Building Small: Notes from a MEMS Watcher

They seem to be anywhere and everywhere. We're talking about MEMS, of course! Despite a prolonged recession that pushed them to the backburner of popular technology, MEMS are making a big rebound. While packaging MEMS is similar to the IC assembly we're so familiar with, it's also different, as we report below.

By Terrence E. Thompson, Senior Editor

The increasingly widespread use of MEMS in end products causes confusion. In microelectronics, it might seem that MEMS are in limbo, but that's certainly not the case.

The mainstream adoption of MEMS (and microsystems and nanosystems) in electronic products was simply slowed by the overall economic slump. Significant recent changes, including better wafer bonding with new or highly refined processes, simplify the needed 3-D stacking, interconnects and sealing.

Think Small

As the industry rebounds, OEMs have much better choices for building small. Microscale and nanoscale, mechanical and photonic components complement IC capabilities in many packages.

Design and simulation software and manufacturing service providers can help with next-generation products. In some cases, a concept can go directly to foundries for fabricating and packaging.

A surge of innovative processes complements these developments, including wafer bonding/stacking/thinning that can integrate much thinner ICs, MEMS and photonic devices into 3-D packages with economical batch processing.

A Sandia technician displays a novel, white-light-emitting invention.

What Are MSTs?

MEMS, a.k.a. MicroSystems Technology (MST), typically integrate mechanical elements—such as sensors and actuators—with electronics on a wafer through microfabrication technology.[1] Many are fabricated using IC process technology. Micromachining processes selectively etch away silicon and deposition to add structures to form micromechanical and microelectromechanical devices.

The late Sen. Everett Dirkson purportedly remarked, "A billion here, a billion there, pretty soon it adds up to real money." He also reputedly said, "There is no force so powerful as an idea whose time has come." He could easily have been speaking about MEMS!

"Five years ago, the market for micromachined devices was dominated by sensor and actuator applications, representing a market segment in the $100 million range. Today, MEMS is an enabling technology for applications such as DNA sequencing, wireless communications and fiber-optic signal routing. This is expected to create a worldwide market exceeding $10 billion by 2007," says Dr. Ralph Hensler, BBC.[2] [bccresearch.com]

Hensler points out, "MEMS applications include household appliances, earthquake-activated gas line cutoff switches and even toys. Which segments will be the most significant and will micromachined passive structures be included in the MEMS market?"

He notes that worldwide R&D efforts are substantial, including major industrial and institutional players with many new MEMS patents. Sales are expected to jump for the automotive, medical, telecommunications, industrial, transportation, environmental and consumer market segments.

The NEXUS (European microsystems network) initial market analysis for MST covered 1996 to 2002. They projected growth from $14 billion in 1996 to $38 billion by 2002. Yet by 2000, actual markets

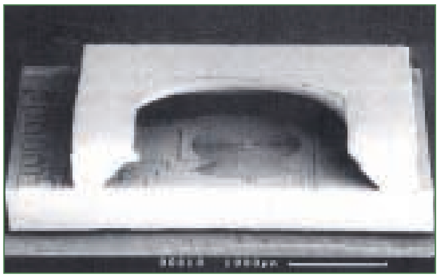

Figure 1. SEM shows cutaway of a packaged automotive gyroscope using glass frit bonding (Robert Bosch GmbH)

reached $30 billion. The second analysis illustrates market growth from $38 billion in 2000 to $68 billion by 2005.

The main applications will be dominated by IT-related peripherals, biomedical, automotive, household appliance and telecommunications.[3] [enablingmnt.com]

20 Percent Annual Growth

The U. S. market for MEMS devices will grow over 20 percent annually through 2006, driven by innovations that lower costs, improve performance and widen applications, according to the report "MEMS to 2006" from Electronics.ca Publications.[4]

The report predicts the strongest markets to be telecommunication switches, biomedical-related products, automotive sensors and telematics, consumer electronics and military/aerospace. [electronics.ca]

The MEMS study profiled key companies including Agilent Technologies, Analog Devices, Corning, Delphi, Honeywell International, Motorola, STMicroelectronics and Texas Instruments.

Roadmaps? Take Your Choice!

The MEMS Industry Group, Pittsburgh, Pa., has a roadmap.[5] It is an association of U.S.-based MEMS and microstructure designers, manufacturers and integrators. It shares technology roadmaps from other organizations, global market information and state-of-the-industry reports with members, and is an advocate in public policy issues. [memsindustrygroup.org]

According to Ellen M. McDevitt, MIG, "To get a clear view of the fabrication issues affecting the U.S. MEMS industry, we surveyed a significant segment of the MEMS industry and over 60 non-captive MEMS fabs worldwide in two broad categories—worldwide MEMS fabs and U.S. MEMS companies that outsource their fabrication."

