

High-Temperature Pressure Transducers

A new line of environmentally rugged, high-temperature pressure transducers combines oxide-isolated piezoresistive sensing elements with oxide-isolated CMOS electronics.

Pressure sensing systems operating at temperatures $>200\text{ }^{\circ}\text{C}$ are required for a variety of present- and next-generation applications ranging from oil field instrumentation to turbine engine control. Quite often, part or all of the sensing system must be physically removed from the high-temperature environment. In some cases, pressure translating devices and capillary tubes are used to isolate the sensing mechanism. Alternatively, the pressure sensor can sometimes be placed in the high temperature environment and its supporting electronics in an adjacent, low temperature location. Unfortunately, these techniques can contribute significant noncompensable errors, e.g., pressure and thermal hysteresis and instability, to the sensing

Although high-temperature sensor operation has been achieved with devices such as strain gauges, resonant quartz, and oxide-isolated silicon, a complete solution that places both sensor and signal-handling electronics (i.e., a transducer) in the high-temperature environment has yet to emerge. The transducer that can do this will enhance system control, efficiency, and performance. The development of silicon-on-insulator (SOI) technology has made it possible to build high-performance pressure sensing systems that will operate up to $300\text{ }^{\circ}\text{C}$.

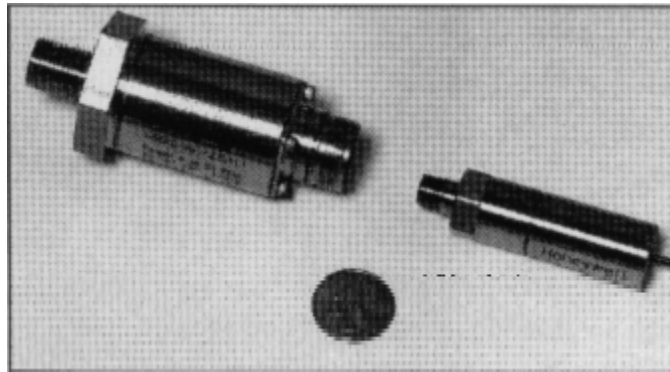


Photo 1. Initial offerings in the high-temperature pressure transducer series include an early unamplified version (left) and a miniaturized, amplified version (right).

A new line of high temperature pressure transducers combines oxide-isolated piezoresistive sensing elements and HTMOS electronics with high-temperature packaging. Initial product offerings (see Photo 1) provide robust performance over a span of $-55\text{ }^{\circ}\text{C}$ to $225\text{ }^{\circ}\text{C}$,

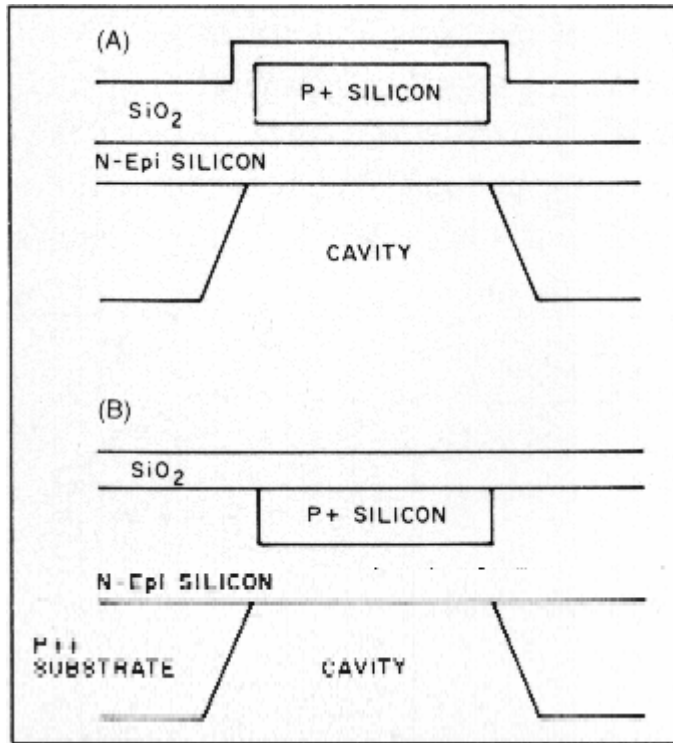


Figure 1. The SOI pressure sensor eliminates the p-n junction of a conventional ion-implanted sensor. This junctionless sensor allows high-temperature operation, improved media compatibility, and improved noise and long-term stability characteristics, and is intrinsically radiation hardened.

with operating lifetimes targeted for five years at 225 °C. Follow-on products are expected to push the temperature envelope to 300 °C and operating lifetimes to 10 years. Anticipated performance improvements include the following:

