

## Position Paper: MEMS Packaging and Reliability

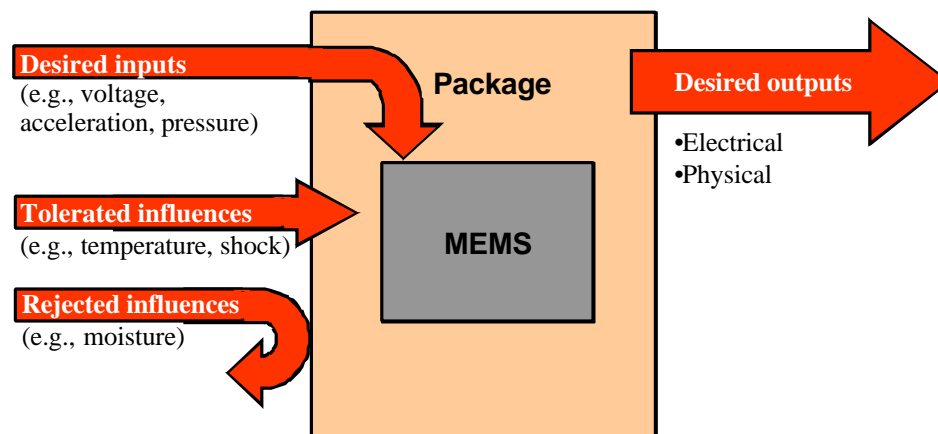
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In recent years an assortment of innovative MEMS devices have been demonstrated. Many of these devices exist solely in clean rooms or are one of a kind. In order for MEMS applications to successfully transition from proof-of-concept to commercial viability, key manufacturability, packaging and reliability requirements must be met. While critical material, design and process challenges certainly remain, the high-volume manufacturability for many types of MEMS is inherent in the MEMS concept. However, both packaging and reliability present new complications that require extensions of today's state of the art microelectronics packaging technologies and reliability prediction methodologies.

### MEMS Packaging

The packaging challenge associated with MEMS is summarized in the figure below<sup>1</sup>.



Like conventional integrated circuit (IC) packaging, there are external influences that should be rejected and external influences that must be tolerated. However, unlike conventional IC packaging, some external influences on MEMS become desired inputs. Also unlike conventional IC packaging, moving parts may be present requiring packaging that does not restrict their motion. Moving microsystem structures create difficulty in applying traditional plastic encapsulation techniques. In an effort to use plastic encapsulation, some researchers bond a protective cap over the moving structures and then dispense around the seams. The assembly is then ready for plastic encapsulation, but the plastic packaging issues don't end there. With the addition of non-traditional interfaces into and out of the package, several new interfaces are added that are potential moisture ingress paths (and potential sources of reliability problems). In addition, the selection of plastic encapsulation material is much more complicated than for IC packaging. The viscosity must be such that the materials will flow around some structures (e.g.,

<sup>1</sup> Adapted from National Materials Advisory Board report, "Microelectromechanical Systems."

wirebonds, fiber optic cables), but not flow into undesirable areas (e.g., moving structures). In addition, the CTE of the encapsulant must be a balance between the many different materials it contacts. Despite the obvious complications, several MEMS sensors have been successfully packaged in plastic packages<sup>2</sup>.

MEMS packaging is not confined to packaging individual MEMS devices (e.g., sensors). It also encompasses system packaging, or more accurately the integration of MEMS into systems. Two elements of system integration must be considered:

- 1) Process compatibility – how can conventional integrated circuit structures be fabricated on the same die as MEMS structures? How are MEMS process materials and temperatures integrated with conventional IC processing to allow the creation monolithic systems?
- 2) Integrated nano-to-millimeter (In2m) systems<sup>3</sup> – integration of diverse functionality that cannot be fabricated monolithically. These systems are characterized by their diverse size and technology domains, conversion of energy from one size scale to another, and mix of electrical, thermal, chemical, fluidic, and biological functions.

## MEMS Reliability

Reliability is particularly a challenge for MEMS because:

- 1) Many promising MEMS applications are in safety critical systems where the cost of failure is catastrophic and the requirements for qualification/certification are stringent and expensive to satisfy.
- 2) MEMS technologies are new, and thereby introduce many new failure mechanisms that are poorly understood (in addition to the failure mechanisms present in conventional microelectronic devices).
- 3) MEMS technology is evolving rapidly with the introduction of new processes, materials, and structural geometries nearly daily.
- 4) In both safety critical and non-critical applications alike design tradeoffs must account for reliability in order to control product warranty costs.

Reliability assessment of MEMS must be developed from a physics of failure (PoF) methodology, because failure mechanisms specific to MEMS are not yet characterized. The need for understanding the physical phenomena and failure of MEMS is complicated by several factors, including multiple materials and interfaces in the system and the interaction of the system with the local environment. Economic pressures will push MEMS packaging toward non-hermetic solutions, that will have to have hermetic equivalent reliability. With non-hermetic

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<sup>2</sup> MEMS plastic packaging efforts include:

C. Hierold, "Intelligent CMOS sensors," *Proc. IEEE MEMS 2000*, pp. 1-6, 2000.

R. Grelland, H. Jakobsen and B. Liverod, "A low-cost fully signal conditioned sensor microsystem with excellent media compatibility," in *Advanced Microsystems for Automotive Applications 99*, pp. 121-131, Springer, 1999.

H. Balthes, O. Brand, and M. Waelti, "Packaging of CMOS MEMS," *Microelectronics Reliability*, vol. 40, pp. 1255-1262, 2000.

<sup>3</sup> H. Last, M. Deeds, D. Garvick, R. Kavetsky, P. Sandborn E. B. Magrab, and S. K. Gupta, "Nano-to-millimeter scale integrated systems," *IEEE Transactions on Components and Packaging Technologies*, vol. 22, no. 2, pp. 338-343, June 1999.

packaging, many long-term reliability issues arise including the impact of humidity (corrosion) and contamination from exposure to pollutant gases and other contaminants.

Closely associated with reliability is qualification. Qualification is defined as a process to verify whether or not the anticipated reliability is achieved under actual life cycle loads for a specified length of time. The purpose of qualification is to audit the ability of the design, manufacture, and assembly to meet reliability goals. Traditional qualification of microelectronics consists of following decades old "one size fits all" standard tests that are often inaccurate, improperly applied, and unnecessarily restrictive. Development of virtual qualification methodologies<sup>4</sup> (coupled with judicious design and use of accelerated testing, i.e., accelerated qualification) will be necessary for the timely and cost-effective fielding of MEMS for many applications.

**Closing Remarks:** The greatest driver of MEMS packaging and reliability development for many systems will not be how small the resulting systems is, but rather the diversity of functionality that can be successfully integrated into a practical, manufacturable, and reliable product. Unless basic packaging and reliability issues can be adequately resolved, the long-term commercial viability of MEMS is at risk.

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<sup>4</sup> M. Pecht, P. Sandborn, and P. McCluskey, "Virtual component qualification," in *Proc. 2nd International Conf. on Modeling and Simulation of Microsystems*, pp. 8-13, April 1999.