# *VLSI REVISITED – REVIVAL IN JAPAN*

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# VLSI Revisited[1] – Revival in Japan



[1] This working paper was prepared while Visiting Professor at the Institute of Innovation Research of Hitotsubashi University in Tokyo which provided superb conditions for my research interest on structural changes in the sector of Information and Communication Technologies ( ICT) in Japan. I want to express my thanks to Professor Hideaki Kohzu, Professor Hiroyuki Chuma and Professor Shuzo Fujimura. They helped me to understand many of the intricacies of the semiconductor landscape in Japan and its relations with overseas actors. This version should be seen as a preliminary entry for an in-depth case of the changing role of consortia in the semiconductor industry landscape. All errors and lack of understanding of this complex industrial and technological landscape remain solely with the author.

Abstract
This paper describes the abundance of semiconductor consortia that have come into existence in Japan since the mid-1990s. They clearly reflect the ambition of the government – through its reorganized ministry METI and company initiatives - to regain some of the industrial and technological leadership that Japan has lost. The consortia landscape is very different in Japan compared with EU and the US. Outside Japan the universities play a much bigger and very important role. In Europe there has emerged close collaboration, among national government agencies, companies and the EU Commission in supporting the IT sector with considerable attention to semiconductor technologies. Another major difference, and possibly the most important one, is the fact that US and EU consortia include and mix partners from different areas of the semiconductor landscape including wafer makers, material suppliers, equipment producers and integrated device makers.

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## *Summary*
In the very early 1980s and for a number of years Japanese companies maintained a very strong market position in almost all aspects of semiconductor production. When the Japanese semiconductor industry reached its peak in the 1980s, DRAM memory circuits were the driving force of the world semiconductor business. The origin of this success can be traced to the VLSI Project in the 1970s that received substantial support from the then Ministry of International Trade and Industry (MITI).

This working paper describes the abundance of semiconductor consortia that have come into existence in Japan since the mid-1990s. They clearly reflect the ambition of the government – through its reorganized ministry METI and company initiatives - to regain some of the industrial and technological leadership that Japan has lost.

The consortia landscape is very different in Japan compared with EU and the US. The development of semiconductor technology has in the US benefited from defence contracts which in a certain sense is still continuing. Outside Japan the universities play a much bigger and very important role. In Europe there has emerged close collaboration, among national government agencies, companies and the EU Commission in supporting the IT sector with considerable attention to semiconductor technologies.

Another major difference, and possibly the most important one, is the fact that US and EU consortia include and mix partners from different areas of the semiconductor landscape including wafer makers, material suppliers, equipment producers and integrated device makers. In Japan, by contrast, the abundance of consortia is basically only focused on the manufacturing sector and only category by category – with limited involvement of application (system) developers. In sum, Japanese consortia have in the past been made up by device makers who still in a major way influence further initiatives for which METI as an industrial ministry takes a major responsibility.

## *Introduction*

This essay discusses the changing roles of two closely inter-related factors in the undulating future of Japanese electronics industry – technology and management. They are observed from a micro-perspective of looking into the country's semiconductor industry in a global context.

In the very early 1980s and for a number of years Japanese companies maintained a very strong market position in almost all aspects of semiconductor production. When the Japanese semiconductor industry reached its peak in the 1980s, DRAM memory circuits were the driving force of the world semiconductor business. They were mass-produced, standard commodity products that did not need to meet particular specifications, and were an optimal product for large, vertically integrated Integrated Device Manufacturers (IDMs) that could produce the devices very efficiently.

This strength derived partly from the success of a single-minded mobilization of resources under the umbrella of the VLSI project sponsored by the then MITI. For a short period in the mid-1980s some 50 per cent of semiconductor devices were produced by Japanese companies of which many had participated in the VLSI project. Other Japanese companies were equally if not more successful in capturing markets for silicon wafers and other materials, and two companies –Nikon and Canon – established a globally almost dominant position for lithography equipment (wafer-steppers) which constitutes the major part of wafer processing equipment.

The global production of semiconductor devices in 2003 reached US$150 billion with major shares taken by the US, Japan, Korea, Taiwan and EU. The market for equipment used in the manufacture of semiconductors reached an estimated US$21.4 billion in 2003 of which wafer process equipment constituted the major part with 14.3 billion followed by testing equipment at 3.9 billion. See table 1. The total estimated outlays for materials utilized in the manufacture of semiconductors amounted to US$13.0 in 2003 of which silicon wafers constituted the largest share with 5.6 billion.

**Table 1**
**Market for Semiconductor Manufacturing Equipment (US billion)**

| | **2002** | **2003 forecast** | **2004 forecast** | **2005 forecast** | **2006 forecast** |
|---|---|---|---|---|---|
| ***Wafer process*** | ***14.15*** | ***14.30*** | ***19.82*** | ***32.76*** | ***21.99*** |
| **Testing** | 2.71 | 3.94 | 5.53 | 6.25 | 5.91 |
| **Assembly & packing** | 1.17 | 1.54 | 2.16 | 2.56 | 2.53 |
| **Other** | 1.72 | 1.59 | 2.11 | 2.43 | 2.25 |
| **Total** | **19.75** | **21.37** | **29.62** | **35.00** | **32.68** |

Source: SEMI briefing February 25 2004

Japanese companies today remain very strong in the production of silicon wafers and many suppliers of other materials have also retained a very strong position. See table 2. The same is also the case for testing equipment. However, the two companies that used to be dominant in the manufacture of lithography have in recent years seen their market share to be seriously eroded by the emergence of a strong competitor in Europe. This has aroused serious concern in Japan which since the mid-1990s has in various ways attempted to create a support structure that would support the re-emergence of a vital and competitive semiconductor industry in Japan.

**Table2**
**Worldwide Wafer Fab Materials (US$billion)**

| | 2002 | 2003 estimate | 2004 forecast | 2005 forecast | 2006 forecast |
|---|---|---|---|---|---|
| **Silicon wafers** | 5.6 | 6.0 | 6.9 | 7.5 | 7.6 |
| **Photomasks** | 2.3 | 2.3 | 2.5 | 2.6 | 2.7 |
| **Photoresists** | 0.7 | 0.7 | 0.9 | 0.9 | 1.0 |
| **Gases** | 1.8 | 1.8 | 2.0 | 2.1 | 2.2 |
| **Other** | 2.6 | 3.0 | 3.2 | 3.7 | 3.9 |
| **Total** | **13.0** | **13.8** | **15.5** | **16.8** | **17.4** |

Source: SEMI briefing February 25 2004

However, devising a strategy to support the national semiconductor industry is today fraught with much greater challenges now compared with the situation in the second half of the 1970s, and the reasons are manifold. First, semiconductors today cover a much larger number of categories. Second, manufacturing technology as such is no longer a single driving force as semiconductors are increasingly tailored to meet wide variety of customer demands to fit into a multitude of electronics products. Third, design of chips and the integration of a various software functions have taken on a paramount role in producing semiconductors that customers require. Thus, mass production of single-line chips has become less important. However, the demand to miniaturized and reduce power consumption and control the form factor is creating heavy demands to continually update production processes for smaller and more efficient chips. This situation has encouraged national efforts in a number of countries/regions to find ways of supporting its semiconductor industry.

Japan has in all likelihood been most active - since the mid-1990s – to formulate government policies and create structures that would support the domestic semiconductor industry. Similar efforts are clearly evident both in the US and in the EU and to a lesser extent in Korea and Taiwan. However, recent development in Japan and elsewhere indicates that domestic companies are no longer intent on following national guidelines and are increasingly looking for national or global partners to strengthen their business strategies.

The industrial structure for chip-making in Japan has undergone major and dramatic changes in recent years – in particular triggered by the rapid decline of DRAM prices in the mid-1990s. The remaining companies include Elpida for memories, established through a merger between Hitachi and NEC and receiving investment from Intel; Renesas for specialised memories and logic devices, created through a merger between Hitachi and Mitsubishi Electric; Toshiba having established a special relationship with Sony for Playstation chips, and also working closely with IBM

Furthermore, a growing number of engineers suggest that production lines will change drastically in the future for the following two reasons. First, today production is still dominated by sequenced step-by-step processing of batch, which must change into flow-line production in order to reduce time from order to final delivery – in order to meet customers need to rush their products to the market. Second, investment costs can be reduced if flow-line production can be established. So, time and costs are demanding changes in the manufacture of chips. Thus, in the future chip manufacture may resemble the character of Toyota car production.

Another major consideration is that China may soon become a serious actor in the semiconductor industry. Today, many IC companies are eager to invest in China, but are for the time being limited to low-end or back-end production while front-end production remains in the US, Europe and Japan. Intel has set up semiconductor plants in China but its front-line production remains in the US and in Ireland. Quality control is a dominant factor and the situation will change when abundant high-quality engineers and scientists will become available in China. Labour cost is not a critical factor in semiconductor production as it typically constitutes only 7-8% of total costs. However, China may gain an advantage in chip design which is labour-intensive although chip integration on boards is increasing done with lithographic methods.

## *Declining Competitiveness*

Many books, articles and conference papers have in recent years expressed pessimism over the competitiveness of Japanese industry and its capability to recover and the following will only provide a few references to such work. There is a general agreement that the recent performance of the Japanese economy inescapably provokes pessimism over its future prospects with a loss of confidence among consumers and business managers. Motohashi[2] suggest that the innovation system with a focus on the central research institutes of the large companies reached a critical point with the collapse of the bubble economy, with one consequence being that the government sector has shouldered a larger burden of total national R&D expenditure. Motohashi suggests that companies are losing their capacity to conduct basic research with the necessary level of funding as business fortunes decline. The result is that the mission of central research institutes has shifted heavily away from basic research to commercialization research. Simultaneously, the intensive global competition has accelerated the speed of new product development, and Japanese companies are increasingly procuring basic research results from outside and focusing on product development. Although the government has introduced measures to promote industry-university partnership and venture companies more significant changes are needed through reform of the large companies. Motohashi says that the large companies must radically change their management strategies and concentrate their efforts in core competencies and engage in collaboration strategies.

The same observation is made by Takahashi[3] in a specific industrial sector. He argues that manufacturers in Japan failed to handle the challenges of required changes because of structural infirmity. He states that Japanese companies delayed drastic re-examination, or strategic decisions in the manufacture of DRAM until they began to financially suffer from semiconductor recession and from low-cost competition by Korean producers. Thus, there exists a general criticism that the lack of good corporate governance permitted management to postpone for a number of years required changes in their business portfolio, which in earnestness only started in 2001 (?). Check. A major factor for the critical delay was the hubris that had been created by the success in the 1980s when successfully exploiting

[2] Motohashi, Kazuyuki, Fall of Japanese Competitiveness in 1990's?: Assessment of structural Factors behind Economic Growth Slowdown since 1980's, Institute of Innovation Research (Hitotsubashi University) Working Paper 2003-01, January 2003

[3] Takahashi, Takuma, The Role of Knowledge and Organization in the Competitiveness of Japanese High-tech industry, International Journal of Technology Management,

technology as a driver for success in the DRAM market. At the time the semiconductor makers in Japan failed to see that new devices were far from derivatives of DRAM, and did not realise the need for new approaches and new ventures. However, the environment may turn in favour of Japanese manufacturers of semiconductors if able to catch the expanding demand for system of chips which will increasingly be used in consumer electronic products where Japan still maintains a strong position.

Japan has since the late 1990s seen major policy initiatives in research and innovation – with government stimulating private innovation activities, and management of public research institutions under market conditions. However, a remaining compartmentalization of the R&D system in China still thwart efficient linkages within the system which is detrimental science-driven industries require knowledge inputs from applied physics and biotechnology. Although recent policy initiatives are changing the system to stimulate linkages it must be realised that changes take considerable time before they yield the desired effects. The national research institutes underwent major reform only in early 2001 and the university reform will be affected three years later, in 2004. Motohashi[4] draws the attention to the fact that the share of competitive funding in total national budget for science and technology in Japan is still less than 10 per cent compared with 30 per cent in the US, and corporate contracts with national R&D institutes.

The IT Strategy Council's December 2000 report boldly aimed to achieve global leadership in the IT sector by 2005. Yes, that's global leadership, as in knocking the U.S. out of first place. The council's scheme sounds especially outmoded because it puts the government at the helm. The government would provide the leadership, make the key investments, and coordinate private-sector activity. It sounds almost like Japanese industrial policy all over again. But we know that a government can't launch an IT revolution. The U.S. leads the world because the government stepped aside and left entrepreneurs to rule in the free market[5].

The chipmakers in Japan have been struggling in recent years following the collapse of the information technology bubble worldwide; while at the same rivals in South Korea and Taiwan have become fiercely competitive on the strength of heavy capital investments. However, as the range of use of chips, once primarily focused on personal computer, expands to cell phones, digital cameras and other digital consumer electronics, the demand has seen a recovery. By focusing on the assembly process, which is considered a relative strength in Japan over overseas competitors, domestic chipmakers are now preparing to be on the offensive.

During the 1980sJapan was harvesting from the seeds that were planted in the 1970s to bring the country's semiconductor industry to the forefront after having trailed the US companies that had benefited from domestic demand in the defence and the computer sectors. NEC, Hitachi, Toshiba and Mitsubishi became leading suppliers of memory chips. Japanese companies dominated the manufacture of memory chips for many years until Korean and later on Taiwanese companies became dominant suppliers. In the meantime US companies had in the main opted out of memory production. At one time in the 1980s the Japanese

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[4] Motohashi, Kazuyuki, Recent Developments in Research and Innovation Policy in Japan, Institute of Innovation Research (Hitotsubashi University) Working Paper 2003-03, March 2003
[5] Vogel, Steven, Look for Japan to narrow gap in IT race – The Japan Times June 20 2002

semiconductor chipmakers, including Hitachi, Toshiba. NEC and Fujitsu were meeting some 90 per cent of the global market for 256K-DRAM.[6]

The success of Japanese companies in memory production was accompanied by equally rapid advances in the manufacture of processing and testing equipment, photo-resist and other chemicals and in silicon wafer production. A central piece of processing equipment in the manufacture of semiconductors is today the wafer-stepper. A US company, GCA, until early 1980s completely dominated the global scene with a market share of around 90 per cent. This situation changed dramatically when Nikon successfully introduced its wafer stepper in 1980 followed by Canon in 1983, and later on Hitachi also entered the market. It was not until the early 1990s that the Japanese position in wafer-steppers started to erode, and ASML in The Netherlands has today become a strong contender for world leadership in the manufacture of this complex machinery that is a reduction projection-type microlithography device.

Thus, Japan and its semiconductor companies have seen their earlier acquired position in the manufacture of semiconductors as well as in production of critical processing equipment steadily being eroded. This article will discuss the origin of the early success and attempt to identify some the factors which have contributed to the demise of the semiconductor industry in Japan and its ascend in other countries – in East Asia for semiconductors and in Europe for critical processing equipment. Subsequently the article will also discuss the attempts in Japan to halt the ongoing decline and similar measures within the European Union, the US, and other countries to assist in developing their semiconductor industry. Finally, this article will also attempt to understand the outcome on global semiconductor industry from an ongoing rapid shift from hardware to a focus on software and chip design. The future role of China in semiconductor production will be contemplated.

## *The Success of the VLSI Project*

Today there exists a consensus that the VLSI project[7] Project in Japan, established in 1976 as an engineering research association, had an exceptional success in promoting technological development. The focus of the project was clearly on micro-fabrication technology, which in essence meant improving and developing new lithography methods. Silicon crystal quality and an improved understanding of physical and mechanical properties were a second focus. The project resulted in firmly raising the level of VLSI manufacturing technology of the five participating companies - Toshiba, Hitachi, NEC, Fujitsu and Mitsubishi Electric. This is a contributing factor in these companies winning an expanded share of the world market for memory circuits.

Before the VLSI Project started in 1976 the semiconductor manufacturers in Japan were dependent on US equipment suppliers. Thus in the past, Japan could only develop its industry along the lines of US industry and could only trail the development of US competitors. But

[6] Chuma, Hiroyuki and Aoshima Yaichi, Determinants of Microlithography Industry Leadership: The Possibility of Collaboration and Outsourcing, RIETI Discussion Paper Series 03-E003

[7] This section is partly extracted from Sigurdson, Jon, Industry and State Partnership: The Historical Role of the Engineering Research associations in Japan (Retrospective Document), in *Industry and Innovation Journal,* Volume 5, Number 2 (December 1998), pp. 209-241, and the original publication: Sigurdson, Jon, *Industry and State Partnership in Japan: The Very Large Scale Integrated Circuits (VLSI) Project* Research Policy Institute, WP 168, 1968

the Japanese semiconductor industry realised that in order to develop a new field it is also necessary to develop and manufacture its production equipment domestically.

The VLSI Project was sponsored for four years by MITI to the sum of 30 billion yen, with the participating companies providing an equal amount. Many foreign observers, often highly qualified in technology or economics or both, consider this project to have provided the underpinning of the market penetration that major Japanese companies were able to make for large scale integrated circuits at the very beginning of the 1980s.

It should be noted that no other joint research projects, under MITI sponsorship, were carried out in connection with the VLSI Project. This meant that the other "participating" companies such as Canon and Nikon were only paid for delivering equipment and services and did not share the research results, nor did they participate in discussions organised within the VLSI Project. This was a conscious policy desired by this ERA and other ERAs as well in order that non-participants should not be able to obtain "unjustified gains".[8] This line of division between the manufacturers of semiconductors and the manufacturers of processing equipment may at a later stage have contributed to an invisible barrier between the two sets of companies.

A common source of surprise in the organisation of the VLSI project is that only five companies were involved as core participants. Dr Tarui, the VLSI Project leader and others, both inside and outside MITI, have pointed out that there were only five companies making general-purpose computers when the project started - although in the case of Toshiba the company had already suspended production of computers. The VLSI project was conceived out of necessity to match IBM's next generation computer. Since then VLSI chips have become a general-purpose commodity items for the electronics industry and many related industries. At the time computers demanded high reliability and high performance - in contrast to consumer electronics, which could do with less sophisticated integrated circuits. *The central purpose of the VLSI Project was to support the development of mainframe computers in Japan.* This was part of the country's national policy - in a context in which computers were considered to be important for national security, as broadly defined. Consumer electronics, at least in the mid-1970s, did not warrant similar attention.

There were initially several ideas -- hopes or expectations -- that the VLSI Project should be followed by a second stage. Already at the start many scientists and company researchers had their eyes set on considerably higher levels of integration and realised that new technologies would have to be developed if these goals were to be achieved. But a projected continuation of joint VLSI research ran into problems for two very different reasons. First, the success of the VLSI manufacturers in Japan created serious concern in the USA, and the US trade representatives at various levels repeatedly criticised the Japanese government for unfair trade practices -- by criticising the support given to private companies under the VLSI Project. Second, the technological expectation that drove the VLSI project, namely that electron-beam technology would become necessary in the 1980s as levels of circuit integration increased, was not in fact borne out. As it happened, optical lithography continued to be refined, so that finer line widths could be achieved with optical steppers and aligners. These developments

[8] The impartiality may in fact have meant that NEC suffered although the joint laboratories were located on their premises. At least there is no evidence that the company received any special benefits from renting its premises to the VLSI Project. A special entrance and dining room were established in order that the geographical proximity should not favour NEC. Similar arrangements were later made for the Optoelectronics Joint Laboratory which used to be located on Fujitsu premises in Kawasaki.

postponed the necessity for a radical breakthrough in process technology, and thus diminished the need for a continuation of the VLSI program.