- Enhanced implementation of distributed control systems
- Dramatic improvement in response time
- Elimination of high-pressure translating devices and capillary tubes
- Overall improvement in system control, efficiency, and performance

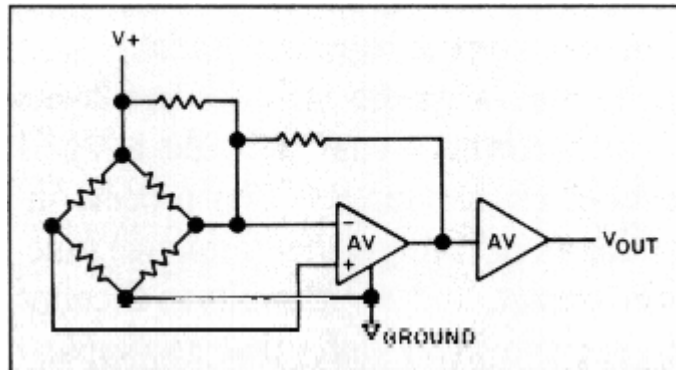


Figure 2. One mid-accuracy transducer design includes on-chip bias, and integrated feedback resistors and operational amplifiers. This configuration provides accuracies better than 0.5% of F.S. over 100 °C spans, including all error sources.

SENSOR AND ELECTRONICS

The pressure sensors are fabricated by means of Honeywell's ion-implantation process. Eliminating the p-n junction in the silicon semiconductor diaphragm by means of an oxide isolation barrier (see Figure 1) allows high-temperature operation. Transducers currently under development include absolute, differential, and gauge configurations in pressure ranges from 0-3 psi up to 20,000 psi, featuring a unique sensing diaphragm in the silicon chip for each range. Different diaphragm thicknesses are achieved by varying the thickness of the epitaxial layer on the substrate material. Pressure ranges > 1000 psi will incorporate a barrier diaphragm to provide robust fail safe operation in virtually any type of hostile environment.

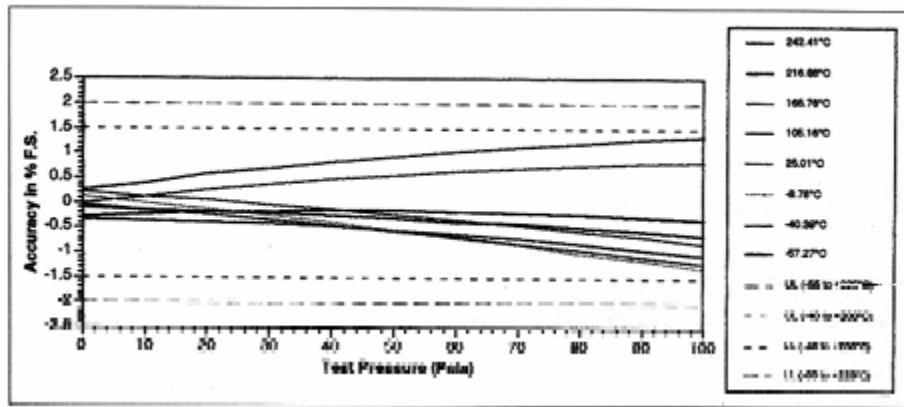


Figure 3. Test results are shown for a 100 psi pressure transducer cycled through F.S. pressure at eight temperatures from -57 °C to 242 °C. Accuracy is shown as a percentage of F.S. output.

Devices without the barrier can be subjected to gases and non corrosive liquids.

The electronic components for the sensors are fabricated by means of Honeywell's HTMOS high-temperature oxide-isolated process, a fully isolated 1.25 micron SOI CMOS technology using SIMOX (separation by implantation of oxygen) substrate material.

The metals system includes two layers of interconnect that provide a VLSI level of circuit density. The process includes modifications that minimize junction leakage, and adjustments to account for the threshold shifts that accompany high-temperature operation.

Additional enhancements such as laser-trimmable resistors and implanted capacitors have been included to allow the design of precision analog devices.

Mid-Accuracy Analog Pressure Transducers

The electronics required for mid-accuracy high-temperature pressure transducers include operational amplifiers and precision resistors. The Honeywell mid-accuracy transducer design includes on chip bias, and integrated feedback resistors and operational amplifiers. This configuration (see Figure 2) provides a temperature-compensated amplified output scaled to application requirements.

With the mechanization shown in Figure 2, transducers can be constructed to perform with $\pm 1.5\%$ F.S. accuracy including all error sources over $-40\text{ }^{\circ}\text{C}$ to $200\text{ }^{\circ}\text{C}$, or $\pm 2.0\%$ F.S. accuracy over $-55\text{ }^{\circ}\text{C}$ to $225\text{ }^{\circ}\text{C}$. F.S. accuracies of better than 0.5% may be achieved for $100\text{ }^{\circ}\text{C}$ spans within the overall temperature band. Figure 3 shows test results of a 100 psi transducer.

