MEMS Packaging Challenges

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INTRODUCTION

MEMS – Microelectromechanical System! The term is a mouthful and may sound like many pieces of unrelated technology all jammed together. But, in a sense, this is what MEMS is really all about – many different technologies merged onto a single chip to create a single system. MEMS represents the highest level of micro-integration yet devised. Motion, light, sound, molecular detection, radio waves and computation all converge on this unusual chip. Microelectromechanical Systems, or nanotechnology, has fired up interest in many industries and articles are even appearing in newspapers. But what's so special about MEMS and what can it do that isn't already being done by other technologies? Don't we already have miniature motors, optical devices, sensors, computers and moving gears? Yes, but not manufactured on a single line and certainly not all on a tiny chip!

We can view MEMS as an extension of semiconductor technology where modified fab processes are used to build mechanical and other features along with common electronic transistors. This ostensibly new technology has actually been around in one form or another for at least 25 years but the levels of success and implementation have increased exponentially in the last few years. Perhaps more significant are the new market drivers where the demand for MEMS products is now extraordinary, especially in the optical area. The Internet giants have already spent billions of dollars this year acquiring most of the MEMS companies that have light control technology.

CONVERGENCE & INTEGRATION

The transistor was just an interesting phenomenon when first invented more than 50 years ago and its value remained limited until the fabrication of the integrated circuit (IC) years later. MEMS has been viewed as a collection of miniaturized devices - gears, movable mirrors, high-speed motors and other assemblages found in the macro world. But this technology is much more than just building unusual devices. MEMS combines and integrates complete systems! MEMS brings about the highest level of integration and functionality that will lead to the true System-on-Chip. Electronics, mechanics, physics, chemistry, biology, optics, sensing, manipulation, computation and control all *converge in one micro-universe*. It's like adding the *eyes, noise, ears*, *hands and fingers* to the silicon brain. The key is integration – but the integration of diverse systems. MEMS places motors, motion translators, sensors and computers all on a tiny piece of silicon in a way that lets it work in a fully integrated and self-contained fab-crafted microcosm. Now lets look more closely at MEMS before taking on the challenge of packaging the incredible nano-machines.

MEMS FABRICATION

Sandia National Laboratories, the University of Colorado and other research organizations have built truly remarkable devices. One example of a fascinating device is a chip-size spectrophotometer that can detect and measure atmospheric gases from miles away. Microscopic pumps and valves have also been built that may be used for medical applications including drug delivery. IBM has developed a MEMS DNA detector that can even sense when a DNA strand is defective. Devices are so small that they could be injected into the body. The day may come when micro-robots, or “nanobots”, travel through the body to clear arteries and make repairs borrowing a scene from the classic 1960’s science fiction movie “**Fantastic Journey**”. But MEMS may also find military uses at least say the science fiction writers like Dean Smith who tells of battles between earth nanobots and alien micro-machines in “**The Tenth Planet**”. Figure 1 shows micrographs of the extraordinary range of MEMS devices from Sandia National Laboratory and other sources. Note the nasty nanobot in the lower right corner that was not born at Sandia.

Fig. 1 – MEMS from Sandia

PACKAGING MEMS

Packaging foundries say that MEMS introduces the greatest set of problems yet faced by their industry. Worse yet, the issues are so application-specific that hard-earned solutions won’t necessarily translate to other products. Problems crop up right away starting with wafer and die handling. MEMS devices can be quite fragile requiring special handling. The packaging must allow movement in all cases and permit entry and exit of light or other forms of energy and matter for some products. A good way to appreciate the *MEMS packaging ch*allenge is to look at real examples.

