CHAPTER 4

FOUNDRIES AND INFRASTRUCTURE

David J. Monk

INTRODUCTION

Before discussing the foundries and infrastructure in place in the Japanese MEMS industry, it is instructive to describe the industry's background in Japan. There are two important points about the semiconductor industry that have influenced Japanese MEMS infrastructure. First, business has become much more global. The last WTEC (formerly JTEC) review of the Japanese MEMS industry was completed in 1994 (Wise et al. 1994) following a decade of nationalistic dominance in the semiconductor industry by Japan. However, the decade of the 1990s saw much more global business. Many corporations are multinational, especially in Asia, North America, and Europe. This expansion of business has changed the way international business and technology are developed.

Second, the industry jargon reflects the origin and focus of the technology. In Europe, the industry is generally called "Microsystem Technologies" (MST). In the United States, it is "Micro-Electro-Mechanical Systems" (MEMS), while in Japan, it is called "Micromachines." The subtle difference, especially between the United States and Japan, results from the roots of the industry. In Japan, initially, micro- and milli-machining were developed in response to the Micromachine Technology Project and were largely started in the mechanical engineering field. In the United States, MEMS technology was developed, at least initially, mostly by electrical engineers from the semiconductor industry. A decade has made the topic much more cross-disciplinary, but the beginnings have affected the thought process and infrastructure that has developed.

This section on foundries and infrastructure is divided into two major areas: the first on technical development infrastructure and the second on business development infrastructure. Further subsections are meant to illustrate functional areas that are required for product development with MEMS- or micromachine-based products.

TECHNICAL DEVELOPMENT INFRASTRUCTURE

MEMS product development includes a significant amount of technical infrastructure from design to fabrication and packaging/testing. The following section describes progress in the Japanese MEMS industry in each of these functional areas.

Design and CAD Tools

The design methodology throughout the global MEMS industry, and Japan is no exception, still tends to be ad hoc. This is especially true when contrasting this process to the design of an IC. Typically, an IC design process would include: architecture development, architecture (or high-level) modeling, specification definition, process parametric model extraction, library development and tool establishment, schematic development, target simulation, “corner” simulation (or sensitivity analysis), floor planning, layout, verifications (layout vs. schematic, design rule check, etc.), mask preparation, and silicon/simulation validation. Depending upon the sophistication of the design effort, these process steps may also be repeated multiple times or omitted, if re-use is being followed.

However, in the MEMS industry, in general, architecture development usually occurs through trial-and-error. Specifications may not include all required parameters as a result of inexperience with a particular device. Furthermore, there is very little mechanical material property parametric analysis, and few good mechanical parametric libraries are in use. Layout is a very manual process, and validation of the design including feedback to future design process is not systematic. There is evidence of use of CAD tools within the industry in Japan, as there is in the United States. For example, during the development of the Omron pressure sensor, finite element analysis (FEA) was used extensively (Horiike et al. 2001). Finite element analysis was used to analyze the impact of adding a post to the center of a diaphragm. The goal was to minimize the effect of nonlinearity by providing more consistent average deflection across the diaphragm (Fig. 4.1).

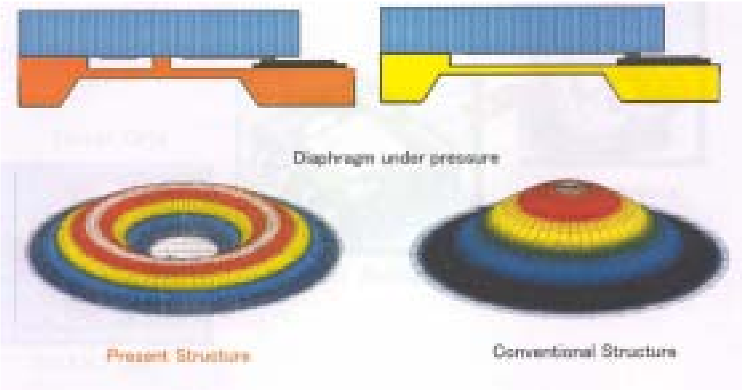


Figure 4.1. Omron finite element analysis on an absolute pressure sensor. The goal was to provide better linearity performance for the device (Horiike et al. 2001).

Other groups also used FEA tools: in addition to Omron’s use of ANSYS, Waseda University was using ANSYS and Coventor, and Toyota Central Research and Development Labs (CRDL) was using NASTRAN.

