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# Packaging MEMS, The Great Challenge of the 21st Century

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*MEMS, Micro Electro-Mechanical Systems, present one of the greatest advanced packaging challenges of the next decade. Historically hybrid technology, generally thick film, provided sensors and actuators while integrated circuit technologies provided the microelectronics for interpretation and control of the sensor input and actuator output. Brought together in MEMS these technical fields create new opportunities for miniaturization and performance. Integrated circuit processing technologies combined with hybrid design systems yield innovative sensors and actuators for a variety of applications from single crystal silicon wafers.*

*MEMS packages, far more simple in principle than today's electronic packages, provide only physical protection to the devices they house. However, they cannot interfere with the function of the devices and often must actually facilitate the performance of the device. For example, a pressure transducer may need to be open to atmospheric pressure on one side of the detector yet protected from contamination and blockage. Similarly, an optical device requires protection from contamination without optical attenuation or distortion being introduced.*

*Despite impediments such as package standardization and complexity, MEMS markets expect to double by 2003 to more than $9 billion, largely driven by micro-fluidic applications in the medical arena. Like the semiconductor industry before it, MEMS present many diverse demands on the advanced packaging engineering community. With focused effort, particularly on standards and packaging process efficiency, MEMS may offer the greatest opportunity for technical advancement as well as profitability in advanced packaging in the first decade of the 21st century! This paper explores MEMS packaging opportunities and reviews specific technical challenges to be met.*

## Introduction

MEMS, Micro Electro-Mechanical Systems, present one of the greatest advanced packaging challenges of the next decade. From beginnings in academic laboratories more than two decades ago, MEMS technology is no longer a novelty but rather an integral part of our daily lives. Accelerometers and micro-gyroscopes enhance automotive safety while combined pressure transducers and temperature sensors along with high precision fuel injection nozzles improve engine performance and efficiency. Even the common ink jet print head frequently owes its consistency and brilliance to MEMS fabrication techniques.

Recently MEMS mirror arrays developed at Texas Instruments found their way into very high performance color projectors. In the near future medical diagnostics along with controlled dispensing of medications will widely employ MEMS based mass flow sensors and implantable micro-pumps. And MEMS robots may soon remove plaque and dangerous blood clots without major invasive surgery.

There are three fundamental micro-machining techniques (bulk micro-machining, surface micro-machining and LIGA or lithografie galvanik abeforming) plus the wafer bonding technique, an extension of bulk micro-machining which allows more complex configurations than can be created using bulk micro-machining alone.

Simply stated, bulk micro-machining takes advantage of the anisotropic etching characteristics of single crystal silicon. Different shapes created by bulk micro-machining can be combined using wafer bonding to create more complex configurations. Bulk micro-machining can also be used to create proof mass accelerometers using piezo-resistors and a Wheatstone bridge configuration, but electronic amplification and control integration into the silicon wafer remains in development.

Surface micro-machining allows the creation of very complex three dimensional sensors and actuators by using poly-silicon glass (PSG) as a sacrificial, photoimageable cast form. The structural components of the sensor are created using doped, structural PSG. The primary limitation of surface micro-machining is that structures greater than a few microns in depth cannot be fabricated. Thus, for example, a proof mass type accelerometer with sufficient sensitivity is difficult to fabricate.

The LIGA process employs organic photo-lithographic materials for cast forms and thus overcomes some surface micro-machining limitations. However LIGA processes are not yet fully developed and precision problems remain. A major advantage of the surface and LIGA micro-machining technologies is the ability to integrate electronics into the base silicon substrate. For example, signal conditioning, simple analogue to digital conversion or even self test and/or self calibration circuits can be designed into the sensor structure. This can eliminate the need for a separate device or IC to serve these functions.

