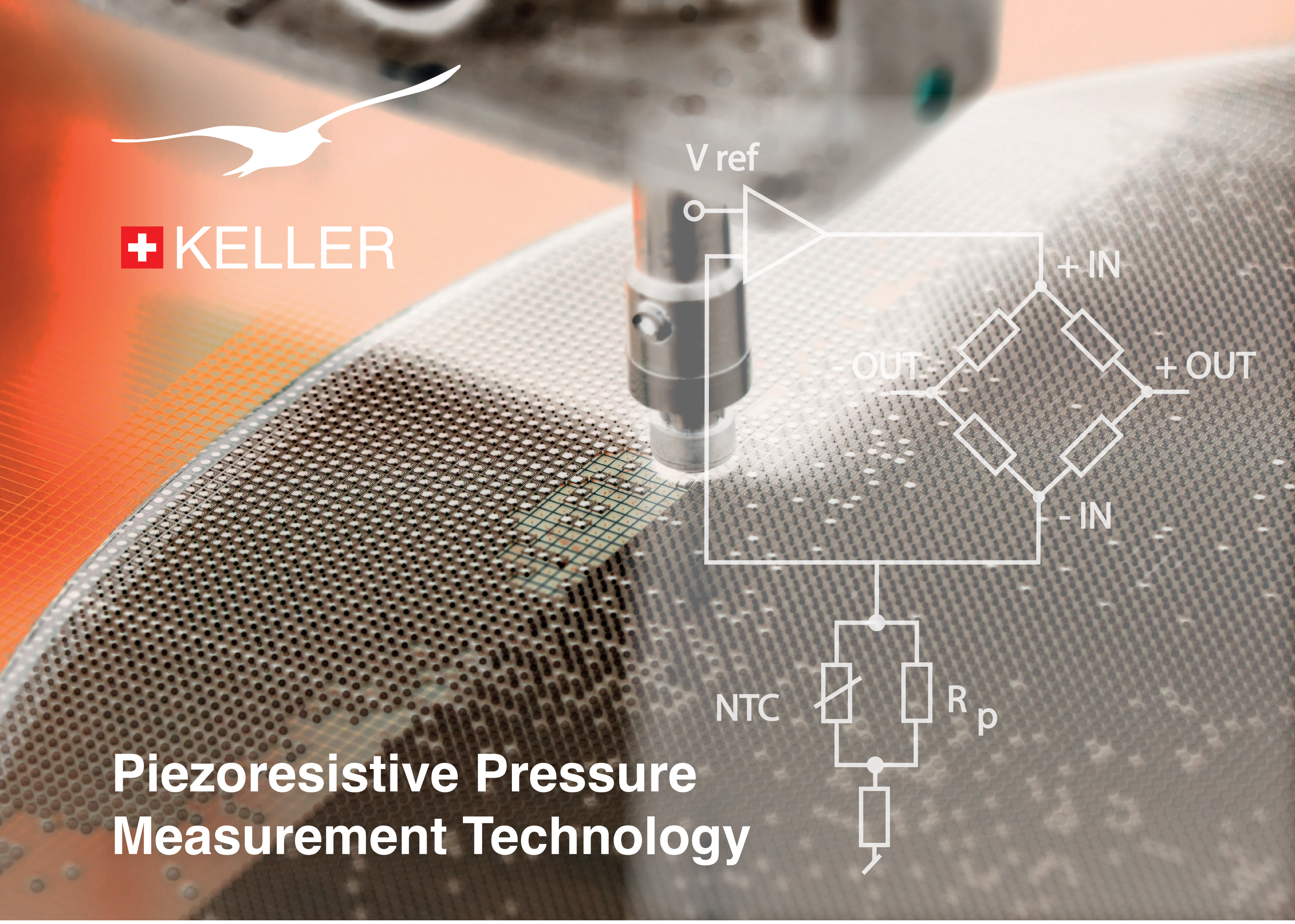

Piezoresistive Pressure Measurement Technology

Piezoresistive technology is often mentioned in the same breath as pressure measurement. But what exactly is the piezoresistive effect? And why is this technology used in pressure measurement?

by Dr. Sören Boyn

Pressure

Along with temperature, pressure is an essential parameter in many technical systems. In addition, a wide variety of industrial processes require precisely controlled pressure conditions. This is why, besides temperature measurement, pressure measurement is the most important and most frequently used technology for monitoring and controlling machines and plants. Additionally, atmospheric air pressure is an important environmental variable and, by measuring the gravitational pressure of the liquid column, for example, groundwater or fill levels can be determined.

