MEMS packaging, assembly, and test for the marketplace

Because P/A/T can account for 60% of MEMS cost, finding new ways to implement these processes is crucial for commercialization

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The role of packaging/assembly/test (P/A/T) in successful commercialization of MEMS (microelectromechanical systems) has historically taken a backseat to device development. In the beginning, MEMS were virtually stand-alone devices inserted into custom-designed mechanical enclosures or standard IC packages, and tested in an ad hoc manner. Now, MEMS are truly becoming systems (as the "S" in MEMS connotes). MEMS devices are being integrated into packages of various shapes, sizes, and materials — along with signal-conditioning electronics, power sources, and communication network (both wireless and connected) ICs — to make MEMS into complete application solutions (see *Fig. 1*). As this occurs, the MEMS community is taking note of P/A/T's importance.

Additionally, P/A/T for a MEMS-based solution can be 60% or more of the total cost. This alone makes initial consideration of the packaging and test strategy a very important part of the design process to optimize cost and performance. Yet half a century since the early days of MEMS, many of the same materials and packaging strategies are still favored by many suppliers.

Packaging challenges

The requirements for MEMS packaging are fundamentally different than those for ICs, although IC package assembly technology is at the foundation of most MEMS package assembly processes. The differences between MEMS and IC packages revolve around two fundamental topics: interface to the real world, and sensitivity to stress.

Because the majority of MEMS devices are intended to sense real-world phenomena, a MEMS package must interface with the outside world. The desired optical, mechanical, magnetic and/or chemical signals must have a path to connect to the MEMS microfabricated die. At the same time, the package must also protect the die from undesired and possibly damaging forces from the outside world, while also providing electrical signal and power connections. Managing this interface so that desired signals are transferred to the die with minimum noise or attenuation is one of the most challenging and costly facets of MEMS packaging.

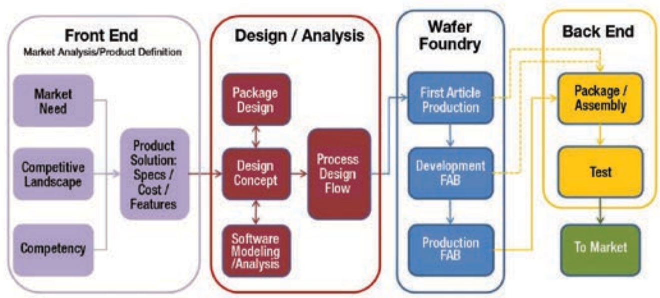

Fig. 1: While much effort has been expended on development of front-end, design/analysis, and wafer-foundry requirements for MEMS commercialization, back-end process creation has not received the serious attention required to make MEMS manufacturing truly mainstream.

The second major difference in MEMS vs. IC packaging revolves around MEMS die often being much more sensitive to stress than ICs. This stress primarily results from differences in the temperature coefficients of the materials that make up the MEMS device and its package. The die stress that results usually leads to a temperature coefficient in the device bias and scale-factor output. While such temperature sensitivity can be compensated for in the interface electronics, the associated calibration process adds significant cost. Furthermore, these temperature coefficient differences can change over time; if a device is not properly designed to accommodate such changes, it may no longer operate to specification or, in extreme cases, fails.

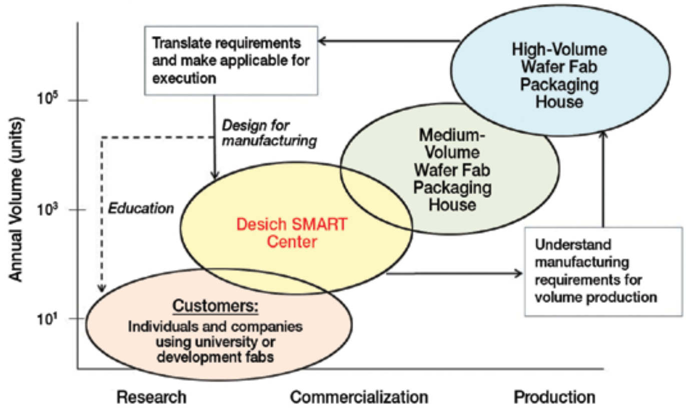

Fig. 2: The DSMC aims to provide a closed-loop information process for seamless MEMS manufacturing transitions.

