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Role of Universities in the Research on Silicon Semiconductor Devices

Kumi Okuwada
Materials and Manufacturing Technology Research Unit

7.1 Introduction

The research on silicon semiconductor devices, which has already entered the area of nanometer order, deals with the finest area among the crowd of nanotechnologies. Despite the fact that there is a physical limit due to the size of a silicon atom, high integration of silicon semiconductors is expected to continue until around 2020 to 2030 at the present pace. Today's information-oriented society will not allow the development of semiconductor devices to come to a standstill, and the present high growth rate of the industry is expected to continue worldwide.

In the past from the latter half of the 1980s to the beginning of the 1990s, research activities for silicon semiconductor devices in Japan led the world and drove other domestic industrial technologies. However, the situation has now drastically changed and there is concern that silicon semiconductor technology cannot be developed in Japan any more. This report presents an overview of the present situation of research activities for silicon semiconductor technology in Japan in a fresh light, and reviews the role of universities in the research on semiconductor devices while anticipating the situation a decade from now.

7.2 Development of silicon semiconductor devices

7.2.1 Values representing the development of technology

Figure 1 shows typical sizes that represent the development of silicon semiconductor devices. As the values that represent the level of miniaturization technology, the line width of wiring of integrated circuits and the gate length of transistors are usually used. To improve these values, the performance of lithography plays an important role. In the United States, a research consortium has been formed to develop the exposure technology that enables the finest fabrication at present using EUV (extreme ultraviolet rays)[1], and the performance of transistors with a gate length of 10 nm or less has been reported[2]. Following this, a project related to EUV exposure technology has been started in Japan[3].

To carry out research on semiconductor devices, silicon wafers of a size appropriate for the fabrication equipment must be used for the preparation of circuits on an experimental basis even when the research is related to a part of the device. Facilities that will be built in the future are mainly for 300 mm (12 inch) wafers, and the development of new semiconductor fabrication equipment is also focused on this size. In semiconductor fabrication equipment, most of the new technology know-how is incorporated into the equipment itself, and the new technology is actualized through the newly developed equipment. Therefore, even the research work cannot neglect the wafer size and it is an important value that represents the generation of research and development as in the case for the assembly of manufacturing lines.

At least until the end of the 1990s, the change of generations of research on semiconductor devices was expressed by quantitative performance indices such as the wafer size and clock frequency. The ITRS (International Technology Roadmap for Semiconductors), which is recognized internationally as a common view, is reviewed every year[4]. In this roadmap, the duration of research and the timing of actual production are shown on a specific schedule. This means that the results of research are evaluated quantitatively and the evaluation methods have been established.

7.2.2 Trends in the research on miniaturization

The ITRS[4] predicts that the line width of most miniaturized silicon semiconductor devices will reach 100 nm or less by 2004, and mass production technology will enter the nano-area soon. Recently, logic ICs aiming at higher operating speeds have become the leader of the frontier technology instead of memory ICs that aim at larger capacities (Figure 2), and the gate length of transistors is now more often used as the index for the development of semiconductor devices than the line width.

The gate length has already become less than 10 nm on the research level, and it was reported in December 2002 that transistors

Figure 1:Typical values representing the development of research on silicon semiconductor devices

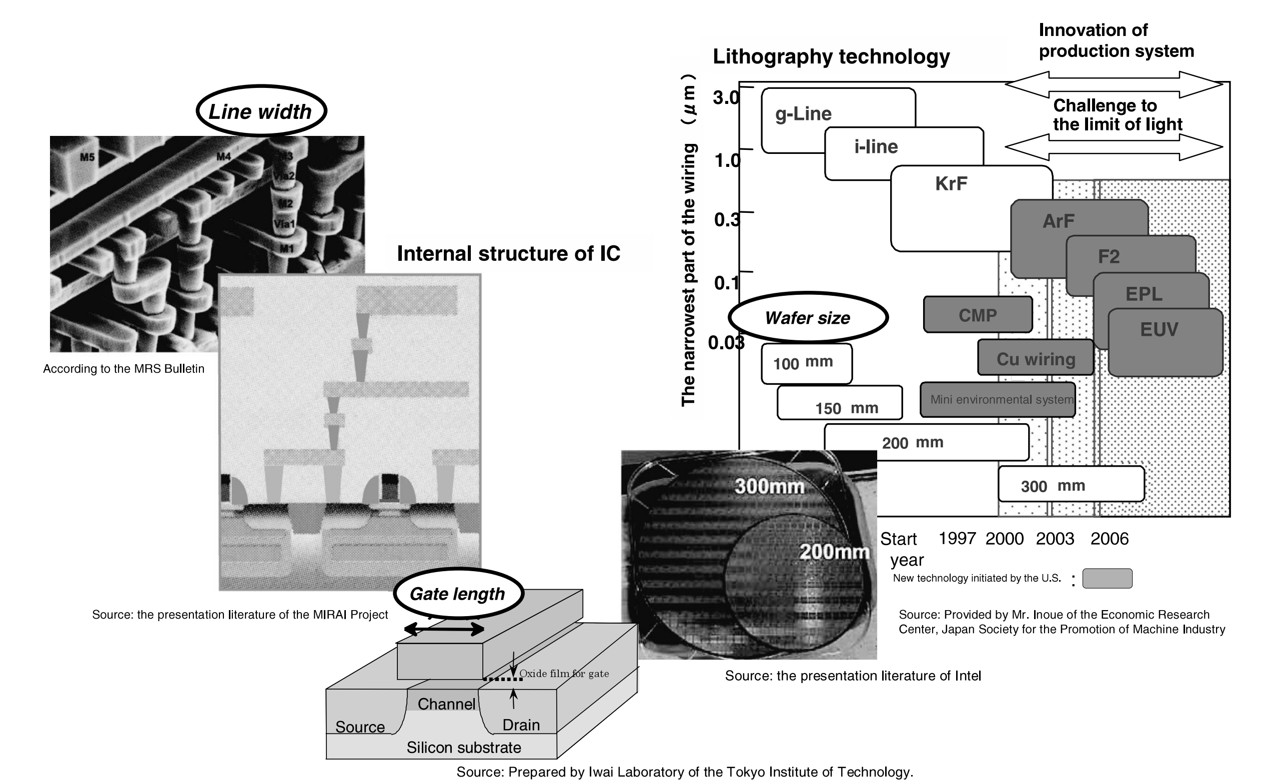
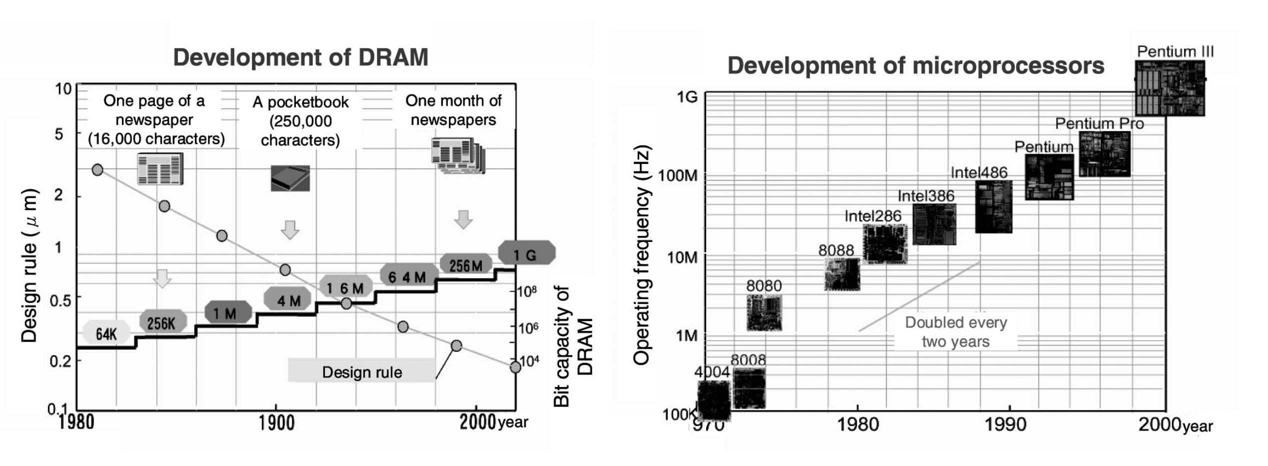
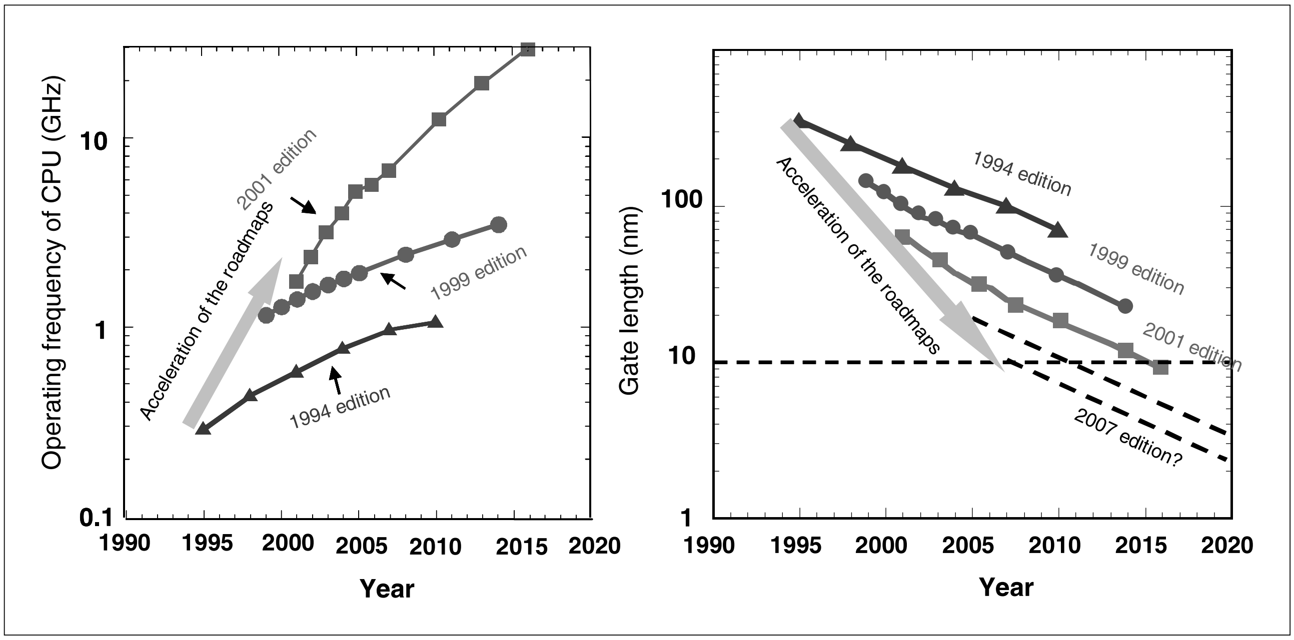