There can be no doubt that the high level of funding was a very significant factor as it meant that the VLSI research funds in 1976 and 1977 increased through this project by approximately 20 billion yen. Thus, the VLSI Project actually contributed research funds of the order of 3-4 percent of the semiconductor sales of Japanese companies during the early years. However, Sakakibara, a Japanese management researcher, mentions that it has been estimated that between a quarter and a third of the total project funds were spent in the USA to purchase the most sophisticated equipment available at the time.[9] Thus procurement of sophisticated equipment was not in the first stage seen as a policy instrument for promoting the Japanese equipment fabricating industry.

## A contrarian view of the VLSI Project

There are company insiders that argue the VLSI project only benefited the equipment makers in Japan, and some them argue strongly that the project was not successful, although accepted by the business community in Japan as it was the first project of its kind and companies were offered funds that were not rejected.

The line of reasoning is that only researchers from the big (computer) companies participated in the joint laboratories which were set up as a major activity of the VLSI project - with little or no support from the business departments of their companies. This was the consequence, the argument runs, that the basic concern of the VLSI Project was to support Japan's position in the manufacture of large computers while companies like Sharp and Matsushita were excluded from participation. There are many different types of semiconductors used for a number of different applications and the VLSI Project was almost exclusively focused on the scale factor in the DRAM process technology. Thus development of software, microprocessors and other logic devices was neglected. One reason for this lopsided focus was the lack of feedback from manufacturers that were not involved in the manufacture of large computers, such as personal computers, VTR and colour TV.

The project only supported the development of process technology without any attention to architecture and devices. However, the apparent success of the project frightened both Europe and US and triggered the establishment of similar support programs such as JESSI in Europe and Sematech in the US. At the same time there is a striking difference between VLSI in Japan which had no academic participation and JESSI and Sematech which involved a number of academic researchers. This reflects on the university environment in Japan where professors have shown only limited interest in supporting research and technological development that would benefit industry.

There is little doubt that the VLSI project gave a tremendous boost and the semiconductor industry in Japan remained the most advanced in the world for roughly six years - from 1984 to 1990. The global market share for Japan in 1989 reached 53% against 37% for USA with its leadership in memory circuits. Not being able to compete against memory makers in Japan the focus in the US shifted towards logic devices at a time when the demand for personal

[9] Sakakibara, Kiyonori; From imitation to innovation: The Very Large Scale Integrated (VLSI) semiconductor project in Japan. (WP # 1490-83) Cambridge, Mass: MIT, 1983, 32 p.

expanded very quickly. An important effect of Japan's dominance in the manufacture of DRAM was that Intel, TI and others gave up the manufacture of DRAM, while simultaneously large buyers of DRAM turned to suppliers in Korea and Taiwan – as if they wanted to punish Japan.

An important reason for the Japanese success was the ability of makers to control quality and thereby achieve high yields. Another important element was the character of the semiconductor makers in Japan that were general electric equipment makers, and continued success rested on being able to mobilize resources for investment. Mass production would cut costs and determine winner or looser in the semiconductor industry. Japanese companies continued to invest in the semiconductor industry with income from other sectors until the early 1990s.

After that it became less costly for competitors to outsource production to fabless companies and it became possible to change direction faster and make the products cheaper than Japanese companies which were also squeezed for investment during the recession that started very early in the 1990s. Moreover, employment cost in Japan was higher than other countries in Asia. Thus, Japan saw the erosion of its earlier dominant position, with the US taking a leading position.

The VLSI Project in the 1970s was successful because it was directed by MITI bureaucrats who were smart and could at the time forecast the next ten years, and changed the world of semiconductor industry. After that Japan didn't have National Project to develop semiconductor technology for some 20 years and USA and Korea, Taiwan were able to catch up – supported by their national governments.

## *Counter-measures in the US and Europe*

The poorly understood success of the VLSI Project in Japan quickly triggered responses booth in Europe and the US – in the creation of Joint European Submicron Silicon Initiative (JESSI) and Semiconductor Manufacturing Technology (SEMATECH). The JESSI project was launched in the late 1980s, and the objective of this project was to re-establish Europe, or rather European companies in micro-electronics, to be able to compete with the electronics companies in Japan. It was set up as an exclusive club for European companies and naturally included Philips, Siemens and Thomson. Philips had to withdraw from, most parts of the programme when the companies suffer a financial crisis in the early 1990s, while Siemens remained a strong partner. Furthermore, R&D alliances are emerging in a global setting which is evidenced by the triangular relationship between IBM, Siemens and Toshiba in the 1990s to develop future generation of very large scale integrated circuits - 256 Mbit DRAM. This is an alliance at the global level in contrast to the Japanese VLSI Project in the late 1970s and more recent approaches like Sematech in the US and JESSI in Europe.

In both JESSI and SEMATECH member companies are interested in terms of more efficient ways to manufacture semiconductor devices. JESSI in an early stage indicated its desire to plan and schedule wafer fabs more efficiently and improve planning and scheduling software systems being used by JESSI member companies. Both JESSI and SEMATECH were interested in developing a better understanding of capacity loss factors they established the

Measurement and Improvement of Manufacturing Capacity (MIMAC)[10] with the expectation to have an improved use of resources and more realistic planning and understand how to close the gap to the theoretical optimal level.

## Joint European Submicron Silicon Initiative (JESSI)

JESSI was the first European co-operative programme in which the development of microelectronics components together with the equipment and materials needed for the production of them and the subsequent applications of these chips were all included. Launched in 1989, the programme was set up with EC support to ensure that European companies gained access to leading-edge chip technology - a last-ditch joint research effort to secure Europe's independence from US and Japanese semiconductor technology in memory and logic chips. The definition and planning phase for the JESSI programme started actively at the beginning of 1988. The programme was launched one year later, on 1 January, 1989, and officially installed as a EUREKA project (EU 127). It was agreed that the programme would run from 1989 until 1996. The organizational structure of JESSI was dominated by the participating firms, with governments in a more consultative role, primarily on issues of funding. The executive body of JESSI was the industrial JESSI board, which has ten members.

JESSI was founded by fourteen companies and research institutes in Britain, France, Italy, the Netherlands, and Germany. The programme's non-governmental participants can be divided into four groups: first, all major European electronic equipment manufacturers active in consumer and telecommunications equipment and automotive electronics; second, all merchant European semiconductor manufacturers, i.e. Firms producing microchips for sale on the open market; third, the main semiconductor production equipment and materials manufacturers; and fourth, major European research institutes and universities.

JESSI was once the largest programme within the Eureka framework, it involved fourteen European countries, as well as the European Commission, who participated in its development and contribute towards its project costs. The initial budget was set at more than 3,000 million ECU($3.5 billion). However, this sum has since been pared back to $2.4 billion. Of this, 50 per cent was provided by the firm and institutes participating, 40 per cent by national governments, and 10 per cent by the European Commission.

According to the EC assessment, the JESSI project had five important technological achievements. The first result of JESSI programme is the development of 16Mbit EPROM chip samples for delivery to customers. The main benefit of this is that the performance of products can be changed or customer wished implemented without modification of the hardware. The development of 16Mbit EPROM technology is part of that JESSI cluster labelled Competitive CMOS Manufacturing. The activities within this cluster are intended to strengthen the know-how of the European semiconductor companies in the field of advanced volume production for memories and logic circuits.

A second development which official documentation cites as proof of JESSI's success in terms of technological achievement is the High Precision Optical Wafer Stepper. This may be perceived as an important advance in a market dominated by Japanese manufacturers.

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[10] Measurement and Improvement of Manufacturing Capacity (MMAC) Final Report, Sematech, Technology Transfer 95062861A-TR

A third achievement of JESSI is the development of flexible, powerful mixed signal VLSI testers, by one of its industrial participants, Schlumberger. It is important to note that the JESSI office states that the presence of mixed testing capabilities is of strategic importance. This is due to the fact that applications requiring mixed signal IC are important future growth markets. A fourth tangible result of JESSI projects is the JESSI Common Frame, an open framework for computer-aided engineering applications. The purpose of a framework for CAD applications is to provide a so-called environment for integrating and running computer-aided design programs. In terms of users, the framework serves tool developers and designers from system houses, and chip manufacturers. Perhaps the most crucial advantage which can be gleaned from this technological development, particularly when related to one the central arguments espoused by this work on Europe's competitive hindrance, is that this framework could help to reduce the time to market.

A fifth JESSI technological development is the transfer of basic know-how on process modules for 0.35μm IC-technology to industrial pilot lines. The knowledge has been transferred from Philips Research to GEC-Plessey's and Siemen's pilot lines. These more sophisticated forms of process technologies are necessary in order to overcome impairments to semiconductor device performance, caused by, for instance, short channel affects on new submicron dimensioned MOS transistors.

Even though the positive assessment of the EC, the $3.6 billion JESSI nearly collapsed in 1991 after the EC decided to cut its contribution, Philips dropped out for financial reasons and Britain's ICL was expelled from key projects after being acquired by Fujitsu Corporation of Japan.  Of course, JESSI has been primarily important in three directions since its introduction in 1989: first, it has built upon the technology networks fostered by ESPRIT, and focused European R&D resources on cluster-to-market orientations. Second, it enables, through public support, technology transfer amongst European firms; and helps these firms to conduct high-risk, high-cost R&D. Third, it illustrates how European chip makers a users, along with national governments and the European Commission, could combine to create partnerships amongst competitors. The important objective of improving co-operation between European industry and research institutes has certainly been achieved. However, in terms of market share, this success does not, as originally intended, seem to have translated into a significant advance in Europe's position in the submicron silicon sector – the global market share actually decreased during the first half of the 1990s.

However, the European Commission did see JESSI quite successful. A rationale for this public affirmation of the Commission's support for JESSI may be political. A further means of evaluating JESSI's relative utility is in terms of the extent to which it has achieved its initial stated objectives. There are mixed opinions, particularly amongst corporate and government actors. One may conclude by arguing that it is not possible to say that JESSI has failed, but its relative contribution has not been significant. This is particularly true when one considers the sheer scale of finance, manpower, and organizational effort which has been put into the initiative. It is doubtful that the expenditure involved can be justified in the future without important technical developments which transform into a significant increase in market share amongst JESSI's main European corporate partners.

## Microelectronics Development for European Applications (MEDEA)

MEDEA is another 4-year (1997-2000) pan-European Eureka project for advanced research and development designed to ensure Europe's continued industrial competitiveness into the next century. The initiative will bring together many of Europe's top electronics companies. MEDEA capitalises on the momentum that has been generated by Europe's recent technological renaissance in the field of microelectronics. It focuses on silicon submicron technology and its integration into systems. There are 11 European countries participating in MEDEA. Nearly two-thirds of MEDEA's budget is targeted for applications. The total effort is about 12.000 man-years with a total cost of about 2.000 MECUs now €millions.

The strategic importance of MEDEA lies in the ever growing role that microelectronics is playing in the key industries such as computers, automobiles, telecommunications systems and consumer equipment. The proportion of electronics systems that can be integrated into silicon chips is rising rapidly, giving an increasing advantage to equipment manufacturers who can make early use of the most advanced semiconductor technologies. This makes it strategically vital for Europe to continue to have world class micro-electronics capability, not only in the volume production of advanced semiconductor devices but also in applications expertise.

MEDEA's mission is to further improve the technical capability to work towards parity between the volume of worldwide production of microelectronics by European semiconductor companies and their use in Europe. This will be achieved through early leadership in both essential technology and application areas. MEDEA's objectives, though similar to those of JESSI, have been rewritten for the remainder of the 1990s and will also allow a quantitative assessment in terms of market share. The six objectives are to:

- Develop core competencies in CMOS processes, design methodologies and computer-aided design tools for next-generation chips.
- Provide IC technologies and systems for the information society.
- Reduce dependence on non-European chip suppliers in critical areas.
- Provide platforms for vertical and horizontal cooperation.
- Use market opportunities to gain global market share.
- Exploit the leverage effect of microelectronics on employment.

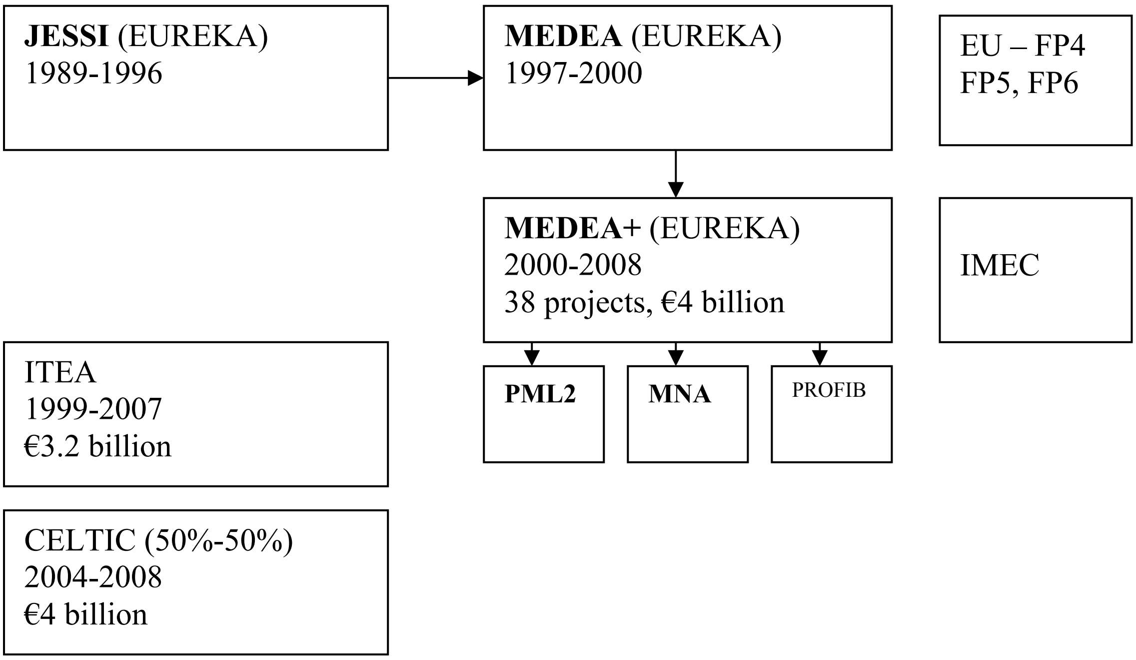
The MEDEA objective shall be reached by concentrating on:

1. Early leadership in those semiconductor technology areas, where Europe has the competences for excellence and leadership at hand
2. Early leadership in most advanced system-on-a-chip applications increasing the exploitation of European silicon technology in the domains of the MEDEA Core Competences, namely Multimedia, Communication and Automobile Systems

In a continuation MEDEA+ in December 2001 announced plans to insure that the ASM Lithography and its European suppliers would have the technology to play part in 157 nm lithography and next-generation EUV. ASML was already involve in the work of EUV LLC in the US, as well as with European initiatives. Thus ASML was considered to have the ability bridge European and US efforts – which would possibly strengthen its position against its Japanese and only rivals – Nikon and Canon.[11] The time horizon for the various EU projects is illustrated in the following diagram.

[11] Opto & Laser Europe, March 2002 – Computer chips

**EU Semiconductor Projects**



The organization of semiconductor technology development programs in the US, Japan and the EU show some distinct differences. First, university involvement has been much more prominent in the US and EU – often in direct collaboration with industry. This has rarely been the case in Japan with the exception of compound materials. However, Tohoku University and Hiroshima University have also been active in process technology for silicon – within the STARC project. Second, eh government agencies in Japan such as NTT laboratories and AIST laboratories have played a major role in Japan for which there are no equivalents in the US or EU.

## SEMATECH[12]

The Sematech concept originated in 1986 from an idea of industry-government cooperation was expected to strengthen the U.S. semiconductor industry. The initiative was prompted by several years of slipping U.S. semiconductor market share, the Semiconductor Industry Association (SIA) and the Semiconductor Research Corporation (SRC) hold a joint meeting in May and issue a call for cooperation to provide the U.S. semiconductor industry with the capability of regaining world-leadership in semiconductor manufacturing. The SEMATECH (SEmiconductor MAnufacturing TECHnology) consortium was formed in 1987, when 14 U.S.-based semiconductor manufacturers and the U.S. government established the organization to solve common manufacturing problems. Austin, Texas, was chosen as the site, and SEMATECH officially began operations in 1988, focused on improving the industry infrastructure, particularly by working with domestic equipment suppliers to improve their capabilities.
By 1994 both device makers and suppliers had regained strength and market share. Thus the SEMATECH Board of Directors voted to seek an end to matching federal funding after 1996, on the argument that the industry had returned to health and should no longer receive government support. However, SEMATECH continued to serve its membership, and the semiconductor industry at large, through advanced technology development in program areas such as lithography, front end processes, and interconnect, and through its interactions with an increasingly global supplier base on manufacturing challenges.
The International 300 mm Initiative (I300I) was formed as a subsidiary of SEMATECH in 1995, with seven non-U.S. companies and six U.S. companies cooperating on 300 mm tool standards and specifications; in 1998 five of those international companies opted to participate in more of the consortium's programs through a subsidiary called International SEMATECH, and then ultimately made the decision to join SEMATECH as full members, and subsequently the organization was renamed International SEMATECH.
In 1990 SEMATECH and the Joint European Submicron Silicon Initiative (JESSI) agreed on their first collaborative projects. A first edition of the *National Technology Roadmap for Semiconductors* is published in March. To parallel technology areas identified in the Roadmap, SEMATECH's Board of Directors broadens the SEMATECH charter to include packaging, test, design, and materials technologies. In 1995 Board of Directors approves a new business model that positions the consortium to operate without federal funding. In 1998 SEMATECH launches International SEMATECH, expanding the involvement of Hyundai, Philips, STMicroelectronics, Siemens, and TSMC. Front End Processes Research Center established with the Semiconductor Research Corporation (SRC) and three universities start to conduct fundamental research on materials and processes for sub-100nm device technology. In 2000 a 157nm exposure capability established in Resist Test Center (RTC) using Exitech

