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Status And Future Of Microsystems / MEMS Foundries

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Executive Summary

This chapter provides management of Microsystems foundries as well as their users assistance in their decision making process. We aim to assist designers in finding appropriate "Fabs" early in their device development phase, help foundries understand the direction of technology, and provide trends in fab construction and conversion. For example, it is comparatively easy for the MEMS designers to find prototypical foundry services. But, there remain prerequisites to finding a reliable path from product concept to commercializable volume.

The contributors to this chapter recognize that the cost involved in changing fabs or processes (see MEMS/MST Cost Modeling chapter), in both time and money, is enormous. A barrier for MEMS manufacturing is the difficulty of creating and maintaining cost-effective fabrication facilities for low volumes that can facilitate also high volumes. Another barrier is time needed to transform university developed processes into industrial ones. The drive to design for performance instead of design for manufacturability is helping to get customers interested, but is also delaying industrialization.

MEMS processes are still an emerging and disruptive process technology with many application specific technology choices. However, as discussed in both the Non-IC and the IC-like processing chapters the trend is toward concentration on fewer but more robust manufacturing. Further, dominant MEMS manufacturing technologies, in many application spaces, are still to be determined. If not the full process, some process steps are becoming more standard. Yet standardization does not exist to any great breadth or depth (Standards chapter). Therefore, MEMS manufacturers must be prepared to deal with multiple substrate materials of various shapes and sizes, as well as supporting multiple process technologies, some of which have little or nothing to do with traditional semiconductor technologies.

Here we also state that the cost of any new MEMS foundry infrastructure is very high and the trend is for that cost to continue to increase. Fortunately, last-generation IC foundries can be used for fabricating present-generation MEMS for IC like process technologies and this has contributed to a larger trend for existing semiconductor fabrication facilities to move to MEMS facilities or dual facilities providing both semiconductor and MEMS based processes for commercial and internal customers. However, as MEMS devices mature, becoming more complex, many contributors foresee more MEMS specific foundries offering unique process capabilities. The roadmap contributors suggest a model similar to the fabled semiconductor concept. Two scenarios will potentially evolve, (1) independent design/development companies will act as liaisons between the MEMS end users and the foundries, and/or (2) foundries will offer integrated product development services by providing turnkey design/development capability as part of the front-end process support, pushing the industry closer to its standards. In the Design Simulation and Modeling (DSM) chapter, contributors provide a short discussion on methods that current foundries and MEMS DSM suppliers are using and suggest future trends.

However, this is still not the case, and many examples show that the foundry customer relation is still more a partnership relation then a straightforward customer-supplier relation. The contributors to the Foundry chapter also have recognized a number of trends. First, there has been a continuous growth of companies offering foundry services in MST/MEMS for the last 5 years. Of the MST/MEMS foundries identified in 1999, only half of them are currently offering similar services. Half of the ex-foundries however are still in existence today, but concentrate don other activities. The gab has been filled by new entrances, partly by the conversion of semiconductor to MEMS foundries, attracted by the increase of volumes transferred to reaming foundries and partly driven by demand from their customer base. Finally, there is a large trend to embrace some sort of quality standards. This is a natural outgrowth, in that there is a rush to embrace quality standards for MEMS manufacturing facilities. Practically all foundries already having some sort of ISO 900X certification or are in the certification process.

In the early days of MST, the foundry concept came up as a way to lower the barriers of bringing a design to market. This is still a viable concept. The market is dynamic, as can be expected in this fast growing segment, and there are forces pulling foundries into the captive market; i.e., the success of their own products or the “IP Hunger” of larger companies. However, now interesting commercial opportunities are bringing new players into the field. The number of foundries is growing, especially in the Far East.

There are 5 categories of foundries:

1) University originated, mostly research oriented and/or SME
2) Smaller semiconductor companies offering MST service for balancing the capacity
3) Larger semiconductor companies offering MST to protect the customer base
4) Smaller non-semiconductor companies offering MST service for balancing the capacity
5) Pure foundries

In particular it is categories 2 and 3, semiconductor companies, which are growing in number.

There are other signs of maturation of this industry. There is now much more attention to quality and production professionalism compared to the early days of MST. The foundries are also concentrating more on smaller areas of technology and marketing. This focus will deepen and improve the technology base of the foundries. This trend is supported by the rising attention of the larger equipment suppliers to the needs of the MEMS market.

1 Introduction

Why does the evolution for microsystem-based devices to become products take so long? This is one of the questions often asked of the microsystems community. Previously, an infrastructure model for discontinuous MEMS innovations was outlined (Walsh, 2001). The four stages identified are:

1) In the initial stage, MEMS based technologists utilize existing techniques optimized for microfabrication to produce expensive products of limited utility, while the market channels are not yet existent. Large corporations and government funding agencies must coerce potential suppliers into manufacturing items they need or obtain required products through internal R&D.

2) In the second stage, the industrial manufacturing begins and initial market acceptance is seen. The pilot or limited production of product results in modifications to existing manufacturing equipment. Market channels widen spin-offs from institutes, universities and large companies appear.

3) In the third stage, the techniques are designed to optimize the characteristics of the technologies resulting from the discontinuous innovation. Market channels increase and widen as variations of the same product are applied to the same market and the same product is introduced into different markets. Industry newsletters and dedicated representative organizations appear. The rising demand for MEMS technologies will result in capital equipment suppliers and vendors

entering the market. The entry of these suppliers and vendors will allow firms that do not have the capability to produce capital equipment, raw materials, and other consumables to enter the MEMS market.

4) The fourth stage shows the maturation and stabilization of the technologies and the new markets emerging.