Figure 2: Development of typical semiconductor devices



Source: Prepared by Prof. T. Kuroda of Keio University

Figure 3: Acceleration of the roadmaps



Source: Prepared by Iwai Laboratory of Tokyo Institute of Technology

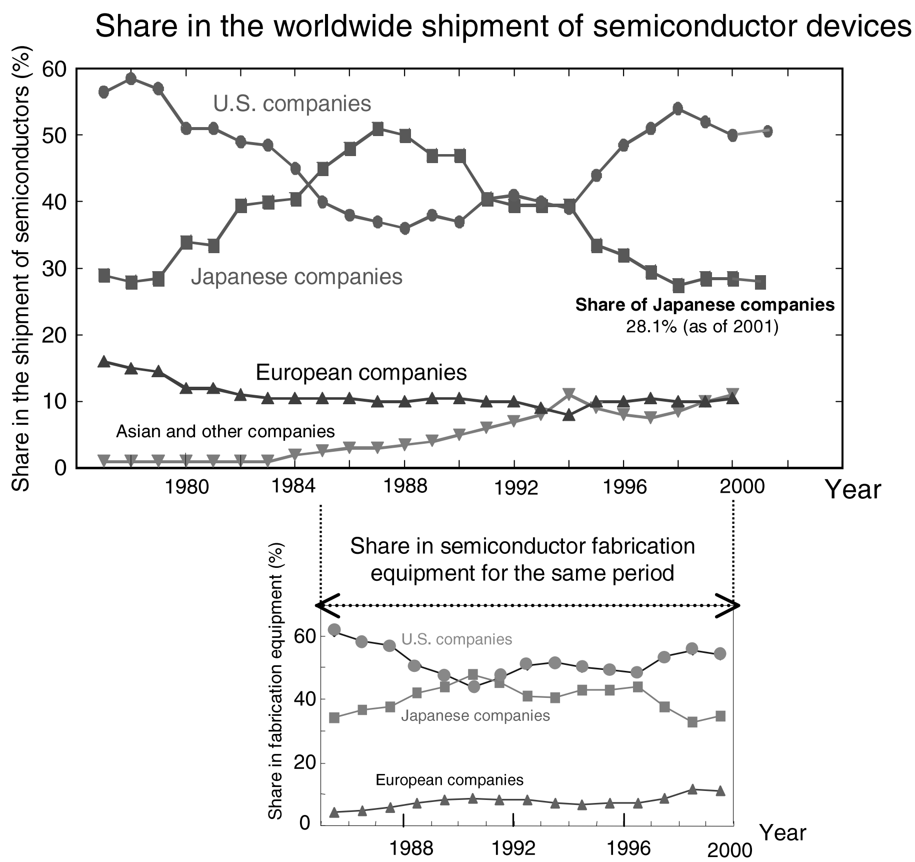
operated with a gate length of as low as 6 nm[2]. Elemental technologies are being developed at a much higher speed than expected. Particularly in the miniaturization and improvement of performance indices in logic ICs, the revision of ITRS is accelerated every year following up on the quickly advancing research results (Figure 3). Furthermore, concerning the silicon oxide films that compose the transistor gates, it has been reported that the devices can be fabricated with a film thickness of as thin as 7 nm[7].

Considering the distance between the atoms of a silicon single crystal (about 0.3 nm) or the distance between silicon and oxygen ions in silicon oxide (0.4 to 0.5 nm), there are only a little more than 10 atoms within a distance of 6-7 nm. It is really amazing that such thin films actually function, which is the basis of the view that the end of the development of silicon semiconductor devices will come between 2020 and 2030. In addition, semiconductor devices cannot be composed using only the above-mentioned elemental technologies. Even in the range that will surely be reached within several years, there are many critical technical problems to be solved (Red Brick Walls)[8], and, furthermore, it is not certain whether these problems can be solved or not.