**Packaging Needs**

Like the traditional integrated circuit, packaging is critical to making MEMS devices usable in real life products. Today, MEMS packaging remains essentially full custom and specific to each particular application, driving cost up, frequently beyond market acceptance thresholds. No standards exist for packaging of MEMS due largely to the unique requirements of each individual application. CAD tools for MEMS package design (let alone MEMS design) remain in their infancy. And few applications bring sufficient volume demand to drive packaging cost down to acceptable levels.

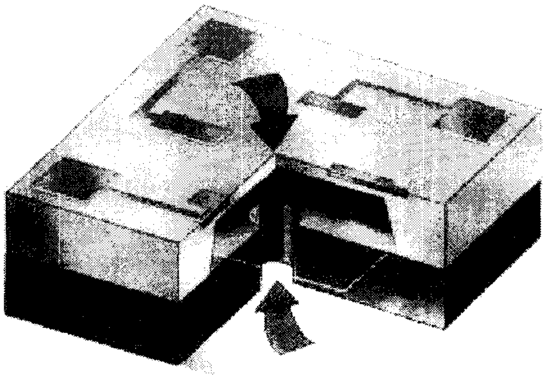

Figure 1. Schematic pressure transducer MEMS.[12]

MEMS packages, far more simple in principle than today's electronic packages, usually provide only physical protection to the devices they house. However, they cannot interfere with the function of the devices and often must actually facilitate device performance. For example, a pressure transducer may need to be open to atmospheric pressure on one side of the detector yet protected from contamination and blockage. Similarly, an optical device requires protection from contamination without optical attenuation or distortion being introduced. Chemical or biological sensors often employ special membranes to selectively pass the target gas or liquid to be measured or monitored and prevent contamination of sensor coatings which distorts sensor accuracy and/or sensitivity.

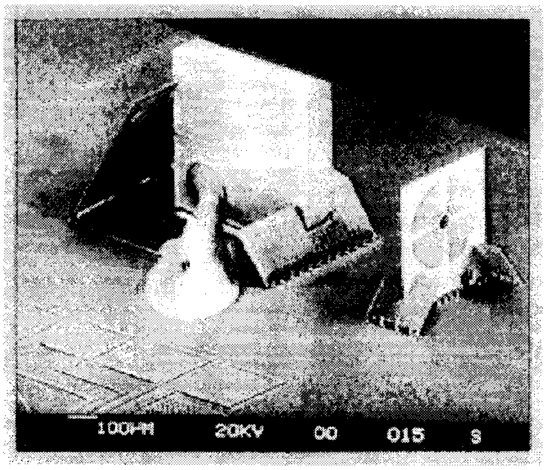

**Figure 2. Diode laser assembly with micro-Fresnel lense (Courtesy M.C. Wu[14]).**

Processing temperatures frequently raise additional issues with MEMS packaging. Mechanical sensor systems can be jammed, stuck or distorted by either uneven or rapid temperature fluctuations. Chemical or biological sensors may breakdown during even simple assembly process temperature fluctuations, especially those employing selective organic or chemically selective membrane filters.

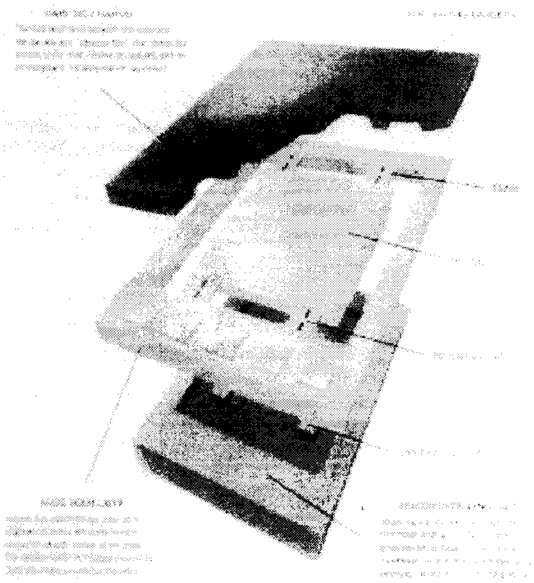

**Figure 3. Schematic accelerometer MEMS.[12]**

## Where do we go from here?

Like the semiconductor industry before it, MEMS present many diverse demands on the advanced packaging engineering community. Unfortunately this means that nearly all MEMS packages end up as full custom designs, justifiable only for very high volume applications. Other than a few automotive and display applications, almost no applications generate the volume necessary to result in low to moderate cost packaging.