This model helps to understand the "How Long" question by demonstrating where it is that the time lag is occurring for each techno-industrial stage of commercialization awaiting on the road to full commercialization. The microsystems industry finds itself challenged across stages two, three, and four of the infrastructure model. (See Commercialization Chapter.) This chapter provides a brief history of today's status of microsystems manufacturers, who act as general suppliers to OEM MEMS foundries. It complements earlier initiatives to describe the development of the MEMS infrastructure (Elders and van Heeren, 1999) by providing an overview of the elements forming the infrastructure; manufacturers and their technologies, products, volume, capacity, performance limits, quality procedures; and markets. Based on this overview, a better understanding of the current status of the new entrants, mergers and acquisitions, and directions within the microsystems industry can be obtained.

The reader should be aware that the terms fab and foundry refer to the facility that actually manufactures the MST/MEMS (or semiconductor) devices. While often used interchangeably, the distinction appears to be one of "Captive" versus "Merchant." A **"**Fab**"** *produces devices for internal use,* whereas a "Foundry" *also produces devices for others* on a contractual basis. Thus a "Fabless Vendor" or "Fabless Business Model" of MST/MEMS devices has no fabrication (production) facility of its own, but procures its product from a separate foundry. This summary uses “Fab” as a generic term meaning “Fabrication Facility.” “Foundry” is employed when referring to a fabrication facility doing merchant production (Gulliksen, Gaboriault, and Aylward, 2000).

The research effort was lead by Henne Van Heeren and our chapter leadership team. The data was gathered through expert interviews, e-mail enquiries, public sources and the MANCEF roadmap team. The manufacturers are compared on different aspects of their business, specifically their background and financial structure; their technologies and technical core competencies; their quality systems; and the market/technology areas they cover. The results are based on the four surveying rounds (1999 – 2003) and partial results from an ongoing fifth round.

2 Foundries and the Market

The reasons for customers to rely on foundries can be quite diverse. These may range from purely economical reasons (investments, costprice) to technical drivers (availability of required technology). The desire to have a second source of supply can also be a reason for outsourcing. Foundries aim at achieving economy of scale by combining several customer orders into volume production. Volumes are necessary, not only to reach the required competitive costprices, but also to reach the needed technical competence level.

Products aiming at very large market segments can reach sufficient high levels of production volumes to be able to sustain dedicated factories. In such cases, captive supply is possible, although outsourcing is still an option as can be seen in the magnetic head markets, where non-captive suppliers operate. The most striking examples are inkjet heads (>435 M heads per year) and magnetic heads (>1.5 B heads per year). Also pressure sensors and accelerometer producers can afford own facilities to produce the quantities demanded (several millions per year).

The cross over point, where building a facility becomes a realistic option, can differ significantly depending on technology complexity, numbers and market value. Also history plays a role, where companies with experience in the production of a device and having established facilities and equipment, will tend to achieve captive production. On the other hand, companies not having a Micro- or Nanotechnology history will tend to outsource. Even if there is a clear case for cost effective outsourcing, there can still be reason to produce in house:

1) Sometimes the MST/MEMS product forms the core of a system, which therefore has a high added value. The system supplier can then bear the burden of the relatively ineffective production facility where the relatively high costprice is hidden within the total system cost.
2) Also, when the production process is very specific, transferring the micro products to a foundry can be too risky or too expensive.
3) Finally, this may happen if the OEM wishes to control the production chain for security reasons.

2.1 Problems Encountered by Foundries

Although the foundry model has proven it self in the semiconductor industry, where it's share of the total market is continuously increasing, it has been criticized heavily in the MST/MEMS community. Not without reason. Many of the companies offering foundry services have forced to change policy or have been disappeared completely. Still we see some of them having success and as a result each year we see new entrants filling the gabs. Therefore the number of companies that offer those services has increased (see figure 1). Even though our 2004 investigations are still ongoing at the time of this publication, there are indications that the growth is slowing down.

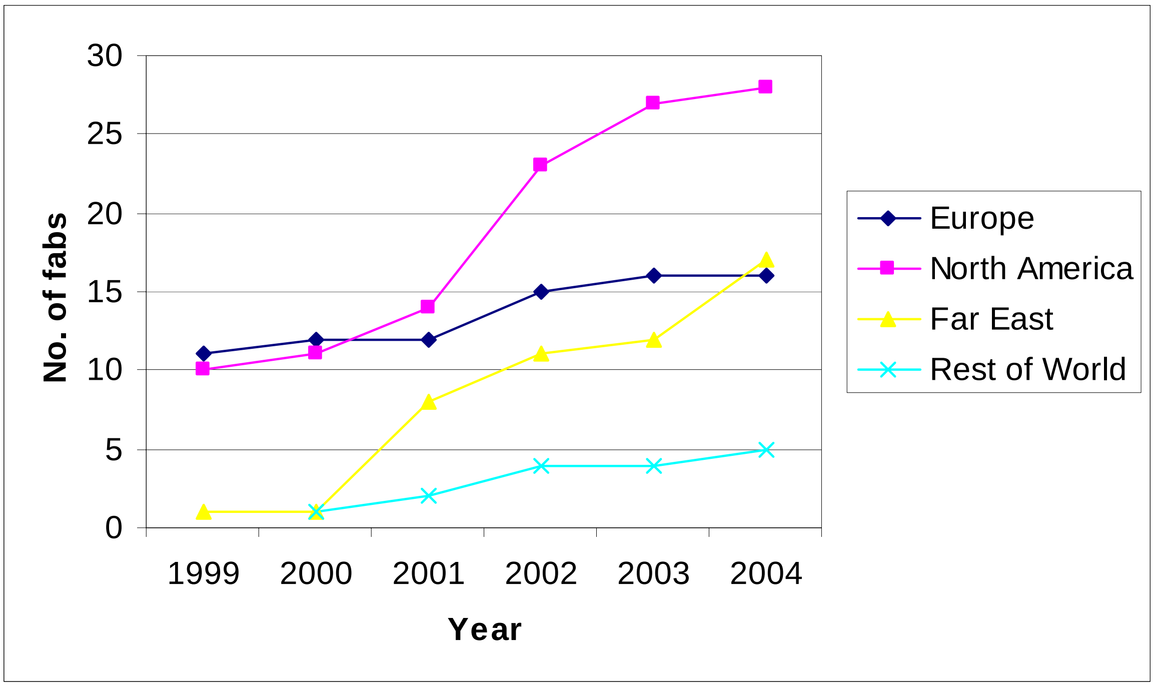

Figure 1: Increase in number of foundries worldwide

Most of the MST/MEMS foundries in existence today are located in the USA, although the share of the Far-East is continuously increasing. Europe foundries, initially leading the market, encountered many difficulties, and many of them disappeared.