Electronic pressure measurement requires a sensor that receives the pressure to be measured and converts it into an electrical signal. Resistive pressure measurement centres around an electrical resistance whose resistance value changes as a function of the pressure to be measured.

Resistive pressure measurement

In the simplest case, classic resistive pressure measurement works with a strain gauge, a thin strip of metal whose resistance value changes depending on deformation. When stretched, the strip becomes longer and thinner, increasing its electrical resistance; when compressed, the strip becomes shorter and its cross section increases, thus decreasing its resistance. In order to translate the pressure to be measured into a controlled mechanical deformation, a strain gauge is applied to an elastic membrane. Normally, this is connected using adhesive. If pressure then acts on one side of this membrane, it deforms and the strain gauge, depending on its position on the membrane, is compressed or stretched (see Figure 1). The higher the pressure, the more the membrane deforms, meaning that the extent of the change in resistance depends directly on the pressure amplitude. For a more accurate measurement, several strain gauges are combined into a Wheatstone bridge circuit and the resistance change is measured as a voltage signal.

Piezoresistive pressure measurement

Derived from the ancient Greek word piezein (meaning to squeeze or press), piezoresistive technology is inherently linked to pressure. The basic principle of piezoresistive pressure measurement essentially corresponds to that of resistive pressure measurement. Here too, -extension or shortening causes a change in resistance. However, in addition to this, in a piezoresistive material the mechanical tension that occurs when it is stretched or compressed also leads to a change in electrical conductivity. This piezoresistive effect is based on shifts in the atomic positions, which directly affect the electric charge transport. The change in resistance resulting from the change in electrical conductivity can be significantly greater than that caused by pure deformation.

Semiconductors are typical piezoresistive materials that exhibit a strong piezoresistive effect. The electrical conductivity of these materials lies between that of electrical conductors (metals such as silver, copper and aluminium) and insulators (such as glass). As a standard, piezoresistive pressure cells are made of Silicon, which is also used in the production of electronic circuits as well. These sensors are therefore sometimes referred to as sensor chips.

The basis for piezoresistive sensor chips is a crystalline silicon disc less than one millimetre thick, known as wafer (see Figure 2). In a process called doping, foreign atoms are introduced in its surface at certain points, which locally influences the conductivity. These doped areas in the silicon form the piezoresistive resistors. In a subsequent step, certain regions of the silicon wafer are thinned in such a way that membranes are formed directly in the silicon and the piezoresistive resistors lie in certain positions, similar to that shown in Figure 1. When a pressure then acts on one side of this membrane, it deforms and thus causes a mechanical stress in the piezoresistive resistors. Depending on the position, the resistance value then increases or decreases. The pressure sensitivity of the sensor chip is defined by the thickness of the remaining membrane.

Afterwards, the back of the silicon is bonded to a glass (see Figure 3). For absolute pressure sensors, this step creates a closed reference space in a vacuum. When measuring relative pressure, the rear glass contains a reference hole.

