Position Paper: MEMS Manufacturing

Michael A. Huff
The MEMS Exchange
Reston, Virginia 20191

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through the utilization of microfabrication technology. MEMS promises to revolutionize many product categories by bringing together silicon-based microelectronics with micromachining technology, enabling complete systems-on-a-chip to be realized. MEMS enables the development of smart products by augmenting the computational ability of microelectronics with the perception and control capabilities of microsensors and microactuators. This technology is extremely diverse and fertile, both in the applications it is expected to be used, as well as in how the devices are designed and manufactured. Because MEMS devices are manufactured using batch fabrication techniques, similar to ICs, it is believed that unprecedented levels of functionality, reliability, and sophistication can be placed on a small silicon chip at a relatively low cost.

Presently, the largest market drivers for MEMS industry include silicon-based pressure sensors, crash-air bag sensors, digital light processors (DLP) for projectors, opto-mechanical switches for all-optical networks, and ink-jet cartridges for printers. Because of these success stories and the applicability of this technology in so many other products, the market potential for MEMS is very promising. Already in the industrial sector MEMS devices are emerging as product performance differentiators in numerous markets. Recent market research by semiconductor equipment and materials international (SEMI), the largest trade organization for the semiconductor industry, has projected that the MEMS device industry will continue to grow by over 50% per year to a world-wide component market size of nearly $10 billion annually by the end of year 2002. Several other market research studies have projected even higher growth. The application areas considered in these studies have been typically restricted to pressure sensors, inertial sensors, fluid regulation and control, optical switching, analytical instruments, and mass data storage. Since MEMS is a nascent and synergistic technology, one can expect many new applications to emerge, expanding the markets beyond that which are currently identified.

Although MEMS heavily leverages the fabrication technologies developed by the IC industry, there are several very important differences between IC and MEMS fabrication that will have a significant impact on how MEMS manufacturing develops and matures. First, the IC industry has converged to a relatively small number of "standardized" or "fixed" processes, such as CMOS, Bipolar, BiCMOS, etc., for making integrated circuits. In comparison, there are virtually no standardized fabrication process technologies in MEMS. Further, there may never be a MEMS equivalent of a standardized microelectronic process such as CMOS that will satisfy a majority of MEMS device fabrication needs. This is because the fabrication process used to implement the MEMS device is dependent on the application of the device. For example, the process sequence for realizing an inertial sensor will inherently be much different from the process sequence to realize a microvalve. Consequently, we find that the process technology for each MEMS device is many times specific to that device.

Another major difference between MEMS and IC fabrication is the vast array of processing capabilities and materials used to make MEMS devices. MEMS fabrication typically utilizes conventional process capabilities borrowed from the IC world such as oxidation, LPCVD, and photolithography and blends these with highly-specialized "micromachining" techniques such as bulk micromachining, surface micromachining, LIGA, DRIE, wafer bonding, etc. Furthermore, these MEMS processing capabilities are typically scattered around the country with no single fabrication site having core competencies in all these technologies. Also, the materials commonly used in MEMS devices such as peizoelectrics, shape-memory alloys, glass substrates, etc., are very exotic compared to the materials used in IC fabrication.

Another significant difference between MEMS and IC fabrication concerns the relative volumes. In the IC manufacturing world the volume of wafers and die produced in a fabrication site each year are truly enormous. ICs are manufactured using batch-fabrication techniques whereby large numbers of wafers are processed in an identical fashion (i.e., a fixed process technology such as CMOS) and each wafer may have hundreds or even thousands of individual, but identical integrated circuits. The advantage of batch-fabrication is that even though the cost of producing a wafer may be high, this cost is spread over hundreds or even thousands of die, and therefore the cost per die is comparatively low. High-volumes are essential for IC manufacturing because the investments which must be made in order to enable state-of-the-art IC manufacturing are now in excess of $1B. The ability to spread this huge cost over a very large volume of products allows the cost per chip to be comparatively low. High volumes are typical in IC manufacturing because most microelectronic circuits are generic elements having a wide number of applications. For example, a microprocessor is a useful circuit for many applications. In MEMS, the situation is quite different. The volumes in MEMS are inherently lower due to the specialized nature of the specific devices. For example, a MEMS inertial sensor designed for automobiles as a crash-air bag deployment sensor is very useful for that specific application, but the process technology used to make this device most likely will not be suitable for other applications.

We believe that a these differences pose a real and enormous challenge to cost effective high-quality MEMS manufacturing and must be adequately addressed for the technology to flourish. Clearly, MEMS needs the development of flexible manufacturing resources whereby different process sequences using a wide diversity of processing capabilities and materials can be performed while still maintaining high-quality, reproducibility, and a relatively low cost.

The MEMS Exchange with support from the Defense Advanced Research Projects Agency (DARPA) is establishing a national-level program that is furnishing extensive support and access technologies to the growing MEMS community. A major goal of the MEMS Exchange is to create a fabrication environment that will suitably address the challenges cited above. A key element of the MEMS Exchange program is the concept of a distributed MEMS processing environment where fabrication and testing of MEMS devices and systems is performed at multiple, geographically dispersed sites. Currently, the MEMS Exchange is primarily a prototyping environment, but has quickly become a national resource for MEMS technologists interested in rapid, flexible, and affordable access to MEMS fabrication resources.

The MEMS Exchange has provided fabrication services to the domestic community for slightly more than 18 months and over that period of time has received over 330 work requests from developers around the country. The growth of work requests has been without the benefit of advertising or marketing and gives us satisfaction that our unique approach to providing MEMS fabrication access is useful. Currently, the MEMS Exchange has several leading commercial and academic fabrication sites providing services and is actively enlisting new fabrication sites each week. The MEMS Exchange offers the most comprehensive and flexible array of MEMS fabrication processes in the world with unique capabilities in integrated MEMS, DRIE, bonding, electroplating, and LPCVD SiGe depositions for low-temperature (<350C) micromechanical fabrication on fully metallized CMOS wafers, as well as many other MEMS process capabilities.

Although we have been focused primarily on prototyping applications where each process sequence is customized by the developer, we believe that many of the features of the program may be transferable to the manufacturing domain as well. In particular, we are pursuing the strategy whereby the foundries offer process modules (a fixed series of well characterized and reproducible processing steps) that can be assembled into a complete process technology. This approach may enable flexibility in the process sequence while simultaneously achieving quality control and low cost.