The Richard Desich SMART Commercialization Center for Microsystems ("Desich SMART Center," or DSMC) provides a unique means to develop appropriate P/A/T technologies by having access to the top equipment and technologies without risking substantial capital. (See side bar.) DSMC's ultimate commercialization role is to provide a developmental P/A/T "bridge" between the suppliers of MEMS wafers and the high-volume MEMS packaging suppliers (see *Fig. 2*). Before DSMC, this function was virtually nonexistent for MEMS, seriously disrupting timely, cost-effective commercialization. (The need for the service and its requirements were determined by Roger Grace Associates.)

The DSMC is centered about a core facility with end-to-end microsystem packaging and assembly capability supported by reliability test equipment and further augmented by software design tools and materials databases. Such a complete packaging capability promotes efficient problem-solving in what is typically a multistep, iterative process. A single facility to investigate and prototype manufacturing processes for microelectronic packaging facilitates product codesign, and reduces the risk of contamination and damage due to shipping to job shop vendors; it streamlines project time frames, communication, and error causality tracking. The primary objective of the facility is to determine a package design for a specific product application, providing a resource for down selecting options from current manufacturable processes as a customer weighs this against product cost and supply chain limitations.

Desich SMART Center

The Richard Desich SMART Commercialization Center for Microsystems ("Desich SMART Center," or DSMC) provides a viable resource to overcome package, assembly, and test barriers to full MEMS commercialization. The DSMC not only provides critically needed resources to the MEMS community, but also serves as the core of an emerging northeast Ohio microsystems technology cluster. Located on the campus and a part of Lorain County Community College (LCCC) in Elyria, OH, DSMC develops manufacturable packaging integration technologies for customers developing next-generation microsystem products. It does so by leveraging world-class facilities and a highly experienced engineering team to accelerate product time to market.

Currently located in a temporary 1,800-sq ft class 10,000 cleanroom in LCCC's Entrepreneurship Innovation Center (EIC), DSMC will soon move to a new, three-story, 47,000-sq ft facility being built adjacent to the EIC building and scheduled for completion this Fall. The first floor of the new facility will house state-of-the-market cleanrooms, adding class 1000 and 100 cleanrooms; the equipment configuration establishes the facility as a "pilot manufacturing plant," thereby easing the transition from lab to manufacturing. The second floor is reserved for incubating new technology startups as well as for established corporations needing a secure environment to innovate new product developments. The third floor will house the computer lab with software design tools, as well as wet labs available for rent.

Case/application studies

It is important to understand the potential trade-offs when a device transitions from the "proof of concept" prototype to a "production intent" design. DSMC has supported numerous customers with this transition by increasing performance and yield with die-to-package interconnects. The replacement of hand soldered connections with aluminum wedge bonding may seem remedial but is not unusual. More complex scenarios, such as gold ball bonding on thermally isolated die mounted in TO headers, or pin dip connections on two-sided custom assemblies, required engineering development before the solution could be delivered.

Since packaging solutions tend to be complex, the Desich SMART Center works closely with customers to ensure that the development pathway is aligned with existing designs and suppliers. Parylene and silicone are materials used to encapsulate sensor devices in ambient and liquid environments. In one case, deposition experiments were run to examine mechanical robustness versus degradation of sensor performance. This work provided actionable data for the customer to update a specification back to their supplier.

In another situation, reliability tests such as HAST, thermal-humidity cycling, high temperature storage, and biased 85/85, were conducted to qualify the design of a commercially available MEMS assembly for an end user. Here an encapsulation material specified for one environment was being qualified for a more stringent environment. The qualification allowed the customer to move their program into the next phase of product development.

A "production intent" design lets customers sample their product while they work their strategy for volume production. Relying on offshore volume packaging houses for assembly development and "proof of concept" prototypes is often very inefficient. Using wafers from small custom lots or shuttle services, DSMC offers "on demand" prototypes. In one example, process development was required for the assembly of high temperature devices using standard ceramic packages. The development was necessary to address the novel high-temperature materials and multiple designs used on the wafer. The turnaround time with the current process is one day. ■