Foundries encounter many problems of which the lack of standards, caused by the diversity of MST/MEMS products is a major one. In essence, this difficulty forces foundries to broaden their technology base, making it extremely difficult to reach economies of scale and meet the necessary high quality levels. The same low volumes offers small development oriented suppliers and universities to the possibilities to compete with them on the bottom of the market.

Another problem is to identify at which phase of the commercialisation lifecycle one should start transferring the production process to a foundry. Doing so too early has the following disadvantages:

1) A less cost effective development, due to the higher cost of foundry processing compared to the cost of small scale production in a development surrounding
2) Frustration; as foundries do not appreciate changes in the process and products they have set up whilst customers demand flexibility in the pre market introduction phase to optimise the product
3) The failure of the product which will sour the foundry/design house relation; while the foundries have invested in the set up of new production technologies and equipment, without having the benefits of production revenues.

Alternatively, transferring the process to commercialisation too late can lead to:

1) A situation where the developed product relies on technologies unavailable at the foundry
2) Ramp-up demands cannot be met

3) Product performance tends to encounter changes due to production transfer at a critical phase of the commercialisation process.

2.2 Intellectual Property

Protection of Intellectual Property (IP) can be a critical issue in dealing with foundries. In general, the design, as expressed by the mask set is the property of the customer whilst the process is the property of the foundry. This appears to be a clear division, although in practice some problems can arise, including:

1) The design can be easily protected by patents and other legal means, therefore, the customer interests are fulfilled. For the foundry the case is less straight forward, as it is often ineffectual to patent the processes. When patented, the information is in the public domain, and easily copied by others. As the employed processes are often not recognised in the final product, competitors can infringe them without risking penalties. Foundries tend therefore to guard their process details even from their customers. Sometimes this secrecy is not in the interest of an efficient development process.
2) During the development process foundries introduce their own ideas. As long as the customer stays with that foundry, there is no problem. Problems, however, arise when the customers wish to use that idea for production at other sites.
3) From the above it can be seen that it is wise to agree on some general principles regarding IP, before the actual work starts.

2.3 Financial/Contracts

When a mature and well documented product is transferred to a production facility, or when a company is hired to do development work, straight forward agreements can, more or less, be reached. In the case of producing new and innovative MST/MEMS products, work tends to be on the borders between development and production, and uncertainties in the field of technology and market developments are usually encountered. In contractual agreements between customers and foundries, elements of development and supply agreements will generally be featured.

During the process of payment transfer from the customer to the foundry costs will shift from NRE (Non-Recurring Engineering) expenses to a price per delivered item.

2.4 The Market for Foundries

The current total market for foundries is difficult to determine. Conservative estimates give a size of approximately $75 million, whilst more optimistic assessments predict it to exceed $250 million. In either case, even the most optimistic figures indicate that foundries are as yet a small part of the total MST/MEMS market. There is general agreement that the market for foundries is growing fast, but that, currently, foundries are encountering difficult times, caused by delayed product introduction and fierce competition. As a result, most foundries are forced to work with many customers in order to reach the required economically-sustainable volumes.

Generally, it is difficult to obtain detailed information about the market and market developments. Most products are in development or at an early stage of commercialisation and limited public information is available. Some information is, however, available from the foundries with regard to their current customers and the markets they target. design houses also provide some additional information relating to current development trends and market reports, such as that from NEXUS, provide more data. Table 1 provides an overview of collated data on market interest.

Applications	Ranking according to market size	Ranking according to foundry customer base	Ranking according to foundry interest	Ranking according to design house interest
Life science	2	1	1	1
Telecom	5	2	2	3
Peripherals	1	3	4	8
Defence		5	7	6
Automotive	3	4	3	4
Industrial			5	2
Consumer			6	
Space & aeronautics				5
Domestic	4			7

Table 3: Market interests compared (Courtesy of EnablingMNT)

From the table it can be seen that life science is generally viewed as a very important and attractive market. Clearly, this is in line with the current interest, worldwide, on biotechnology and related medical/biochemical developments. Peripherals, on the other-hand, by far out-number all other applications with regards to market size according to all MST/MEMS market surveys. Remarkably, peripherals as an application is not seen as attractive enough for foundries, probably because the large numbers and special demands fall outside the scope of the average foundry.

2.5 Alternatives to Foundries

A number of organisations have, over the past few years, come to being which may be considered as viable alternatives to foundries. The following provides a brief overview on some of them:

1) MEMS Exchange (http://www.mems-exchange.org/) co-ordinates a network of fabrication centres that allows users to draft process sequences, performed across the USA, at several individual facilities. The service is available for commercial, academic, and government organisations alike. The MEMS Exchange staff handles the planning, logistics, and billing. Thy act as an intermediary between the fabrication service providers and the users. The fabrication service providers consist of academic labs, commercial fabrication facilities, and government laboratories. The network elements are interconnected via the World Wide Web and package courier services. The method is very transparent, while all the information concerning prices and specifications is freely available. (Also forming a benchmark for other foundry and process service activities). MEMS Exchange is at first sight an attractive route to cost effective commercialisation. It claims to have 22 production centres and approximately 1000 process technologies ready for use. It is however more suitable for development and prototyping, as being dependant on many loosely connected suppliers can be a risk in terms of long term reliability of supply (and maybe even during the development phase).

