# SOLID STATE SENSOR RESEARCH AT HONEYWELL: ACTIVE THIN FILMS PLUS MICROSTRUCTURES

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The development of Si-based solid state sensors has proceeded over the last decade and a half at Honeywell. Many such sensors, based on several technologies, are in production at Micro Switch and the Solid State Electronics Divisions. The first of these sensors utilized physical phenomena in the silicon itself to sense the desired quantities: The Hall effect for sensing magnetic fields, optical carrier generation for light sensing, and the piezoresistance effect for strain sensing. A vast number of Hall chips have been produced for keyboards, automobile distributors, and other high-volume applications. Auto-focus chips using arrays of photodiodes and sophisticated signal processing are used in many types of cameras. A large family of silicon piezoresistive pressure sensors is produced. These types of sensors are easily and inherently "integrated," since they are actual silicon devices.

Since the range of phenomena useful for sensing in silicon is limited, more recent developments have utilized thin films added to the silicon, active films in which useful interactions take place. Examples include thin film metals with high TCR for resistive temperature sensors, and thin films of magnetic alloys for sensing magnetic fields through the magnetoresistance effect. These devices utilize silicon only as a convenient substrate with well-developed processing technology. Integration with active IC electronics is generally possible, but requires development of compatible processes. The decision to integrate or not is usually based on business and economic arguments. Such devices are described in a talk elsewhere in this conference.

The most advanced solid state sensor research at Honeywell involves combinations of active thin films with silicon microstructure technology. The thin films utilized include zinc oxide (ZnO) piezoelectric films, useful for strain sensing or for generating acoustic waves. Microstructure technology includes use of simple silicon diaphragm structures etched from the back side of the wafer, and more complex structures formed by etching from the front side. Devices being studied include acoustic and seismic sensors, and an air flow sensor. These devices will now be described in more detail.

The acoustic and seismic sensors are similar devices using a piezoelectric film of ZnO as a strain sensor on the top of an etched silicon diaphragm. A unique annular electrode design is used to cancel signals due to the pyroelectric effect in ZnO; it also allows all connections to be made in the ZnO/Si interface plane, avoiding step coverage problems, and increases the sensitivity by a factor of two over a simple circular electrode design. Typical devices use diaphragms 3mm in diameter and 30 microns thick, with ZnO films of 1 to 3 microns. When packaged so as to expose one side of the diaphragm to an acoustic signal, sensitivities of 25 microvolts per microbar were obtained, with a signal to noise ratio of 5:1 at 2 microbars. The response was flat to within 3 to 5 dB over the measured frequency range from 10 Hz to 10 kHz, and a low frequency cutoff of 0.1 Hz was obtained. The excellent low frequency response is a unique feature of this sensor. Some of these devices have been integrated with simple MOS electronics. Integration is particularly desirable for this sensor, since high sensitivity requires direct, low-capacitance connection of the ZnO structure to a high input impedance amplifier.

The same basic device can be used as a seismic or vibration sensor by attaching a proof mass to the diaphragm. Under acceleration along the axis perpendicular to the chip plane, the proof mass deflects the diaphragm. This strain creates a piezoelectric charge in the ZnO which is detected by a high-impedance amplifier. The mass can be as simple as a lead ball glued onto the diaphragm, or can be a more complex etched structure. Analysis predicts sensitivities of about 25 millivolts per G for proof mass of 30 mg. Several of these seismic sensors have been fabricated and are currently being tested.

A sensitive, miniature gas flow sensor has been demonstrated, using a combination of thin film resistive elements and an etched microstructure. Its operation is much like a miniature hot wire anemometer: A central thin film resistive heater element is flanked by a pair of resistive thin film temperature sensors. The heater and temperature sensors are part of a microstructure formed by etching, and are thereby thermally isolated from the silicon chip. The difference in temperature between the two sensors is measured. In the absence of flow their temperatures are the same. With flow along the structure, the upstream sensor is cooled and the downstream one heated, resulting in an output signal. The sensor has high sensitivity to flow and low power requirements because of its small size and the thermal isolation provided by the microstructure. Air flow response from a few feet per minute up to thousands of feet per minute has been obtained. Differential pressure response well below 1 inch of water column (249 Pa) is obtained in air. The response is bidirectional, indicating flow direction as well as velocity.

The total response is dependent on the sensor chip characteristics, control of the air flow, and the electronic mode of operation of the device. Performance such as this in a low cost, low power Si chip device capable of measuring low gas flows and even differential pressures leads to many exciting application possibilities which cannot be addressed by existing sensors.

The new sensors described here are only the beginning of what can be developed with the combination of thin films and silicon microstructures. Complete integration with electronics may be more difficult because of the cascading of process sequences for fabricating electronics, active thin films, and microstructures. The payoff is in the creation of sensors which have unique capabilities unavailable in conventional devices.