

**PERSPECTIVES ON MICROSENSOR SYSTEMS:  
PAST, PRESENT, AND FUTURE**

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**HISTORY**

The word Microsensor is typically used to mean a sensing device that is fabricated using microelectronic technology, either based on silicon integrated circuit technology, thin-film electroforming technology, or thick-film hybrid-circuit technology. The field of Microsensors has a fifty-year history starting with several key developments in the 1950's:

- > The invention of integrated circuits.
- > The discovery of piezoresistance in silicon.
- > The discovery of selective etching of single-crystal silicon.
- > The development of thin-film read heads for magnetic recording.

Pioneers in the 1960's and 1970's developed silicon diaphragm pressure sensors with piezoresistive readout, ceramic gas sensors, ion-sensitive field-effect transistors, Hall-effect magnetic sensors, and various specialty devices. But it was only in the early 1980's that the field of Solid-State Sensors and Actuators became identified as a clear discipline, with its own special technologies and capabilities, expanded now to include not only etching into silicon wafers to make interesting shapes but also the use of what is now called surface micromachining: deposition, patterning, and selective etching to remove sacrificial materials, creating complex structures attached to a substrate wafer [1].

In November 1981, the Materials Research Society meeting in Boston included a seminar on Solid-State Sensors [2]. It drew about 80 people from Japan, Europe, and the US. Along with the pressure sensors, Hall-effect sensors, and gas sensors, there were some interesting specialty sensors: a dielectric sensor for monitoring the cure of resins, and an ISFET fabricated on the tip of a needle. This meeting was a turning point in the development of Solid-State Sensors, because at that meeting, the decision was made to set up the International Steering Committee on Solid-State Sensors and Actuators, the governing body for the highly successful series of biennial international conferences, starting with Transducers 83 in Delft, and rotating between Europe, the US, and Asia on a six-year cycle. This meeting now attracts roughly 1000 persons from all over the world.

By 1987, the Defense Advanced Research Projects Agency (DARPA) of the US Department of Defense became committed to this emerging field, hosting a meeting in Hyannis, MA, which convened not only groups working on sensors but also those interested in motors, actuators, and robots [3]. It was at this meeting that a consensus began to develop around the term "MEMS," an acronym for MicroElectroMechanical Systems. Since then, the terms MEMS or Microsystems have come to mean any device or system that has at least one sub-millimeter dimension that does something interesting besides pure electronics, and includes what was formerly called Solid-State Sensors. The term, MEMS, being the shortest name, will be used in the remainder of this paper.

During the last twenty years, emphasis in this field has gradually shifted from basic research on materials and process technologies toward product development. Each year new products

appear, and with these, an expansion of potential future opportunities. It is useful, though, to consider an important distinction between two product types: MEMS commodity products, and MEMS-enabled products. This is explained below.

### **COMMODITY PRODUCTS**

A MEMS commodity product is a product with a market size measured in millions of units per year. Emphasis is on low cost. Examples include pressure sensors, accelerometers, rate gyroscopes, RF switches, and cell-phone microphones. These devices are incorporated into systems by the MEMS customer: the automobile manufacturer or the cell-phone manufacturer. Compatibility with the customer's system is critical: sensitivity, noise level, dynamic range, operable temperature range, resistance to shock and vibration, packaging form factor, and compatibility with system assembly procedures, such as surface-mount thermal cycles. Market acceptance is based on a combination of performance specifications, cost, and demonstrated reliability.

As an example, consider the Knowles silicon SiSonic™ cell-phone microphone (Figure 1) [4]. This is a product that seeks to displace the electret capacitive microphone (ECM). The addressable market volume is on the order of 1 billion units per year. The price is set by the ECM market, and constrains the silicon microphone to a cost point well below \$1 per unit. However, the silicon version is better able to handle the temperature challenges of surface-mount technology, providing a potential cost advantage to the cell-phone manufacturer.

### **MEMS-ENABLED PRODUCTS**

A MEMS-enabled product is a product with a market size measured in thousands of units per year. Emphasis for the MEMS part of the product is to create a uniquely valuable functionality. The example to be discussed here is the Polychromix PHAZIR™ portable materials analyzer (Figure 2) [5]. This analyzer is a hand-held battery-operated near-infrared spectrometer, with an embedded microcomputer and display which support not only the operation of the device as a spectrometer but also the real-time analysis of the spectrum to achieve material identification. The spectrometer uses a unique MEMS chip: an electrically programmable diffraction grating (the polychromator: Figure 3) [6]. The polychromator enables a compact, rugged, fast, and robust spectrometer architecture which, because of the Hadamard-based modulation scheme used to capture the spectrum, is insensitive to stray light, is drift-free, and has a wide dynamic range.

Because product volumes are far smaller than for MEMS commodity products, the cost pressure on the MEMS part is less than for a commodity. In fact, because of the low product volume, manufacture of the MEMS part must be treated as a fixed cost rather than a variable cost: it is necessary to manufacture enough MEMS to keep the process qualified, even if this means building more MEMS than are needed to support actual product sales.