In the past, however, as has been described above, results of research on elemental technologies for semiconductor devices have always advanced ahead of the roadmap, with the technologies that had not seem possible having been made possible by keeping pace with the development of elemental technologies. As a result, the development of semiconductor devices appears as if it proceeds linearly following a law as shown in Figure 2. This relationship is called Moore's Law, named after its proponent. In other words, the history of the research on semiconductor devices is a series of breakthroughs of anticipated technical limits.

Recently, it has been commonly recognized that the excessive heat generation due to the concentration of consumed electricity, rather than the limits of miniaturization, may become a critical problem[9]. To reduce electricity consumption, low-voltage driving is the key and prompt review of the circuit design is required. In this respect, devices based on a new principle superior to the semiconductor transistor[10] have been proposed, and research on the improvement of conventional semiconductor devices and research on the creation of new devices will proceed alongside each other in the next decade or two. However, we cannot rely only on the results of research for the creation of new devices based on unforeseeable technologies.

Figure 4:Trends in the position of Japan in the semiconductor device industry



Source: Provided by Mr. Inoue of the Economic Research Center, Japan Society for the Promotion of Machine Industry

7.3 Situation surrounding research on semiconductor devices

7.3.1 *Situation of the Japanese semiconductor industry*

At one time, from the latter half of the 1980s to the early part of the 1990s, Japan led the world in research on semiconductor devices. Owing to superior technical development concentrating on large-scale integrated memories, "Japan is an electronics state," and "semiconductors are the rice for industry" were the catchwords for Japan[11]. The average growth rate of Japan's semiconductor device industry since the 1970s was 11% in value of production, and the value in 2000 reached about 1% of Japan's GDP[12]. In the 1990s, the ratio of investment in research and development and equipment to the total amount of sales was kept at a high level of about 15 to 20%. These values show that the semiconductor device industry led research and development and equipment investment in Japan.

While the semiconductor device industry in Japan showed remarkable development in the past, it rapidly declined in the latter half of the 1990s as shown in Figure 4[5, 12]. At present, Japan's share in the world market is at the level of the 1970s. The amount of production in the world during this time has constantly increased with some margin of fluctuation, however, Japan is the only country that has lost competitiveness. Following the decline of the device business, related industries such as semiconductor fabrication equipment manufacturers are also losing their world market share. Specifically, in the production of DRAM (Dynamic Random Access Memory: volatile random access storage device) that used to represent the competitiveness of Japan, Japanese companies are now far behind those of Korea, the United States and Europe, being pushed into a corner where a comeback is groped for by integrating the business into one company. The technology of the United States for MPU (Micro Processor Unit) is far ahead of other countries. Although Japan still holds a dominant position in game machines, CCD (Charge-coupled device), and Flash memory (nonvolatile memory), these fields are also being attacked by foundries—the new Asian business model of the 1990s that provides only the production part. Since many reports have been published on this subject[5], additional detailed data are not given here.

Furthermore, Japan has a particularity that the semiconductor device industry belongs to the electric industry. As the Japanese electrical industry has its structural problems[13], it is not possible to discuss the semiconductor industry separately. Because the Japanese electrical industry has adopted the strategy of exhaustive assortment of merchandise (conglomerate integration) like a department store, which is considered to be effective only for certain limited areas, the overall competitiveness of semiconductor devices is being lost in the world even if there are some product groups that have their own advantages. The Japanese semiconductor industry is burdened with serious problems. In any event, it is apparent that Japan made a misjudgment around 1990. There is an analysis that the past successful experience delayed the noticing of changes in technologies and business models[14].

7.3.3 Changing the direction of the perspective on research and development

When Japan took international initiatives in silicon semiconductor devices around 1990, the field in which Japan showed the highest strength was memory production technology centered around DRAMs with miniaturization leading the development of technology. In the 2000s, however, "DRAM" and "miniaturization" are not necessarily keywords any more. As a background for this phenomenon, a business model that specializes in specific products or application fields, or in a particular part of production steps was established in the 1990s. Only Japanese business firms stuck to the old-fashioned business model of department store strategy, enclosing every step of the production process within the company, which used to be prevalent until the beginning of the 1990s. Now, the strategy to specialize in a particular field of products or a particular stage of the production process, thereby obtaining a worldwide lion's share in the narrow areas, brings about high profits. Consequently, targets of research and development differ according to the devices and application fields that are aimed at, and it does not make sense to simply pursue miniaturization. For example, now that many Japanese companies have withdrawn from the DRAM business, setting targets for the next-generation to "SoC (System on Chip)" and "communication devices", priority of research and development is not placed on "miniaturization" as it once was and, instead, "reduction in power consumption" has become a more important subject. In retrospect, concentration on DRAM and emphasis on miniaturization were results of pursuing industrial efficiency. From the viewpoint of users, "DRAM" is not necessarily an ideal memory. Although "miniaturization" brings about merits in performance such as low capacitance, the primary objective is the reduction of production costs due to the small size and large capacity. That is, these keywords did not represent the customer's perspective. On the other hand, "SoC" and "reduction in power consumption" are somewhat closer to the pursuit for customer satisfaction. Based on what has been described above, some people doubt the importance of serious discussion on the limits of miniaturization for silicon devices.

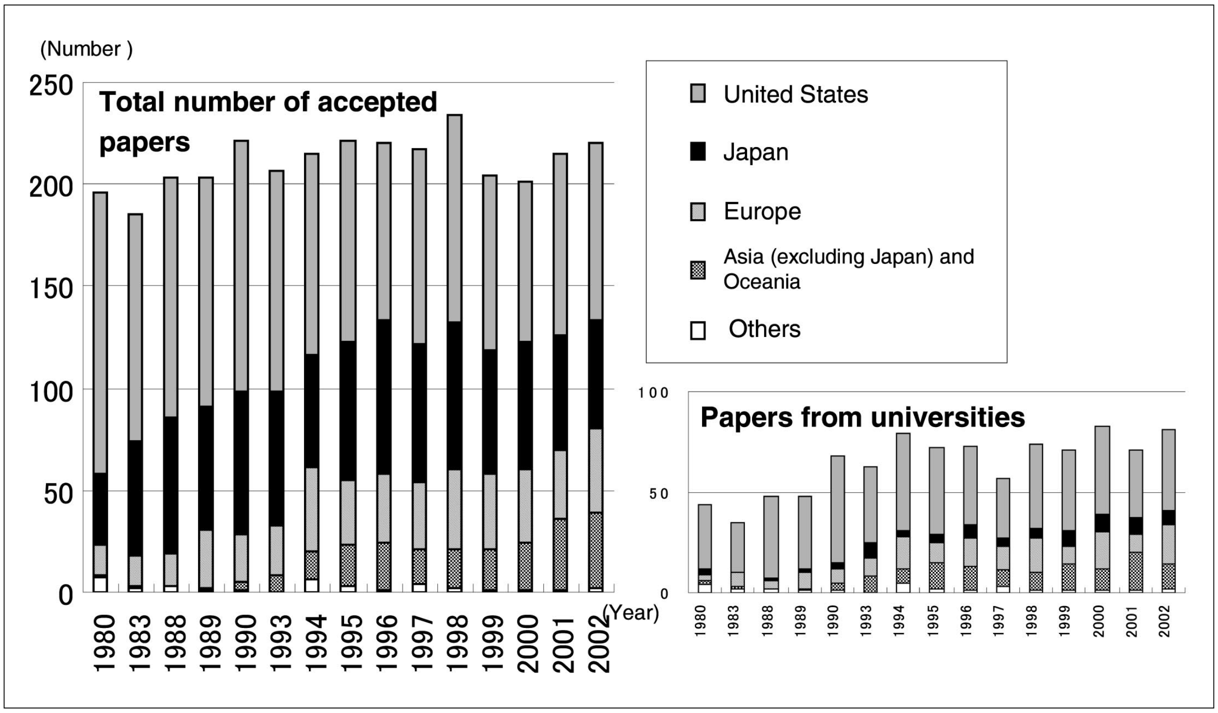
7.4 Leading organization conducting research and development in Japan