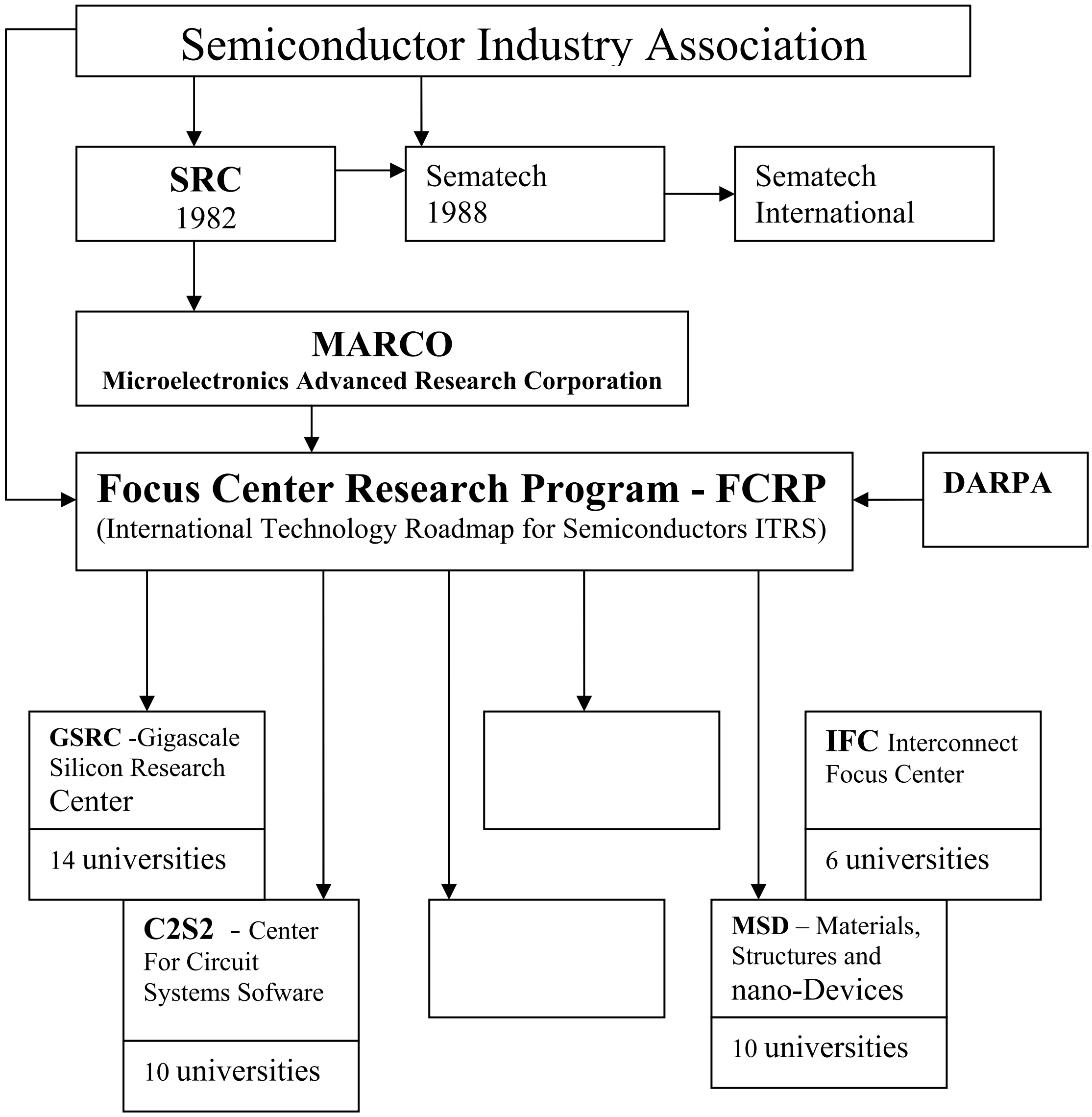
[12] This section is mainly based on information contained in http.//www.sematech.org/corporate/history.htm

157nm Microstepper.[13] In 2001 collaboration was initiated with Japanese consortia Selete and JEITA for global standards consensus. For the first time in its history, International Sematech places assignees outside the U.S., at IMEC in Leuven, Belgium to work on a joint program. In early 2003 ISMT opens its advanced EUV program at the University of Albany. In November the same year ISMT launches a new, wholly owned consortium, International SEMATECH Manufacturing Initiative (ISMI) to assist semiconductor manufacturers reduce cost per wafer, and ultimately cost per die.

The Microelectronics Advanced Research Corporation[14] (MARCO) plays a major role in US support for semiconductor technology development that involves universities, government and industry. Semiconductor Industry Association (SIA) originally took the initiative to create Sematech that later on was transformed into International Sematech. SIA also initiated Silicon Research Corporation (SRC), a subsidiary of MARCO that is closely linked to universities. Another important subsidiary of MARCO is Focus Center Research Project (FCRP) that gets 25% of its funds from DARPA, another 25% from US equipment makers and the remaining 50% from chipmakers. FCRP under MARCO organizes a number of activities which include the following ones: Giga Scale Integration (GSI), which is a design-oriented project, with a strong focus at UCLA-Berkeley, Multi-level routing, and LSI process industry, with a strong focus at Georgia Technical University. See diagram.

[13] Exitech 157nm Microstepper[13] was the world's first F2 VUV laser processing system commercially available

[14] The Microelectronics Advanced Research Corporation (MARCO) is a not-for-profit research management organization that funds and operates a number of microelectronics technology oriented, university-based research centers. MARCO is a wholly owned, but separately managed, subsidiary of the Semiconductor Research Corporation (SRC). SRC is a research management consortium that was established in 1982 as the university research arm of the Semiconductor Industry Association (SIA).



Semiconductor Industry Association
SRC 1982
Sematech 1988
Sematech International
MARCO
Microelectronics Advanced Research Corporation
Focus Center Research Program - FCRP
(International Technology Roadmap for Semiconductors ITRS)
DARPA
GSRC -Gigascale Silicon Research Center
14 universities
C2S2 - Center For Circuit Systems Sofware
10 universities
IFC Interconnect Focus Center
6 universities
MSD – Materials, Structures and nano-Devices
10 universities

## *Semiconductor Research Initiatives in Japan in the 1990s*

In the 1990s three main projects were started – Selete, ASET and STARC – to provide support for the development of individual elementary technologies, e.g. Fr Lithography. Selete was mainly focused on assessment; ASET was organized as a research project while STARC is more complicated. The 1990s were characterized by elementary technology development, assessment, and academic and theoretical approaches. Brief descriptions are given in the following.

### Selete

The Semiconductor Leading Edge Technologies (Selete) was established on February 20, 1996. Ten Japanese semiconductor companies are the stockholders. Selete consists of the Manufacturing Technology Research Department and the Advanced Technology Research Department.

Selete set up a temporary office in Kanda in February 1996 and announced that it started on its 300 mm program two months later. The office was moved to Yokohama in October the same year. Samsung Electronics joined Selete in October the following year. In March 2000 Selete and International SEMATECH (ISMT) announced a policy for cooperation on software implementation strategy for 300 mm production tools, and later on the same year the two consortia issue functional requirements for 300 mm manufacturing equipment for automatic production. In April 2001 Samsung Electronics and Seiko Epson joined in all programs as R&D contractors. In October the same year Selete established a Tsukuba branch, with a 600 m2 clean room inside NEC Tsukuba Research Laboratories, after which follows a relocation of Selete headquarters to Tsukuba in April 2002. In April 2002 the "ASUKA Research Line" – a development centre –was moved from Yokohama to Tsukuba. In advanced lithography Selete is work both on optical lithography and mask, as well as electron beam lithography. In 2003 Selete started the Fab Productivity Improvement Program.

In its plans for the future regarding 157nm lithography, Selete says that it will further improve the overall performance of new resist materials and develop process technologies for practical use. As for 193 nm lithography Selete will step up the development of module-ready processes by taking maximum advantage of the performance of the new high-NA 193 nm exposure tool, and also try to improve lithographic materials and develop elementary process technologies to enlarge the process tolerances. As for mask technology, Selete is committed to expediting the development of 65 nm-node-ready masking technologies and equipment and also identifying and developing 157 nm lithography mask using a 157 nm-ready mask evaluation machine scheduled for installation during fiscal 2003.

### ASET

The Association of Super-advanced Electronics Technologies (ASET) is funded by MITI and established in February 1996. It is a consortium of 22 member companies which perform basic research in three major areas: semiconductors, magnetic storage, and liquid crystal displays for market application after the year 2005

ASET is working in cooperation with government and the academic world to increase the overall strength of the industrial sector. The research alliance which started with 21 companies now has increased to some 50 member companies which include not only semiconductor and related companies but also companies in construction and automotive industry as well as companies from a wide range of other industries. The themes being undertaken by ASET are extremely important technologies in the field of semiconductors, not only for Japan but for the entire world. These include insulation film materials for separating low dielectric layers to increase the performance of semiconductors research which is being carried out as part of the MIRAI project. Another activity is the “minifab manufacturing” project which has been adapted for small production volumes of multiple model types – studied in conjunction with the HALCA project.

## STARC

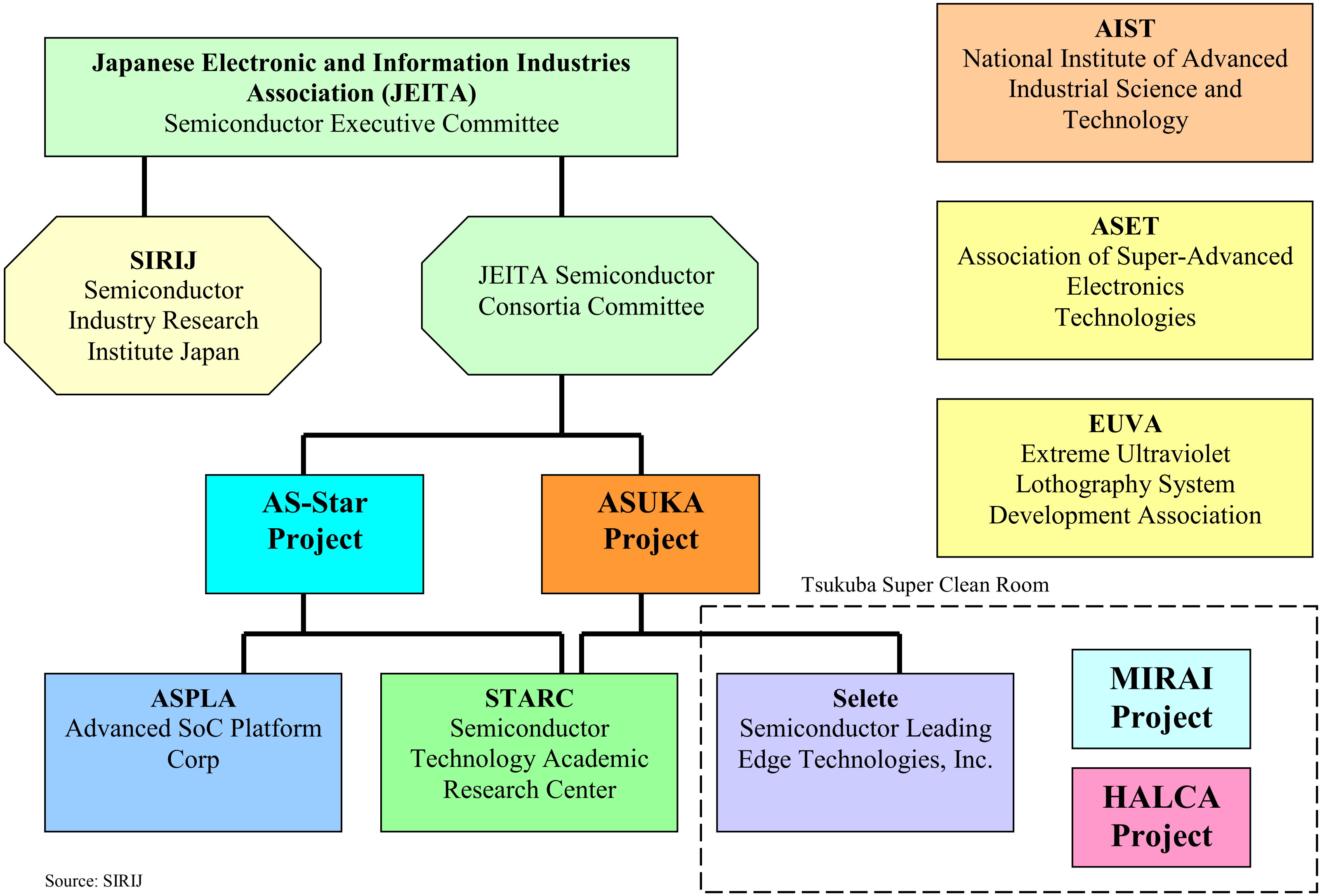
The Semiconductor Technology Academic Research Centre was established on December 28, 1995 to promote cooperation between industry and academia. It is modelled after the Semiconductor Research Corporation (SRC), which is a US consortium of private companies and government agencies that plans and manages funding for pre-competitive, long-term research at universities and research institutes in the area of microelectronics.

The original goal was to seek out new and effective technologies through the cooperation of industry and academia with the expectation to achieve breakthroughs in semiconductor technology. In 2000 STARC started new efforts targeting new operations aimed at increasing the efficiency of system LSI design. The evolution of the semiconductor technology has enabled the production of SoCs, in which entire systems are mounted onto a single chip, but at thee same time the industry is confronted with a formidable dilemma in that circuit designs containing tens of millions of individual transistors must be completed in a short time. STARC is thus promoting technological developments aimed at resolving this issue using a new approach – the automation of upstream system design processes and the reuse of existing design assets. STARC is also directing its efforts into technological developments related to low-power technologies and physical design technologies to respond to new design issues accompanying increasingly dense and increasingly fine LSI circuits.

The Japan Electronics and Information Technology Industries Association (JEITA) in 2001 initiated a new project, “ASUKA”, which has the objective to developing leading technologies and common infrastructure technologies in the field of semiconductors. In this context STARC is responsible for the development of SoC design technologies. STARC will through these activities attempt to re-establish a leading position of the Japanese semiconductor industry.

Two groups of actors were behind the new initiatives in the 1990s. One was the Japanese Electronic and information Industries Association (JEITA) which has a Semiconductor Consortia Committee and also operates the Semiconductor Industry Research Institute Japan (SIRIJ). See diagram which also includes programs and projects which were started in the 2000s. See diagram.

# Semiconductor Consortia in Japan




Source: SIRIJ

## *Semiconductor Initiatives in Japan - in the 2000s*

The Ministry of Economy, Trade and Industry is moving to overhaul public/private research-and-development projects for next-generation microchip technologies to make more effective use of resources. The current joint R&D system for advanced chips was launched in fiscal 2001, and consists of three projects - MIRAI, Asuka and ASPLA. The MIRAI project handles government-led basic research; Asuka aims to apply the results of the research to the manufacturing; and ASPLA plans to make the technology available to a broader range of companies through standardization.

## Advanced SoC Platform Corporation (ASPLA)

ASPLA, which stands for Advanced SoC Platform Corporation – is a research firm that has been set up by ten chipmakers, including Fujitsu, Toshiba and Renesas Technology with the objective to develop sophisticated chip technology platforms. ASPLA works together with AIST – the National Institute of Advanced Industrial Science and Technology – and wants to standardize production technology system and other advanced chips, with the apparent aim to improve the competitiveness of the semiconductor industry in Japan. However the President of ASPLA was at the end of 2003 not very hopeful and declared[15] "although Japanese chipmakers are ready to adopt an ultra fine processing technology next year for chips with a 90nm line width, the technology is unlikely to be standardized before its introduction."

The government wants the industry to agree on a common platform for next-generation chips with line-width of 65 nanometre, although company representatives suggests that each company could end developing production on its own – even if this would be considerably more costly. The government calculated that lessening the burden of research on manufacturing technology would help them reduce annual R&D costs by 10 billion yen ($93 million) per company.[16] However, METI is advancing a plan to merge the MIRAI and Asuka projects in fiscal 2004, with the goal of standardizing production technology.

Making chips smaller and less power-hungry requires that their circuit dimensions constantly have to be reduced. The leading chipmakers have been acting more or less independently, collaborating with materials and manufacturing equipment makers to develop the necessary technology for the next chip generation. METI now suggests that by pooling their knowledge for the 65nm generation of chips, the chipmakers in Japan can share the costly burden of development and instead focus their work on the actual design of circuits for customers[17]. ASPLA recently began operating a prototype line for system chip devices with a 90nm rule. Two similar consortia have been set up overseas, one by a group of four companies that includes STMicroelectronics NV of France/Italy and Royal Philips Electronics of the Netherlands, and another by a group of four firms that includes Infineon Technologies AG of Germany and IBM Corp. of the U.S.

Eight semiconductor-related companies, including Toshiba, Texas Instruments and Taiwan Semiconductor Manufacturing are working with California's Stanford University to develop

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[15] METI attempts to redefine advanced chip projects, Nikkei, December 15, 2003
[16] ibid.
[17] Chipmakers push standard for next-generation designs, Sharing cost of development will help Japanese firms regain tech advantage, Nikkei, October 13 2003

semiconductor technology two generations ahead of the present level. The group expects to develop the basic technology in a period of about three years and commercialize products around 2012. Intel and Tokyo Electron are also participating in the project, as are nine professors from Stanford. Current semiconductor-manufacturing technology can produce chips that have circuit widths of around 130 nanometres. The joint projects aims to bring that figure down to around 32-45nm. If researchers can succeed in achieving circuit widths of 32nm, then manufacturers will be able to produce memory chips with capacities of 32G -- more than 30 times the present level[18].

## ASPLA[19] raison d'être

The early emergence of ASICs and the more receive development of System-on-Chip (SoC) pose new challenges, and force companies to quickly respond to increasingly varied customer needs. Further, ASIC and SoC required device manufacturers to accumulate extremely large amounts of data on development achievement covering design assets through process technologies clarified by each design rule.

The conventional Japanese Integrated Device Manufacturers (IDM) model, relying on internal resources, faced a barrier to meet the rapid development speeds needed to keep up with new product development. Because of this, a new model that has attracted a lot of attention. Thus, so called Fabless & the Foundry models, with a horizontally arranged division of design and manufacturing became an optimal solution for attacking the ASIC market. The foundries could concentrate on manufacturing with much less financial risk from less attention to R&D, thus allowing them to invest in leading edge manufacturing technology.

As a result the foundries opened required design rule and parameters to their vendors which contributed large quantity of design assets such as chip libraries and EDA tools. This contributed greatly to the growth of fabless companies which established professional marketing capabilities and design strength. In the process the fabless companies were able to develop and create innovative products. Today the fabless and foundry models have become the best business mode to facilitate appropriate investment and efficient return on investment.

However, the design rule of less than 130nm era, which came into existence around 2000, created difficulties for the fabless and foundry models, in maintaining technical consistency among horizontal partners. To execute on this business model, it is essential to establish an infrastructure of technologies both for development and manufacturing. Moreover, in order to be able to meet customer's needs timely, it is also essential to prepare and then stock a large reservoir of Intellectual Property assets. In order to be able to match the challenges of a changing business environment, the product development strategies for making System on Chip (SoC) must be altered radically.