Toyota CRDL collaborated with several U.S. groups in an NIST-sponsored round robin to evaluate polysilicon fracture strength. Figure 4.2 shows an example of the structure Toyota CRDL is using to make the measurements.

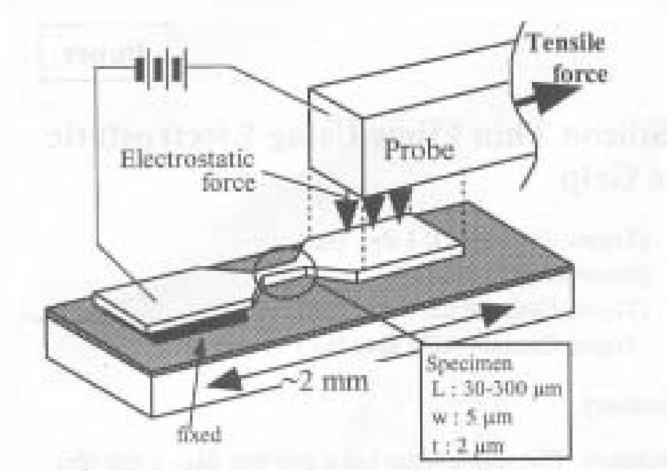


Figure 4.2. A dog-bone-shaped polysilicon fracture strength test structure being used by Toyota CRDL to provide some material property data on polysilicon for the design process (Tsuchiya et al. 1996).

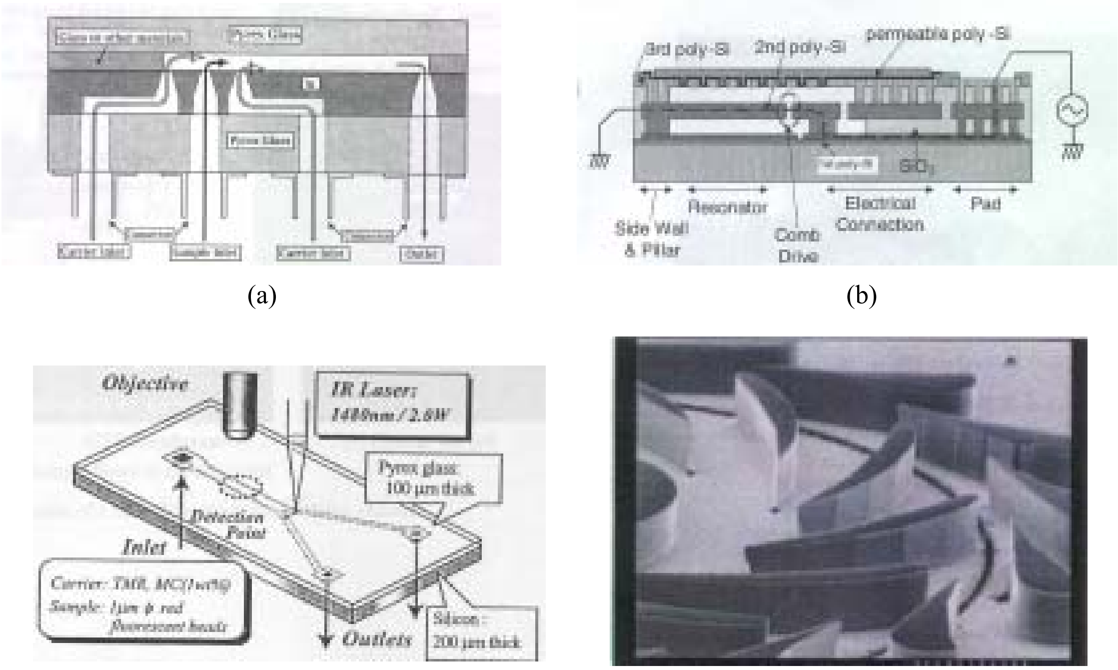
However, there is very little evidence of an integrated design flow that includes tools to go from architecture development to silicon. The MEMS design process being used in Japan, and in the United States to a large extent, appears to be a "build and test" approach.

MEMS Fabrication Technologies: Development and Production

Perhaps because mechanical engineering has influenced the MEMS industry in Japan, the processes being evaluated for MEMS and Micromachine applications are varied and much less silicon-centric than in the U.S. MEMS industry. Figure 4.3 shows four figures that exemplify this.

The so-called "standard" MEMS processes of bulk micromachining (Fig. 4.3a) and surface micromachining (Fig. 4.3b) are in practice in Japan. In Figure 4.3a, Waseda University is using bulk micromachining and wafer anodic bonding to create a microfluidic cell. In Figure 4.3b, Toyota CRDL is using three-layer polysilicon surface micromachining to produce an angular rate sensor.