7.4.1 Number of papers presented in international conferences

In around 1990, when Japan was taking international initiatives in silicon semiconductor devices, Japan showed the highest strength in the field of memory production technology centered around DRAM, for which miniaturization was the key. A question here is who contributed to such research activities in Japan. Figure 5 and 6 show the results of investigation on the numbers of papers that were accepted by the two international conferences, IEDM (International Electron Devices Meeting)[15] and ISSCC (International Solid-State Circuits Conference)[16]. These international conferences are known to have a relatively severe standard for accepting papers, requiring completeness as device research as well as originality.

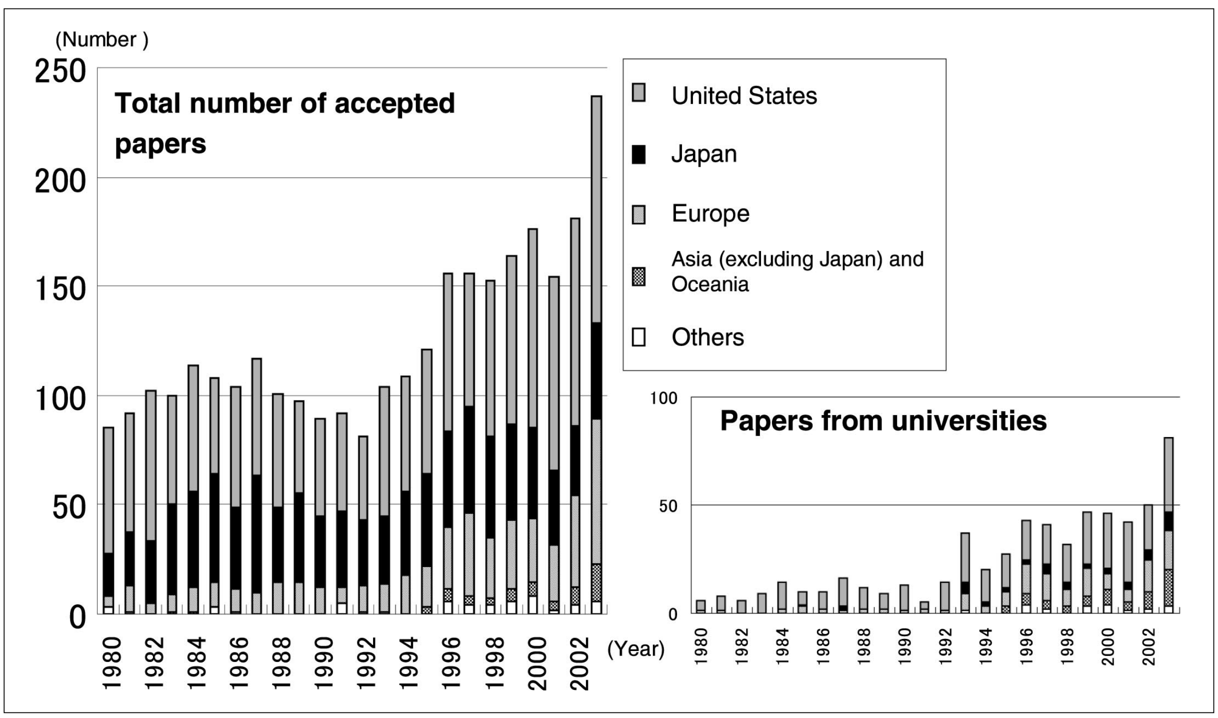
The number of papers presented from Japan maintained moderate levels during the 1990s, before it started to show a downward trend in 2000. While the United States has held the dominant position since the 1980s, the number of papers from European and Asian countries has been indicating a remarkable growth since the latter half of the 1990s. This increase of

Figure 5:Number of papers accepted by IEDM (comparison by areas)



Source: Provided by Iwai Laboratory of the Tokyo Institute of Technology

Figure 6:Number of papers accepted by ISSCC (comparison by areas)



Source: Provided by Iwai Laboratory of the Tokyo Institute of Technology papers from these countries directly reflects their leap in industrial competitiveness. What is particularly notable is that the papers presented from Japan around 1990 consisted in large part of those from private companies and included few papers from universities. This is in contrast to the United States, where universities have constantly been making substantial contributions. Another noticeable point from Figure 6 is that almost all of the papers from Asian and Oceanic countries, excluding Japan, have been presented from universities. The imbalance between business and academia in Japan was rather unusual in such a large research field at the early stages when the industry was not mature. A detailed look at Japanese research activities reveals another unique trend in Japan: research on semiconductor devices at universities has been more focused on compound semiconductors than silicon semiconductors.

The research on silicon semiconductor devices including production technology cannot be carried out without research facilities of a considerable scale, which require a large amount of investment. In the period around 1990 in Japan, such research funds were only available in private companies, where research work was conducted within the closed environment of each company. The industry in those days considered the universities only as a supply source of graduates, and expected little research achievement from the universities.

In the latter half of the 1990s, there was an increase in the number of papers presented by Japanese universities, although it is still small in total number. Some measures based on the First Stage Basic Program for Science and Technology Policy may have attributed for it. For example, some university faculties were recruited from private companies and an organization began to support university laboratories by commission of prototyping to private companies (VLSI Design and Education Center: VDEC, started in 1997)[17]. Similarly, in the United States in the latter half of the 1980s, many researchers moved to universities from the Bell Laboratory, which had been the center of research on semiconductors, and these researchers are said to contribute as major players in the U.S. in the 1990s[18]. In Japan as well, the flow of human resources since the latter half of the 1990s must have led to the increase in the number of papers in international conferences. Furthermore, it is believed that the presence of the VDEC and other private foundry services allowed universities to enhance their research ability particularly in the area of design technology. This is an example of successful industry-academia collaboration that effectively linked the research efforts at universities with private manufacturers. Now, the system LSI design technology in universities has reached a level acceptable for the industry. Some laboratories in universities have started up businesses by using foundry services for their prototyping and productions[19]. In this technological field, a researcher can participate in a research project wherever in the world he/she is, which potential suggests even a virtual research institute would prove effective. Disadvantages of universities are thus being removed in research areas that do not require large-scale investment.