As process nodes get finer, power supply voltages become lower and operating speeds improve, parasitic elements and other parameters which have not required full consideration are bringing adverse effects on LSI performance and a decrease in reliability and an increase in failure rate are taking place. By taking a look at the design and manufacturing strengths of the IDM model, and combining these with the high efficiencies of the horizontally integrated model the AS-Star Project was established in Japan

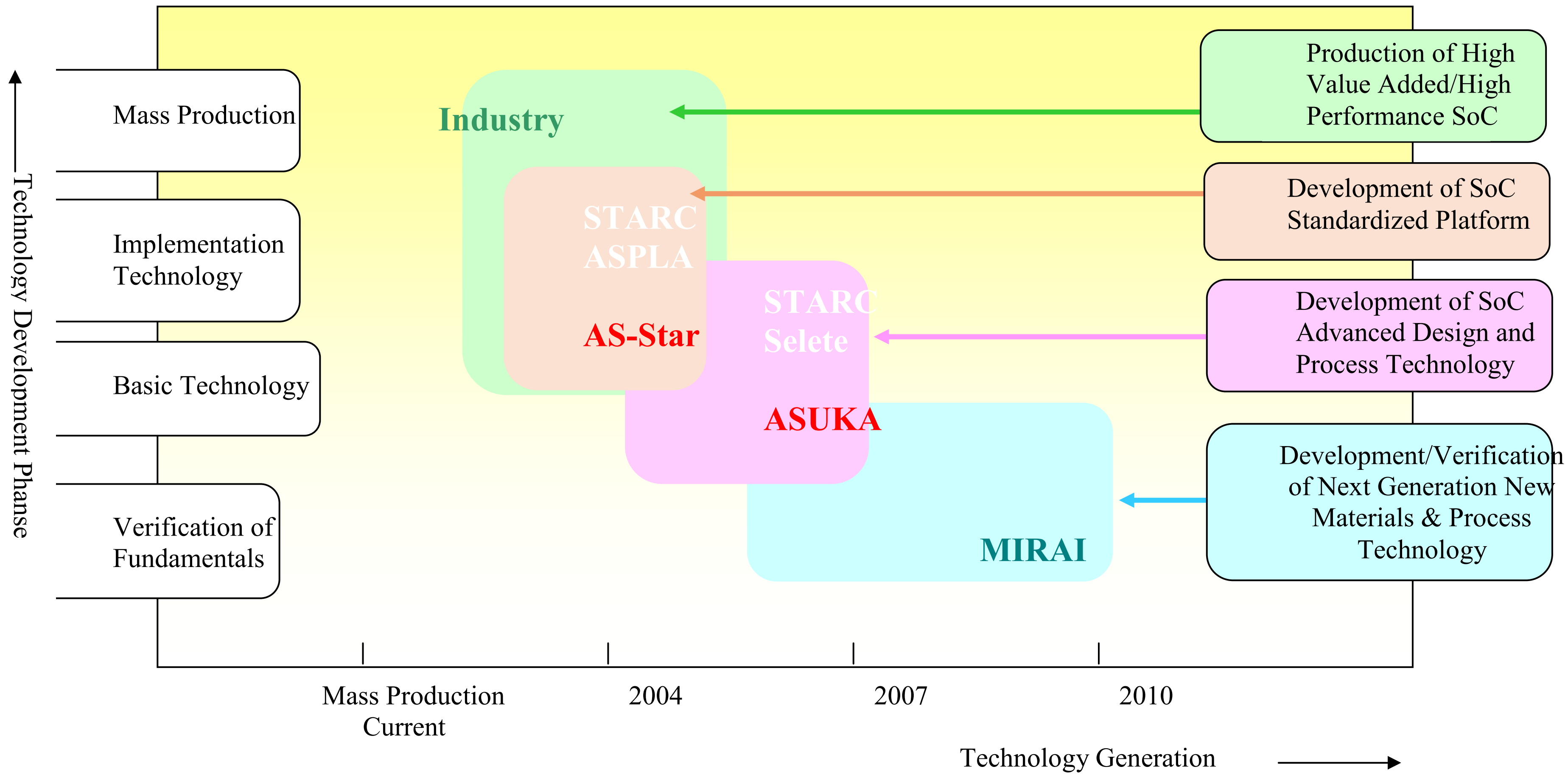
[18] 8 Firms, Stanford Univ Aim For Technological Leap In Chips, Nikkei, August 18, 2003
[19] This section is based on ASPLA official information (www.aspla.com.eng.project

Thus, the Advanced SoC Platform Corporation (ASPLA) and the Semiconductor Technology Academic Research Center (STARC) established the AS-Star Project, a technology platform with which will develop a complete and consistent design and manufacturing process for next-generation SoCs. The benefits are state in the following way.

> For the partners who develop their business using this platform, AS-Star Project will provide a high qualified standard process technology that has a high degree of completion, providing clear process management parameters that, when transferred to fab production, will bring yield highly-reliable, accurately performing LSIs that meet the partners' targeting market needs. In addition, this SoC technology platform is flexible and expandable and has been constructed to cope with the different companies' various business models, strategies and structures, allowing essential technology transfers to participants at different stages.
>
> It has become essential to reduce development costs to lead to qualitative improvement in financial strength, and to enhance mobility of design assets among companies by buying and selling essential IP in order to meet diversification of the market's needs. There is one solution for this issue. This solution is standardization. Standardization reduces development costs in pre-competitive area, and then allows companies to increase their strength in core and differentiated area. As the development environment for SoC changes with standardization, it is expected that the competitive area will keep on changing too.
>
> Standardization will lead to drastic changes in product development strategies. Moreover, companies are able to utilize standardized common process module into their core and differentiated process. Product development used standardized platform will reduce complexity of development itself. Through its aim of minimizing duplicated resource consuming and providing an optimized joint development program, AS-Star Project expects to establish a framework that will achieve excellent ideas and significant development results.

The creation of ASPLA should be seen as an attempt to incorporate all government and private sector consortia into working relationships that would not only provide the underpinning to directly support the industrial technology base and also create an efficient platform for future science-based development for System-on-Chip (SoC) technology. See diagram. The expectation is that the suggested approach would close the productivity gap between semiconductor manufacturing and chip where the latter is taking on a larger and larger share of total costs.

## Positioning of SoC Technology Development Projects and Consortium




Source: ASPLA home page

## Millennium Research for Advanced Information Technology (MIRAI) and ASUKA

The Ministry of Economy, Trade and Industry plans to drastically reshape research aimed at developing advanced semiconductors. Private-sector companies, including Toshiba and Matsushita are participating in Project ASUKA, which focuses on the practical development of next-generation chips with circuit line-widths of 65 nm. At the same time, the Millennium Research for Advanced Information Technology project, known as MIRAI, which is led by the National Institute of Advanced Industrial Science and Technology, is conducting basic research in developing advanced semiconductors with circuit widths of 45 nm. By merging Project Asuka and the MIRAI project in mid-2004, METI hopes to speed up the shift from basic research to practical application and the development of advanced chips for digital appliances.[20]

ASUKA is a private-sector project in which Hitachi, NEC and ten other semiconductor makers will invest 70 billion yen through fiscal 2005[21]. MIRAI is led by the Ministry of Economy, Trade and Industry with participation from the National Institute of Advanced Industrial Science and Technology, 25 private-sector firms and some 20 universities[22]. A related project is HALCA which has the aim to develop ways "to make chip-making technologies more efficient and energy-efficient".[23]

The three projects, involving more than 400 researchers, will be the largest ones engaging the private, public and academic sectors since the VLSI Project conducted in the latter half of the 1970s. This is in response to Japan having lost semiconductor competitiveness to the US, South Korea and Taiwan who during the 1990s mobilized national resources to strengthen their semiconductor industries. A Super Clean Room will be the centre of three flagship R&D projects of the most advanced semiconductor technology. MIRAI research project includes new materials, material processing, device technology and measurement technology for the next generation semiconductor technology, whereas the objective of HALCA project is the development of highly efficient and energy-saving manufacturing systems which accommodate a variety of types of products or production volume. ASUKA project aims at the development of new materials and total processing technology for the next generation of semiconductors.

## Highly Agile Line Concept Advancement - HALCA

The HALCA project started in early 2001 and has the objective of developing tools to produce small quantities of a large variety of chips as well as advancing energy-saving technology and developing other devices. It was completed in early 2004 and has involved 14 companies including Toshiba, Sony and Sharp and its total budget has been 8 billion yen.

Toyota is involved in the development of computer chips and other key electronic components as Toyota has come to regard the HALCA project as useful for its chip plant, which adopts the minifab concept of making products in small lots when necessary. Thus

[20] Nano-scale circuit projects to merge, Nikkei, December 8 2003
[21] Three Major Chip Projects start at New Facility in Tsukuba, Nikkei June 17 2002
[22] ibid.
[23] ibid.

Toyota sent one its researchers to the project in 2002 in the expectation of establishing a reliable production system that can reduce both total lead time and inventories[24].

Toyota is considering introducing the kanban system in the process of etching chips on wafers and plans to introduce technologies developed by the HALCA project, such as sharing devices capable of handling multiple processes, developing a production line adjustable in response to changes in demand as well as aiming to cut processing time. It is reported on the project that[25] "Cost reduction has been difficult for chip production because it is greatly affected by yield on output. But Toyota's move to introduce the kanban system for microchip production is starting to affect other participants in the project. For example, chipmakers are much impressed by Toyota's efforts to grasp standard processing time at each stage of manufacturing operations as part of its drive to reduce cost."

## EUVA – Extreme Ultraviolet Lithography System Development Association

Japan, with its previously leading lithography stepper manufacturers, Canon and Nikon has been somewhat slow to handle the challenges for drastically complicated new approaches. However, the EUV System Development Association (EUVA), a consortium of nine Japanese firms, is now seeking to redress the balance and is making heavy investment to catch up. However, it will be the major semiconductor companies with chip- Intel and Texas Instruments in the lead that will induce the development with the lithography production tool developers - ASML, Canon and Nikon.

EUV lithography is regarded as a promising technology for realizing future generations of semiconductors. It will enable production of semiconductor chips with features of 50 nm or less[26]. Japan has capabilities in basically all segments of semiconductor production - from materials and equipment to light sources and device fabrication. Mr. Masashi Ogawa, executive director of the Extreme Ultraviolet Lithography System Development Association (EUVA), argues that "(T)aking advantage of those resources, we believe that our EUV R&D work will catch up and take the lead in overall performance and cost, though we came late"[27].

To strengthen the future basis of the semiconductor industry in Japan, government, academia and manufacturers reached a consensus to accelerate EUV R&D. To manage the R&D efficiently, the Extreme Ultraviolet Lithography System Development Association (EUVA) was formed from ten EUV related companies, under the auspices of the Ministry of Economy, Trade and Industry (METI). The EUVA organisation[28] was established in the middle of June 2002, to develop an EUV lithography system, in particular EUV light source and exposure tool. From fiscal 2003 EUVA scheduled R&D on Absolute Wave Measurement system, succeeding the R&D results conducted by ASET from 2001. Laboratories will be operated within the facilities of Canon, Nikon, Komatsu, and Ushio – with headquarters at Canon (?) Check. A complete EUV prototype machine is expected by 2005 – to be completed by EUV

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[24] Nikkei Interactive, Nonaka, Takahide, Toyota Eyes 'Kanban' System For Chip Production, August 20, 2003
[25] ibid.
[26] The EUV system requires development of advanced technologies, for example, a light source to realize 13.5 nm wavelength high quality light, extremely precise mirrors, a very high quality projection system, and EUV wave measurement system
[27] Hara, Yoshiko, Japan plays catch-up on EUV lithography, EE Times, September 2, 2003 (http://www.eetimes.com/story/OEG20030902S0031)
[28] http://www.euva.or.jp/about/overview.html

lithography manufacturers who will provide assembling conveyers, stages and temperature control system.

EUVA members in April 2003 founded Renesas

The EUVA Project includes the following activities

1. EUV light source
   - R&D on high power and high quality EUV light source
   - Evaluation of EUV light source and its impact on the rest of the EUV system, including debris, contamination and damage to mirrors[29]
2. EUV exposure tool
   - Exposure system (illumination and projection optics), including manufacturing
   - Development of test system for exposure system and evaluation of exposure performance
3. EUV Absolute Wave Front Measurement system
   - Development of at-wavelength measurement system for calibration of the projection optics of EUV tools.
   - Research on at-wavelength measurement
4. Design and evaluation of EUV lithography system
   - Specification of exposure system of 50 nm
   - Evaluation of prototype system
5. Survey on EUV lithography technology
   - Analysis of world trend on next generation lithography (NGL) technologies

The Extreme Ultraviolet Lithography System Development Association (EUVA) was established in June 2002 ( www.euva.or.jp) - under the auspices of Japan's Ministry of Economy, Trade and Industry (METI)[30]. See figure. The association includes the two main lithography manufacturers Canon and Nikon; the two main light source manufacturers Komatsu and Ushio and the joint venture between light source makers – Gigaphoton. EUVA also includes device manufacturers Fujitsu, NEC Electronics, Renesas Technology Corporation, and Toshiba. Hitachi and Mitsubishi Electric were each EUVA members before they founded Renesas in April 2003.  Competing efforts are Cymer in the US (San Diego) and Xtreme Technologies GmbH in Germany (Göttingen).

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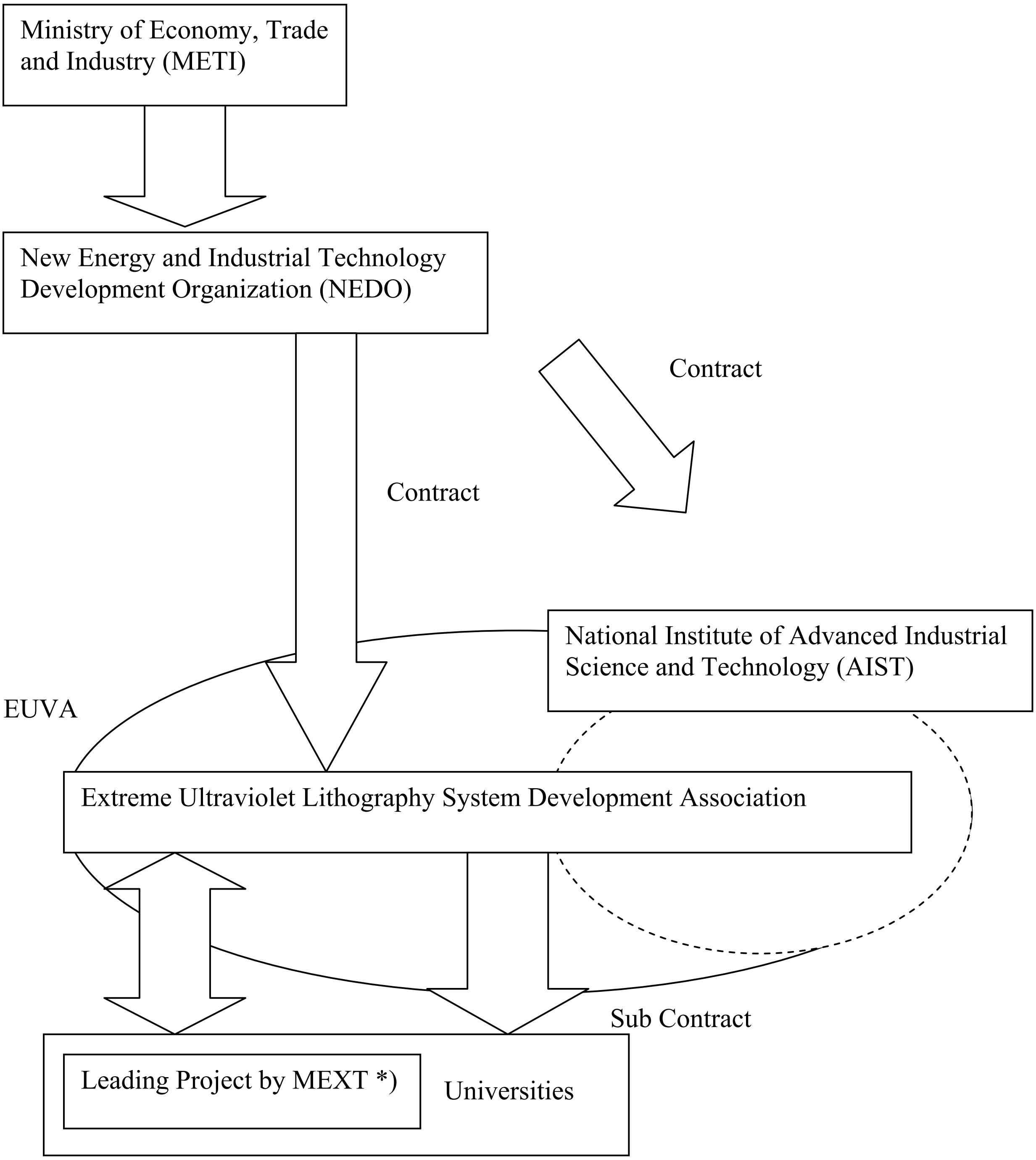
[29] Controlling debris is essential to keeping the cost of ownership for EUV systems within the budgets of semiconductor makers. The collector is particularly vulnerable to debris, and the set of mirrors in the collector must be kept free from carbon and other contaminants in order to reflect EUV radiation precisely.

[30] Hara, Yoshiko, Japan plays catch-up on EUV lithography, EE Times, September 2, 2003 (http://www.eetimes.com/story/OEG20030902S0031)

**Extreme Ultraviolet Lithography System Development Association (EUVA) Support Structure**




*) Ministry of Education and Science

Based on EUVA's work, commercial vendors expect to develop beta tools in 2007 and production systems by the end of 2009, according to the EUVA road map[31]. EUVA is supporting two parallel movements to develop a source of EUV radiation[32]. The association set up work on exposure tools and metrology at Canon and Nikon in April 2003. EUVA is pursuing parallel development efforts for the EUV radiation source: a laser-produced plasma (LPP) method, which is being pursued at Komatsu's Hiratsuka R&D center, and a discharge-produced plasma (DPP) method, which is being worked on at Ushio's Gotenba lab. The two groups are competing to reach a goal of 4 W of output power – which should eventually reach 100 W - at the intermediate focus of the reflective optical system by March 2004[33]. Other companies and research organizations have reported better performance of their prototype light sources. Cymer Inc. (San Diego) has reported an efficiency of 0.5 percent and a repetition frequency of 4 kHz to get nearly 60 W of usable power. Xtreme Technologies GmbH (Gottingen, Germany) achieved about 0.55 percent efficiency and a repetition rate of 6 kHz, but with usable power of roughly 45 W.