Precision Pressure Transducers

The electronics required for precision transducers include some form of A/D conversion; resistors; capacitors; rudimentary logic; 8-bit (or better) microprocessor; stable reference; clock source; $\sim 8\text{K}$ of memory; and either a D/A interface or digital bus support chip such as RS 232. A wide variety of configurations are possible, but these basic functions must be satisfied. Figure 4 shows one architecture for a high-temperature precision transducer.

The electronic components necessary for high temperature precision transducers are currently under development. The device cannot be constructed until all the key components are qualified for high-temperature operation. For example, the A/D, microprocessor, and the D/A interface are not fully usable without a stable high-temperature clock. The system is not fully functional until sufficient memory is available to store the unique polynomial coefficients that describe the performance of the sensor over temperature and pressure. High-temperature precision transducer performance has been modeled based on expected component limitations (see Table 1).

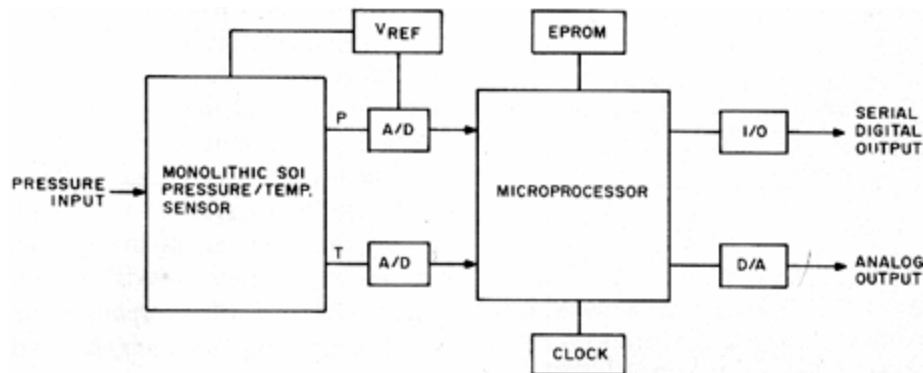


Figure 4. Some of the primary functions shown here for constructing a high-temperature precision pressure have already been developed; others are under way.

Package Development

High-temperature sensing elements and signal handling electronics are of little use without a package capable of cycling through temperature extremes. Critical elements include mechanisms to translate the signal from silicon to out put format, and overall mechanical survivability over the entire operating temperature envelope. In general, the pack ages feature glass-to-metal seals, high temperature solder seals, and laser weld in a vacuum. Barrier diaphragms are used for pressure ranges > 1000 psi, or where highly corrosive media are expected.

The products currently available (see Photo 2) are designed to withstand 1000 temperature cycles from $-55\text{ }^{\circ}\text{C}$ to $225\text{ }^{\circ}\text{C}$ with five-year lifetimes under full environmental vibration and shock requirements.

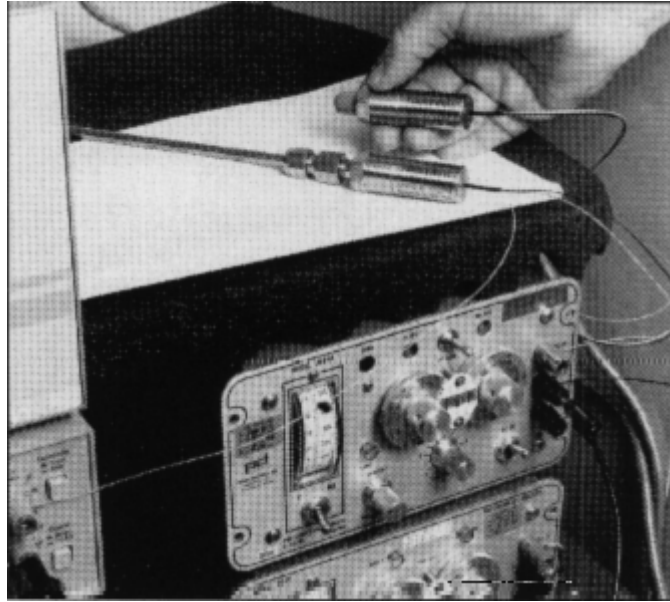


Photo 2. *This miniaturized, amplified high-temperature pressure transducer was developed primarily for oil well logging and aerospace applications.*

