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Recent Trends in Semiconductor Microfabrication Equipment Technology
— Proposals for Industry-Academy Cooperation on Research and Development in Japan —

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1 Introduction

From the beginning of this year, electric companies in Japan have been intending to invest capital in semiconductors and liquid crystal products, mainly motivated by the hot sales of digital consumer products. Capital investment is again surging from its low point of ’99 to ’00 after the IT bubble burst. In fact, Renesas Technology (consolidated semiconductor company of Hitachi and Mitsubishi) attained the No. 3 position in sales, if nominally, next to Intel and Samsung. A portion of their capital investment in on microfabrication equipment that transfers LSI (large-scale integration) patterns on masks onto semiconductor wafers. This equipment controls the critical features that define the specifications of leading-edge semiconductor products and LCDs. Global competition is increasing over the share of the microfabrication equipment market. Maintaining an advantageous position both in technology and in market share is strategically important for Japan to retain world leadership in the technology industry and the semiconductor industry.

Japanese companies have dominated both in technology and in the application of product segments of optical technologies such as optical disks, optical fiber components for communication, cameras, microscopes, endoscopes and laser printers. This is especially important in semiconductor microfabrication equipment that extensively uses optical technology, and the optical exposure systems that we discuss here. Optical exposure systems require the most advanced optical technology. We should not be complacent about Japan’s future position since a European maker once took the No. 1 market share[1] in the semiconductor exposure system market.

This report shows that industry-academy collaboration is an important way of retaining international competitiveness in the development of exposure systems, an area where Japanese companies have been strong in an increasingly competitive semiconductor microfabrication equipment industry. In addition, we discuss the action required to make collaboration fruitful in Japan.

2 Semiconductor device roadmap and lithography solution

2-1 Semiconductor device roadmap

In semiconductor LSI segments produced recently, competition in development has been kept strong for MPUs (Micro Processor Units) that are the core components of PCs, which form the basis of the information-communicatio n equipment, DRAM (Dynamic Random Access Memory) and SoC (System on Chip) for mobile devices and digital consumer products. These semiconductor devices have evolved with further integration as a goal. For example, DRAM has untiringly pursued fine patterning technology called “half pitch,” or “gate length” for MPUs.

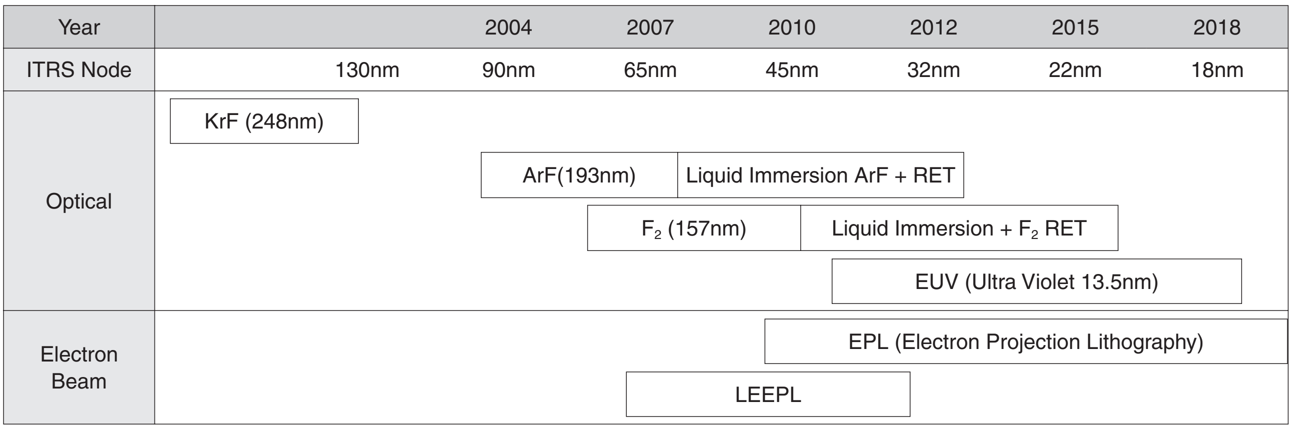
Table 1 is a roadmap indicating basic trends in integration improvement[2]. The roadmap is