In a separate effort the National Institute of Advanced Industrial Science and Technology (AIST), a public research organization operating under METI, is also working on the source challenge to add to the efforts of EUVA[34]. See figure for actor involvement in EUVA activities

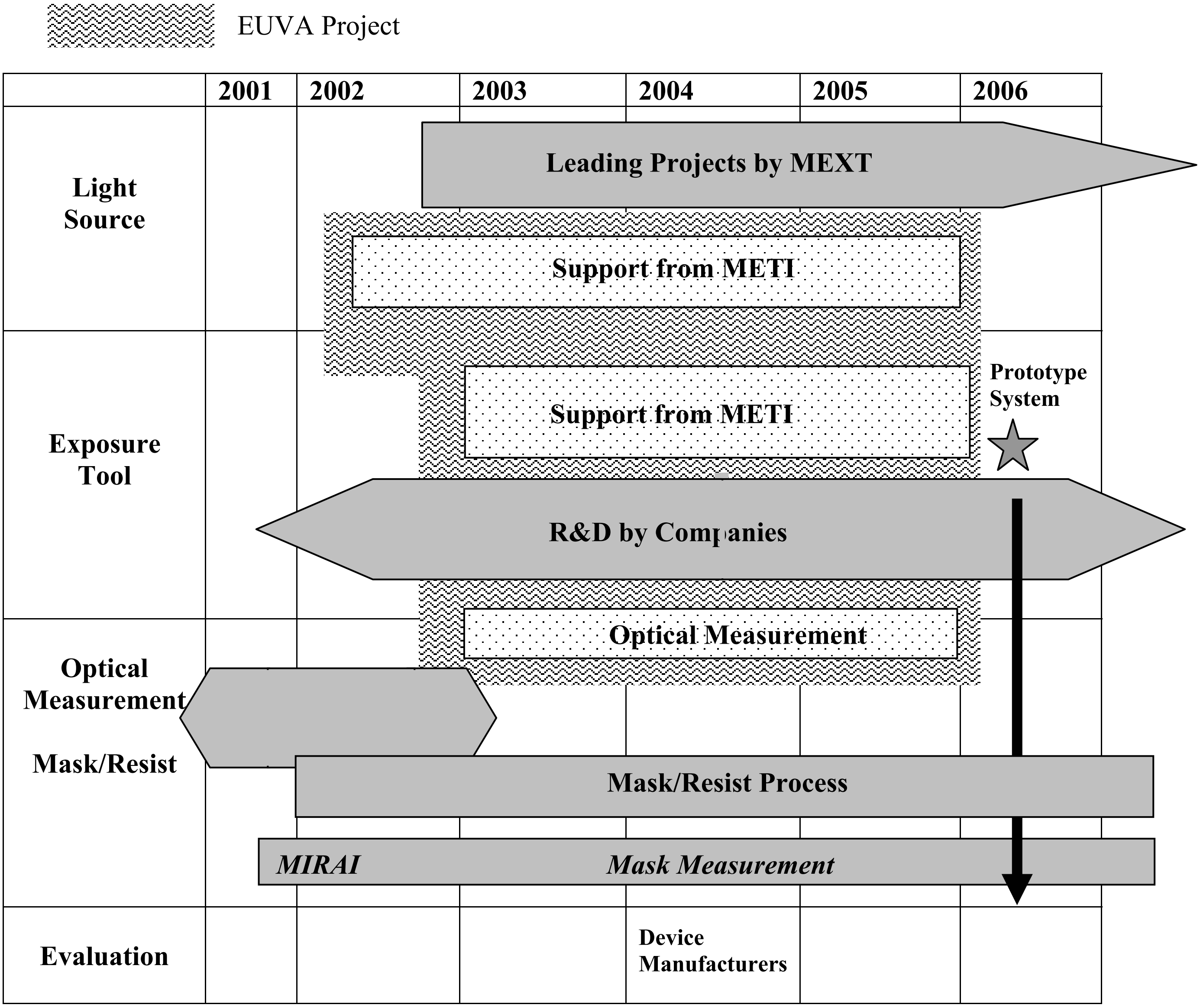
[31] EUV lithography requires reflective optics, employing a series of mirrors with some 40 precisely deposited layers of silicon and molybdenum, rather than the refractive lenses used in today's scanners. Developing a source of EUV radiation is particularly challenging, with the associated task of ensuring that debris from the source does not contaminate the optics.

[32] Commercial EUV scanners will require 110 W or more of EUV power for high-throughput systems – at the 13.5-nm wavelength. The current EUVA source generates only 0.6 W, although it has a frequency of 10 kHz, the highest reported to date. EUVA began source development work last year at corporate labs operated by Ushio and Komatsu.

[33] The Hiratsuka lab recently reported that it has generated plasma using xenon gas and a pulsed laser at a 10-kHz repetition rate with a pulse width of 30 nm. The lab is now changing to a laser with a pulse width of 7 nm. The engineers are predicting that the reduction in pulse width will raise the EUV power fourfold.

[34] AIST is experimenting with tin (Sn) as the target material, and the researchers claim to have developed a method for controlling the debris generated when tin is used.

# EUVA Research Schedule



## Gigaphoton – Komatsu & Ushio

EUVA has already been successful in achieving collaboration between universities and private companies followed by the government initiative bringing together laser makers Komatsu, Ushio and Gigaphoton into a cooperative EUV source program to develop excimer laser business. Those three companies will develop the powerful lasers needed to generate the EUV radiation[35]. Komatsu at the time reported that I had more than 15% of the global market for excimer lasers[36].

Komatsu Ltd. and Ushio Inc have announced that they have agreed to form a joint venture to undertake R&D, manufacture, sales, service and all other aspects of business related to excimer laser as the light source for lithography tools **Gigaphoton Inc.**, also in Tokyo, which was effective Aug. 1. The new company will use the founders' facilities in Kanagawa, Tochigi and Tokyo to research, develop and produce excimer lasers for semiconductor lithography. Gigaphoton will employ 180 and have total assets of ¥9 billion. An initial public offering of shares is planned. Akihiro Tanaka, president of Ushio, will serve as chairman and CEO of the company, and Yuji Watanabe, president of Komatsu's Electronics Div., will be executive vice chairman.

Komatsu started R&D of excimer lasers in the early 1980s, with successful development in 1987 of an excimer device. Entering the excimer laser business in 1996, the company claimed to have more than 15 percent of the excimer laser market. Komatsu began producing excimer lasers in 1985 in Japan, introducing its first KrF laser for photolithography in 1987.

Ushio, best known for its range of mercury lamps for g-line and I-line steppers responded too late be a player in the KrF excimer laser market and only as recently as 1997 started working on the development of an ArF excimer laser. Both companies at the time have publicized that they had started joint development of an F2 laser by participating in the F2 lithography development project commissioned to the ASET (Association of Super-Advanced Electronic Technologies) by NEDO (New Energy Industrial Technology Development Organisation).

Under the basic agreement, plans call for each joint venture partner equally sharing its capital of 2,000 million yen and utilising both companies' existing facilities for production, development and sales. The core strength to the JV relationship is the service and support capability established over many years by Ushio. The high maintenance cost’s of laser’s ads

[35] Competition is also heating up in other countries and South Korea's Ministry of Industry and Energy established a 10-year EUV program that started in late 2002.

[36] Three unique and essential technologies have been developed by Komatsu for this next generation laser. The first technology is a 193nm coherent light source, which enables highly accurate measurement and inspection. This has enabled Komatsu to start ArF production prior to competitors. In order to minimize damage to optical components, the density of the laser was lowered while the pulse width was widened (or stretched) to maintain the energy of each pulse. This technology is call "pulse stretching." This is second technology Komatsu has developed. The third one is a unique gas technology. ArF lasers have, as a physical nature, less stable discharge than KrF lasers and suffer from impurities in laser gas ten times more than KrF. With Komatsu's original gas measurement technology, effects by a variety of impurities were carefully studied, resulting in an optimal gas mixture for ArF lasers. The new mixed gas, with the addition of Xe (Xenon), doubled the energy stability and more than doubled gas life, from 20 million pulses to 50 million pulses. Source: Komatsu Announces Next Generation Advanced Argon Fluorine -- ArF -- 193nm Excimer Laser for Semiconductor Lithography Systems. Business Wire, July 10, 2000, www.findarticles.com/cf_dls/m0EIN/2000_July_10/63276441/p1/article.jhtml

significantly to the overall cost of ownership with service and repair becoming a key purchasing decision.

The semiconductor manufacturing equipment industry has entered an age of competition in technological innovation, in which the company that is able to develop these devices most rapidly will attain a first developer advantage in the industry.
The key to finer-width semiconductor circuit patterns is the resolution capabilities of the stepper (reduction projection exposure device). These resolution capabilities, in turn, are largely dependent on the capabilities of the stepper's light source.
Gigaphoton, Inc., a joint venture between Ushio and Komatsu Ltd., has been developing light sources for laser steppers since its August 2000 inception, beginning with KrF (krypton fluoride) excimer lasers. Currently, Gigaphoton is now developing the ArF (argon fluoride) excimer lasers used in 90nm ($10^{-9}$m) manufacturing processes. Gigaphoton will introduce a mass production model in 2002, a step ahead of its U.S. competitors.
Gigaphoton is currently engaged in the development of candidates for next-generation light sources such as F2 (fluorine dimmer) excimer lasers, and next-next-generation EUV (extreme-ultraviolet) light sources. The Company continues to meet semiconductor makers' need for light sources as they struggle to make the fanciful semiconductors of the future a reality.

### CASMAT

A new institute, Consortium for Advanced Semiconductor Materials and Related Technologies (CASMAT)[37] was established in early 2003 with the objective of supporting the revival of Japan's semiconductor industry by developing new materials that are competitive not only in domestic but also in global markets. The ten member firms of CASMAT will jointly rent clean room facilities at the Central Research Laboratory of Hitachi Ltd in Kokubunji, Tokyo, to share production lines to try out new materials. CASMAT will test and demonstrate the technological capability. The materials themselves are to be developed by individual member firms of CASMAT.

The setting of the semiconductor industry is forcing materials makers to come up with a major technological breakthrough as existing materials will no longer be sufficient for the density of the circuits of system chips in equipment such as cell phones and digital TVs. A major function of CASMAT is in evaluating technology for insulating film and photosensitive resins needed in the development of semiconductors with a circuitry of 70 nanometres or below. Nikkei reports that the ten companies plan to spend a total of 6 billion yen on the CASMAT project over three years and expect to receive the same amount of funding from the Ministry of Economy, Trade and Industry (METI)[38].

## *From MITI to METI – A New Role in Semiconductor Development*

MITI played an important role during the 1970s in promoting industrial technology development of which the Very Large Scale Integrated Circuits (VLSI), organized as an engineering research association (ERA) among a total of some 150 such organizations,

[37] Although Japanese manufacturers account for an estimated 25% of the global chip market, they have captured almost 70% of the world market for chip materials, including silicon wafers, insulation and wiring materials, and maintain a high level of technological sophistication. ( Nikkei June 2 2003, Chip materials makers pool resources in development)
[38] Nikkei May 23 2003, Chip materials makers aim for joint tech breakthroughs

became famous around the industrialized world, and emulated in different ways. The success of this project and the concern in the US at the time of an increasing strength of Japanese semiconductor industry prevented Japan to launch additional public-private initiatives within the semiconductor field. The bubble economy of the 1980s and the hubris of Japanese electronics industry further contributed to the neglect of new support measures, compounded by weaknesses in government administrative structures. MITI was reorganized in 2001 and became METI while at the same time a major overhaul of government research institutes was carried out.

However, observers have long considered that Japan requires changes in its administrative structure that can quickly respond to changes in the IT industry, as the country faces intense competition from other countries over the development of IT technology and software. In response to this the Prime Minister of January 17 2004 instructed his Cabinet ministers to consider integrating the various information technology sections of different ministries – which could eventually form a new ministry[39]. Japan carried out a major administrative reform in 2001 which involved the R&D structure to support IT development but government-level responsibility is still divided and non-involved Cabinet ministers agree about the importance of improving the country's IT competitiveness, and refer to the success of South Korea, where the relevant administrative structure has been integrated.

METI has through its National Institute of Advanced Industrial Science and Technology (AIST) supported the creation of large scale research facility in Tsukuba. This will support the development of semiconductor technologies – with major public-private-academic projects playing a major role. ASPLA that started activities by July 2002, having a total budget of more than 100 billion yen. See details in separate sections.

The MIRAI project handles government-led basic research; ASUKA aims to apply the results of research into manufacturing, while ASPLA envisions making the technology available to a broader range of companies through standardization. However, collaboration across public-private borders and among private companies is not always easy, and reflects on METI stating its role in the following way, "the planned rationalization of public/private research projects has not proceeded smoothly mainly because the participants have failed to move in step. Since higher added value is incorporated into sophisticated chips, design and production are generally considered inseparable".[40] This not withstanding METI is planning to merge the MIRAI and ASUKA projects in fiscal 2004, with the goal of standardizing production technology as soon as possible.

It was reported in late 2003 that METI[41] plans to drastically reshape research aimed at developing advanced semiconductors. By merging the ASUKA and MIRAI projects in mid-2004 the ministry hopes to speed up the shift from basic research to practical application and the development of advanced chips for digital appliances which could allow Japan to take a global lead in the field.

To further support structural changes AIST purchased, at 31.5 billion yen, facilities within a NEC building in Sagamihara and created a center, which features a 4,500-sq.-meter clean room. The new facility can create system chips with 90nm line-width on 300mm silicon wafers. In addition AIST and ASPLA have set up a joint research organization including 11

[39] Koizumi proposes new IT ministry to reduce red tape, The Japan Times, January 18, 2004
[40] METI attempts to redefine advanced chip projects, Nikkei December 15 2003
[41] Nikkei, December 8 2003, Nano-scale circuit projects to merge

staff from AIST and another 87 from ASPLA. The new team started to work, with the aim of developing and standardizing circuit processing technology, during fiscal 2003[42].

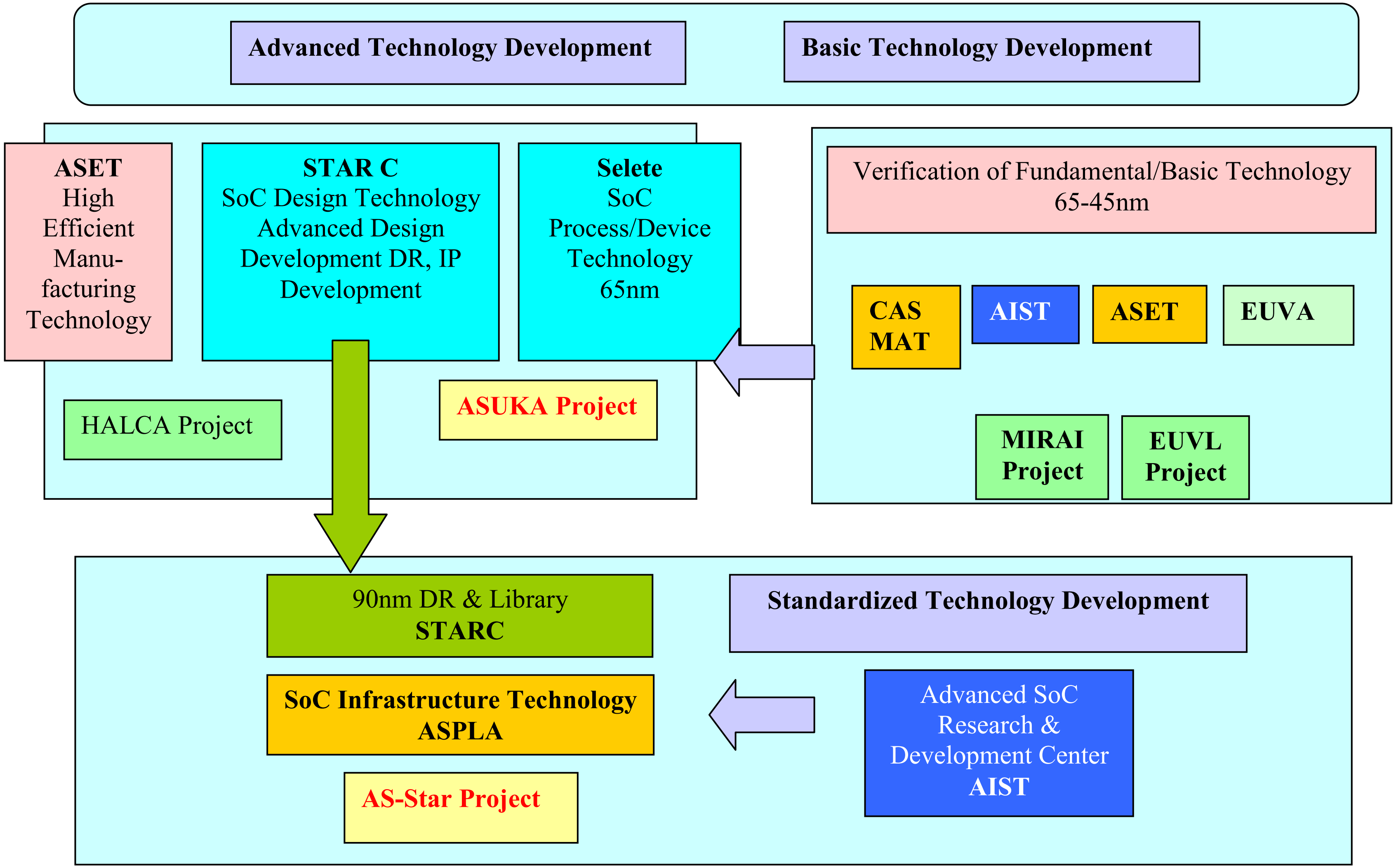
## Variety of approaches in the 2000s

The 2000s has seen the launching of a variety of semiconductor programs/projects. However, the viability of government support may have changed since the late 2003 and in January 2004 which may change the fate for the continuation of ASPLA after April 2004. A major reason is evident in company desire to chart its own course for which Sony provides a striking example. The company decided in October 2003 to join forces with Toshiba to jointly develop semiconductor devices fro future consumer products. Toshiba already has a strong alliance with IBM which emanated from the partnership to jointly develop DRAMs in the 1990s in a partnership that also involved Siemens in Germany.

A different approach has been adopted during the 2000s with more variety and higher complexity. Mirai is similar to projects initiated during the 1990s and is supported by the government at the level of 100%. Its focus is on basic technology and n important objective is to develop a 45 nanometer chip with special attention to EUV mask inspection technology. The Asuka project is in a way a combination of Selete and STARC. Selete aims at 65 nanometre chip is completely financed by the private sector It includes lithography development and e-manufacturing system - knowledge-based equipment and connection system. Both Selete and MIRAI are oriented towards basic process technology. See diagram.

[42] Nikkei June 30 2003, Cutting-edge chip research center

# Collaboration in Japanese Semiconductor Development



HALCA is a new concept and aims to conceptualize a minifab that is highly automated and is scalable for monthly wafer production from 300 wafers up to 30,000 wafers – using low-cost equipment. Most lithography processes are not scaleable which is true for production lines that are using Nikon and Canon equipment. The HALCA project will be completed by the end of March 2004. Large companies with the exception of Toyota have shown no or limited interest in the HALCA project. The EUVA project is equipment-oriented and supported on a 50-50 basis through NEDO. Gigaphoton is a private joint venture that receives some subsidy through EUVA, and possibly from Selete (?). ASPLA is a technology platform and includes characteristics of new programs that are increasingly business-oriented. Standardization has become a major issue in the support of the ASPLA technology platform. ASPLA has five key actors Toshiba, Renesas, NEC Electronics, Fujitsu and Panasonic.

Hitachi and Mitsubishi Electric are indirectly involved as is also Sony, Sharp and Sanyo The participation of Toshiba, NEC and Fujitsu has a historical background as they have participated in joint programs and were also key actors in the earlier VLSI project. However, this is the first new project with only a limited number of key actors. Sony has decided to chart its own way in semiconductor development and production, and has also resigned from its participation in the government program to develop TFT panel display technology in Japan for which METI provides support.

## *Restructuring of Japanese Semiconductor Industry*

It has become obvious that the Japanese electronics industry has been competing poorly against its foreign rivals since the collapse of the IT bubble at the very end of the 1990s. This has not only been a concern to the companies involved but also to the government and its various agencies. Thus, in December 2002 the then director-general of Commerce and Information Policy Bureau of the Ministry of Economy, Trade and Industry (METI) called the Presidents of Hitachi, Fujitsu and NEC and asked to consider integrating their telecommunications equipment business.[43] The Ministry at the time had actually mapped out a grand plan to set up a new corporation that would cover everything from fixed-line phones to telecom equipment, with sales of three trillion yen, and with prospect to challenge its foreign competitors.