2) MOSIS now supports CMOS-compatible micromachining to realise micro electro mechanical systems (MEMS) http://www.mosis.org/

3) Multi Project Wafers (MPW) are schemes where wafers runs, shared by several designers, are offered by foundries. The benefits are cost savings

in development and an easy route to industrialisation. As this necessitates a highly standardised processing system, the concept is only fit for a few high volume applications such as accelerometers.

A list of currently available MPW services is shown in Table 2.

Foundry/organisations	Process
Bosch	surface micromachining, bulk starts fall 2003
SensoNor	bulk micromachining with piezoresistive sensing technology
Tronics	Epi-SOI surface micromachining
X-fab	SOI-based Surface-Micro-Machining-Technology
FLX micro (design house)	Silicon Carbide
Fujitsu	
Olympus	
Sumitomo	

Table 5: Multi Project services offered

MPW's are promoted in Europe by the European Union's collaborative project: Europractice. (http://www.europractice.com). Europractice Microsystems Service provides access to design and manufacturing of microsystems, including feasibility studies, brokerage, consulting and other technical services for small and medium companies. The following groups have been clustered to provide these services:

Manufacturing Clusters often offer design and manufacturing services for different technologies from small (Multi Project Wafers) to large volumes.

Design Houses offer design services in co-operation with the Manufacturing Clusters, but also as a 'stand-alone' service for other manufacturers.

Competence Centres offer feasibility studies, brokerage, consulting and other technical services for different technologies/application fields.

A network of design houses has been added to the programme for the third phase of EP to facilitate the route from concept through design/simulation to manufacturing of microsystems, especially for SMEs. In the course of the EP project, foundry specific design kits have been developed in co-operation between manufacturers and design tool vendors. Not all design houses work with all manufacturers, but a wide range of design support is available for each manufacturer. Some of the design houses also work with non-EP manufacturers in Europe or Overseas. All competence centres, and some design houses are based at research labs and universities. More information can be found at www.europractice.com.

3 Characteristics of Foundries

3.1 Regional Differences

There are striking differences between the foundries in different regions. For instance, MEMS foundry activities have started in Europe and USA and are much more embedded in the industry. In the United States foundries are oriented more towards the semiconductor processing industry, while in Europe more variation between foundries exists.

The Japanese foundries are currently more focused on engineering services, aiming at achieving high quality prototypes, while the Taiwanese firms aim at cost-effective production based on available standard processes. The Japanese focus on achieving high quality for prototypes. This is, possibly, the background behind the reported difficulty of the Japanese industry to produce MST/MEMS in small quantities at reasonable cost.

As a consequence, Japanese foundries start with providing services purely for the domestic markets, while the Taiwanese foundries, immediately and aggressively enter oversees markets.

3.2 Typecasting of Foundries

No two foundries are alike, but there are some generalities making it possible to divide them into groups. For many foundries (over 50 %) their core business is in producing their own products, often IC's but also sensors and other components. A large group is oriented towards R&D work, while the rest (about 25%) can be regarded as general foundries, with core business in foundry work.

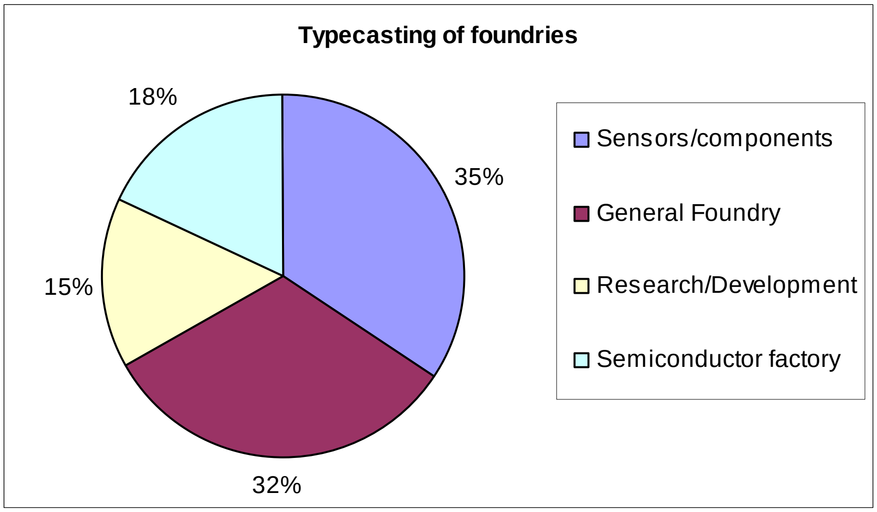

Figure 2: Typecasting of foundries

These different groups are described in more detail, below:

1) Semiconductor/MEMS foundries: These foundries have as a core activity the production of IC's for external customers, they added MEMS technologies to their process list and offer them to new and old customers. The MEMS process steps are often performed at a separate facility, in order to prevent cross contamination. These facilities are limited in the range of products they can produce, but, with their solid semiconductor base, they can offer cost effective and high quality processing. Their capability to integrate MEMS and ICs onto one chip, makes them especially suited for high volume sensor markets such as the automotive market.

2) Sensor/component suppliers: This category of foundries produces mostly for their own company in order to sell the products under their own brand name. As a side activity, they offer production services to others, mostly driven by economics and sometimes to establish new inputs from the market. As with IC factories, they often rely on well proven

processes. There is a disadvantage, however: even if the company is not competing on the same market as their customers, they certainly compete in the facility itself with regards to resource availability and priorities. Generally, external customers with limited funds, tend to end up last in the list.

3) R&D service suppliers: In the high volume electronics business, the border between development and production is strictly defined. In MST/MEMS, with its lower volumes and less organised infrastructure and lifecycle, this is not generally the case. Often development & research organisations (independent companies or specialised departments of large organisations) tend to offer small scale production capabilities. The fact that they can do both, makes them an attractive option to make the transition from development to production easier.

4) General foundries: For this group, the foundry work is the core and practically the sole activity.