Accelerometers

Let’s begin with the air bag accelerometer, one of the earliest and most successful MEMS devices now used in almost every vehicle. The popular accelerometer chip made by Analog Devices uses a pair of interdigitated combs to sense changes in motion. One set consists of very tiny cantilevered silicon beams that are free to bend in response to changes in motion. The other comb is fixed to the silicon substrate and remains stationary. The comb pairs are designed as capacitors. Deceleration instantly changes the spacings between the comb pairs, which in turn changes their capacitance. Electronics within the MEMS chip analyzes the capacitance values and translates them into an electronic signal corresponding to acceleration/deceleration. Vehicle impact causes the MEMS device to send the signal for air bag deployment.

Accelerometer packages are typically ceramic or metal hermetic enclosures that permit mechanical movement. While such classical high vacuum hermetic package work well, the industry seeks a way of using low cost plastic molding. Some of the newest packaging ideas will be covered later. Now we’ll look at a MEMS device found even closer to home in the ink jet printer.

Ink Jets

The popular ink jet chip built into most ink cartridges represents the next level of packaging difficulty. The ink jet uses a MEMS chip that rapidly propels droplets when an electrical impulse is received. The chip consists of microscopic jet nozzles that discharge droplets using piezoelectric or thermomechanical pumps inside the chip. The numerous micro-nozzles must be kept free of packaging but the chip-to-substrate interconnect must be protected and made robust for handling by end-users. This can be accomplished by “selective packaging”. HP uses TAB (Tape Automated Bonding) for the package. This flex-based package incorporates cantilevered metal beam leads that are bonded to the IC pads. But instead of the common outer lead bond (OLB) termination, HP incorporates a pressure contact connection that mates with the printer when the user installs the cartridge. This unusual and non-hermetic MEMS package therefore serves additional purposes as a 3D circuit and connector.

The IC connection zone is selectively encapsulated using robotic needle dispensing to apply liquid pre-polymer sealant. Today’s needle dispensing equipment allows the selective encapsulation process to be accomplished accurately, efficiently and automatically. The deposited encapsulant is hardened thermally or with UV energy. Figure 2 shows the integrated flex package-connector circuit while Figure 3 shows an automatic needle dispenser of the type used to selectively encapsulate a MEMS ink jet device.

Fig. 2 – Ink Jet Cartridge

Fig. 3 – Needle Dispensing Machine - Speedline

Micro-mirrors

Optical MEMS products, also called MOEMS, add one more level of complexity. The Digital Micro-Mirror Device™ (DMD) from Texas Instruments is presently the most sophisticated commercial MEMS product and a preview of what lies ahead[1]. The MEMS chip uses light beam-directing mirrors that move independently and almost instantaneously during operation. A pixel is turned “on” by pointing a mirror at a projection lens while turning “off” involves pointed away. Large arrays of tiny mirror are being used for digital projectors but are also being tested in digital cinemas. Many believe that mirror-based optical switches will soon be used for Internet routers since most of the long-haul segments use fiberoptics. Figure 4 shows a section of the micro-mirrors with some pointed “on” and others “off”.

Figure 4 – TI Micro-Mirror Array from Texas Instruments

The MOEMS chip must be hermetically sealed but a light path is certainly required. The solution is somewhat obvious. A light-transmissive lid or “port hole” must be designed into the package. The micro-mirror module from Texas Instruments is one of the best examples of the packaging of complex optoelectronic products. Figure 5 is a diagram of the Digital Micromirror Device package showing its window and other components.

Figure 5 – TI’s DMD Package Drawing

MEMS PACKAGING CHALLENGES & SOLUTIONS

Software

One issue has been that lack of dedicated MEMS software for simulation and analysis. This gap is being rapidly filled. MEMS required new software to bring order and product design efficiency to the industry. IntelliSense, a fast rising MEMS star in Wilmington, MA, claims to be the only MEMS manufacturer with a full compliment of software. Their IntelliSuite™ CAD for MEMS includes a fabrication process database, materials libraries, 3D structure graphics and a performance simulator/analyzer. The software is said to simulate and optimize MEMS to reduce cost, the number of prototypes and time-to-market. Figure 6 shows a micro-mirror simulation