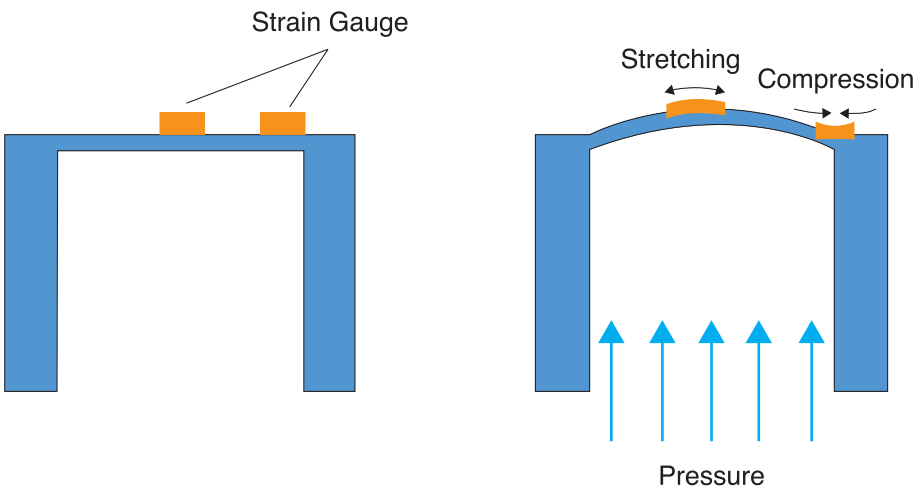

Figure 1: Positioning of strain gauges on a pressure-sensitive membrane.

In piezoresistive pressure measuring cells, unlike in strain gauges, the measuring resistors are therefore integrated into the membrane. This technology thus eliminates the need for gluing and thus the weak point, namely the adhesive, which is an important prerequisite for stability over time and temperature as well as freedom from hysteresis (hysteresis = after-effects of the previous deformation state). In addition, the piezoresistive effect leads to a change in resistance up to 50 times larger than what can be achieved with metallic strain gauges.

In order to isolate the sensor chips from the medium, they are mounted in a pressure-tight metal housing which is filled with oil and sealed at the front with a thin membrane (see Figure 4). The pressure then acts on the sensor chip via this membrane and the oil as a transmission medium. This isolated measuring cell also allows pressure measurement in aggressive liquids and gases.

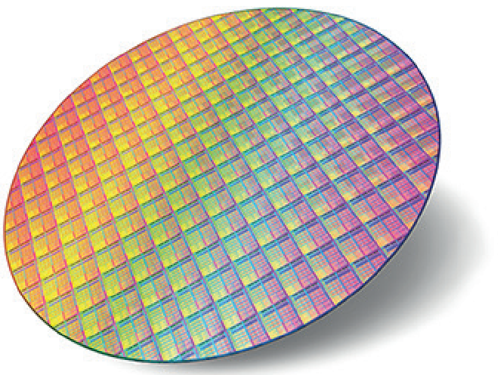

Figure 2: Silicon wafer on which various metal structures are applied.

Why use piezoresistive technology in pressure measurement?

Due to the large output signal and the established manufacturing processes, piezoresistive technology has become established in pressure measurement. Another major plus point is that there is no need to glue the strain gauge, which is critical for stability.

The crystalline silicon of the sensor chip deforms in a purely elastic way during operation, preventing any fatigue or stability problems, even after many pressure cycles. The sensor chips can be produced in established semiconductor technology processes, and integrating the relevant membrane for pressure measurement into the sensor chip allows for the manufacture of extremely compact and long-term stable pressure measuring cells. As piezoresistive pressure transducers are built without moving parts, they are very resilient against shocks and accelerations. The much larger change in resistance in piezoresistive measuring cells compared to conventional metal strain gauges leads to a large output signal and thus allows for a low-noise electronic conversion with high resolution. In combination with analogue or digital com-