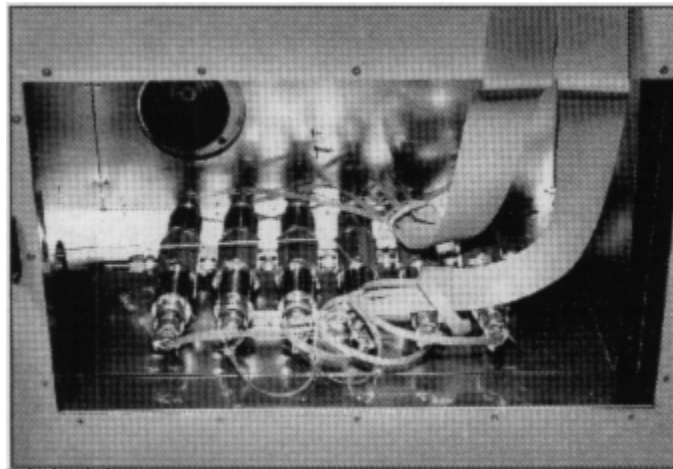


Photo 3. *The high-temperature pressure transducers were tested for long-term stability.*

Reliability

The sensors and electronics have proven their performance and reliability in the most demanding military and commercial applications. Honeywell transducers using bulk silicon devices currently provide 0.01% of F.S. accuracy over -55 °;to 125 °C, with a service life of 20-25 years. One industrial sensor product line has a demonstrated MTBF of > 400 years (3.5 million hours).

Oxide-isolated processing of the sensors and electronics, and robust packaging, yield environmentally rugged high- temperature transducers. Initial lifetime studies of electronic components have shown more than 5000 hours of operation at 250 °C. Over 1000 temperature cycles of the sensor assembly from -55 °C to 200 °C have demonstrated the integrity of critical packaging components. Null stability better than 0.4% of F.S. over more than 1000 hours of testing at 225 °C is shown in Figure 5. The test setup is shown in Photo 3. Reliability and life

demonstration tests to verify 225 °C operation continue. Targeted life- times are five years over -55 °C to 225 °C.

Summary

A family of environmentally rugged, high-temperature pressure transducers combines oxide-isolated piezoresistive sensing elements with oxide-isolated CMOS electronics. The initial products have an operating range of -55 °C to 225 °C, with targeted operating lifetimes of five years at 225 °C. Follow on products are expected to push the temperature envelope to 300 °C and operating lifetimes to 10 years.

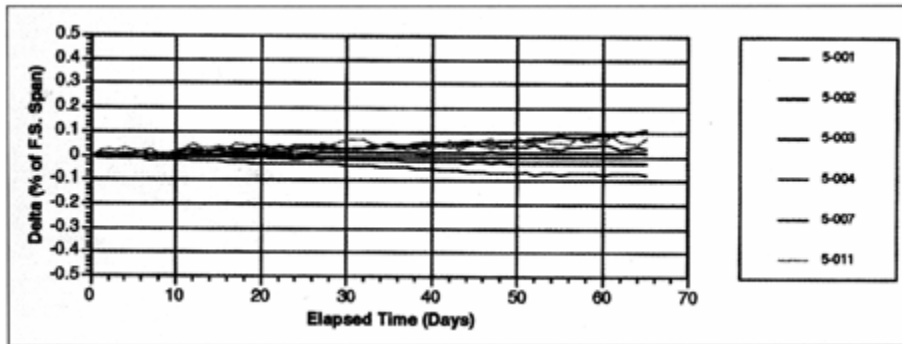


Figure 5. This graph shows more than 1500 hours of null stability test results of six mid-accuracy pressure transducers after a 1 000-hr preconditioning burn-in. Drift is typically within 0.1% of F.S. span.

Acknowledgments

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For Further Reading

Brusius, P. et al. 1994. "Reliable High Temperature SOI Process," *Transactions*, Second International High Temperature Electronics Conf, Vol I, II:15 19.

Bryzek, J. Oct 1993. "The Evolution of Smart Sensor and Transducer Design," *Sensors*: 12-22.

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Table 1: High-Temperature Transducer Performance				
Temp. °C	Limiting Characteristic	Performance		
		Sensor Only	Mid-Accuracy Analog Transducer	Precision Digital Transducer
-55 to 125	Repeatability Stability (year)	0.01%	1%	0.02%
		0.01%	0.05%	0.015%
-55 to 225	Repeatability Stability (year)	0.02%	1-2%	0.04%
		0.05%	0.1%	0.08%
-55 to 300	Repeatability Stability (year)	0.04%	2-4%	0.08%
		0.15%	0.3%	0.25%

Pressure transducer performance as percentage of F.S. operation over the entire temperature band. Performance-limiting characteristics include repeatability as a function of thermal and mechanical hysteresis, and instability as a function of long-term drift.

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