One key to success for MEMS clearly lies in standardization of package designs, but this must be based on a thorough understanding of the various demands of MEMS packaging, particularly non-interference with MEMS functionality as mentioned earlier. This in turn requires development and exploitation of alternative technology approaches to packaging such as blow molding to incorporate cavities in molded packages which provide appropriate protection without mechanically impacting the MEMS devices being packaged. Other important technologies may come from such diverse areas as ceramic photodefinition, electro-forming, imprint patterning and super plastic metal molding.

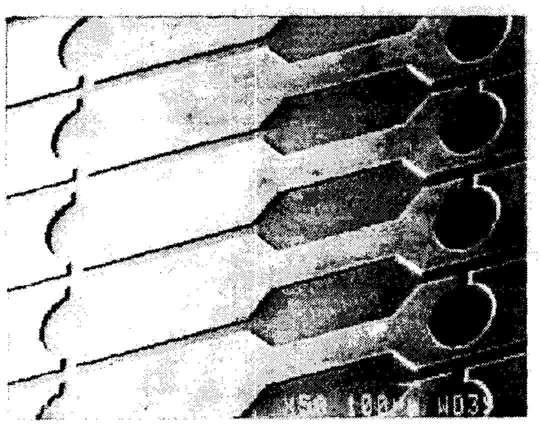

**Figure 4. Chemical separator/analyzer showing reagent reservoirs (circular) and testing chambers (hexagonal). (Courtesy Caliper Technologies.)**

Materials must accommodate these processes while simultaneously meeting the performance and functionality requirements of each application. For example, dimensional stability currently only available using crystalline polymers may be required for certain medical or chemical analysis products. Specialty glasses will be required to package optical devices such as laser control systems and color display tools.

## Conclusions

Despite the obstacles, MEMS markets likely will exceed US $10 billion within the next few years. In order to achieve, or even exceed these expectations, coordinated efforts in materials, process and design technology development for the packaging of MEMS is absolutely necessary. The most crucial objectives include:

1. Standardization to reduce costs
2. Development of processes compatible with MEMS characteristic requirements
3. Application specific materials which match both the product requirements and the process capabilities
4. Integrated design tools that enable cost effective combination of materials, processes and assembly techniques for low and moderate volume applications as well those few high volume applications.

The MEMS arena offers tremendous opportunity and those who leverage the experiences of the semiconductor industry to this new arena will lead the way to success. With focused effort, particularly on standards and packaging process efficiency, MEMS may offer one of the greatest opportunities for technical advancement and achievement as well as profitability in advanced packaging in the first decade of the 21st century!

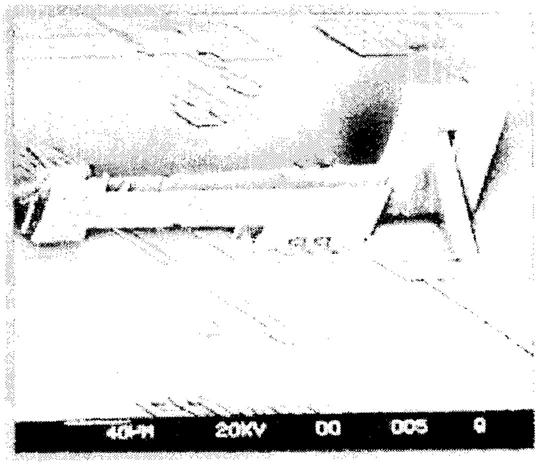

**Figure 5. MEMS heart cell contractile force measurement clamp (polysilicon).[12]**

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