MICROSYSTEMS: MANUFACTURING AND PACKAGING CHALLENGES

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INTRODUCTION

Microelectromechanical systems, or MEMS, is also referred to as Microsystems and as Mechatronics. These systems are manufactured by microfabrication or microassembly approaches. Initially, MEMS was associated with the integrated circuit industry where mechanical and electronic functions were integrated on a single silicon chip. Today the term MEMS tends to refer to a complete device with all the packaging requirements. Miniaturization technologies typically employ silicon-based electronics, but the miniature mechanical parts can be fabricated from silicon and from a variety of materials depending upon the application.

Over the last ten years, MEMS has matured from a laboratory curiosity and a favorite of science fiction writers, to a viable technology with potential widespread applications. Initially, MEMS was introduced to the public with a great deal of hype and visions of microrobots running through ones blood vessels, removing plaque and plugging holes. At the present time, the first MEMS devices are entering commercial production. In silicon based MEMS, integrated circuit fabrication techniques are used to reduce the size of mechanical devices to the miniature dimensions of microelectronics. Integration of these mechanical devices with electronic circuits on the same chip offers a wealth of new product opportunities not possible with conventional design and manufacturing approaches.

Simple MEMS devices have begun to appear in commercial applications, particularly in pressure sensors for medical and automotive applications and in automotive accelerometers for airbag sensors. Advanced MEMS devices have applications in the following industries:

- health care
- automotive
- aerospace
- information storage
- consumer electronics
- telecommunications
- scientific instruments
- environmental monitoring
- defense
- heavy equipment
- industrial machinery
- semiconductor manufacturing

More specifically, MEMS technology can be used to fabricate extremely sensitive sensors for a variety of applications including pressure, sound, mass, motion,

acceleration, rotation, flow, chemicals, vibration, and temperature. The technology can also be used to fabricate field-emission tips and probes for use in high-brightness specialized displays, electron-beam sources, information storage applications, and precision temperature sensing. Actuators can be fabricated for use in optical switching, flow control, micropositioning, adaptive optics, and displays. Finally, a variety of passive, three-dimensional, micromechanical structures can be fabricated with applications in telecommunications, electronic components, and sensors.

Various marketing studies have estimated the worldwide market for packaged functional MEMS systems will be approximately $100 billion in the year 2000. It is estimated that the MEMS device within the package is expected to have a market value of approximately $10 billion by the year 2000. Although still a topic of active academic research, in certain applications MEMS technology has reached a level of maturity where it is being commercialized and transferred into products. Products on the market today include accelerometers for airbags sensors, pressure sensors for automotive applications, micromotors for medical drug delivery systems, jetting systems for ink jet, and microvalves for consumer appliances.

PACKAGING OF MEMS DEVICES

The silicon MEMS chip is of little value to anyone unless it is put into a package. As stated above, the value of a packaged system is an order of magnitude higher than the chip. Once the silicon processing of the MEMS chip is complete, the challenges are just beginning. The chip cannot stand alone. It must be integrated with other components to make a functioning device. For example, a mechanical actuator on a chip does no work unless it can be "connected." Conventional connection and interconnection approaches do not play a role in the fabrication of a MEMS device or microsystem. In fact, conventional connection technology does not appear in MEMS devices. Connections and interconnections become integrated into the packaging and become a part of the process of making the MEMS package itself. One cannot define a distinct connection. Multi-disciplinary connections and interconnection approaches must be developed for MEMS devices that include electrical, fluid, thermal, optical, and motion transfer. In nearly all devices, a combination of two or more connection disciplines are integrated, with electrical generally being one of the disciplines. Miniature parts can also be fabricated in non-silicon based technologies. As in the silicon case, the connection is an integral part of the device. The work or function that any MEMS device performs must be delivered to the world outside of the device for mankind to benefit. The challenge is to develop technologies that can permit the connection, interconnections, and packaging of the MEMS chip into a MEMS system.