Following the METI proposal the vice presidents of the three companies and their senior managers in charge of telecommunications started unofficial discussions. However, as Nikkei reports, these negotiations came to nothing and a serious stumbling block was the fact that NEC and Fujitsu, which have already posted substantial losses in the two preceding years were not willing to carry out restructuring programs that involve huge extraordinary losses in fiscal 2003, and the unofficial negotiations came to an end[44].

Similarly, the heavy electrical machinery sector, which used to be highly profitable, has arrived at completely new position which reflects a substantial reduction in capital spending by electric power utilities. The ten major ones invested close to 5 trillion yen in fiscal 1993, which has been reduced to two trillion in fiscal 2003 and may be even further reduced in

[43] IT REVIVAL (1): Breakup Of Comprehensive Elec Machinery Makers Urged Nikkei Monday, September 29, 2003
[44] ibid.

fiscal 2004. Acting on their changing fortunes Toshiba and Mitsubishi Electric have consolidated their transmission and distribution businesses, while Mitsubishi Heavy Industries and Hitachi formed a business alliance in nuclear power generation[45]. Thus, the long overdue consolidation of the electrical machinery industry in Japan has finally started.

Many of the electrical goods companies have concentrated their efforts on the Japanese market which is exemplified by the fact that domestic output of refrigerators totalled 320 billion yen in 2002, versus exports of only 1.9 billion yen[46]. A very gloomy state of affairs exists within the electronics and information industries. Since deregulation moved into high gear in 1996 the 102 listed companies that belong to the Japanese Electrical, Electronic & Information Union have in the seven-year period from 1996, reported total losses of 434.9 billion yen. The ratio of operating profit to sales of eight major electrical machinery makers in the past 10 years averaged 2.6%, far below the 4.4% of the top eight automakers[47].

In the 1980s, Japanese chipmakers controlled 80% of the global market for DRAM chips. Their share of the world market for all microchips, after exceeding 50% in the late 1980s, decreased to below 30% by 1998 as Samsung Electronics Co. in South Korea and other foreign competitors rapidly captured markets shares. In 2003 the business environment, has been improving for Japanese semiconductor companies as demand for chips used in digital consumer electronics started to expand. This has been a danger in disguise as, whenever demand picked up; chipmakers began to slow their restructuring.

However, substantial although slow changes are take place in the semiconductor industry in Japan, which reflect the cumbersome decision-making process in Japan. In the middle of 2002 Fujitsu entered into an alliance with Toshiba for joint development of system chips with the possible aim of merging their chip operations. However, Fujitsu feared that a merger would mean control by a larger partner, and decided against the merger when chip prices started to recover[48].

Elpida, the only remaining DRAM maker in Japan being a joint venture of Hitachi and NEC has since 2002 undergoing a metamorphosis since Yukio Sakamoto became President of the company. Not only will the original owners invest more capital but Sakamoto has also persuaded Intel to invest US$100 million and another 30 corporations have agreed to make additional investment.[49]

Another significant change is the creation of Renesas Technology Corp., a semiconductor firm to be established jointly by Hitachi and Mitsubishi Electric in April 2003. The company will also have a subsidiary Renesas Solutions that will develop software to be used in conjunction with system chips and microcontrollers as well as equipment to test chips. The new firm will take over the 380 employees of Mitsubishi Electric Semiconductor Application Engineering Corp, and some 20 Hitachi engineers will also join the new company[50].

[45] ibid.
[46] IT REVIVAL (2): Japan Appliance Makers Stuck With Slim Profits, Nikkei September 30, 2003
[47] IT REVIVAL (1): Breakup Of Comprehensive Elec Machinery Makers Urged Nikkei Monday, September 29, 2003
[48] IT REVIVAL (3): Slow Decision-Making Hurts Japan Chipmakers, Nikkei October 1, 2003
[49] Industry chips in Elpida restart, Nikkei, June 9, 2003
[50] Hitachi-M'bishi Chip Firm To Form Application Engineering Unit, Nikkei March 17, 2003

The creation of Renesas also affected Trecenti was established in March 2000, with Hitachi taking a 60% equity stake and United Microelectronics Corp. (UMC) of Taiwan a 40% stake, with a view to making it the world's first LSI mass production plant handling 300mm wafers. However, it became a wholly owned subsidiary of Hitachi two years later[51].

Further restructuring of the semiconductor industry has meet with many hurdles which is evident from the spring meeting of some 20 representatives of Japan's chip industry, in the resort town of Atami, Shizuoka Prefecture. The meeting included the senior vice president of Toshiba, the president of Elpida Memory Inc. and the official then in charge of the IT industry at the Ministry of Economy, Trade and Industry. The subject of their discussion was Trecenti Technologies Inc. that had been created through the integration of the chip businesses of Hitachi and Mitsubishi Electric Corp. Trecenti, which is equipped with fully automatic production lines that can process wafers measuring 300mm in diameter, is believed to be a world-class manufacturer in the field of system chips for use in digital consumer electronics products. The participants at the meetings agreed that five to 10 more chipmakers, including NEC Electronics Corp. and Sharp Corp., would buy into Trecenti, which would become a common production base for the chipmakers. The plan failed as it ran aground on the objections of Trecenti's parent firm, Renesas, that is now negotiating with two firms to set up another chip foundry[52].

## Elpida Memory Inc. (Hitachi-NEC)

Japan has many leading producers of digital home appliances and cellular phones with advanced functions. These firms will need increasingly advanced memory chips to handle progressively more sophisticated image processing in their products and this gives DRAM manufacturers new business opportunities. This will benefit Elpida which has become Japan’s sole producer of DRAM[53] after Hitachi and Mitsubishi Electric merged their operations, and has the aim to enter among the top three global manufacturers. Since the beginning of 2003 Elpida has signed outsourcing agreements with three foundries based in Taiwan and China. Combined with the increased capacity at a plant in Hiroshima, the firm expects to have product supply capacity enough to enable it to regain a 15% market share in 2004[54]. In 2002 the companies that now have formed Elpida had a miniscule four per cent of the global market for DRAM for which Samsung Electronics with 32% took a leading positions followed by Micro Technology in the US (17%), Infineon Technologies in Germany (13%), Hynix in Korea (13%)[55].

Intel has made a substantial investment in Elpida, which is a consequence of a declining demand for microprocessors used in computers for which Intel has a 80% market share. Subsequently, Intel has increased its efforts to improve the performance of its microprocessors so that personal computers can feature such new functions as those fro DVD recording and W-LAN. However, if the DRAM chips do match the upgraded computing capabilities of microprocessors in handling processed data then the overall performance of a computer will not improve. Since 1998 Intel invested in DRAM manufacturers such as Samsung Electronics in Korea and Infineon Technologies in Germany. Apparently, Intel has

[51] FRESH START: Hitachi, Mitsubishi To Integrate Chip Ops, Nikkei March 28, 2003
[52] IT REVIVAL (3): Slow Decision-Making Hurts Japan Chipmakers, Nikkei October 1, 2003
[53] Toshiba pulled out of its commodity-grade DRAM business in the spring of 2002, but has decided to produce high-speed DRAM suitable for a new microprocessor that it is jointly developing with Sony Computer Entertainment Inc. and IBM Corp.
[54] Elpida Seeks To Spearhead Japanese DRAM Recovery, Nikkei, June 4, 2003
[55] Sole DRAM maker sets bar high, Nikkei, November 24 2003

not been fully satisfied with the performance of available DRAM chips and decided to make a fresh investment in Elpida since a new president was appointed in the autumn of 2002, although Elpida came into existence already in 1999. This interest of Intel is not surprising considering that some 70% of all DRAM chips are used in personal computers[56].

However, Elpida has its sight se up fast large-capacity DRAMs that are likely to continue to dominate in advanced digital appliances. To that end Elpida in May 2003 signed contracts to outsource production of commodity-grade DRAMs for personal computers to three foundries in Taiwan and China, including Powerchip Semiconductor Corp. of Taiwan, and Semiconductor Manufacturing International Corp. (SMIC) in China which will allow the Elpida plant in Hiroshima to concentrate on sophisticated DRAMs such as those used in mobile phones[57]. Elpida will provide SMIC with the technology to manufacture 0.13 micron DRAM and SMIC started delivery in autumn 2003. It was reported that Elpida will consign production of most advanced DRAM chips to midsize chipmaker PorMOS Technologies.[58]

The President of Elpida, Mr Yukio Sakimoto, has introduced a number of in Japan revolutionary management practises that can be summed up in the following comments[59].

> To upgrade its R&D capability, Elpida has taken steps such as "scrapping wasteful meetings to enable engineers, who are inherently highly efficient, to focus their efforts on their real duties," said Sakimoto. As a result, Elpida was able to develop a 1-gigabit power-saving DRAM, the DDR2, ahead of Samsung Electronics Co. of South Korea and other foreign rivals.
> ….
> The quick pace of Elpida's revival is thanks partly to conditions Sakamoto set before becoming president. To speed up decision-making, he demanded that NEC and Hitachi give him authority to approve up to 10 billion yen in investment. He also ended the practice of appointing executives alternately from the parent firms.

This is part of major program to speed up the production process and the aim is to shorten the production period for DRAMs by more than 40% to 45 days. This will require major changes in the production process which chips involves as many as 570 separate steps, and chips must travel a production line that is 2km long. Elpida aims to increase the efficiency of this complex process by optimizing the scheduled use of production equipment, particularly machines such as steppers that are seen as bottlenecks in the production process[60].
However, when many parties are involved the decision-making process often slows down which is evident from the following comment. Elpida decided in June 2003 to procure more than 100 billion yen in order to compete against Samsung Electronics. But negotiations with NEC) and Hitachi), which jointly own Elpida Memory, delayed the opening of a new production line by about four months from the initial plans. “The opportunity cost was about 20 billion yen," said Elpida Memory President Yukio Sakamoto, explaining that delays in production result in the firm missing the chance to charge a higher price[61].

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[56] Elpida Seeks To Spearhead Japanese DRAM Recovery, Nikkei, June 4, 2003
[57] Elpida and Toppan will work together to develop photomasks for DRAM chips with circuit line widths narrower than 100 nanometres.
[58] Elpida To Outsource Advanced DRAM Output To Taiwan's ProMOS, Nikkei, Tuesday, May 6, 2003
[59] Elpida Seeks To Spearhead Japanese DRAM Recovery, Nikkei, June 4, 2003
[60] Elpida Aims To Slash DRAM Production Time By 40% To 45 Days, Nikkei November 7, 2003
[61] ANALYSIS: Japan Firms Lose Edge Due To Slow Decision-Making, Nikkei July 17, 2003

## Renesas Technology Corp. & Trecenti Technologies (Hitachi-Mitsubishi)

Renesas Technology was established in April 2003 from the merger of the semiconductor divisions of Hitachi and Mitsubishi Electric. The original spending plan called for Renesas to invest 90 billion yen on plant and equipment in fiscal 2003, with 70 billion earmarked to boost production capacity and the remainder going for information systems. This total of 90 billion is nearly double the combined spending plans of the semiconductor divisions of Hitachi and Mitsubishi before the merger[62]. Hitachi holds a 55% stake in Renesas and Mitsubishi has the remaining 45%.

Renesas Technology announced in the autumn of 2003that the total investment for a new chip plant it plans to jointly build with Japanese companies will amount to Y200 billion. The company said it is in talks with two other Japanese semiconductor producers regarding investment in the plant, and that it aims to conclude a deal by the end of 2003, and has said that it would prefer to have one more company join the agreement. The plant, to be built in Japan, will start operations in 2004, making state-of-the-art 90-nanometer chips using 300-millimeter wafers. The joint investment agreement is aimed at sharing the heavy expenses involved in the production of cutting-edge semiconductors[63].

Renesas Technology will enter the high-capacity flash memory market in a major way as demand for the products grows with the rapid spread of digital cameras and cellular phones with built-in cameras. Renesas plans to begin volume production of 1-gigabit memory chips in autumn 2003. The global market for high-capacity flash memories, which are used for such purposes as storing image data, is estimated at Y300 billion a year. Toshiba and Samsung Electronics in South Korea have nearly half the market each, but given annual growth in the 10-20% range, Renesas expects to establish a position for itself with products containing proprietary technology[64].

### Trecenti

Trecenti was established in March 2000, with Hitachi taking a 60% equity stake and United Microelectronics Corp. (UMC) of Taiwan a 40% stake, with a view to making it the world's first LSI mass production plant handling 300mm wafers. It became a wholly owned subsidiary of Hitachi two years later. The main Trecenti plant, which fully came on-stream in March 2001, at an investment of 70 billion yen, features production lines which process wafers individually. The batch method, under which several tens of wafers are processed collectively, is common in imbedding circuits on wafers. However, it is not suitable for system chips, which are turned out based on small-lot manufacturing of a wide variety of products, since it tends to manufacture too many products. Trecenti's production method makes it possible to adjust production even by one wafer and helps shorten the manufacturing time. Trecenti can shorten the production time of some memories from 25 to just fewer than six days.[65]

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[62] Renesas To Boost Spending Plans To Bolster Cutting-Edge R&D, Nikkei, November 11, 2003
[63] Renesas In Talks With Several Cos To Build Chip Plan, Nikkei, September 9, 2003
[64] Renesas targets high-capacity flash memories, Nikkei, June 30 2003 Nikkei
[65] FRESH START: Hitachi, Mitsubishi To Integrate Chip Ops, Nikkei, March 28, 2003

## *Other Industrial Partnerships*

### Fujitsu and Sumitomo Electric Industries Compound Semiconductors

Fujitsu and Sumitomo Electric Industries have agreed to merge their compound semiconductor[66] operations into a joint venture that will start operations in April 2004[67]. Sumitomo Electric is the world's leading companies of wafers forming the base for compound semiconductor devices, and Fujitsu makes compound chips used in communications devices. By combining operations the two companies will be able to more efficiently use funds for research and development and for capital investment. The new company will have around 1,000 employees and be capitalized at about 20 billion yen, and expects to have sales of 100 billion yen in 2006, which would correspond to 20 per cent of the global compound chip market.

Fujitsu had before its agreement with Sumitomo Electric four of its semiconductor subsidiaries, located in various places, into a new integrated company – Fujitsu Integrated Microtechnology[68]. The new company will concentrate on the assembly of sophisticated large-scale integrated circuits to be used in notebook computers, mobile phones, car navigation systems etc.

Fujitsu had already sifted its compound semiconductor business to Fujitsu Quantum Devices in 1997, while Sumitomo Electric was primarily producing wafers for the manufacture of compound ICs. Compound semiconductors enable high-speed data processing and are therefore of special attraction in telecommunications equipment and digital home appliances and the new joint venture is aiming to meet the expected growth in demand for such products of which DVD recorders is one prominent example. However, presently the sales of compound semiconductor constitute only some two per cent of total global semiconductor sales of some US$150 billion. Fujitsu Quantum expects to capture one tenth of the global market for compound semiconductors.[69]

### Photomask Industry

Photomasks utilized in the lithography process used to be commodity products. Mask making has been increasingly complex and the chip makers have outsourced the manufacture of masks to specialised companies that have moved from being engineering-based to science-based. Electron-beam technology is being used for making masks and leading companies are Toshiba Kikai, Nihon Densho, Hitachi High-technology (formerly Nissei Sangyo). The increased sophistication of the printing process with increasing fine line-widths has propelled the mask making into a technologically highly advanced activity in which two Japanese companies remain dominant players – Toppan Printing and Dai Nippon Printing – moving into close partnerships with the makers of semiconductor devices.

Dai Nippon Printing and ST Microelectronics, a major IC manufacturer in Europe have jointly set up a plant in Italy that will initially supply ST and later on also to other semiconductor

[66] A compound semiconductor is an integrated circuit that uses other material than silicon, such as gallium arsenide
[67] Fujitsu set to forge chip alliance with Sumitomo Electric, The Japan Times, December 26, 2003
[68] ibid.
[69] Nikkei Interactive, Fujitsu, Sumitomo Elec To Merge Compound Chips Ops, December 25, 2003

companies with photomasks.[70] The plant will at first produce photomasks that can print 130 nm lines on silicon wafers and will in future turn out masks that can handle 90 nm lines. The company is owned jointly by the two companies with majority share of 81% taken by Dai Nippon Printing.

Similarly Elpida Memory and Toppan Printing have agreed to collaborate on the development of photomasks for the next-generation DRAM memory circuits.[71] The two companies will work together to develop the special plates that are needed to transfer circuit patterns to the silicon wafer – for DRAM with circuit lines narrower than 100 nm. The recently developed photomasks will enable Elpida to use its 300 mm wafer site to produce ICs with circuit patterns that would have been possible with the photomasks that are commercially available.

## Sony Partnership with Toshiba and IBM

Sony announced in April 2003 that the Group will invest 200 billion yen during a period of three years, ending in March 2006, to manufacture advanced semiconductors to be jointly developed by IBM and Toshiba[72]. Sony Computer Entertainment Inc. (SCEI) will start production of microprocessors for next generation game consoles that will integrate two chips to save power consumption and production costs. Presently Sony produces only some 20 per cent of its total annual consumption of about 1,000 billion yen.

## Silicon leaders in Japan

The worldwide market for silicon wafers amounted to US$5.7 billion in 2002. The market[73] is dominated by three major companies Shinetsu Handotai (28.9% in 2002), SUMCO which is the consolidated operations of Sumitomo Chemical and Mitsubishi Electronics (23.3%), and Wacker Siltronic AG (15.4%) who acquired wafer manufacturing plant in Japan in 1999. Toshiba Ceramics is specialized in annealed wafers (4.3%). Other companies include Komatsu Electric Metals (8.6%) and Okimetic in Finland (1.0%).

**Table**
**Silicon wafer production in Japan ($m^2$)**

| | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|
| **5”** | 400,995 | 193,403 | 230,101 | 199,089 |
| **6”** | 496,830 | 242,894 | 341,881 | 331,497 |
| **8”** | 868,591 | 632,009 | 754,548 | 829,493 |
| **12”** | 16,448 | 58,128 | 115,895 | 230,971 |
| **Total** | 1,772,964 | 1,136,634 | 1,442,425 | 1,591,050 |

Source: SUMCO data

Sumitomo Mitsubishi Silicon Co (SUMCO) was formed in 2002 through the merger of the Mitsubishi Materials Silicon Corp. (Mitsubishi Electric Group) and the consolidated silicon activities of Sumitomo Metal Industries (formerly Sitix Division). In its mission statement it says that the company will be the world’s number one silicon wafer supplier. The merger encountered a number of hurdles and challenges and as the two companies brought different

[70] Nikkei Interactive, Dai Nippon-ST Micro Photomask Plant in Italy Comes Onstream, October 14, 2003
[71] Nikkei Interactive, Elpida, Toppan to Co-Develop Photomasks fro DRAMs, August 27, 2003
[72] Sony unveils huge chip investment plan, The Japan Times, April 22, 2003
[73] Dataquest figures

cultures and mentality to the new venture. One serious issue existed in handling customer relations as they were distinctly different between the two partners. An initial way of handling this was that factories maintained direct customer relations until the sales organisation was consolidated at a later stage.