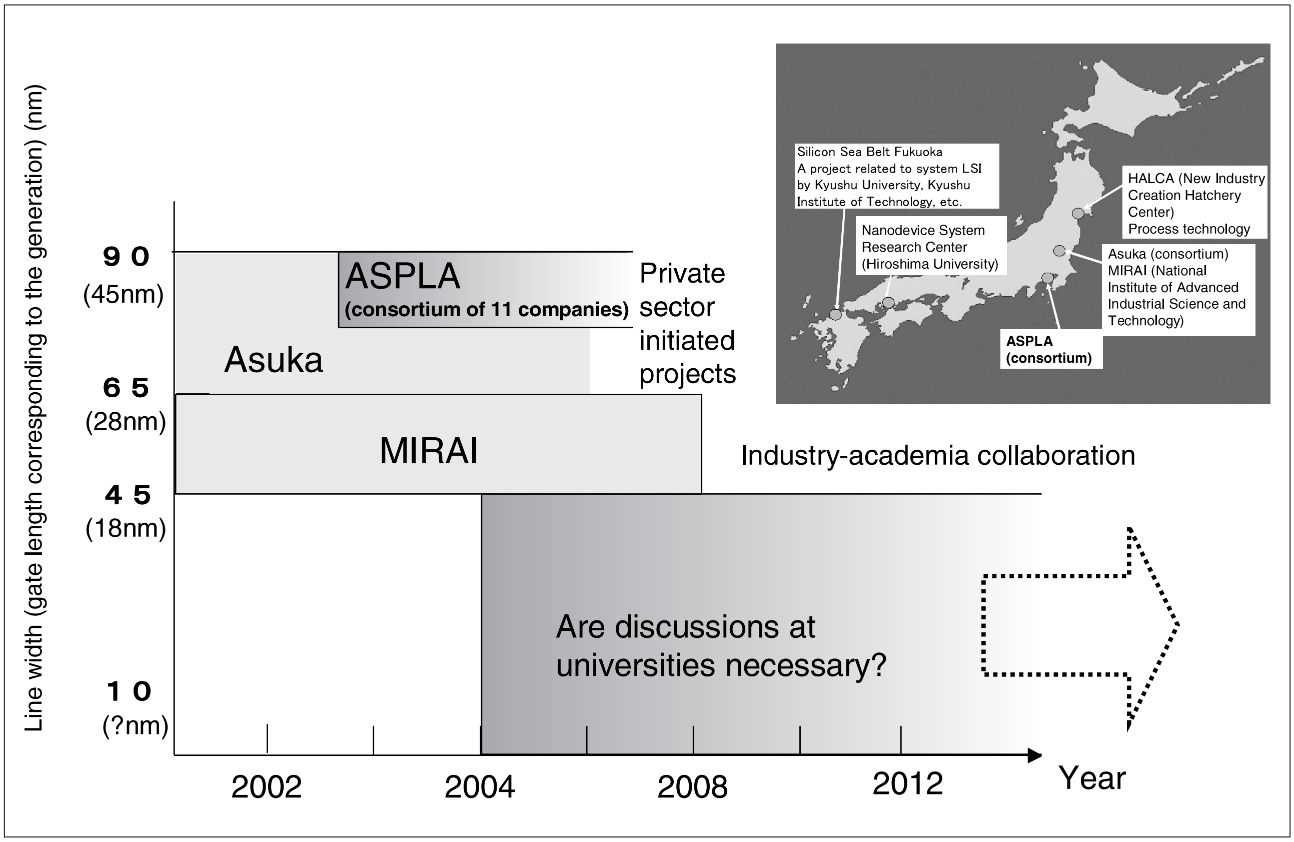
7.4.2 Research and development projects (consortium) under way in Japan

Figure 7 shows an overview of research projects (consortium) in Japan related to silicon semiconductor devices in terms of line width (and gate length) and time. It indicates that several projects spanning through 2007 are already under way. These projects share an objective of improving research efficiency by concentrating research investments. Most of them aim at breaking through the above-mentioned Red Brick Walls.

Since only simple explanations of the parent organizations of each project (consortium) are given below, please refer to the respective websites for the objectives and scale of these projects.

"Asuka", that is led by the private sector with a view to developing the technology for system on chips (SoCs), is promoted by Semiconductor Leading Edge Technologies, Inc. (SELETE)[21], a company that is under the control of the Semiconductor Consortium Committee (consisting of 11 companies) of the Japan Electronics and Information Technology Industries Association

Figure 7:Schedule of semiconductor related projects



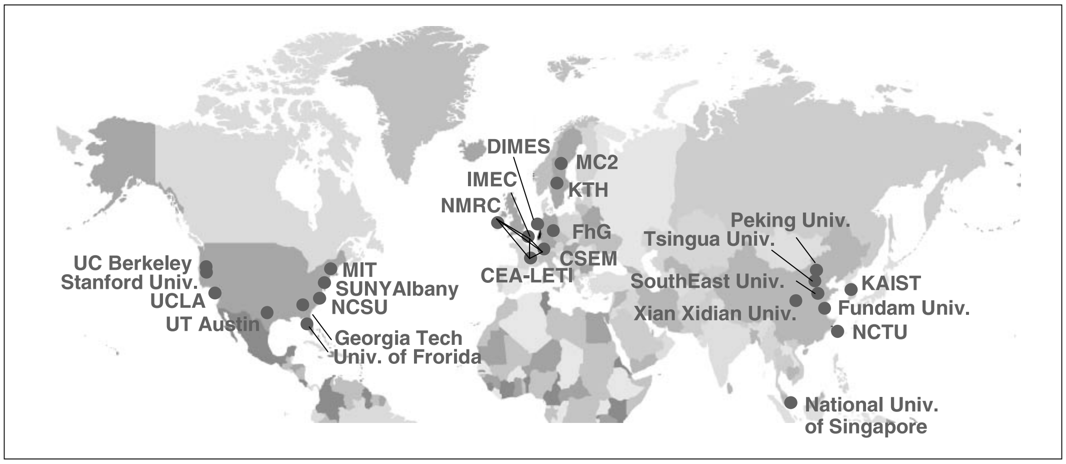
Source: Prepared by Iwai Laboratory of Tokyo Institute of Technology

(JEITA)[20]. Most of the researchers involved in this project are on loan from the corporate investors (11 companies) and contractors (2 companies). These companies are all device makers, including a foreign company participating as one of the contractors. The participants of the "MIRAI" [22] include the Advanced Semiconductor Research Center of the National Institute of Advanced Industrial Science and Technology (AIST), the 25 member companies (14 semiconductor manufacturers + 11 equipment manufacturers and material suppliers) of the Association of Super Advanced Electronics Technologies (ASET)[23], and 20 university laboratories. Although this is an industry-academia -government collaboration project, most of the personnel are on loan from private companies or persons with experience in private companies. The "HALCA", which is another industry-academ ia-government initiative, has a different objective from others. This project seeks to enhance semiconductor production technologies tailored for wide variety of production with limited quantity, which is therefore not listed in Figure 7. Manufacturers of fabricating and peripheral equipment have been playing an important role in the project, although little of the results have been disclosed.

These three projects are mainly implemented in the "Super-Clean Room Industry-Academia-Government Joint Research Building"[24] in AIST (Tsukuba), which was built at a total cost of ¥25.2 billion in June 2002. The laboratory has two clean rooms: a Class 3 room of 3,000 m^2 in use for the Asuka Project and a Class 5 room of 1,500 m^2 in use for the MIRAI and HALCA projects. It is reported that a total of more than 400 engineers and technicians work there and the total investment exceeds ¥100 billion. Even though originating in separate schemes, these projects have recently started joint efforts on a limited basis[25].