Most of the MST/MEMS foundries are very young activities; nearly half of them started their business in this market within the last four years as shown in the figure 3. In general, foundries are rather small activities, where, on the average, the foundry staffs has as size of approximately 90 people, although some of them are part of (much) larger organisations. (See Figure 4)

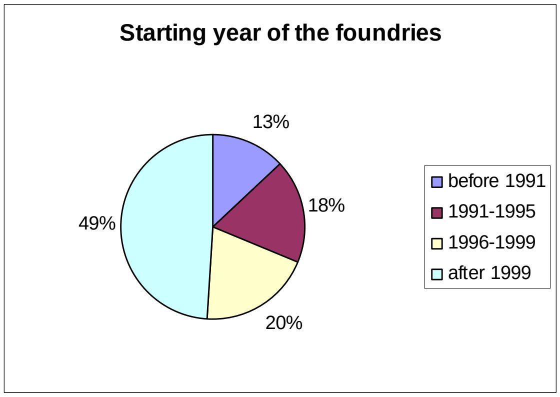

Figure 3: Starting year of the foundries

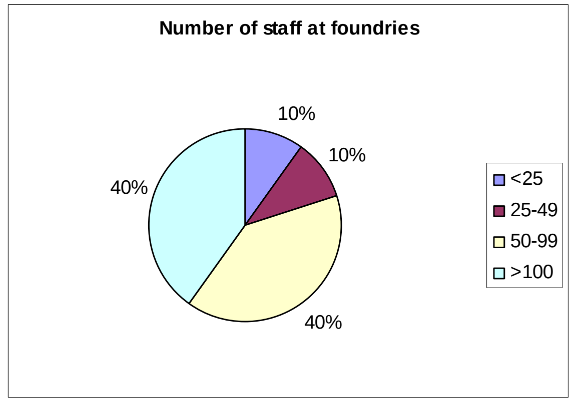

Figure 4: Number of staff at the foundries

Although still small, the mean size of the companies has increased, 4 years ago a typical foundry operated with a staff of about 50 –60 people.

3.3 General Trends

Negative developments in markets as ICT, optical and data storage, was behind the disappearance of several foundries: StandardMems, Cronos, Haleos and OnStream, although some of their activities have been continued in other forms.

At the start, when the foundry community was dominated by small (university based) start-ups, quality standards were lacking. Stimulated by market demand and the entrance of more experienced large (semiconductor) companies, foundries started to take the quality issue seriously. The trend for higher quality is continuing where, following the large companies, now also the small ones are achieving ISO qualifications.

In addition, through the entrance of new players, the foundry installed base was also increasing by continuing investments. Investment has slowed down lately, under the influence of the declining economic climate.

In Japan the interest for MEMS (and nanotechnology) foundries are rising. Members of the MEMS Foundry Industry Committee co-operate in order to provide users with easy access to information about the foundry services available from participating companies. Members include Oki Electric Industry Co., Ltd., Omron Corporation, Olympus Optical Co., Ltd., Hitachi, Ltd., Fujikura Ltd., Matsushita Electric Works, Ltd., and Fuji Research Institute Corporation.

Of note is the continuing but slow trend to large wafer sizes as shown in figure 5.

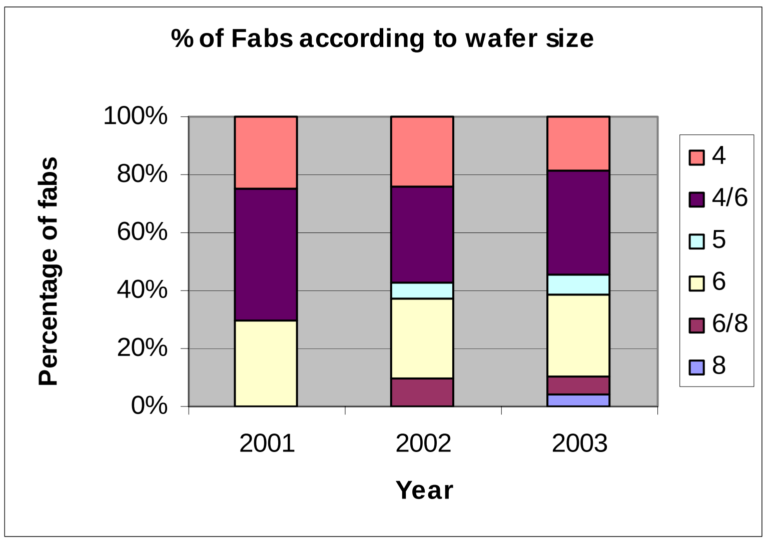

Figure 5: MEMS Foundries shift to larger wafer sizes

This shift is by the way accompanied by increasing flexibility towards other the use of other substrates of which glass and SOI are the most notable.

3.4 Investment Trends

The years 2000 and 2001 were dominated by many investment activities especially in the USA. Investment activities slowed down substantially after that, but flared up in the Far-East in 2002. This flow dried practically up in 2003, to be starting again in 2004. (See Table 2 below.)

From Table 2, one can also discern another trend. In 2000, the major focus was on mergers and acquisitions among industry players. However, in 2001, investments expanded infrastructure and capacity. As captured in the table, the shift to larger wafer sizes supports this conclusion. The increase in capacity can also be seen from the estimation of wafer usage in 2000/2001, whose total usage in 2001 is estimated at 500,000 4-in. equivalents.