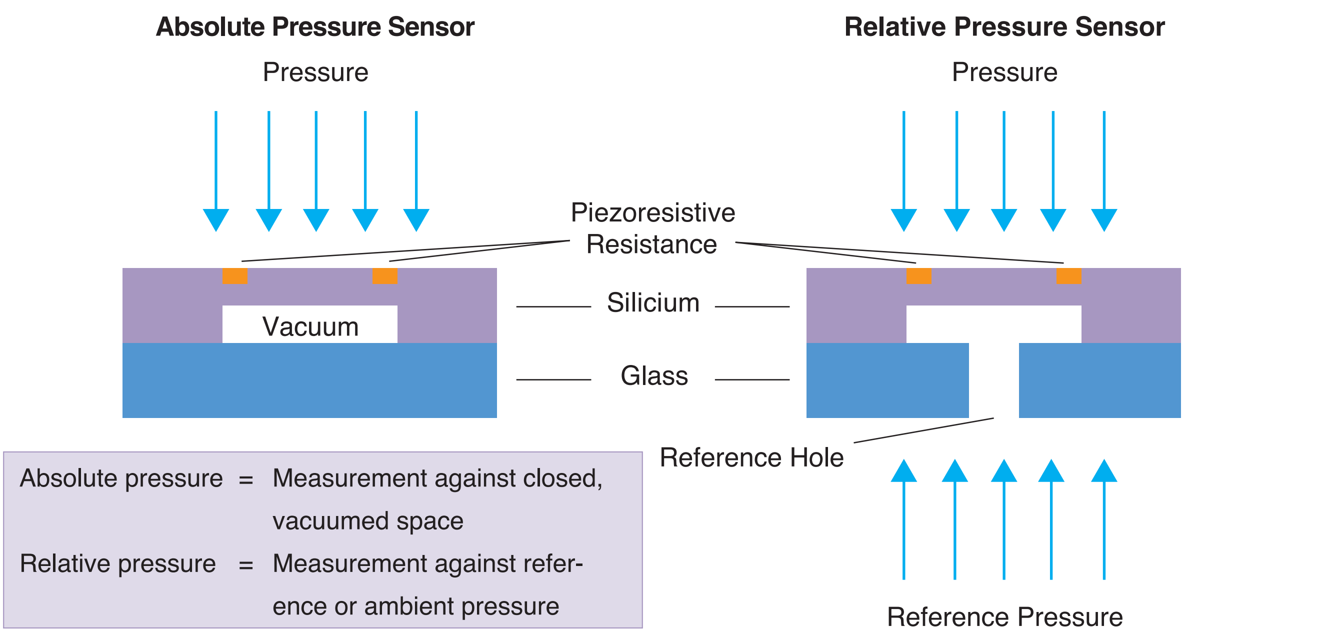

Figure 3: Structure of a piezoresistive sensor chip.

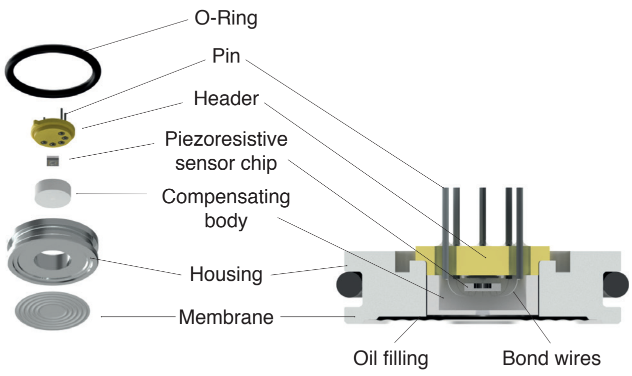

Figure 4: Construction of an insulated, oil-filled piezoresistive pressure sensor.

pensation solutions, an extremely precise, temperature-independent pressure signal is thus available.

The isolated piezoresistive pressure measuring cell distinguishes itself by its versatility: it is compatible with various media and covers wide pressure ranges. The specific construction of the housing achieves great flexibility for many industrial applications, even in critical environments. What makes KELLER AG für Druckmesstechnik stand out is the essential knowledge of designing and manufacturing isolated measuring cells. Thanks to 45 years of experience in piezoresistive pressure measurement, the company can also implement special applications. Insulated piezoresistive pressure cells from KELLER AG für Druckmesstechnik are used in demanding industrial applications and in research.

Figure 5: Insulated, piezoresistive pressure sensor for universal applications.

Advantages and disadvantages of piezoresistive technology

+ Established processes in the production of piezoresistive sensor chips, long experience with piezoresistive technology
+ Coverage of wide pressure ranges
+ Very good long-term stability
+ No signs of fatigue, even after many pressure cycles
+ High overload resistance
+ No hysteresis of the silicon sensor chip
+ Compact pressure measuring cells
+ Good shock and vibration resistance
+ Suitable for measuring relative and absolute pressures
+ Isolated measuring cell for wide range of media compatibility
+ Can be used in a variety of industrial applications
+ Large output signal allows for simple read-out electronics with high resolution

• Temperature compensation required
• Design and manufacturing of isolated measuring cells requires comprehensive expertise

– Measurement of very small pressures limited (< 0,01 mbar)
– Additional measures required at very high media temperatures (> 200 °C)