MIG also selected a group of MEMS industry participants to identify the most critical MEMS fabrication issues.

MIG believes the most significant obstacle to growth is the segmented market

Figure 2. SUSS MicroTec's new wafer bonding system

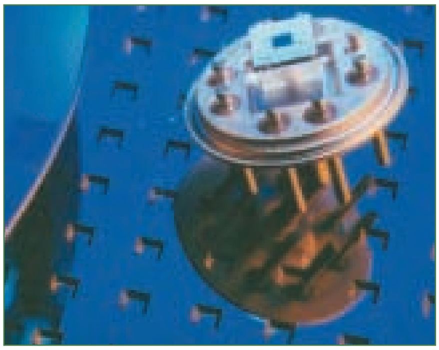

Figure 3. Manifold absolute pressure sensor uses anodic bonding (Robert Bosch GmbH)

and high cost of entry. There is a perception, and acceptance that MEMS will enable sensor pervasiveness, leading to significant new markets.

While these markets are envisioned, they have yet to emerge. The investment needed in the design and simulation of multi-domain devices, as well as in the fabrication of these highly diverse structures is costly and has delayed widespread adoption.

The MIG survey of worldwide MEMS fabs reached some key conclusions. Ninety percent of all MEMS devices produced fall into the following six categories: inertial sensors (accelerometers, gyros, motion sensors, etc.); optical mirrors; microfluidic devices/micro-arrays (channels, reservoirs, mixers, pneumatic actuators, etc.); components for RF communications; physical sensors (pressure, flow, radiation); and inkjet nozzles.

MEMS Standards

The roadmap of an EC-funded project is "IST-200 1-37682 Standardization for Microsystem Technology: The Way Forward." This study forecasts MST trends standardization and discusses the current industrial landscape.

The roadmap reviews seven major applications: materials, manufacturing technology, packaging technology, handling and assembly, metrology, design and modeling, and interfacing with the external world. Standardization needs are identified for 2004 to 2008. [memstand.org]

Unlike the microelectronics industry, where CMOS dominates, the dominant characteristic of the MST industry is the diversity in terms of the technologies employed and the multitude of applications. These trends will be even more apparent in the next decade.

A recent survey included 368 MST-oriented companies offering MEMS fabrication and services worldwide. There are many other companies with products associated with MEMS in some manner. In the USA, over 40 percent of MST companies were funded between 1995 and 2001, with an average of ten companies funded per year in the last three years.

A Few Big Players

The MST industry is a fast growing one with only a few big players, including Analog Devices., Hewlett Packard and Motorola. It is also a very dynamic field.

In 2002, MIG surveyed nearly 200 companies previously associated with the MST business in the U.S. Approximately 20 percent were no longer in business. A MIG follow-up survey in 2002 identified 153 MST-related U.S.-based companies still operating.

"MEMS promises to revolutionize nearly every product category by bringing together microelectronics with micromachining technology, making possible the realization of complete systems-on-a-chip," says Michael A. Huff, director, The MEMS Exchange, Reston, Va.[6] [mems-exchange.org]

"This enabling technology," reports Huff, "allows the development of smarter products, augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators and expanding possible designs and applications."

ICs are the brains of a system and MEMS augments this decision-making capability with "eyes" and "arms," allowing micro-systems to sense and control the environment.

Sensors gather information from the environment through measuring mechanical, thermal, biological, chemical, optical and magnetic phenomena. Electronics process the information and direct actuators to respond by moving, positioning, regulating, pumping and filtering, thereby controlling the environment for some desired purpose.

The Future Is Packaging

Bryan K. Patmon, managing director, SenzPak Pte. Ltd., a division of MemsTech, Singapore, says, "MEMS packaging is not an art. It tests our ability to understand and exceed the fundamental restraints of physics and chemistry. The most challenging aspect is MEMS sensor packaging."

MEMS have been packaged for many harsh applications in the past 20 years. However, with new smarter sensor technologies and smaller die sizes, packaging technique becomes less forgiving.

"Customers want more compact packages at low cost. With sensor packaging, unlike IC packaging, there are other critical parameters for achieving best performance. These are the physical, mechanical and electrical characteristics of the sensor along with stress and strain from the assembly," notes Patmon. There are other factors too, figure 4.