Figure 6 - CAD Software Display of Micro-Mirror from IntelliSense

Novel Package Designs

While the common hermetic package works well for most MEMS, it adds cost and complexity. The goal of the large packaging foundries like AMKOR is to move to a low cost, high volume packaging method that fits the infrastructure. One idea from AMKOR, IMEC (Belgium) and several others is wafer-level hermetic enclosure that produces a protected chip that can be overmolded. This cap-on-chip concept is also called 0-level packaging. A silicon, ceramic or perhaps a low-expansion metal cap is bonded over the active area of the MEMS device while leaving wire bond pads clear. The capping step must be done under clean room conditions in a vacuum. Once sealed, the wafer can be singulated and the chips bonded and overmolded. Figure 7 shows the cap-on-chip package before the plastic packaging step. A thin silicon cap may require pre-encapsulation to protect it from collapse during transfer molding. New materials could eliminate this added step.

Figure 7 – Cap-on-Chip

Stiction

The tiny MEMS elements, once making contact with one another, are held together by surface tension and atomic-level forces. This has been a serious problem. For example, an accelerometer can be tested, calibrated and shipped. During transportation and installation, the device can experience enough G-force to make the combs stick together. The stuck sensors are now immobilized and the product is useless. Analog Device was able to solve the problem after years of work. One solution was to coat the MEMS device with a low surface energy reactive silane. Specialty Coating Systems, a major vacuum coater, suggests that a very thin Parylene film may solve the problem. Not much has been done in this area, but SCS is ready to work with the industry to test several Parylenes including a newer non-stick fluorinated product.

Package Atmosphere Control

MEMS, especially optical systems, requires a dry hermetically sealed package. Many researchers recommend a very high vacuum while others suggest a specific range for gases. Moisture is a problem for nearly all devices causing corrosion, aggravating stiction and fogging optics. Sandia researches suggest that some moisture can be good since it acts like a lubricant for moving parts[2]. One additional concern is that materials can outgas after packaging and MEMS devices can even generate micro-particles during operation that can "crash" the system by jamming moving parts.

One answer is "getters", packaging agents the "get and hold" specific contaminants. Moisture getters, for example, are desiccants that keep the package dry. One useful commercial form incorporates an efficient desiccant into polymer film or paste that can be bonded to the inside of the package or to the bottom of the lid. Particle getters attract and hold even the smallest particles. TI's DMD mirror package uses both moisture and particle getters.

Hydrogen can also be a problem for some devices, especially GaAs since this semiconductor can be "poisoned". Hydrogen is a common outgas from metal, RF absorbers and some die attach adhesives. Using a getter such as H2-3000 developed by Allied-Signal and now made by CSPM easily solves this problem. The getter contains PdO that converts H_2 to water that is absorbed by a desiccant.

New atmosphere control materials are certainly possible such as oxygen getters and perhaps systems that could keep moisture within a specific range. Now that high-level MEMS is coming out of the lab and into the commercial sector, more dialog is needed. Solutions exist and others can be quickly developed, but not unless those within the MEMS industry start expressing the problems and issues.

CONCLUSIONS

MEMS will be a hallmark technology for the 21st century. The capability to sense, analyze, compute and control, all within a single chip, will provide new and wonderful products during this decade. While package challenges are substantial, progress is accelerating. Many solutions may already be at hand and ***the problem may be a lack of knowledge, not a lack of technology***.

References

[1] Mignardi, M., "From ICs to DMDs", TI Technical Journal, pp. 56 – 63, July - Sept. 1998 (http://www.TI.com).

[2] Miller, W. M., "MEMS Reliability and Testing", IMAPS Packaging of MEMS Microsystems Workshop, Chicago, Oct. 23 – 24, 1999.

Editors Note: The MEMS monster in figure 1 was graphically-assembled by the author, but the next one, too small to see, could be real.

CSPM is Cookson Semiconductor Packaging, a division of Alpha-Fry Technologies.