BASIC ADVANTAGES OF THE ANISOTROPIC ETCHED, TRANSVERSE GAGE PRESSURE TRANSDUCER

By Robert M. Whittier
Manager, Development Engineering

INTRODUCTION
Endevco’s innovative design approach provides miniature pressure transducers that are not only small and have high frequency response, but have excellent lineairties, high sensitivities, and stability characteristics superior to many other pressure transducers. Nonlinearities of 0.1% FS (Best Straight Line) are not unusual, along with 300 mV output at full scale with 10 V input. Ranges to as low as 2 psi (~14 kPa) are feasible in a case diameter of 0.092 inch (2.34 mm).

Are these transducers subminiature flat-diaphragm diffused silicon designs? In one word, no! They use four piezoresistive silicon elements in a Wheatstone bridge, but their similairties to earlier designs end there. The patented design implementation is novel and provides basic advantages to earlier designs.

Traditionally, miniature silicon pressure transducers have been made similar to most large flat diaphragm strain gage transducers. When pressure is applied to a flat diaphragm, bending stress is distributed over its surface, changing from compression in one area to tension in another. Strain gages can be positioned on a diaphragm to provide increasing and decreasing resistance. For more than two generations four-arm Wheatstone bridge transducers have been made this way, by simply cementing gages to one side of a metallic flat diaphragm.

Figure 1 — Photograph of diaphragm taken with scanning electron microscope 0.05 in. (1.25 mm) O.D.

Now for almost a generation transducers have been made with piezoresistive gages diffused into flat circular diaphragms of silicon, thus providing atomically bonded elements. By using silicon semiconductor technology, miniaturization was achieved. The process has not, however, provided other technical advantages. It simply reduces the diameter of the circular diaphragms and permits extremely thin diaphragms.

A pressure transducer design can be made dramatically more efficient if the stresses can be concentrated at the locations where the strain gages are placed. Stress should not be spread over a large area such as on a flat circular diaphragm. In general, if a structure is under bending stress, stress concentration can be achieved by varying the thickness of the bending element. This is one of the basic conceptual differences which provides the superior performance of all Endevco transducers.

THE SCULPTURED DIAPHRAGM
Endevco diaphragms are shaped to concentrate stress using a combination of plate and beam theory. This can be visualized by referring to Figure 1 which shows a circular diaphragm having two thicknesses. It is considerably thicker at the outer edge and has two islands in the middle section. Notice how close the islands come to each other and to the edge.

Figure 2 shows a photonicograph of a diagram sectioned to show this. One can
to the flat diaphragm. The gage elements for our design are diffused into the diaphragm over the entire grooves at points A, B and C.

Formed by Anisotropic Etching
Our diaphragms are fabricated from single-crystal silicon. This material is anisotropic, meaning that its physical properties vary according to the direction in which they are measured. Another characteristic of anisotropic materials is that their chemical reaction rates vary according to crystalline directions. When placing a crystal of silicon in a chemical bath, such as hot hydrazine, the material is etched faster in certain directions than others. Simply put, the material seems to have a mind of its own, and it forms well-defined patterns and contours. By controlling bath parameters, the ratio of etching rates is equal to 30 to 1. This results in precise control of shape. As can be seen by Figures 1 and 2, the technique provides deep notches and flat bottoms to the thinned sections. To obtain optimum transducer performance, the crystal must be correctly oriented. Then, using a multiplex step lithographic, etching, and diffusing process, the part is fabricated. This technology is basic to the semiconductor industry. It should be mentioned that varieties of etch patterns and contours can be achieved which permit the concept to be used over a wide range of pressures and sizes.

Transverse Gage Approach
The sculpturing of the diaphragm explains a significant part of the benefits of the Endevco design, but it is still not all. Optimizing the piezoresistive characteristics is also important. The piezoresistive coefficients of silicon semiconductor materials vary with the direction of stress in the crystal and with the dopant material and its amount. Most prior art devices have been designed to stress the gage material so that the gage increases its length. If such a gage were placed in the stress concentration groove of the sculptured diaphragm, it would be stretched back and forth from one end to another — a miniaturization of the larger wire and foil gage approaches. As the groove bends, the effective gage length would change. Another approach is to use a transverse gage; that is, one that is laid lengthwise in the groove. As the groove bends, this gage is strained so that it effectively changes width.

P-Type (110) Silicon Gage Material
A fundamental benefit from using the stress concentrated transverse gage is that pressure transducer amplitude linearity can be excellent. The change of resistance with stress for a single parallel P (110) gage is a more linear function than that for a transverse gage. When used in a bridge configuration, however, with one element in tension and the other in compression, the transverse gage approach can be better. A parallel gage has decreasing sensitivity with increasing stress in both tension and compression. The bridge nonlinearity is the average nonlinearity of both. The transverse gage has decreasing sensitivity in tension and increasing sensitivity in compression, so that the average nonlinear is close to zero.

The requirement for equal and opposite strain fields is a restraint on transducer design. This is the reason for the relatively wide central groove shown in Figure 1. On the other hand, the designer can counteract other nonlinearities in a design by shifting the strain balance between the increasing and decreasing gages. In production practice, the balance of strain levels can be maintained closely enough to provide nonlinearities to full scale of about 0.1% to 0.4% BSL, depending on product and range. The combination of using stress concentration and transverse gages provides about three times better linearity to full scale than the alternative flat-diaphragm approaches. This advantage can be even greater for pressures above full scale. Many of the Endevco pressure transducers provide 1 volt of output with less than 1% nonlinearity.

Sensitivity and Stability Advantages
The output from these transducers is about 300 mV at full scale when 10 Vdc is applied. This higher than normal value is a result of two factors:

1. The transverse gage approach, which is more linear than the parallel gage approach, permits higher outputs for equivalent nonlinearities.

2. Concentration of the stresses over the entire area of the 4 strain gages, and only over that area, increases efficiency.

From a practical standpoint each of these transducers can be used over a very wide span of pressures. They can even be used for measurements below the specified full range. The Endevco specifications show a value for typical nonlinear for pressures to 3 times full scale, and all transducers are tested to 3 times full scale. In many ways, this suggests that full scale has been chosen conservatively. It is a pressure level where the transducer still has an unusually high overrange capability. Because silicon is an excellent spring material the transducers have low hysteresis, usually below 0.05%. At temperatures below 600°C, the silicon stress-strain curve has no plastic zone and the material has essentially no creep. Even at pressures above full scale, and sometimes to diaphragm fracture, the transducers perform with little error. Single crystal silicon is a strong material whose strength depends significantly on the quality of the material. The tech-
Examples of Endevco's Line of Pressure Transducers