Japanese Technology Evaluation Center

JTEC

JTEC Panel Report on

MICROELECTROMECHANICAL SYSTEMS IN JAPAN

Kensall D. Wise, Chair
Joseph M. Giachino
Henry Guckel
G. Benjamin Hocker
Stephen C. Jacobsen
Richard S. Muller

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EXECUTIVE SUMMARY

BACKGROUND

This report summarizes recent activities in the development of microelectromechanical systems (MEMS) in Japan. It has been prepared under the sponsorship of several U.S. governmental agencies and under the auspices of the Japanese Technology Evaluation Center (JTEC). The report is felt to be particularly important at the present time because of the high potential impact of this emerging field on many areas critical to national needs, including health care, industrial automation (including automated semiconductor manufacturing), automotive systems (both vehicles and smart highways), global environmental monitoring, environmental controls, defense, and a wide variety of consumer products. It is also important because of the many contributions Japan has made to this area in the past and its aggressive commitment to its future. The report will summarize important recent technological progress in Japan in MEMS and approaches being taken there to overcome the remaining challenges confronting this area. While, as should be expected, there are many similarities to the general nature of programs in the United States, there are also some important differences, particularly in approach and emphasis; these are discussed in some detail. The views expressed here are necessarily those of the panel members alone, but are nonetheless thought to accurately reflect the current situations in Japan and the United States, both in academia and in industry.

For the purposes of this study, "MEMS" means batch-fabricated miniature devices that convert physical parameters to or from electrical signals and that depend on mechanical structures or parameters in important ways for their operation. Thus, this definition includes batch-fabricated monolithic devices such as accelerometers, pressure sensors, microvalves, and gyroscopes fabricated by micromachining or similar processes. Also included are microassembled structures based on batch-fabricated parts, especially when batch assembly operations are used, but the study does not focus on individually-fabricated devices that are unlikely to see wide use. It is expected that electronic signal processing will exist in most future MEMS, which implies that they will be composed of sensors, actuators, and integrated electronics. Trends to increasing levels of integration are driving toward realization such devices as monolithic chips or multichip modules. These microsystems will be critically

important as they extend microelectronics beyond its traditional functions of information processing and communications into the additional areas of information gathering (sensing) and control (actuation). Semiconductor Equipment and Materials International (SEMI) has estimated that the world market for MEMS devices could reach $8 billion by the turn of the century. This does not count the much larger markets for finished products that could be leveraged by the price/performance advantages of MEMS devices incorporated into such products.

New materials and processes such as LIGA (see Glossary, Appendix E, for definition) were also an important part of the study, along with testing, packaging, and many issues associated with the design and developmental infrastructures needed for MEMS. Image sensors, chemical sensors, and purely thermal or magnetic devices, however, are not covered specifically in this report even though they are often based on technology and generic microstructures developed for MEMS and are often lumped under this acronym.

APPROACH

In conducting this study, activities in MEMS were divided into the following six areas:

- Advanced materials and process technology
- Sensors and sensing microstructures
- Microactuators and actuation mechanisms
- Sensor-circuit integration and system partitioning
- Advanced packaging, microassembly, and testing technologies
- MEMS design techniques, applications, and infrastructure

A total of seventy-four specific questions covering these six areas were prepared and mailed to twenty-three organizations in Japan (five government agencies or laboratories, six university laboratories, and twelve industrial sites) that were known to be working in MEMS-related areas and were felt to represent a cross section of current activity there. The questions were intended to raise important issues as a framework for subsequent discussions. In some cases, they were addressed specifically in the ensuing site visits in Japan, while in others the answers became apparent through formal and informal discussions that occurred on site. The panel spent one week in Japan visiting these twenty-three organizations (listed under Appendix C in the Table of Contents).

CONCLUSIONS

Table E.1 summarizes the JTEC panel's qualitative comparisons of Japanese MEMS R&D and applications activities with those in the United States.

The other principal conclusions of this study can be summarized as follows:

- Overall, Japanese industry is emphasizing approaches to MEMS that are similar to those taken by U.S. industry. These efforts are primarily based on silicon integrated-circuit technology and are focused on sensor applications. Japanese industrial capabilities in these areas are comparable to those in the United States.
- Substantial efforts to develop microactuators, microelectromechanical systems, and micromachines based on advanced lithographic processes exist in both countries. The United States is perceived to have the lead in these areas and in sensor-circuit integration, although the Japanese programs are quite competitive, especially in realizing commercial products.
- Research efforts on MEMS in Japanese universities are generally less well equipped than their U.S. counterparts and involve a more diverse array of approaches and processes. While university research is one of the real strengths of MEMS in the United States, the research potential of Japanese universities is probably underdeveloped and underutilized.
- Japan is perceived to lead in nonlithographic approaches to MEMS, although it is not clear that such approaches can achieve the batch-fabrication and compatibility with electronic signal processing that most high-volume applications would appear to require.
- The ten-year large-scale ($250 million) MITI-sponsored program in micromachine technology (formally titled the Micromachine Technology Project) emphasizes the miniaturization of more traditional (nonlithographic) machining processes and involves projects chosen to complement efforts already underway in industry. This program involves twenty-four Japanese companies, many of which have larger ongoing internally-funded programs in MEMS-related areas. Still other Japanese companies are strongly involved in MEMS, but do not participate in the MITI program. MITI is encouraging participation by foreign companies in its micromachine technology program, which currently has one Australian and two U.S. participants.
- Packaging technology is application-specific and is considered a major challenge in both countries. Japanese efforts in low-temperature wafer-to-wafer bonding are applicable to the realization of wafer-level device encapsulation/packaging as well as to the creation of advanced batch-fabricated microstructures.

- The infrastructures for MEMS development in the United States and Japan are different, but both are effective. Strengths of the Japanese efforts include the relatively high involvement of industrial residents at Japanese universities and the ability in Japan to set long-range goals and establish multidisciplinary multiorganizational teams to accomplish them.

TABLE E.1
Japan Compared to United States in Microelectromechanical Systems

	R & D		Applications	
	Status	Trend	Status	Trend
Advanced Materials & Processes				
lithography-based	—	⇑	o	⇒
non-lithography-based	+	⇑	+	⇑
Sensors & Sensing Microstructures	—	⇒	o	⇒
Microactuators				
lithography-based	—	⇓	—	⇓
non-lithography-based	+	⇑	+	⇑
Sensor-Circuit Integration &				
System Partitioning	—	⇒	o	⇒
Advanced Packaging, Microassembly,				
and Testing	o	⇑	o	⇑
Design Techniques	o	⇒	o	⇒

Legend:

+	Japan now ahead
o	Japan and U.S. now about even
-	Japan now behind
⇑	Japan gaining ground
⇒	Japan and U.S. progressing equally
⇓	Japan losing ground

Microelectromechanical systems promise to lead microelectronics into important new areas that will be revolutionized by low-cost data acquisition, signal processing, and control. These microsystems are expected to have a profound impact on society, but their development will require synergy among many different disciplines that may be slow to develop. Global leadership and cooperation will be required to realize the benefits of MEMS in a timely way. This report examines recent activities in Japan in tackling these problems and contrasts them with U.S. approaches and perceptions. In so doing, the authors hope that the report will further the development of the field to hasten the utilization of MEMS by the global community.