Foundry	Date	Amount invested in the company	Purpose of investment
Cronos	Nov 1999	?	Expansion fab
JDS Uniphase	April 2000	750 M US$ in stock	Acquires Cronos
Tronic	May 2000	5 M FF	Finance growth
Analog	July 2000	150 M US$	Acquires BCO
Corning	Aug 2000	500 M US$ in stock	Acquires Intellisense
AMS	Oct 2000	8 M US$	Financing growth
Haleos	March 2001	?	Opening new facility
OnStream MST	April 2001	?	Expansion of foundry activities
PHS MEMS	May 2001	31 M Euro	Funding growth
HL-Planar	mid 2001	14 M US$	6-in. fab
MEMS optical	July 2001	18 M$	Infrastructure
Colibrys	July 2001	12 M US$	Start up/expansion fab
Tronic	2001	10.5 M Euro	6-in. fab
Microwise	2002	?	New fab
Walsin Lihwa	2002	50 M US$	New fab
Memscap	2002	10 M US$	Acquire ex Cronos activities
AMP	2002	50 M US$	Start up
TSM tech	2002	12 M US$	6-in. fab
Silex	2003	9 M US$	Funding growth
Infineon	2003	56 M US$	Aquire Sensonor
Kionix	2004	28.5 M US$	Unknown
Memstech	2004	4 M US$	Unknown
NeoPhotonics	2004	40 M US$	Industrialization of products

Table 2. Foundry Mergers and Investments

It must be noted that were we saw in the past press release announcing investments and production expansions, we now see release announcing new customers and partnership, showing the coming of age of this segment.

3.5 Technologies used by Foundries

An assessment of the technological capabilities of foundries provides a very good impression of the wide breadth of the technologies associated with MST/MEMS. This breadth ranges from semiconductor processing to ultra precise machining. The most common technologies are shown in Figure 6.

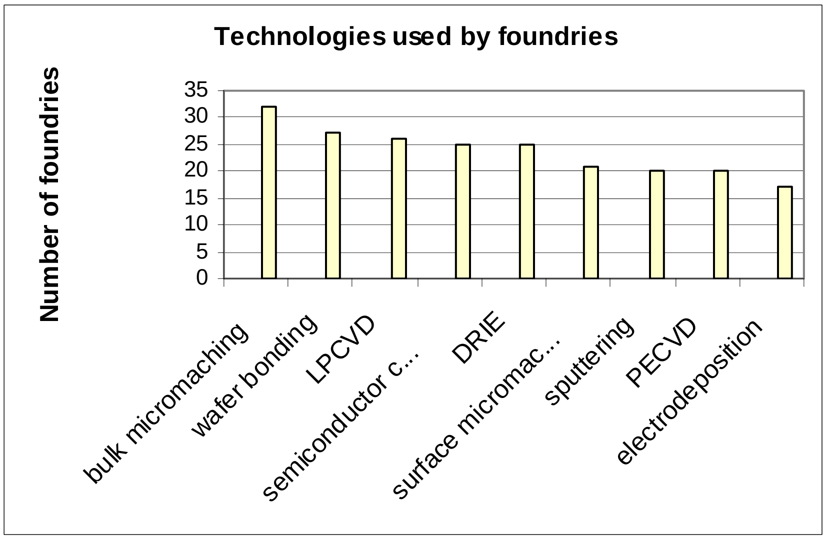

Figure 6: main technologies in use at foundries

Of the technologies used to create three dimensional (often moving) structures, bulk micromachining is the most commonly used, followed at a distance by Deep Reactive Ion Etching and surface micromachining.

The four more traditional thin film deposition technologies: LPCVD, sputtering, and PECVD are still the workhorses of the thin film technology, with electro-deposition being offered by a rising number of suppliers.

Waferbonding, used for waferscale packaging and to create microfluidic products is also very widely used. LIGA or other high aspect lithographical technologies, on the other hand, are less often offered, although is should be mentioned that one of the foundries is concentration on LIGA technology based products. Besides some university activities no noticeable foundry activities for nanotechnology have been identified.

The presence of the (ex) semiconductor foundries in the foundry list explains the ample supply of semiconductor compatible processing. (They are often used to create integrated MEMS products such as sensors.)

Although there is a slow tendency over the years to achieve smaller feature sizes, the majority of the products will be made by > 1 micron technologies. Exceptions are integrated sensors, where improved IC performance can be of interest and products where the feature size is directly linked with product performance, including, micro-sieves and optical gratings

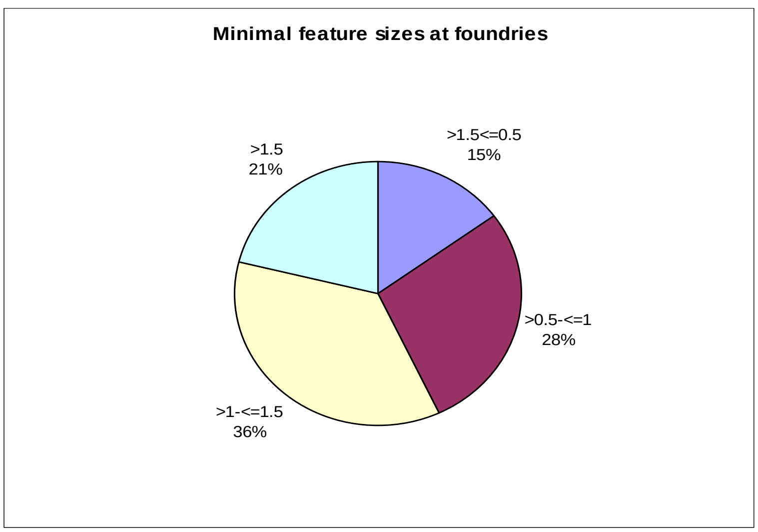

Figure 7: Minimal feature sizes at foundries

with feature sizes, the specifications of the clean rooms used by the MST/MEMS foundries are also very relaxed when compared to state of the art IC industry.