However, the Japanese appear to be much more willing to explore non-standard semiconductor processes and materials. Figure 4.3c is an example of a polymer being used in microfluidics. In this case, the gel material is embedded within the fluidic channel. Upon irradiation from a laser, the gel goes through the gelation phenomenon, which blocks the fluidic channel, thus allowing a fluidic switch. Furthermore, Figure 4.3d shows an example of the use of a ceramic material for ultra-high temperature applications. In this case, Tohoku University is using sintered silicon carbide to create a micro-combustion engine.



(a) (b)

(c) (d)

Figure 4.3. A variety of MEMS materials and processes are in use in Japan. (a) Bulk micromachining and wafer bonding (Tashiro et al. ND); (b) Surface micromachining (Tsuchiya et al. 2001); (c) Polymeric materials exhibiting the gelation phenomenon during operation (Tashiro et al. 2001); and (d) Sintered ceramics for high-temperature applications (Tanaka 2000).

Additional details that show the variety of technologies used in the Japanese MEMS industry will be presented in Chapter 6. Ultimately, as a result of the mechanical engineering influence on Japanese MEMS/micromachining industry in contrast to the semiconductor-based electrical engineering approach that is used in the United States, solving product development problems by employing a variety of processes and materials is more flexible.

Interface ICs, System Partitioning, and Integration

There was very little discussion of interface analog or mixed-signal ICs used with MEMS-based products in Japan. Omron discussed the value of surface micromachining and CMOS integration as a way to improve return on investment and presented the Analog Devices ADXL series of accelerometers as an example. Murata discussed their plans to integrate multiple (inertial) sensors into a sensor cluster device. Their approach, however, was not through integration on silicon but through a system-in-package.

There were, however, several instances where MEMS was used as the “golden screw” for a product. For example, the Olympus laser-scanning microscope (LSM) utilizes an optical MEMS-based scanner. Figure 4.4 shows the levels of integration and system partitioning used to create this LSM.

(a) (b) (c)

Figure 4.4. The Olympus laser-scanning microscope (LSM): an example of a MEMS-enabled product. The MEMS device is a very small portion of the system cost, but it provides the capability for the equipment to function (Katashiro et al. 2000). (a) The optical MEMS device. (b) The packaged scanner. (c) The Olympus OLS1100 LSM.

Other examples of MEMS-enabled products include some of the features on the Sony Aibo dog. This toy can right itself after falling over as a result of the MEMS gyroscope that is embedded in the product. Also, Hitachi uses some microfluidic devices to enable a water-filtering product.

Research and Development Facilities

Several types of MEMS research and development facilities can be found in Japan. Companies like Murata, Toyota CRDL, and Omron use a centralized R&D lab for their development work. There are industry-academic collaborations, including Waseda University and Olympus in microfluidics and Tohoku University and a variety of companies. Tohoku University is employing a “slim” philosophy to acquire tools for lagging edge technology (3”) and yet maintain close to state-of-the-art tools. This augments their older labs where homemade equipment is plentiful. Other new R&D facilities have appeared at the University of Tokyo IIS and are planned at Waseda University and Ritsumeikan. But, the mainstays in Japan for academic R&D facilities are “drop in” fabricating labs (fabs) that are built within existing buildings. The most telling example of this was a broom closet that had been converted into a photolithography room at Waseda University. The Japanese appear to be much more willing to “build their own” than Americans. Perhaps this is because the American MEMS industry emerged from the semiconductor industry where industry-standard tools were already present. Instead of buying tools, the Japanese are willing to build them. The Japanese tend to espouse the philosophy that we saw under a homemade reactive ion etch system in the old fab at Tohoku University: “don’t worry just try.”

Foundries: Development and Production

Foundries for MEMS have been slow to develop within Japan. In the United States, it was recognized much earlier that foundries were essential for the commercialization of MEMS products. This may, again, be the result of the U.S. MEMS industry emerging from the semiconductor industry where the foundry-culture had already been established. In the “job shop” mechanical engineering culture is much more prevalent. Nevertheless, the Japanese are realizing the need for MEMS foundries: to minimize long development cycle times, to maximize return on investments, and to improve the innovation process by providing facilities for manufacturing development devices. While some foundries are being established in Japan, there still is a need for a foundry infrastructure organization to direct use to the appropriate foundry facilities (e.g., like the MEMS Exchange in the United States). Professor Sugiyama of Ritsumeikan University is starting a company poised to provide such a service.