Furthermore, Advanced SoC Platform Corporation (ASPLA)[26] has been established, that is expected to yield results ahead of the other projects ongoing in this area. While being a private-sector project, it has been treated like an industry-government collaboration, since it is scheduled to receive national funding of about ¥35 billion under the second supplementary budget for fiscal 2001 as one of the "joint research

Figure 8:Research institutes for semiconductor devices throughout the world (excluding Japan)



Source: Prepared by Iwai Laboratory of the Tokyo Institute of Technology

facilities for next-generation semiconductor design and fabrication technology" to be set up by AIST. The actual facilities of ASPLA are located within the clean rooms of a private company. This project intends to embody the research results of SELETE[21] and STARC[27], which are under the umbrella of JEITA. Any university does not directly contribute to its activities. Another attempt is "Advanced Assessment of Next-Generation Semiconductor Nano-Materials Project," a three-year project starting from fiscal 2003 that focuses on the development for materials in wiring process. Private companies will bear 50% of the cost of this project.

In the period through 2007, semiconductor research community should place the highest priority on achieving concrete results from these projects, because they are fully need-oriented initiatives launched with an eye toward overcoming the Japanese semiconductor industry crisis. Their failure to yield results might lead to further deterioration of the competitiveness of Japanese industry.

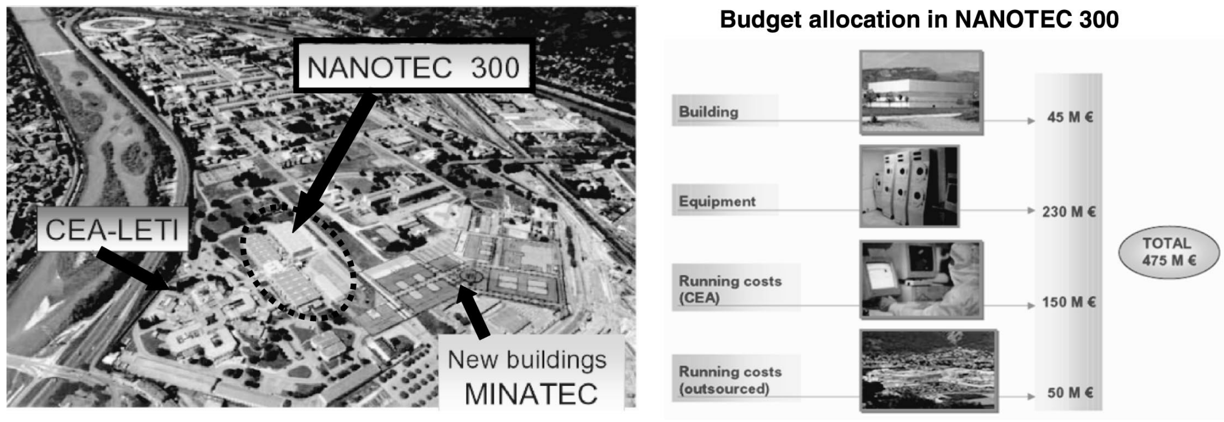
The present ongoing projects in Japan concerning the fabrication technology of silicon semiconductor devices are still heavily dependent on private companies, with virtually no project that is led by universities. Furthermore, as of now, there is no research project in Japan that pursues devices of a line width of 50 nm or less (10 nm or less for gate length) with a view a decade ahead. Based on these facts, the FED (Research and Development Association for Future Electron Devices) Salon discussed as the 2002 conference challenges about the sub-10-nm generation semiconductors (coordinated by Prof. T. Hiramoto of Tokyo Univ.), that are expected to appear in about 10 years, and proposed the concept of a university-led project [28].

7.5 Examples of overseas research facilities

7.5.1 Research facilities for silicon devices in the world

Figure 8 is a world map showing the locations of advanced device prototyping facilities that are readily available to university researchers. As seen from the map, most of these facilities are located within or adjacent to universities, indicating that forming regional high-technology clusters through industry-academia-government collaboration is the key to facilitating research. The active involvement of universities is crucial in providing companies with personnel who can immediately bring benefits to business, while it promotes the progress of university faculty members themselves. Of the institutes shown in Figure 8, SUNY Albany, IMEC and CEA-LETI (MINATEC) serve as the homes of projects sponsored by national or local governments. Some of these institutes are already equipped with lines to treat 300 mm wafers or are ready to upgrade their existing equipment to them. The construction of a 300 mm wafer line requires a massive investment of over several tens of billion yen. In these countries, what justifies such enormous investments is a common perception that silicon-based devices will continue to be in the mainstream of high-technology electronics for the next few decades or more.

Figure 9:Research facilities under construction in Europe



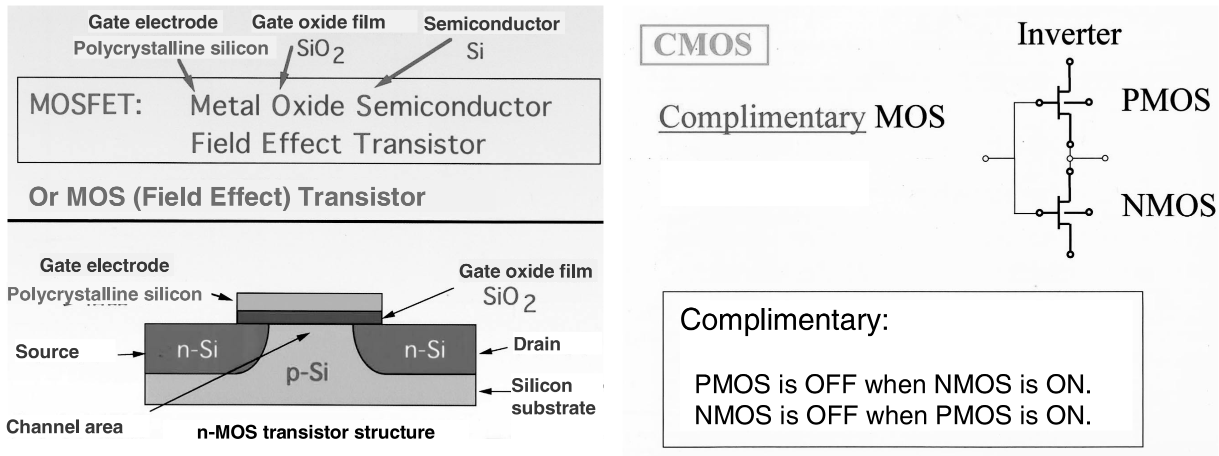
7.5.2 An example in Europe

An example in Europe is NANOTEC 300, that is a research establishment on 300 mm wafers, under construction as part of the French MINATEC Project (Figure 9)[29]. Details of MINATEC have already been introduced in the fourth issue of this bulletin[30]. It consists of laboratories for common use with the most advanced equipment, science and technical universities and graduate schools and incubation centers for venture businesses. Research for silicon integrated circuits are placed at the center. The expected numbers of personnel for each platform are: 500 faculty members and 1,500 students in the university and the graduate school; 800 personnel in applied research and 400 personnel in basic research (1,000 in the field of miniaturization technology) in the laboratories; and 500 to 1,000 people in the business sector. The city of Grenoble, where MINATEC is located, has had solid industrial organizations of semiconductor, biomedicine, and other electronic devices, as well as a heavy concentration of affiliated research laboratories of national and European institutions and of universities. These organizations form the parent body of MINATEC. As shown in Figure 9, the facilities of the MINATEC project are located adjacent to CEA-LETI (Electronics and Information Research Center of the French Atomic Energy Commission), which is one of the supporting organizations. Since CEA-LETI places emphasis on the procurement of funds from the industry, the external research funding for silicon semiconductor devices accounts for 60% (41 M euro) of the total funds, and silicon technology is positioned as the "Driver in CEA-LETI." In addition, many divisions of STMicroelectronics, K.K.[31], which is the largest communication device manufacturer in Europe, are located in the neighborhood.