The driving force behind this product is the customer's need to identify materials. An example is in carpet recycling. With the high price of oil, the carpet fiber now has recycling value. However, each recycling process works with a specific fiber, and would be contaminated if another fiber is present. Nylon 6 and Nylon 6-6 are chemically similar, but must be correctly identified for recycling purposes, Nylon 6 going to one recycling vendor, Nylon 6-6 to another. For this market, the PHAZIR is programmed with a chemometric analysis program that not only identifies major fiber groups (wool, nylon, polyester, cotton), but can distinguish accurately between Nylon 6 and Nylon 6-6. No costly trips to a

laboratory are required. The carpet can be identified within seconds directly in the warehouse.

Another example is incoming materials inspection in the pharmaceutical industry. At present, a 55-gallon drum of material must be quarantined while the package is opened, the polyethylene liner is opened, and a sample removed for laboratory analysis so that the accuracy of the labeling can be confirmed. The PHAZIR<sup>TM</sup> permits the measurement to be made through the polyethylene liner within seconds, greatly reducing the time to inspect incoming materials and doing so without having to open the liner, thereby maintaining maximum shelf life for the material.

These examples illustrate the difference between MEMS-enabled products which, at the system level, perform a function of value to the customer, and MEMS commodity products, that are sold in large volumes as components in systems created by the customer.

## **THE FUTURE**

Microsensors have a bright future, both in the commodity arena and in the MEMS-enabled arena. The physical sensors, pressure, acceleration, rotation, and acoustic (microphones) continue to find new commodity-level markets, including highly popular video games. The fact that these commodities exist in the marketplace also allows new system builders to create their own MEMS-enabled products that incorporate the commodities along with specialty components, such as the polychromator. Sensors, whether commodity sensors such as the cell-phone microphone, or system sensors, such as the PHAZIR<sup>TM</sup>, are becoming smarter, more capable, and are finding new markets every day.

## **REFERENCES**

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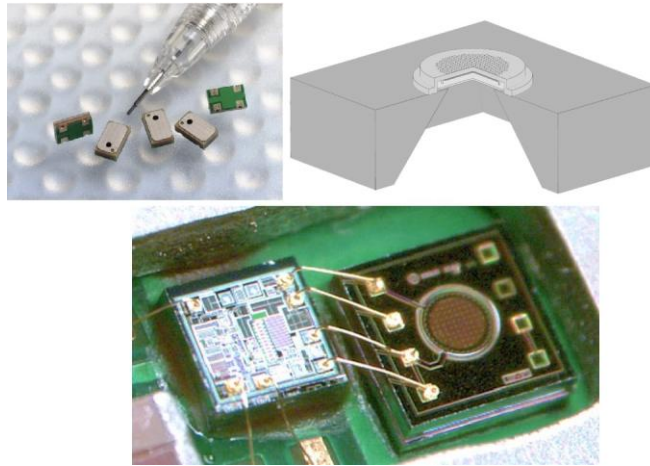


Figure 1. A MEMS commodity product. Knowles SiSonic™ silicon microphone: upper left – fully packaged; upper right – schematic of chip; below – packaging details.

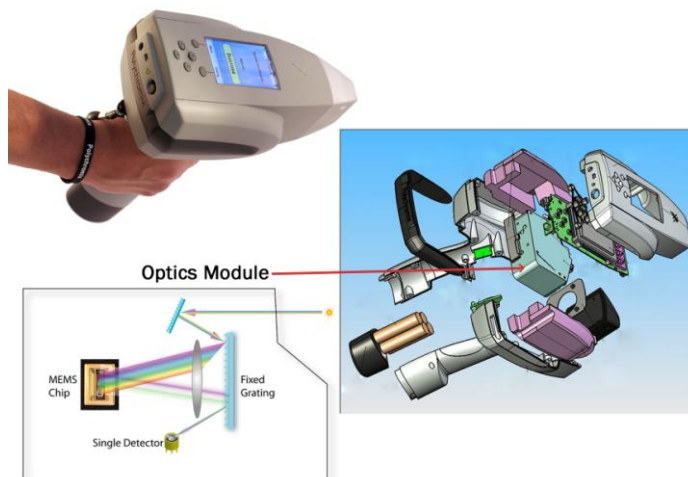


Figure 2. A MEMS-enabled product. Exploded view of Polychromix PHAZIR™ portable near-infrared spectrometer used for materials identification.

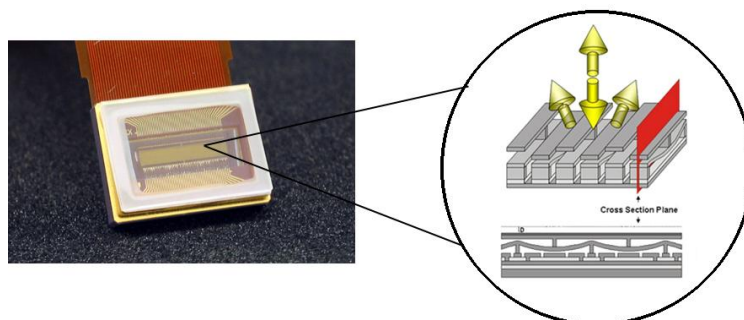


Figure 3. Packaged polychromator MEMS chip with schematic illustration of actuation to create diffraction.