Several notable foundries have begun service in Japan for the MEMS industry. Omron is advertising the capabilities shown in Figure 4.5. This fab has been in place since 1975 and employs 230 people with separate capability for bipolar and MEMS. The strategy at Omron with this fab is to fill the existing capacity and "harvest" benefits from the established bulk micromachining capabilities that are used to produce pressure and acceleration sensor products today (Fig. 4.6).

We have started MEMS Foundry Service.
We can meet your needs for both silicon & Glass wafer Processing of MEMS devices.
We are equipped with a 4" wafer fabrication facility.

Processes for Foundry

Design → Silicon Process → MEMS Process → Dicing → Mounting → Inspection

- Anodic Bonding
- Electrical Chemical Etching
- Vapor Deposition
- Photolithography
- Etching
- Sputtering

Figure 4.5. The Omron foundry service for MEMS (Horiike et al. 2001).

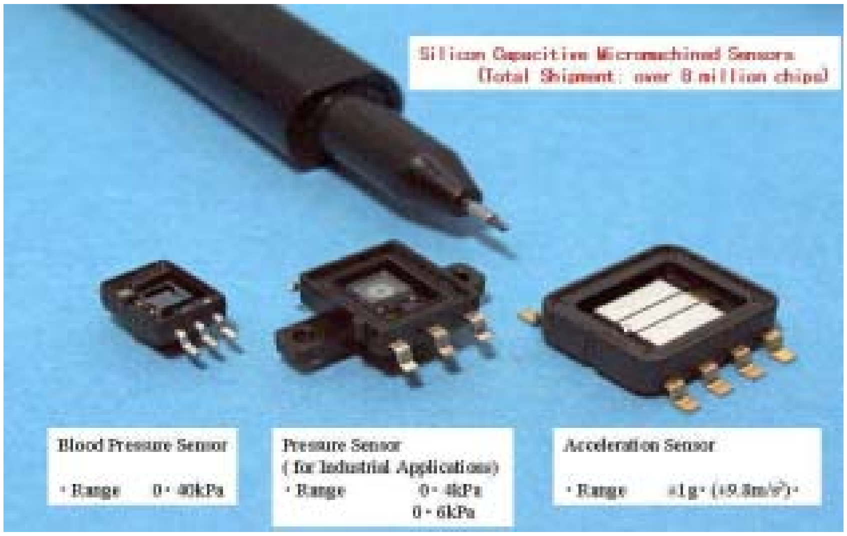


Figure 4.6. The Omron foundry strategy is to augment production demand that is also being used to produce these pressure sensors and accelerometers (Horiike et al. 2001).

Similarly, Olympus just announced their 4" foundry service at the Micromachine Exhibition in Tokyo from 30 October to 2 November 2001. They, like Omron, are interested in augmenting production demand. At present, their MEMS fab produces small volume production for optical MEMS devices (e.g., for the LSM).

However, unlike Omron, Olympus is advertising a “turnkey” operation that will include design, prototyping, and production. Production capability includes the following: project aligners, I-line steppers, double-sided aligners, thin film deposition, electro-plating, dry etching—including DRIE, wet etching, wafer bonding, testing, and packaging.

Other MEMS foundries in Japan that were not visited explicitly but were discussed with users during the site visits, include the following:

- Sumitomo (6” surface micromachining)
- Dai-Nippon Screen Printing (surface micromachining)
- Yokogawa (surface micromachining)
- Sony USA-San Antonio (http://www.foundry.sony.com/default.shtml: 6” MEMS-capable facility for surface, bulk micromachining)
- Ritsumeikan (LIGA)

Also, several groups remarked on the development of MEMS foundries within Taiwan.

Finally, although the Japanese are following the lead of the United States and Europe and developing MEMS foundries, there is a capability that the United States (and possibly Europe) could follow the lead of Japan in developing: specific, low-cost, fast turnaround plastic microforming and similar job shops. Several of these small companies in Japan are becoming much more available for work as the keiretsu groups become more loosely organized.