Customers do not want to purchase a chip; they want a completely packaged device. Suppliers who can 'build" the connections in place are very difficult to find. Finding a source with process capability to build a prototype is nearly impossible, and certainly the ability to design and build microassembly automation equipment to manufacture the microsystem is very limited. Within the United States, there is a lack of an infrastructure of MEMS packaging capability to produce a microsystem. There are limited developed metrics, specifications, experience bases, depositories for knowledge, and infrastructures from which to select microfabrication and microassembly packaging

and connection schemes. Each product that is conceived starts from ground zero in the development of the microfabrication and microassembly packaging and connection concepts.

Companies have not stepped up to integrated microfabrication technologies because of philosophical conflicts with current manufacturing methods, an existing large monetary investment in current assets and infrastructure, and lack of personnel who are skilled in this new approach. This difficulty starts at the very beginning of the product design cycle. The typical engineer at most companies, at best, has little capability and experience in a microfabrication approach to product design. Even if the engineer has the interest and sees the advantages of using microtechnology, he must work with an institution, a supplier, or a consultant who has an experience base to draw upon to create a design. Otherwise, his risk of failure is far too great. Those who develop the understanding for the metrics of microsystems design find that getting their design concepts built to test functionality can be a problem. The silicon-based MEMS technology has been more successful as compared to, for example, piezo materials, because the infrastructure exists to build a proof of concept /device and, to a lesser extent, to build prototypes and for scale-up. However, even with silicon, the established infrastructure does not fully support MEMS fabrication because of differences in the circuit fabrication process and the MEMS process. Additionally, silicon fabrication capabilities are geared to extremely high volume production beyond the requirements for MEMS devices. There is little interest by the silicon fab community in meeting the relatively low volume of MEMS devices.

The microfabrication approach requires the integration and development of various technologies, such as photolithigraphy, electroforming and electroplating, vacuum and chemical vapor deposition, injection molding, and hybrid electronic fabrication processes to "package" miniaturized MEMS devices. The devices must be packaged in such a way as to move from the micro world of the silicon chip, or other substrates which can contain electronic and mechanical functions, to the macro world of the human, for the communication of inputs and outputs. Table1 illustrates the various microfabrication technologies that are used to package MEMS devices. The packaging and "connections" use plastics, metals, and ceramics in combination with each other, and generally with silicon. Microfabrication by subtractive techniques, where material is removed, and by additive techniques, where material is added or grown in place, are used to form microparts. These microparts are assembled together or form connections with each other by a variety of bonding techniques such as diffusion and anodic bonding, as well as by using adhesives. Mechanical fasteners are not used because the surface areas that they require limit the ability to miniaturize. Also, stress concentrations result from features in the part and from the uneven forces when parts are mechanically fastened. Fasteners also limit the size reduction possible and the tolerances that can be held. Microfabrication technologies are generally used in such a manner that one process can build upon another. For example, photolithography creates a pattern, followed by the plating of a metal to form a metal structure of connections or fluid pathways. The part may be put into a molding machine and plastic micromolded around the part to insulate, seal, or protect the device, as well as to provide mechanical and fluid connection to the outside world.

The trend toward microsystem products is significantly hampered by the lack of microfabrication and microassembly engineering capability and infrastructure to design and package MEMS and microsystem-based products. Enabling technologies in the areas of micropositioning, imaging, and in attachment and packaging need to be developed further to support the development of microfabrication and microassembly equipment. This will aid in establishing a healthy industry infrastructure to support deployment of MEMS related technologies for commercial products.

Table 1: Microfabrication Processes

Material	Subtractive Process	Additive Process	Attachment Process
silicon	* wet etching * dry etching * dicing	* PVD * CVD * sol gel	* bonding * adhesives
plastics	* plasma etching * ion beam etching * LASER ablation	* LIGA * PVD * electroforming * micro molding	* welding * adhesives
metal	* wet etching * micro machining * LASER ablation * dicing * EDM	* LIGA * electroforming * PVD * LASER CVD	* adhesives * micro-welding * micro-soldering * LASER welding * sonic welding
ceramics	* LASER ablation * dicing * ion beam etching	* LIGA * sintering * LASER CVD	* plating * adhesives * soldering * bonding

Adapted from MicroParts - Dortmund Germany