An important element in the merger was the creation of a merger baby before the full merger took place. This consisted of a full-scale 12” wafer production plant that was jointly operated after having started in 2000. The plant was jointly operated while direct customer relations were maintained separately by Mitsubishi Materials Silicon Corp. and Sumitomo Metal Industries.

SUMCO today has three plants in Japan and another two abroad. Important silicon production plants exist in Korea, Taiwan and China, with the latter country to become a very important producer in the future. Taiwan has already been active in bringing foundries to China. China is already quire successful in operating 5” silicon wafer plants but is experiencing difficulties in the operation of 8” and 12” wafer plants.

The growth in demand for semiconductor devices expands and dips in parallel in the US, Europe, Japan and Asia Pacific. However, the reduction in Japan’s in the manufacture of silicon wafers has been limited. There are several reasons. First, silicon companies in Japan started a restructuring process in 2001, a process which would have been unthinkable ten years earlier – that merger across “zaibatsu” borders would take place. Second, companies in Japan are biggest customers for silicon wafers. Check. Thus it was possible for Japanese silicon makers to maintain its strong market position which is also a consequence of concentrating production in Japan while closing silicon wafer plants overseas, while keeping plant in Japan in operation. So Japan’s silicon wafer production has remained flat while worldwide production has seen substantial dips.

Shinetsu Chemical is one of the world’s largest manufacturers of semiconductor silicon and has already reached n annual production of 200,000 300 mm wafers and is scheduled to raise production by 50 per cent during 2004 to meet a rising demand in the digital electronics sector.

Sumitomo Mitsubishi Silicon Corporation was founded in 2002 through the merger of the silicon operations of Mitsubishi Materials Silicon Corp. and the Sitix division of Sumitomo Metal Industries. The two companies had already established a joint venture in 1989 after a Sitix division had been established during the preceding year inside Sumitomo Metal Industries. Sitix originated from the Osaka Titanium Co. that changed its name in 1993[74]. The new company with 4,000 employees is highly specialized on silicon wafers, which includes production of single crystal in ingots, slicing, lapping, etching, polishing and various other procedures before delivery to final customers who are foundries and full-scale IC manufacturers.

The company is the world second-largest maker of silicon wafers and decided in 2003 to concentrate its future investment on 300 mm wafers in domestic locations. Thus, it already closed one of its plants in California and will close another two plants in Oregon, while three plants in the US will remain in operation.

[74] SUMCO web site February 2, 2004

The lithography market  offers a different insight where Nikon and Canon has suffered substantial market losses. One explanation might possibly be that technology has move from simultaneously from tacit to non-tacit and from continuous to non-continuous development while silicon wafer production has not seen similar drastic technological changes.

### *Wafer-stepper Resurgence in Europe*

The market for lithography equipment used in the manufacture of semiconductors has undergone a dramatic change since the late 1990s. The supply of the dominant piece of equipment – the wafer stepper – used to be controlled by two Japanese companies – Canon and Nikon in Japan, with Hitachi also having a sizeable share. This is no longer the case as ASML in The Netherlands has rapidly increased its global market share to close to 50% in 2002 being boosted from its merger with SVG Lithography in 2001, from less than 10% in 1990.[75]

It has now become apparent that extreme ultraviolet (EUV) lithography will become the method of choice for the method to migrate beyond 157 nm lithography that is to produce sub-nm features. However a number of investment projects exploring the use of electron-beam x-ray lithography have been underway for several years. Also known as soft x-ray lithography EUV employs radiation so short - 13 nm – that normal optical lenses become opaque. Thus, reflective methods of focusing and masking must be used.[76] Research on EUV lithography was initiated in the US in the late 1990s in a consortium under the leadership of Intel, including members such as AMD, Micron Technology, Motorola, IBM and Infineon who were joined by researchers at Lawrence Berkeley, Lawrence Livermore and Sandia laboratories[77]. The consortium called the EUV LLC has become as the Virtual National Laboratory.

EUV optics are based on extremely high-tech multi-layered mirrors, which are coated with several dozen layers of either molybdenum and silicon or a compound of boron and carbon, and have perfectly even surfaces to tolerance of one atom. They offer specifically engineered reflectivity at the required wavelengths and can guide the radiation with incredible precision.[78] Zeiss is considered  a leader in this field, and is developing projection and illumination systems. Important areas for development are the illumination source and the mask technology. A major concern is how to achieve sufficient illumination source power to enable fast throughput on the production line. To this end a EUV Light Consortium has been established under MEDEA+, and participants include Alcatel, Carl Zeiss, Innolite, Jenoptik, Lambda Physik, Philips and several universities. As an additional effort Jenoptik and Lambda Physik have established a joint venture called Xtreme Technologies.[79] ASML is working together with no less than 130 European companies in this endeavour which may pose a conflict with US partners. However, the achievements to be reach lie in three critical areas – tool development, optics fabrication and source development – and European efforts will concentrate on the R&D necessary to commercialize EUV lithography

[75] Chuma, Hiroyuki and Aoshima Yaichi, Determinants of Microlithography Industry Leadership: The Possibility of Collaboration and Outsourcing, RIETI Discussion Paper Series 03-E003
[76] EUV can produce features as small as 30 nm and processor built by using EUV technology are expected to reach speeds as high as 10 GHz
[77] Opto & Laser Europe,  March 2002 – Computer chips
[78] Opto & Laser Europe,  March 2002 – Computer chips
[79] Opto & Laser Europe,  March 2002 – Computer chips

## ASML

ASM Lithography (ASML) owes it origin to group of engineers who left Philips in Eindhoven to establish the company and was at the time jointly owned by Philips and ASM International, which was a producer of semiconductor equipment. Disappointed by economic results ASM transferred a major share of its equity to Philips that became the dominant owner in the late 1980s, after which the company became a fully-owned subsidiary of Philips. ASML was introduced on NASDAQ in 1995 and Philips sold its share in spring 2000 – at the peak of the IT bubble – and retained 5.8% of equity thus remaining the second largest owner of ASML.[80] The board membership includes people from Philips and the supervisory board has members from IBM Microelectronics, Carl Zeiss and TNO which is the Dutch national organization for applied research.

The RIETI research report for the Ministry of Economics and Industry in Japan mentions that Carl Zeiss supplies all projection lenses to ASML, and also indicates that an exchange of scientists and engineers is carried out on a regular basis. A rapid movement of the wafer stage, while accurately controlling positions is essential and ASML works very closely with Philips hat is responsible for all stages of this piece of equipment. Light sources are procured from Cimer in the US. Other parts of the wafer stepper are subcontracted while software development and overall development of equipment remains under ASML direct control. The RIETI report mentions that software includes three major categories. First, software controls the computer that is installed in each major unit. Second, software controls integration across major units from an entire lithography system. Finally, an important part of software is programs that deal with various problems occurring in the design and manufacturing stages by collection various data that are later on essential in volume production.[81]

The RIETE report further mentions that does not have a R&D department in the traditional style that exist in Canon and Nikon, and many other companies in Japan. ASML argues that the firm is primarily a manufacturing company without an outstanding research environment. One reason given is that ASML does not have the standing to recruit the outstanding scientist that would be required to develop, design and manufacture its advanced pieces of semiconductor equipment. Instead ASML has a very close working relation with R&D engineers in Philips Semiconductor Division that supports development of precision machine technology, while Carl Zeiss engineers share a similar responsibility for projection lenses and the illumination system.

Further, the RIETI report mentions that collaboration between microlithography makers and photomask companies has become very important which reflects a new situation in which masks are no longer a commodity but again a vital component of the lithography process. In addition the advances in microlithography are held up by delays in developing inexpensive resist materials. Thus, the RIETI reports states that “(A)ll these trends have dramatically increased the need for intimate R&D collaboration between microlithography makers and outside companies that produce products having a direct interactions with an exposure process, such as resists material, coater-developers , and photomasks”. To this end ASML already in the early 1990s adopted its own distinctive strategy for research collaboration and its major

[80] EUV can produce features as small as 30 nm and processor built by using EUV technology are expected to reach speeds as high as 10 GHz
[81] EUV can produce features as small as 30 nm and processor built by using EUV technology are expected to reach speeds as high as 10 GHz

partner is IMEC in Belgium, which is seen as the most advanced research institute of semiconductor technology in Europe.

Finally, the RIETI report also suggests that ASML is further along the road to develop a modular system for its wafer-steppers, which gives an advantage in terms of production lead time which has become increasingly important with rapidly shortened product life cycles of DRA and logic ICs. More important says the report is “that the source of ASML’s competitiveness resides in its extensive use of outsourcing, interfirm R&D collaboration. ASML seems to more effectively put a potential demand on the chipmakers, and it is reflected in software that enables improvement of throughput”.

## IMEC

IMEC is a semi-government non-profit organization that was founded in 1984, and has some similarities but also major differences with Sematech in the US. The two research centres are roughly the same size but have different business models and decision structures. In a real sense, they compete for funding from companies that are increasingly unwilling to duplications of effort between them.

A major difference lies in the way forming research groups and making decisions. The charter Sematech's requires its members to agree on new programs in consensus fashion, so new ideas are generally slow to gain approval. The management at IMEC on the other hand quickly defines an interesting research program, recruits a few industrial partners that want to attack the issue in a shared research environment to cut costs, and can start very quickly. This difference in style and speed has prompted Agere, Conexant, Hynix Semiconductor and STMicroelectronics to withdraw their membership, reducing Sematech to nine members. Furthermore, the remaining two European members of Sematech - Philips and Infineon Technologies - are considering to leave.[82]

There is another important difference as IMEC is by itself not seen as a consortium, and the distinction may be one key to its success. While major equipment vendors such as Dutch lithography vendor ASML and other "program affiliates" provide input into new directions, it is management at IMEC and not participating companies that decides on new research programs. The members of the management of IMEC are almost exclusively recruited from the renowned microelectronics research centre at the nearby Catholic University of Leuven, although many of the new researchers being hired to work at IMEC are from outside of Belgium.

Sematech was established to set equipment standards and to foster development of equipment and materials, while IMEC was set up as a microelectronics research centre with less of an emphasis on manufacturing. Large corporations such as AT&T's Bell Labs, HP Labs and even TI and IBM have in recent years as, have substantially reduced their research programs, IMEC has been exceptionally fast to offer new collaborative research programs. However, Sematech has responded to the challenge and a Sematech nanotechnology R&D centre is now taking shape in Albany, N.Y. - "Sematech North" – being modelled the IMEC approach, to become  major research centre on extreme-ultraviolet mask blanks and EUV resists.

[82] Lammers, David, Has IMEC built a better co-op?, EE Times, October 20, 2003

A news report in October 2003 gave details about the increasing success of IMEC to attract new members to one of its most advance research programs: "IMEC announced that Intel Corp. and Samsung Electronics Co. had signed on as "core" partners in a research effort here aimed at developing process technologies at 45 nanometres and beyond. The pair joins Europe's three major semiconductor companies-Infineon, Philips Semiconductors and STMicroelectronics-in that effort. And Texas Instruments-which now participates in five of the seven IMEC programs that make up the 45-nm platform-asked that its name be included in the announcement, signalling its intention to become the sixth core partner".
This means that IMEC should now be seen as a really international research centre when Intel, Samsung and TI have joined as core partners, rather than a research organisation mainly charged with re-establishing the technical base in Europe[83]. China has indicated that it would like at least one of its emerging semiconductor manufacturers to join IMEC, but the country is for the time being excluded as both the U.S. government and the European Union restrict exports of a number of technologies, as the official explanation goes. However, the existing European partners may consider China's emerging foundries a threat and thus want to prevent intellectual-property transfers to Chinese researchers.

IMEC expects one major Japanese semiconductor company to join as a core partner for the 45-nm platform, is very interested to se up a complementary affiliation with Selete in Japan. IMEC has an expanding relationship with Sematech aimed at avoiding duplication of research efforts

The new core partners will participate in all seven of the research programs that are components of the 45-nm platform and will receive certain advantages over companies that remain outside the core. The same report says that seven programs include the effort to develop the process technologies needed for germanium-based CMOS devices, an area where IMEC plans to cooperate with another, more fundamental research effort into germanium MOSFETs that is under way at Stanford University's nanotechnology centre.

## *Taiwan, Korea Singapore*

### Taiwan – A Future Silicon Island

Taiwan has established a leading position in the market for notebook computers, motherboards, LCD monitors and recently for video projectors. They are supported by domestic semiconductor fables manufactures of which six out the world's leading companies are located in Taiwan. Similarly Taiwan also has a number of strong design companies which include MediaTek and Via. Two of the now leading companies – UMC that started in 1980

[83] There is no doubt that IMEC has played and continues to play an important role in Europe's technology support programs. For example the coordinator of HUNT (Hundred Nanometer CMOS Technology) is based at IMEC in Leuven – with GRESSI, Infineon, Philips, ST Microelectronics and Marconi Caswell as members. The project which is funded at the level of 50% by the EU Commission only has European members. The objective of HUNT is the development and advanced module integration for 100 nm mainstream high performance front-end CMOS process technology with emphasis on the manufacturing issues and reliability.

and TSMC that started in 1987 – owe their origin to government support and close relations with ITRI[84].

Subsequently, semiconductor companies in Taiwan have taken on a significant role in the global market, partly as a consequence of successfully competing with Japanese counterparts in memory circuits. Furthermore, Taiwan has established a very strong position not only in semiconductor foundries, which are serving companies all over the world, but also in chip design which reflects a very strong position in the design of many electronics products that are designed in Taiwan but manufactured in China. The IC foundry industry in Taiwan is challenged from the US and China. IBM has entered the market with advanced technology and processes using 300 mm fabs – still in relatively small volumes and high prices by targeting non-competing customers.[85] China provide another challenges with its emerging foundries which still have to prove their quality and yields and are for the time being limited by economies of scale and library infrastructure. However, the IC industry in China has strong government support and is able to compete on low prices to enter new markets.

To counter the China threat the Taiwan government is supporting its IC industry in three stages

1. 1980-2000 Manufacturing and Foundry Focus, with a concentration of science parks, such as ITRI
2. 2001-20020 Production Innovation and Focus, with the aim to establish a silicon economy through innovations in science, engineering and liberal arts.
3. Establishing Taiwan brands and marketing channels through advanced product development

This would result in independent SoC platform development and strong domestic R&D based on a number of initiatives such SoC design training programs, development of design platforms, with design centres which provide infrastructure, service support and virtual vertical integration

## Korea - Dominance in IC Memories

Two Korean companies – Samsung (29%) and Hynix (16%) – together control almost one half the global markets (2003) for DRAM and flash memory. Other significant shares are taken by Infineon (17%) and Micron (19%), with remaining DRAM manufacturer in Japan – Elpida – having a miniscule 3% (2003). This development started in the late 1970s, with OEM playing an important role in the 1980s before Korea companies in the 1990s became independent makers and Samsung presently having established the leading position. Today the semiconductor companies in Korea supply about 8 per cent of the global demand for semiconductor devices, and no other manufacturing industry contributes more to the Korean national economy in terms of value-added than Korea's semiconductor firms. This industry and related industries have undergone a rapid process of globalization to stay competitive and

[84] Both UMC and TSMC have relations with Texas Instrument. Furthermore, UMC have close R&D relations with AMD and Infineon while similar relations for TSMC with Motorola, Philips, NEC, LSI Logic and STMicron.

[85] Presentation by Aimtron technology Corp. at Asian Semiconductor Industry Conference 2004, organized by Sangyo Semiconductor News Agency, January 1 2004

is committed to heavy investment in research and facilities, including development and production of equipment and materials.[86]

By the end of 2003 Samsung had become the global leader in commissioning 300 mm wafer production facilities closely followed by Infineon and Taiwan at the (aggregate level), and Elpida not far behind. The semiconductor industry is a to a considerable extent domestically meeting its demand for materials, with the remainder mainly from Japan, while most processing equipment is being imported

### Foundry Semiconductor Industry in Singapore

The semiconductor industry in Singapore consists only of companies manufacturing devices – with strong relations to overseas counterparts and/or investors. Chartered Semiconductor Manufacturer is one of the main foundries which have established close collaboration with Infineon to established latest available processing technology, where IBM will be given access in 2005. This will not only provide dual-sourcing for IBM but also give Chartered access to technology leadership and innovation at 90 nanometre and beyond, and also securing access to intellectual property.

## *The Future of the Semiconductor Industry in China*

Intel is the global leader in semiconductor production and development following by Samsung in Korea, which is still heavily focused on the manufacture of memory circuits. In early 2004 US semiconductor companies are leaders in both design and process R&D and their global market share in manufacturing remains above 20 per cent and are even higher in the production of leading-edge devices. However, drivers of the IC industry are moving to East Asia as is IC production. Thus it is predicted that the manufacturing capacity in Taiwan will increase from 16 per cent of global share in 2003 to more than 20 per cent in 2006, and its design industry will continue to grow at a very high rate. However, China will remain in the rear with an expected increase to 4-6 per cent of global share in 2006, which is still a dramatic increase from its present two per cent. IC design remains at the lower end targeting the domestic market. Most semiconductor fabs are still a couple of generations behind but the Chinese IC industry is quickly diminishing the gap. The Yangtze River Delta with Shanghai, Suzhou, Hangszhou and Wuxi has taken on a prominent role as a regional centre for China's semiconductor industry.

The microelectronics industry in China, especially the integrated circuit segment, has always been regarded as strategically important, and was awarded priority when China formally announced the four modernizations program in the late 1970s. Simon refers in his work to the investment levels that during the period 1980.99 were woefully behind that of South Korea and Taiwan[87]. Total investment during the period was reported to have been US$3.11 of which foreign companies provided 1.52 billion. Today it is within the sector in China realized that the lack of investment rather than international export control restrictions that has delayed the modernization and growth of the sector. In a recent interview with the Ministry of Information Industry an official argued that China should rely on foreign direct investment to

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[86] The mission of he Korea Semiconductor Industry Association includes 1. arrange domestic and foreign industry/academia joint research projects on advanced technology; and 2. establish a long-term development plan for Korea's semiconductor industry.

[87] Simon, Denis, The Microelectronics Industry Crosses a Critical Threshold, The China Business Review 2001

establish the costly and complex production facilities that are required for IC production[88]. This would be the quickest way to improve the IC industry, while China domestically would concentrate its resources on chip design. China Center of Information Industry Development (CCID) argues that now is the right time for the multinational companies to enter China's IC market as it will be one of the important bases of global electronic and information products will be an expanding basis in the domestic market[89]. CCID argues that the development of a robust domestic IC is one of the government's main industrial priorities which are supported by favourable policies and – with an advantage in low cost and rich human resources.

China has become an important actor in global semiconductor industry and a potentially very large domestic market that is expanding at annual growth rate of close to 30 per cent. Check. Industrial infrastructure is quickly developing is design, testing and packaging with increasingly sophisticated end markets and abundant human resources. This has attracted a number of foreign companies to establish advanced foundries, a trend that is likely to be accelerated over the remaining part of the decade.

Until recently, there hardly existed any wholly foreign-owned enterprises in any Chinese industry. However, the Chinese government has made it clear that such investments are now welcome and several 100 percent foreign owned semiconductor producing enterprises now exist or are being established, including the following ones[90].