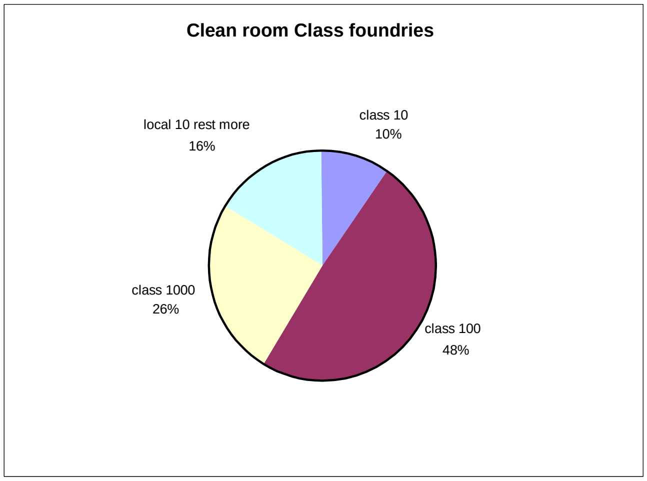

Figure 8: Clean room class foundries

3.6 Products of Foundries

"Traditional" MEMS products such as pressure sensors and accelerometers are still the most commercialized product groups offered by the foundries, followed by optical products (switches and mirrors), RF devices and other sensors in general. This is shown in Figure 9.

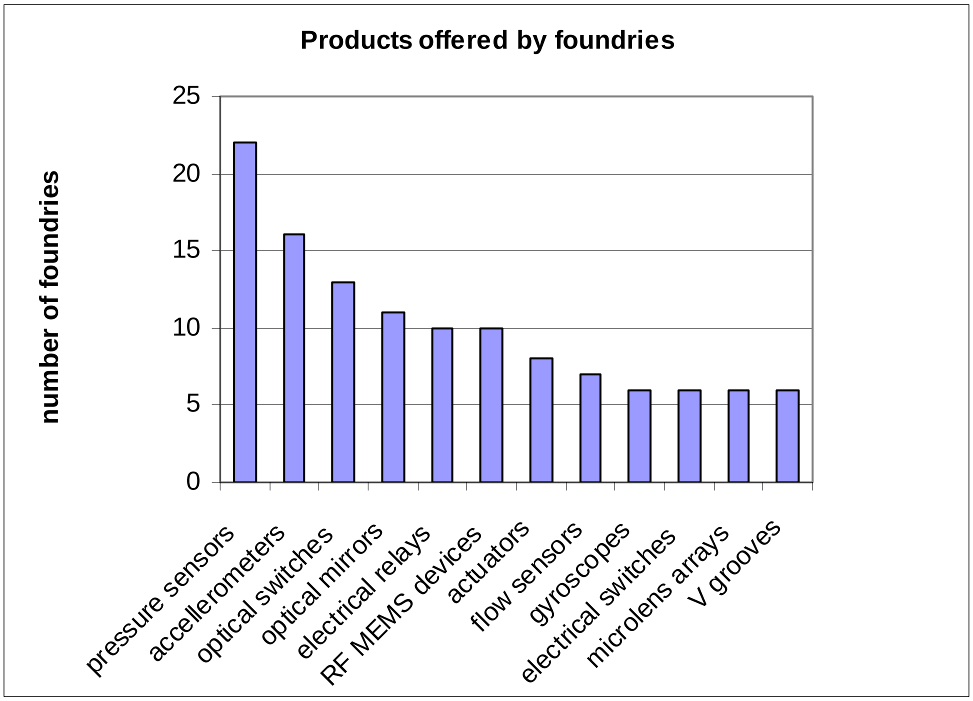

Figure 9: Products offered by the foundries

4 Design Houses and Foundries

The quadrangle model of software supplier, design house, foundry and packaging supplier is still valid, perhaps even expanding to include CMOS design and fab suppliers for certain products that combine MEMS and circuitry. Customers and universities are taking over the role of the design house more and more, but there will still be a role for the design house, though smaller, in the future, while MEMS devices previously built at a research or development lab with a view on industrialization and then transferred to a commercial source is very successful because the technical risks from the process are reduced and the customer is further along with their product development for the balance of the product/system that uses the MEMS component.

While foundries form the natural partner for design houses, it is interesting to understand what both entities have in common and where their paths deviate. The following chart demonstrates the products offered by the foundries and the design and engineering companies:

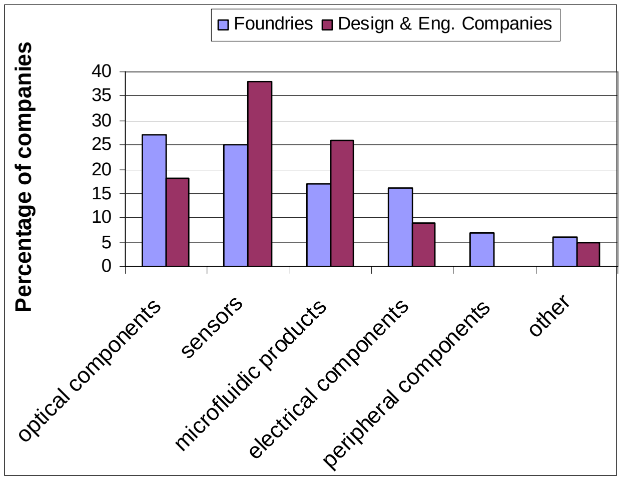

Figure 11: Products offered by foundries and design & engineering companies

Whereas most of the design houses are oriented towards the life science market, with its many niche opportunities, the foundries maintain a focus on the high volume markets such as telecommunications and peripherals. The reasons are clear, namely, high production /mass markets offer the most efficient means of maximising the utilisation of a foundry's infrastructure. In other words, the return on the high cost of investment is secured through large/long-term orders. design houses seek the lucrative investment opportunities associated with, for example, the bio/life-sciences. These opportunities attract the funds from the speculators. In addition, the infrastructure and capital investment of the design houses is well below that of the foundries.

Whatever the differences between design houses and foundries are both agree on the commercial potentials of microsystems in general and micro-sensors in particular. Generally, the foundries are developing sensors for the automotive market whilst the design houses tend to focus on the industrial market. This difference is again explained by the difference in volumes (large automotive market is attractive for foundries) versus diversity (being a strong characteristic for the industrial market).