Chemical and physical degradation from environment to which the sensor is exposed prior to assembly might mean more stringent storage. Robust package design, used with the appropriate assembly process and suitable materials, can

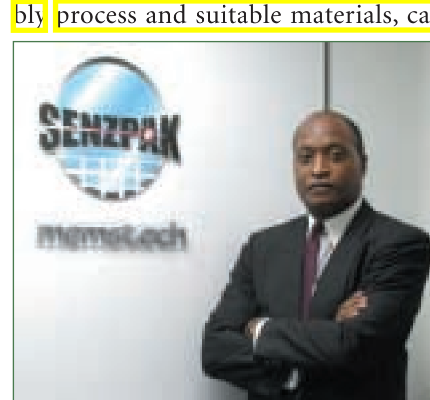

Figure 4. Bryan K. Patmon, managing director, SenzPak Pte. Ltd. In the lobby of SenzPak's Singapore plant.

accommodate the sensor and yet protect it from the environment. Not all sensors are exposed to the environment; however, these sensors may require suitable material due to long-term reliability, figure 5.

The most successful IC packaging approaches in the past met market demands. MEMS, however, require a different approach. Patmon notes, "Because it's more personalized packaging, in terms of application, one assembly approach does not work for all products.

Technology for MEMS packaging is as elusive as predicting the next packaging trend. Currently most sensor products are based on two- or multiple-chip solutions."

A sensor is packaged with signal conditioning chips. As more integration takes place where sensor and signal condition become monolithic solutions, it requires more in-depth knowledge of packaging to succeed.

"We firmly believe the future of MEMS is dictated by packaging, and the ability to integrate specific sensor technology with packaging technology is the MEMS packaging future," says Patmon.

"The term SIP can take on a dual meaning, not just a 'system-in-package' but also 'sensor integrated package.' We know that different packaging technology is needed for specific sensors. That transforms SIP into CIB (chip-in-board) and 'multi-component system' packaging is why MemsTech CSPs are called MTcSpak."

Alignment and Wafer Bonding

"Bonding is the final step in the process sequence in which multiple wafers or substrates are attached using a number of physical and chemical effects," explains Christian Ossmann, market development manager for MEMS at SUSS MicroTec AG.

Substrate bonding is the key technology within the packaging process flow for leading MEMS devices, figure 2. This technology allows a permanent stack of more than two wafers while trapping a well-defined atmosphere inside two wafers. [suss.com]

According to Paul Linder, product manager, EV Group, "The impact of MST is particularly significant in the automotive industry. Today, virtually every automobile has a MEMS pressure sensor in its electronic engine control system and an acceleration sensor for triggering an air bag. More recent MEMS-based devices include person detection for intelligent airbag deployment and tire pressure, and temperature monitoring." [evgroup.com]

Linder says, "Wafer bonding solves tasks at wafer level versus chip level. Over the years wafer bonding matured to be a key enabling technology." He summarized the key wafer-level bonding functions for MST devices as bonding, stress isolation and controlled ambient.

"For first-level packages, the assembly and packaging goal is to either attach the two halves of a device (generally used in bulk micromachined sensors) or to provide a protective cover (for surface-machined parts)," says Linder. "Sealing at wafer level allows cleanliness as it is performed prior to dicing. Cleaning chips after dicing is not very effective."

In the case of surface micromachined technology, bonding a cap wafer to a sensor wafer provides the required protection for subsequent, less-clean process steps. Figure 1 shows a surface micromachined gyroscope that is first-level packaged at wafer level to protect the sensitive mechanically suspended features from the environment.

Stress Relief

"A bonded wafer pair can allow for a hermetically sealed mounting into the final package," says Linder.

"Mechanical stress at the interface between package and board has to be isolated from the sensor silicon chip. Wafer-level bonding provides sufficient mechanical stability and decouples mechanical stress acting on the package from the sensor chip."

Figure 3 shows a pressure sensor with a thick glass pedestal serving as rigid mechanical base for the silicon sensor chip. The anodically bonded glass pedestal that is generated at wafer level absorbs any stress introduced to the final package.

Figure 5. Production floor at the SenzPak Singapore plant

Conclusion

Expect widespread adoption of MEMS in electronics and other products this year. The equipment and materials producers have been busy getting what manufacturers need ready for volume production. And foundries and other EMS providers can design, fabricate, package and test the devices for prototype or production volumes.

References

1. *The Beginner's Guide to MEMS Processing*, MEMSNET. [memsnet.org/mems/beginner]
2. Research Report #GB270, *MEMS Technology: Where To?*, Dr. Ralph Hensler, Business Communications Co.
3. EC project IST-200 1-37682, *Standardisation for Microsystem Technology: The Way Forward.*
4. Research Report # FR1580, *MEMS to 2006* (Micro-Electromechanical Systems), Electronics.ca Publications.
5. *MEMS Technology Roadmap*, MEMS Industry Group, Pittsburgh, Pa.
6. M. Huff, *MEMS Manufacturing*, The MEMS Exchange, Reston, Va.

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