1. **Motorola** Tianjin Integrated Semiconductor Manufacturing Complex, Operational in 2001 with a total investment in the range of US$1.5 billion
2. Suzhou **Matsushita** Semiconductor
3. Wuxi Huazhi Semiconductor Co. will be transformed into a wholly-owned Toshiba subsidiary
4. Taiwan Semiconductor Manufacturing Corporation (**TSMC**) Shanghai, Songjiang HiTech Park
5. Ultimate Semiconductor (a Malaysian enterprises that signed an agreement with Shanghai government in 2003)

China has also attracted a number of multinational foundries. The report commissioned by the Semiconductor Industry Association (SIA) in the US says that the new semiconductor foundries being established in Chin are unique in the country's context not only because they separate the design function from production, but because the enterprises themselves much more closely resemble Western multinational corporations than any prior Chinese semiconductor enterprises, all of which have been at least partially government owned and controlled. They include the following ones (see diagram for additional details)[91]:

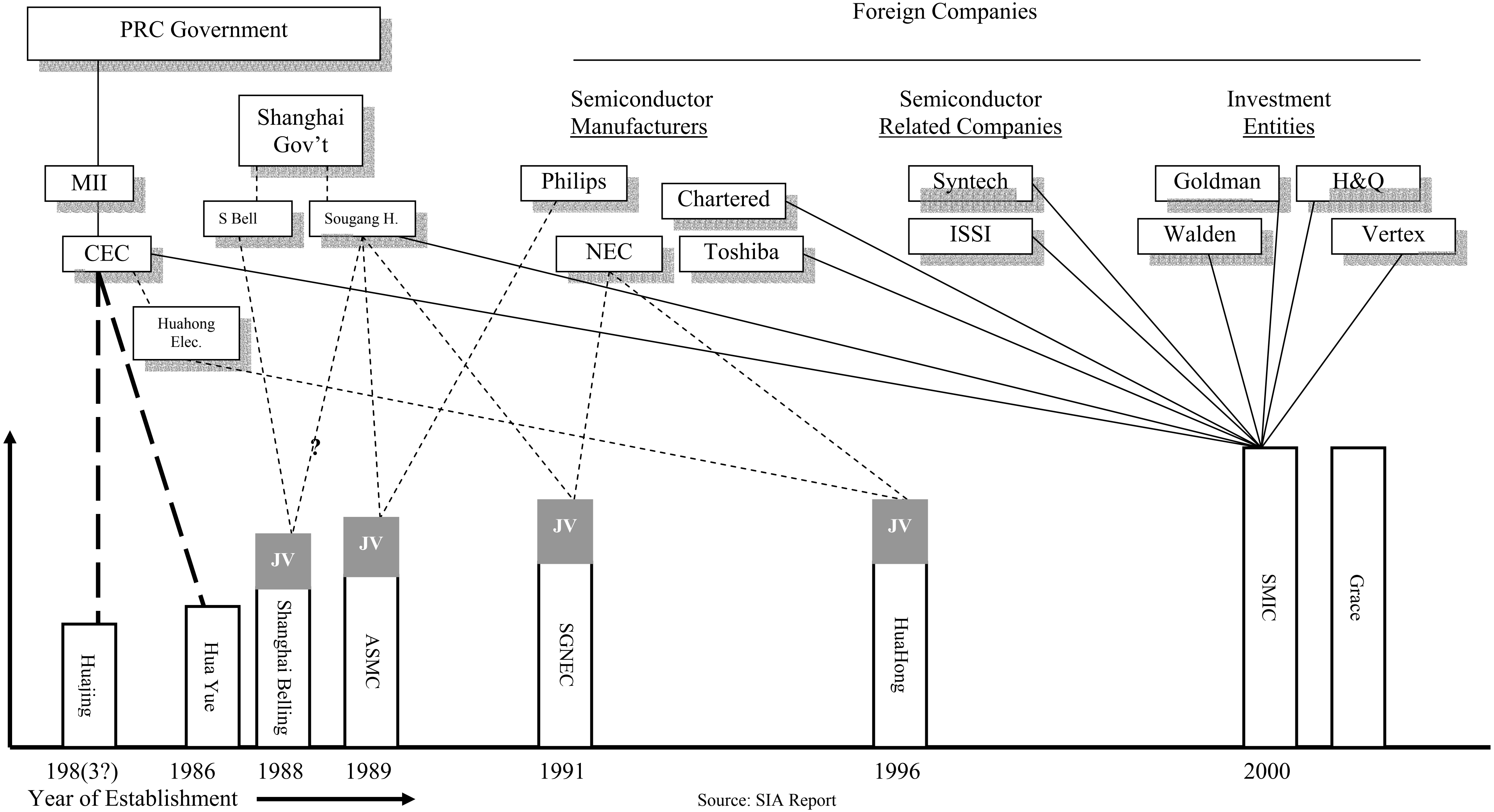
1. Semiconductor Manufacturing International Corporation (SMIC), Shanghai, with investment from Shanghai Industrial Holdings, Avanti, and others
2. Grace Semiconductor Manufacturing International (GSMC), founded in 2000
3. He Jian Technology Corporation, China-Singapore Suzhou Industrial Park
4. Beijing Semiconductor Manufacturing Corporation (BJSMC), in collaboration with the Beijing Municipal Government, Beijing Economic and Technical Development

[88] Private communication from MII official, November 2003
[89] CCID presentation at Asian Semiconductor Industry Conference 2004, organized by Sangyo Semiconductor News Agency, January 1 2004.
[90] Howell, Thomas R. et al., China's Emerging Semiconductor Industry – The Impact of China's Preferential Value-Added Tax on Current Investment Trends, Prepared by Dewey Ballantine LLP for the Semiconductor Industry Association, Washington. D.C. October 2003
[91] ibid.

Area (BDA), and Shougang Iron and Steel. (BJSMC will accommodate facilities for the partnership between SMIC and Infineon Technologies

5. Wuxi CSMC-Huajing, has been operating since 1997Dunnan Science and Technology, production facility will be established in Wuxi

# Changing Ownership Patterns in China's Semiconductor Industry




Source: SIA Report

The SIA report also states that a long-standing source of weakness in Chinese semiconductor industry has been the shortage of makers of semiconductor equipment and materials, assembly, testing, packaging and logistics firms. Simon in his review of the Chinese semiconductor industry assesses the equipment situation in the following words. "China is still incapable of producing most of the equipment used in an 8-inch IC production line, though it can produce some supplementary machinery. As for 6-inch lines, Chinese firms are technically capable of producing almost all required equipment but no one firm is manufacturing enough to be considered a world-class producer." However, the SIA report argues that this problem is rapidly being address in both Shanghai and Suzhou as leading semiconductor enterprises, as well as materials, design and support are establishing operations in Zhangjiang HiTech Park, with its Shanghai Zhangjiang Semiconductor Industry Base (ZSIB) and the Suzhou Industrial Park. ZSIB is well on its way to become a major centre for semiconductor production in China, while Beijing Economic-Technical Development Area plans to establish a complete industry chain surrounding the new semiconductor foundries being located there.[92]

China has in the past not been a major market for major equipment suppliers because of the low production volumes inside China as well export-control restrictions. However, by 1010 China could have become one of the biggest markets for semiconductor- related equipment. In the meantime China will have to import most of needed equipment and Simon mentions that domestic sales met less than 10 per cent of demand in 2000, and technology improvement projects rely heavily on imports.

## *Managing success in turbulent markets and capturing high-speed technology progress*

A strategic transformation is taking place in the semiconductor industry which will revolutionize existing business models. Decade after decade the ever-increasing miniaturization has made it possible to incorporate an increasing number of transistors on a single chip and following Moore's Law the number of transistors on a chip has more or less doubled every 18 months. This development has created the prospect to build large-scale electronic systems on a single chip - SOC. The semiconductor industry has experienced functional integration in the past. However, SOC has potential to offer considerable enhancements in functionality and costs of electronic end products. Although a SOC incorporates processor(s), memory and any number of functions a complete system will still require additional passive devices and functional chips. The increasing miniaturization and the emergence of SOC are in major way confronting the semiconductor industry, and individual companies are faced with important challenges on how to mobilize resources for research and development and how to efficiently integrate R&D for timely and efficient production[93].

The mode of utilizing resources committed to R&D may often be a better indicator of success than the absolute size of employed resources. This is an important perspective brought out by

[92] SIA report
[93] Linden, Greg & Somaya, Depeek, System-on-chip integration in the semiconductor industry: industry structure and firm strategies, Industrial and Corporate Change, Volume 12 (2003), Number 3, pp. 545-576

West and Iansiti[94] who emphasize organizational changes. They mention that organizational changes underlies sustained performance gaps on a range of important dimensions, including: production quality, product development speed, new manufacture process development, productivity of research project and manufacturing efficiency. Their analysis of corporate data, although referring to the early 1990s, indicates that there exist substantial differences in the capability of companies to perform development of new processes. Furthermore, a poor understanding of the development processes has serous consequences on competitiveness. Finally, they show that one group of companies, several US firms, where able to dramatically improve their performance - in the early 1990s. They conclude that experimentation perform two important functions. First, it makes it possible for the firm to determine with a higher degree of confidence precisely which of available options would solve the problem it faces. Second, it urges the firm to widen its span of vision to consider potential choices outside its existing frame of reference.

As Japanese companies reached the technology frontier they were slow to re-orient their R&D efforts from application and improvement of effective technologies, and were less concerned to generate more fundamental innovations. Facts and the discussion in this essay clearly indicate that the vertical integration of R&D in many high-technology companies Japan is slowly giving way to new structures that include networks that incorporate competing companies and universities. Such changes have been facilitated by government initiatives and a growing awareness that radical corporate restructuring is necessary. However, many firms have been forced, under the long-lasting recession, to restrict their expenditure on R&D and shift such personnel into operational tasks.

Branstetter[95] suggests that "(P)erhaps the most important step the Japanese government can take in the short-run to revive Japan's innovate performance is to stimulate macroeconomic growth. He argues that technological factors have not been the primary drivers of the recession that has lasted for more than decade and points to the collapse of asset prices crisis in the banking system and the inappropriate macroeconomic policy responses of the government as much more significant. Still, an apparent decline in Japanese innovative capacity poses serious challenges in the longer perspective if innovative power is growing at a slower rate than in the past, as Branstetter has shown that firm-level data indicate a slowdown in the growth of R&D productivity in Japan in the 1990s, controlling for R&D spending and other firm attributes. However, he mentions that the research productivity of the electronics industry, broadly defined, has continued to grow in line with the trends of the 1980s and early 1990s, while firms outside this industrial sector have performed less well.

## Global Innovation System – GIS

The semiconductor industry provides an example of a sector where a Global Innovation System (GIS) has emerged from the interaction of Corporate Innovation System(s) with National Innovation System(s). This is exemplified by events relating to the future technological front for semiconductor production[96].

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[94] West, Jonathan & Iansiti, Marco, Experience, experimentation, and the accumulation of knowledge: the evolution of R&D in the semiconductor industry, Research Policy 32 (2003) 809-825

[95] Branstetter, Lee & Nakamura Yoshiaki, Is Japan's Innovate Capacity in Decline, NBER Working Paper 9438 (http://www.nber.org/papers/w9438)

[96] Nikkei, Monday, August 18, 2003 8 Firms, Stanford Univ Aim For Technological Leap In Chips

A group of eight semiconductor-related companies, including Toshiba, Texas Instruments and Taiwan Semiconductor Manufacturing has established a partnership with Stanford University to develop semiconductor technology two generations ahead of the present level[97] - for products that would be commercialized around 2012. Intel and Tokyo Electron are also participating in the project, as are nine professors from Stanford University. The research will focus on developing new materials in order to make technological breakthroughs. Germanium will be used as a semiconductor material. Japan currently has two public-private-academic partnerships on advancing chip technology: Project Asuka, which is aiming for circuit widths of 65nm, and the Mirai Project, which aims for circuit widths of 45nm. The effort with Stanford seeks to develop technology a generation beyond.

## *Conclusions*

The objective of a National Innovation System (NIS) is to control and guide the NIS to improve technology performance of "national" actors. This requires an adept understanding on how the various actors relate to each other in a system of knowledge creation. The argument in the following is that the character of actors and their relations have in recent decade(s) undergone fundamental changes which have only partly been grasped by national policy makers and translated into new national, supra-national policy structures.

Technological change has been accelerated by globalisation, as markets opened and competitors looked to innovation as a means of gaining market advantage. The globalisation has raised several fundamental issues not only for developing and latecomer countries but also for industrially advanced countries. First, national governments want to assist their own national companies but it is no longer clear which companies are national as the identities of firms are increasingly blurred. Second, national policy makers have to formulate science and technology programs that are in tune with an increasingly rapid technological development. The first issue prompts a shift in policy focus from the macro to the micro-level, where governments seek to influence the performance of firms and industries. The second issue requires an increasingly close interaction with a global system of innovation.

Thus it becomes important to understand that technology of production and the organizational structure that controls production are two interrelated but conceptually distinct systems[98]. The semiconductor industry in Japan has been faced with serious challenges within both systems. The R&D system to support semiconductor development – technology of production – has failed to be reorganized to efficiently incorporate various sources of knowledge and the interests of various actors. The companies – structures that control production – have not been able to change their organizations in order to meet an increasingly harsh competition. Both companies and R&D systems are information-processing systems that must observe and understand a multiplicity of signals from its environment and modify its behaviour in light of these signals – like a biological organism that has to change in an environment that is variable and uncertain.

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[97] Current semiconductor-manufacturing technology can produce chips that have circuit widths of around 130 nanometers. The joint projects aims to bring that figure down to around 32-45nm. If researchers can succeed in achieving circuit widths of 32nm, then manufacturers will be able to produce memory chips with capacities of 32G -- more than 30 times the present level. Data processing could also be increased by several times.

[98] Langlois, Richard N., The vanishing hand: the changing dynamics of industrial capitalism, Industrial and Corporate Change Volume 12 (2003), Number 2, pp 351-385

Assuming an ongoing integration into a global economy, as exemplified in transportation, IT infrastructures, financial services and last but not least in manufacturing, it may be increasingly practical to identify a Global Innovation System (GIS) to represent the structure and environment in which technological change and technological progress take place.

The dynamic character of global competition necessitates for nations to pursue policies that provide significant elements, which are critical for a firm's competitive advantage. A company pursuing a competitive advantage in the global economy would look for access to skilled and trained manpower, good infrastructures, good political and economic environment and access to government research institutes (GRI). This might indicate that global companies have actually taken hegemony in setting the relations between corporate technology strategy and national R&D policy.

## Managing national development

The management incompatibility between major companies have prevented them to join forces, although no single one can afford the heavy investment of some US$ 2 billion for a new semiconductor production line. Actually, there are hardly any companies except Intel and Samsung that can manage this size of investment. Toshiba has decided to "go-it-alone" through alliance with Sony and IBM, while other Japanese semiconductor companies have handled the challenges in different ways.

A restructuring of the semiconductor industry in Japan is needed which is exemplified by the joint venture for DRAM production between Hitachi and Mitsubishi Electric - Elpida. This company has targeted new segments as drivers for its DRAM business such as digital cameras and other digital consumer electronic products, as the PC market is no longer the driver for DRAM that used to be the case. Thus, the CEO of Elpida has enticed Intel to provide investment in order to have access to advanced DRAM.

Japan has a high level of quality in its technology, and also has depth of technology. But the drivers for fundamental change are still missing. The VLSI Project became a success story because technology was the driver. The semiconductor industry is still faced with technological challenges but more serious are management problems which have until recently almost seemed to be un-surmountable Japan. For example there are only weak working relations between major research consortia such as ASPLA which is a privately funded consortium and MIRAI that is completely funded by the government. The former is business-oriented and is aiming to establish a pilot line for a complete SoC device while MIRAI is researching basic technology to identify physical properties. A new mission is needed to make the various parties collaborate. However, a serious problem resides in the control – parents – of the various consortia, as budget and stockholders decide on key issues, while most engineers in the field understand and realize the need for change. However, METI[99] is contemplating an organizational change that will create a new structure in which one of the existing programs will take on a leading role – starting in 2004 – with major responsibility for coordination possibly given to Selete[100].

[99] Machinery Development Association (Kikai Shinko Kyokai) plays a major role in analyzing the future of the semiconductor industry in Japan and publishes annual reports. The association maintains a research institute and ASPLA members are observers in its deliberations.

[100] Today Selete and MIRAI do almost the same research – independently. The share the same building in Tsukuba, although located on different floors while the sharing the same clean room with a partition among them.

Professor Tarui[101], a key actor in the 1970s by mobilising and guiding Japan's joint research in semiconductor technology, reflects on the number of new government initiatives to support technological advances in the Japanese semiconductor industry in the 1990s and early 2000s and argues that there are too many projects – with no clear focus and with nobody to take up the responsibility of coordination. Tarui also ponders the lack of government initiatives in the 1980s and recall the approaches of professor Shoji Tanaka who constantly nagged the Japanese government – MITI at the time – to move forward on joint development projects, including the abated 100 Megabit project to be a follow-up of the VLSI project. However, the US government was informally and formally pressurizing Japan not to establish any project that would increase the competitiveness of the national semiconductor companies in Japan. Tarui suggests that the Japanese government and MITI were not strong enough to resist these pressures[102].

However, Japan and its semiconductor industry may at the time have caught a unique possibility at a very favourable time and with a skilled and dedicated coordinator, and no similar situation exists today neither in Japan, USA or Europe. Since those days the focus of semiconductor development has shifted to the US as logical devices became important rather than memory devices for which Japan has been out-competed by companies in Korea and Taiwan – with China looming on the horizon as a potential giant in the semiconductor industry.

Professor Tanaka Shoji, now President of the International Superconductivity Research Centre (ISTEC), reflects on the 100 Mbit Memory project that was once promoted by MITI and himself[103]. This proposal became impossible once the trade friction conflict with the US reached the boiling point. However, he says that semiconductor technology has become a less exciting area to support as technology is stabilizing with limited possibilities for longer-tem advances. A major interest has already shifted to the design of devices rather development of devices and their underlying technology although Japan does not have enough engineers that can work on device design.

Tanaka has retired from advising the government on semiconductor development some five years ago. His latest contribution was to advise the government on the System-on-Chip technology which was to become the ASPLA project. However, he says that the semiconductor field has become so broad that it is no longer possible to identify the development issues in one single stroke which was the case some 20 years ago. Today there emerges a bifurcation between semiconductors as device design and device technology development are moving in different directions. However, Japan may capture new possibilities in applications where logical devices have become increasingly important.

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[101] Professor Yasuo Tarui is now managing director of Takeda Foundation - established by Takeda Riken (now Advantest – not directly involved in the VLSI Project supported by MITI but befitted from a parallel collaborative project which was supported by NTT Laboratories), one of the benefactors of Japan's Leap Forward in the semiconductor industry in supplying advanced testing equipment. He is proud of his earlier achievements in managing semiconductor development in Japan during a critical stage, and stresses that he would do it again if he were 20 years younger. He underlines that the VLSI project was a singular project when people were brought from various companies for which he was instrumental in making them work towards a common goal. The idea of joint development for semiconductor development was supplicated in the US and Europe and Tarui considers these efforts to have generally failed.

[102] Extracts from interview with professor Yasuo Tarui, February 8, 2004

[103] Extracts from interview with professor Shoji Tanaka, February 23 2004

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