Backend Technologies: Package, Test, and Reliability

Backend technologies tend to be much more proprietary within the global MEMS industry. It has been well documented that MEMS devices must be designed in concert with their packaging because packaging can affect device performance. This appears to be recognized in the Japan MEMS industry as well; hence, few are willing to discuss details of these processes. Nevertheless, a couple of new techniques were described for packaging MEMS. Murata is using a vacuum packaging technique that includes sandblasting through anodically bonded Pyrex to create vertical feedthroughs. It is also considering multisensor packaging to create inertial sensor clusters. Moreover, the University of Tokyo IIS is performing work on interconnection enabled by micromachining techniques. Figure 4.7 shows an example of a “rack” of silicon-based devices that are interconnected in a process akin to circuit-board packaging.

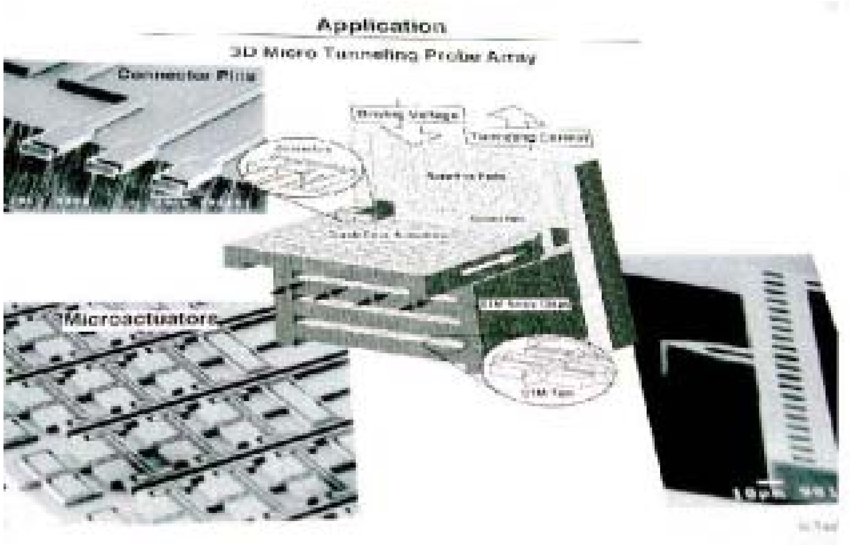


Figure 4.7. A packaging technique for mounting multiple silicon devices together that is enabled by micromachining techniques (Berlin et al. 2001).

While there is little published about MEMS packaging, even less is published about MEMS tests and/or reliability. The conclusion that is drawn about this is that most companies, like those in the U.S. MEMS industry, typically keep this technology proprietary, e.g., as a trade secret.

BUSINESS INFRASTRUCTURE

Product development and commercialization involves an equally elaborate business development infrastructure. This section will describe some of that business infrastructure. It does not go into details on business operations, marketing, and sales, as those are left for such conferences as the series "Commercialization of Microsystems" to address.

Funding Sources

Funding sources for R&D in Japan are varied, but they include the notable absence of venture capital funding. Few startups exist in Japan, so R&D funding is generally either based in large companies and funded internally (e.g., Hitachi, Sony, Murata, Olympus, Omron); a joint company-academia arrangement (e.g., Tohoku University and Toyoda Machine Works and their ISFET development or Tohoku University and Ball Semiconductor and their spherical 3-axis accelerometer); or government-based (e.g., through the Micromachine Center/Micromachine Project or through Prefecture Funding). Two substantial differences in government funding regulations in Japan are that Japanese R&D funding is not used for funding students and that approximately 90% of it can fund facilities. This is contrary to the approach in the United States where government funding cannot be used to fund facilities, and it is used to a large extent to fund students.

International Interactions

As was mentioned in the introduction to this section, international collaborations are much more prevalent in 2001 than they were during the late 1980s/early 1990s. Two significant categories of international interactions were identified. The first are marketing arrangements. For example, Wacoh out sources much of its sales and marketing functions to the MEMS manufacturer with whom it out sources its production. Wacoh is actively seeking global partners (especially in the United States) for similar arrangements. Other groups, like Omron, are multinational corporations that have significant sales and marketing presence in the United States already.

A second type of collaboration is on the academic level. The former Mechanical Engineering Labs in Japan is currently hosting several researchers from outside Japan (China, Korea, and Singapore, to note a few). Also, Professor Fujita et al. at the University of Tokyo have developed a Center for International Research on Micromechatronics (CIRMM) with CNRS in France. In fact, several professors commented that they add to their research core with industrial employees from around the world (e.g., Prof. Esashi at Tohoku University has researchers from Germany at present). It was notable, however, that during the 17 site visits, we did not notice any U.S. researchers in the Japanese labs.