7.5.3 Examples in Asia

In Asia, not only semiconductor research facilities but also the other industrial and interdisciplinary research facilities are centralized in a more distinct manner because of the national policy of each country. One example is the Hsin Chu Science-Based Industrial Park, which was established by the government of Taiwan in 1980. Various privileges have been granted to this area. There are Industrial Technology Research Institute (ITRI), National Qinghua University, National Chiao Tung University, and more than 290 companies related to the six major industries (semiconductor, computer parts, information and communications, optoelectronics, precision instruments, and biotechnology). The estimated population of researchers and engineers working in the area totals to as many as 72,000. National Chiao Tung University (NCTU) is known as a community-based technical college since 80% of the graduates find jobs in the industrial park. The university owns a semiconductor prototyping facility (Semiconductor Research Center)[32] since the 1980s, which is made available to anyone for a fee. The fabrication lines are easily accessible through its website. The main purpose of this facility is offering fabrication services for outside as well as training students. While the current facility is a mix of machines fitted for different wafer sizes ranging from 4 to 6 inches, a new

Figure 10:CMOS structure expected to be maintained as the basic principle over the next decade



Source: Prepared by Iwai Laboratory of the Tokyo Institute of Technology

nanotechnology one is soon to be added with clean rooms covering a total area of 3,300 m^2 and will start operations in 2004. However, what this university emphasizes most from now is not research on hardware but the national project called as Si-Soft (the National Si-Soft Project)[33]. This large-scale scheme intends to increase the number of professors dedicated to LSI design by 250 in three years and to produce 1,000 designers every year. It stands on a following perception. Taiwan had successfully made the transition from labor-intensive industry to investment-oriented one during the latter half of the 1980s and through the 1990s. However, it should go on to a next step of a knowledge-based one, because the center of the investment-oriented business is forecasted to move to Mainland China sometime during the 2000s.

7.6 Technological foresight for the next decade

The prospects of semiconductor devices for the next decade based on the opinions of a number of researchers I have interviewed are listed below.

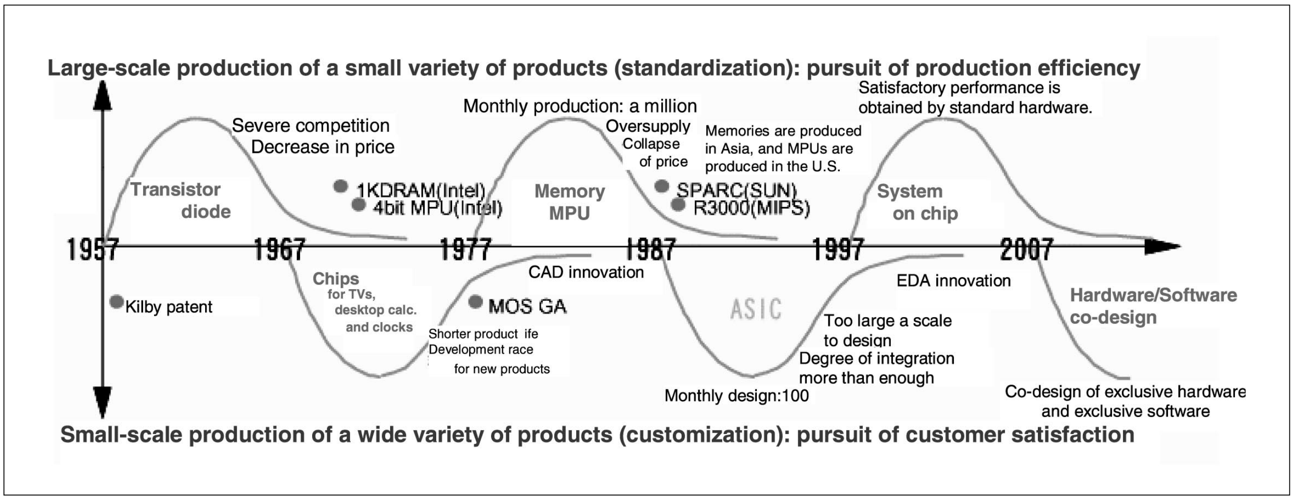
(1) Many researchers believe that at least two features of present semiconductor devices will remain unchanged over the next decade: semiconductors are formed on silicon wafers and have a CMOS structure (Figure 10). That is, the basic principle that complimentary circuits using MOS (Metal-Oxide-Semiconductor) structure are formed on silicon wafers will not change even if the semiconductor materials are changed from silicon to other new materials, for example, carbon nanotube and so on.

(2) Provided that the prospects of ITRS roadmap are realized in general, a ubiquitous computing society will be achieved on the extension of conventional silicon devices without having to wait for the introduction of devices based on a new principle. For example, the operating speed of MPUs for practical use is expected to exceed 10 GHz in 2005 or afterwards.

(3) As an immediate issue, there is an urgent need to lower the operating voltage to reduce power consumption. The realization of (2) is likely to depend more on progress in this aspect than progress in miniaturization technology.

(4) In the history of the research on devices, there has been two trends that appeared alternately: standardization and customization (Figure 11). The present trend is standardization that features SoC technology. However, the research and development enthusiasm about this topic may wane by around 2007, followed by rising interest in customization that will dominate after ten years in the world of semiconductor research. The key concept for this customization trend is thought to be hardware/software co-design.

Figure 11:Trends of standardization and customization in the research on semiconductor devices



Source: Provided by Prof. T. Kuroda of Keio University

(5) In the area of miniaturization research, the size of MOS transistors will be reduced at the fastest pace, with their gate length expected to shrink to 10 nm or less sometime between 2010 and 2016. Miniaturization, however, means not only the establishment of the miniaturizing technology for 10 nm or less, but also obtaining performance corresponding to a line width of 25 nm or less and a gate length of 10 nm or less.

(6) To realize (5), it requires aggressive deployment of new materials, new processes, and new structures. In addition to advances in these new technologies, large innovation in circuit technology is also essential.

(7) It is no doubt that ten years from now the focus of research on miniaturization will have shifted to the range of less than 10 nm. Since this is close to the physical limits, completely different new technologies may begin to emerge from that time forward.

The question is whether research community in Japan should cover all of these technologies or not. The research in the fields stated in (5) to (7), in particular, would not be conducted without large-scale projects comparable to the ones conducted in foreign countries and massive investments. A serious discussion is needed to decide whether Japan should invest in these themes in preference to other research subjects.