With regard to the fabrication technologies that underline the products of both design houses and foundries it is also worth noting that some important technologies, from the perspective of the design houses, such as nanotechnologies, surface micromachining and electroplating, are not as attractive to foundries as others. On the other hand typically high volume production processes such as LPCVD, DRIE and other semiconductor compatible technologies tend to be favoured by foundries.

5 Conclusions

Most elements from the four stages of commercialization mentioned in the introduction and detailed in the Commercialization chapter can be recognized when examining the history of the foundry community described above. This market segment seems ready to enter its fourth stage. A complete manufacturing infrastructure is becoming available. A sign of maturing is the growing attention of customers to process control and capacity management where in the past MEMS process details was the most important subject of discussion. This leads to recognition of foundry infrastructure. We provide a list of MEMS foundries in appendix A.

The niche position of LIGA and the popularity of bulk micromachining can be explained by the infrastructure cost. Similarly, the initial unpopularity of integrated technology is explained realizing the cost of maintaining the CMOS technology. Now more funding is becoming available for the MEMS industry. The availability of integrated technology is growing. The weakest point for the MEMS foundry community as a whole was quality. The influx of large companies forced the older ones to give more attention to this.

Although the MST foundry industry molded itself on the successful IC foundry industry, there are remarkable differences. The MST foundry has to cope with a much more diverse technology demand from the customers. This will lead to a higher number of technologies to sustain and a smaller series. Therefore, it will be difficult to reach the quality and economy of scale achieved by the IC industry. Due to the disruptive nature of the MST products, market acceptance and system development time will take more time.

However, the MST foundry industry is growing in capacity and many signs of maturation are visible: larger organizations, more focus on customers and less on investment and expansion, fewer clients per foundry, increasing use of quality systems. It has to be seen if the forces supporting the foundry market, economy of scale and cross-fertilization, will be stronger then the forces minimizing the role of the foundries in the MST market, control of technologies by the MST system supplier and success of their own products.

In terms of the future structure of the MEMS foundry industry, there will be a several large fabs, not the size of TSMC or IC foundries, but large, 6 inch fabs. The small fabs will have a difficult time making enough money to stay alive in the long term without enough wafer throughput to pay for the equipment. They are often forced to accept many projects with different processes. Fabs that can combine product sales with contract manufacturing, using a multi-client process have a cost and quality advantage in this regard as opposed to Fabs that cannot.

The industry would see an important step forward if could go beyond the current stage of just achieving acceptable quality levels for a diversity of immature processes into a framework of common technology platforms, supported by process engineers, equipment suppliers and designers.

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8 Appendix A: MEMS/MST Foundries

Company (short name)	Website	Country
ACSI	www.acsensor.com	USA
Alpha	www.alphat.com	USA
AMMI	www.sensors.goodrich.com	USA
AMS (USA)	www.advancedmicrosensors.com	USA
APM	www.apmsinc.com	Taiwan
Applied MEMS	www.appliedmems.com	USA
Axsun	www.ligafoundry.com	USA
Blu-Si	www.blu-si.com	USA
Bosch	www.europractice.bosch.com/en/start/index.htm	Germany
Colibrys	www.colibrys.com	Switzerland
Dai Nippon		Japan
Dalsa	www.dalsasemi.com	Canada
Fairchild	www.fairchildsemi.com	USA
Fujikura	www.fujikura.co.jp	Japan
Fujitsu	edevice.fujitsu.com/en/foundry/technology/mems.htm	Japan
HL-Planar	www.hlplanar.de	Germany
Honeywell	www.memsservices.com	USA
HTE	www.htelabs.com	USA
IMT	www.imtmems.com	USA
Issys	www.mems-issys.com	USA

Kionix	www.kionix.com	USA
MEMS Optical	www.memsoptical.com	USA
MEMSCAP	www.memscap.com	France
MemsTech	www.memsenz.com	Singapore
Metrodyne	www.metrodyne.com.tw	Taiwan
Micralyne	www.micralyne.com	Canada
microFAB	www.microfab.de	Germany
Oki	www.oki.co.jp	Japan
Olivetti	www.olivettii-jet.it/	Italy
Olympus	www.olympus-pdg.com/	USA
Omron	www.omron.com/ecb/tec/h/h_1.html	Japan
QuickSil	www.quicksil.com	USA
Sarnoff	www.sarnoff.com	USA
Semefab	www.Semefab.co.uk	UK
SensoNor	www.sensonor.com	Norway
Silex	www.silexmicrosystems.com	Sweden
SMI	www.si-micro.com/	USA
STM	www.st.com/mems	France
Sumitomo Metals.	www.e2-lab.com/technology/mems/	Japan
Supertex	www.supertex.com	USA
Tronics	www.tronics-mst.com	France
Walsin	www.walsin.com.tw	Taiwan
X-FAB	www.xfab.com	Germany
Branchy	www.bcv.com.tw	Taiwan

MBT	www.microbase.com.tw	Taiwan
Chipsense	www.chipsense.com.tw	Taiwan
Delphi Delco ElectronicSystems	www.delphi.com/	USA
USI	www.universalsemiconductor.com	USA
NKT	www.nktintegration.com	Denmark
SCL	www.sclindia.com	India
Neophotonics	www.neophotonics.com/	USA
AMS (Austria)	www.austriamicrosystems.com/05foundry/200mm.htm	Austria
Chromux	www.chromux.com	USA
SCS	www.scs.com.tw/02-Product/02-1-Mems.html	Taiwan
MEW	www.mew.co.jp/e-press/2003/0309-01.htm	Japan
SiWave	www.siwaveinc.com	USA
Trion	www.triontech.com	USA
Allied Coatings	www.alliedcoatings.com	USA
MEMS E&M	www.memsengineering.com	USA
Jazz	http://www.jazzsemi.com	USA
UPAEP	http://web.upaep.mx/	Mexico
Peregrine	http://www.peregrine-semi.com	USA