Intellectual Property

Intellectual property is becoming a much more important factor in commercialization, both in the academic ranks and in the MEMS industry. Several universities that were visited are initiating technology licensing offices. Among those that are starting this practice are Osaka University, Tohoku University, and Waseda University. It is likely that others will follow suit. This is a direct result of following the lead of U.S. universities that began this practice in the 1980s.

Nevertheless, groups like Tohoku University state very clearly that they have an "open" policy for IP sharing. At places like Tohoku and University of Tokyo IIS, the unwritten policy appears to be for industrial researchers to file background IP prior to beginning their tenure on campus. Any IP that results from their work at the university is jointly held by the company and university.

A unique company in Japan today is Wacoh. First, it is a startup, which is rare in Japan. Second, the business model that is followed is one that relies on intellectual property. Wacoh's business performance, which has always been in the black, includes revenues from licensing, outsourcing of manufactured products, and royalties. The business was set up specifically for this purpose. The proprietor, Okada-san, started the first phase of his business by obtaining more than 100 patents. Once these were in place, he began working with outsourced manufacturing sites to develop products. This is one example of a U.S.-style start-up. When asked why there are not more such businesses in Japan, Okada-san recited business laws in Japan that state that one's personal finances are not completely separate from corporate finances. So, corporate bankruptcy also means personal bankruptcy. Furthermore, personal bankruptcy results in the loss of some civil rights, like the right to vote.

Standardization and Information Exchange

As in the United States, there are very few MEMS standards in Japan. As described earlier, there is even a wider range of fabrication technologies and several small-volume niche markets. And, backend processes are generally considered proprietary, so they are not usually open for standardization discussions. Nevertheless, the Micromachine Center has recognized this issue and has dedicated part of its resources to promote standardization. In fact, standards for thin film materials testing methods are being proposed during 2002, following a three-year exercise on the subject. Detailed information can be found at the MMC website: http://www.mmc.or.jp/ (Thin Film Testing Methods, MMC TR(S001)).

The Micromachine Center is also responsible for some information exchange efforts, including conferences (the Micromachine Summit and the International Micromachine Symposium) and the elementary school Micromachine Picture contest that is intended to develop awareness among the younger generation about the importance of this technology.

There is a society for MEMS in Japan as well. The IEE Sub-Society on Sensors and Micromachines has 1500 Members, 400-500 of whom attend an annual symposium sponsored by the society. Membership is not restricted to Japanese. There are some non-Japanese members (mainly Koreans), and 60% of the papers are in English.

Several universities are developing MEMS coursework (including Waseda, the University of Tokyo, and Tohoku University). This includes both undergraduate and graduate courses on MEMS.

Finally, MEMS/micromachining museums exist at two locations, in Tokyo and at Tohoku University.

CONCLUSIONS

The Japanese have done a very good job at promoting the field through primary and secondary school education programs and museums. Both the Micromachine Center and the IEE have organized MEMS/micromachining conferences in Japan. Moreover, academic institutes are developing MEMS undergraduate and graduate level courses and are training industry personnel as well as students.

As has been described, the Japanese have a wider view of processes and technologies, probably because of their mechanical engineering roots in MEMS and micromachining. Because of this wider view, the Japanese researchers are more willing to use milli-machining and rapid prototyping methods than their U.S. counterparts. However, several researchers visited recognized the need to drive standards in this industry. worldwide. There are too few standards, so the cost of production for MEMS/micromachined devices has been negatively affected. Furthermore, in Japan, a "build and test" approach exists in the design of MEMS/micromachined devices, and there is very little exposure to MEMS packaging, test, and reliability.

Foundries are beginning to emerge in Japan. The typical goal is to augment production demand in existing facilities. Both Omron and Olympus cited this during our visit. Other companies and universities, including: Sumitomo, Dai-Nippon Screen Printing, Sony USA—San Antonio, and Ritsumeikan, are also now offering foundry services. The coordination of foundries (i.e., similar to the MEMS Exchange) has not yet developed but is being pursued by the former Mechanical Engineering Labs (now, ISEMI) in Japan.

The Japanese have also developed several international collaborations, especially with Asian and European groups. During the visit, we did not encounter any American researchers in the Japanese labs. Our belief is that this could be beneficial, as it would provide an American a broader view of the technology, as well as language and cultural training.

A clear future trend for Japanese MEMS/micromachining is toward the MicroTAS/Microfluidics application. We encountered several groups tailoring their research to this field and heard several times that the next government initiative in MEMS would likely be in this area.

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