Participants of this discussion must recognize that the technical hurdles to be crossed before introducing new materials and so forth are very high, because relatively easy issues have already been resolved. The industry has adopted some of the new solutions, including the intermetallic compound of silicon (silicide), nitrides that can replace oxides, solid-solution metallic films, new wiring materials, and low dielectric constant materials for interlayer films[34]. None of the remaining technological challenges is easy, since they are left unsolved despite a number of attempts over a long time. For example, materials for insulating films with a dielectric constant higher than that of silicon oxide have yet remained to be a issue after investigations for more than 30 years from the early stage of IC development. To put it another way, silicon oxide is an excellent material with stability, and discovering a material superior to it is a task of considerable difficulty. The development of high dielectric constant films to be used for DRAM capacitors has also been attracting so much of the attention of researchers for more than 10 years[35] that a multitude of papers on the subject have been presented at technical conferences. However, none of them could provide reasonable solutions in time to stop most Japanese companies from withdrawing from the DRAM business. These new materials cannot be developed by simply following the strong-arm tactics that have been taken for miniaturization technology based on the principle "a combination of human, material, and financial resources can solve everything." According to past experience, when it comes to the choice between a change in structure (miniaturizing in most cases) or development of new materials to solve a certain problem, the former has always won.

Another noteworthy concept is the co-design of hardware and software described in (4). In this approach to customization, the optimization of the total system will take precedence over improvement in the performance in individual parts of circuits, while, with respect to hardware in specific, total robustness will become more valued than partial sophistication with limited reliability.

7.7 Consideration to the device research in universities in Japan

7.7.1 Importance of focused investment

Since future research on semiconductor devices requires enormous investment, it is ineffective to spread relatively small amounts of a budget to many research institutes. In order to establish facilities comparable to the major facilities of foreign countries, initial investment of tens of billion yen or more and further maintenance costs are necessary. That is, research activities must be concentrated from the viewpoint of national policy as well as from the viewpoint of budget allocation in a university, and a consensus must be built among parties related to the budget allocation. Although this was a difficult job, a favorable environment is being established with priority in the national policy for measures to develop science and technology and the institutionalization of universities to be independent administrative agencies scheduled to be enforced in 2004, which will accelerate the centralization of authority to the presidents of universities.

There is also an utterly different way of thinking. Recognizing that Japan is already behind foreign countries in the establishment of research systems, some universities prefer to concentrate on the development of design technologies rather than make half-hearted investments on the research on devices. For example, the Silicon Sea Belt Fukuoka Plan [36] is not constrained by the administrative boundaries of Japan, which is viewed from a broader perspective as a member of Asia.

7.7.2 Building a consensus

To realize the concentrated investment on research and development as described above, it is necessary to build a national consensus that such research and development is truly needed. It must be seriously discussed in universities as to what Japan should pursue in the future. Regretfully, it is generally recognized that Japanese universities have not contributed much in this field, and this situation may not be improved so easily. Such a superficial slogan as “it is necessary for the establishment of an electronics state” that was accepted in Japan in the 1990s cannot be tolerated any more. It seems that Japanese universities do not have persuasive reasons, which aim toward a Japan a decade from now, for their research activities to require a large amount of investment. Particularly, it may not directly contribute to the strengthening of Japanese industry to blindly aim at the top level of the world by developing the miniaturization technology in the future, and the keyword “miniaturization” by itself will not help build a national consensus. Until the Japanese economy completely recovers, it will be difficult to obtain a consensus for research that does not conform to the national industrial strategies.

7.7.3 Possible concrete measures

From an objective perspective, the research forces and facilities of present Japanese universities are weakening compared to those of foreign countries. Particularly, facilities of universities are very poor because they have not been changed since the 1980s. The facilities of Tohoku University and Hiroshima University, which are now considered to be effective for research on silicon devices, are setup for 2-inch wafers and have been closed to outside researchers. (Note: experimental production facilities of Tohoku University in the new integrated field are open to the outside, and the facilities of Hiroshima University are now accessible from outside since they have been integrated into the “Nanotechnology Support Project” of the Ministry of Education, Culture, Sports, Science and Technology in 2002.) For this reason, it may be an inevitable result that research leaders in the development of silicon devices have not come on the scene from purely university circles for a long time. The only way to achieve outstanding results on a world level at present is to utilize consignment systems such as VDEC[17].

For Japan to continue research on specific devices and processes, it would be effective to create a high technology cluster placing a university or universities in its center and involving local private companies, or for the government to take over existing research laboratories and experimental production lines owned by private companies and convert them to public research facilities. Yet another idea is to promote the establishment of programs in universities that are contributed by private companies practically creating public research laboratories within private companies. This method does not require building new facilities. In either case, it is necessary to establish a system in which university officials act as intermediaries between their laboratories and private companies.

When Japanese universities intend to carry out research work in this field at the world level, not only investment in facilities but also significant reformation of consciousness is indispensable. It is necessary to make the facilities open to outside researchers and to provide onerous foundry services. Research activities should be made effective by lowering the fences of conventional disciplines and involving material, chemical and mechanical technologies, and by rigorously exchanging researchers among internal and external organizations. Even professors should be able to challenge completely new fields. For this purpose, just one establishment will be enough in Japan. If the transfer of a whole laboratory of a university or transfer of related faculty members among universities is opposed, the benefit of such establishment will be greatly reduced.

More specifically, many technicians other than researchers are required for the maintenance or control of clean rooms and equipment. Since Japanese universities do not have the know-how to control most advanced clean rooms, new facilities cannot be operated based on the conventional university system even if such facilities are built. Regarding this point, it is difficult at present for national and public universities to hire technicians other than researchers. However, this problem will be solved when the institutionalization of universities is realized. It is reported that Japanese companies are suffering from a surplus work force and there are many excess personnel not only in the device industry but also in the instrument and material industries. Therefore, it is a key point as to whether national and public universities can establish a system to flexibly receive the necessary personnel.

7.7.4 When can universities go into action?

In the 2000s, the competitiveness of Japanese industry has been further weakened and will not recover for a while. Although consolidation by product line among large companies is proceeding in Japan, its speed is significantly slow when compared to the world standard. It will take several more years before the consolidation is completed to ensure profits at the level of European countries. For a while, no single company will be able to provide sufficient investment to carry out medium- and long-term research at the world level. It is questionable whether the present projects initiated by private companies can continue to the next-generation if they do not bring about the expected results. They may be even reviewed from a political viewpoint before they are finished. In a sense, this present time of turmoil is a good chance for universities to enter the scene.

From the perspective of the industry, it may become a new key point in how to utilize the force of universities and public research institutes. The “Basic Research Center” boom of private companies that was prevalent around 1990 has gone and medium- and long-term research activities have been significantly cut down. In the future, there will be a type of industry-academia collaboration in which universities and public research institutes bear a part in medium-term and long-term research. There is a strong opinion in Japan’s business world that the academia, whether they like it or not, cannot evade participation in industrial research in the future. Private companies cannot fund research and development as they did in the past. It is difficult for them to keep all the staff required for research and development, and even if they manage to keep the personnel, they can no longer come up with the necessary research expense. Taking the past failure into consideration, the industrial world, moreover, should approach the academia.

7.8 Conclusion

Under the current conditions in Japan, large-scale investment for research on silicon semiconductor devices cannot be unconditionally approved. In the world, however, research on silicon semiconductor devices is on the cutting edge of nanotechnology research, holding an important position in the industries that support today's information society. In the past-day Japan, it was true that universities did not contribute much to the research on silicon devices. At this point, they must decide whether to continue to look on with folded arms waiting for the recovery of the semiconductor industry or to positively participate with the industry in the research work with a perspective for the next decade.

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