Table 1 : Semiconductor Device Roadmap

Device/Year	2004	2007	2010	2012	2015	2018
DRAM	4Gb	8Gb	16Gb	32Gb	64Gb	128Gb
Half Pitch	90	65	45	32	22	18
Contact Hole	110	80	55	45	35	25
Overlay control	32	23	18	14	10	7.2
Linewidth Variation (3s)	11	8	5.5	4.3	3.1	2.2
MPU						
Half Pitch	107	76	54	42	30	21
Gate Length	53	35	25	20	15	10
Contact Hole	122	80	59	46	33	23
Linewidth Variation (3s)	3.3	2.2	1.6	1.3	0.9	0.6
SoC						
ASIC/LP gate	75	45	32	27	19	13
Contact Hole	122	80	59	46	33	23
Linewidth Variation (3s)	4.7	2.9	2	1.7	1.3	0.8

Source: Prepared by the author based on the table on the ITRS home page.

Figure 1 : Lithographic solution



called ITRS (International Technology Roadmap for Semiconductor) and is defined by major electronics companies in the world including Intel Corporation in U.S.A. At first, the minimum line width was in the order of microns, and this continuously decreased over time, and now a 90-nm node will be in production with the size of a DRAM with this line width corresponding to 4 Giga bits. The target for 15 years from now is set to an astonishing 18-nm line width for 128-Giga-bit capacity.

2-2 Lithographic solution

This micropatterning of LSI in the ITRS roadmap is created by microfabrication equipment that fully uses lithographic technologies and is called the lithographic solution at each node[3,5]. This equipment employs ultraviolet light or an electron beam as the light source, and can be classified into two categories as shown in Figure 1. We now outline these categories.

The first category is the stepper, or recently, the scanner, which employs an optical method using ArF (argon fluoride) or F_2 (fluoride gas) laser that emits ultraviolet light as the light source. This method has the advantage of optical parallel processing capability in space, as shown in Figure 2, which means all the points on the mask pattern are simultaneously transferred onto a wafer. It gives higher throughput, guarantees production and is widely used. The wavelength of the light source shortens with the generations because the line width is defined by resolution of the lens optics of the exposure system derived from the equation below, called Abbe's equation (or Rayleigh's equation).

Line width: $\delta = k \cdot \lambda / NA$ ...(1)

where λ: wavelength, NA: Numerical Aperture, k: Engineering factor.

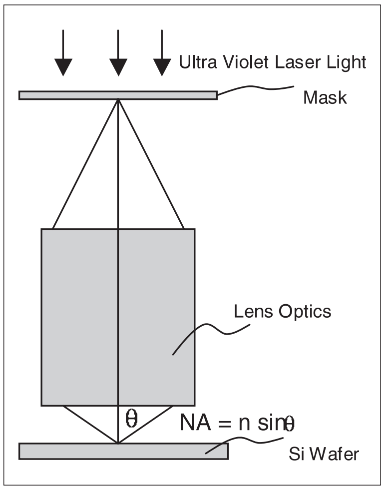
NA is given by NA=n • sin θ where θ is the one-half angular aperture

We now briefly discuss liquid immersion technology, which was a technical breakthrough and a strong candidate for future lithography at Microlithography2004[6] held in February 2004 in Silicon Valley (Santa Clara) in U.S.A. This technology extends the life of the ArF laser-sourced wafer exposure system. It fills the space between the projection lens and the wafer with pure water and improves effective NA because of its refractive index, 1.4. Equation (1) clearly explains the improvement in resolution. Another big advantage is the better focal depth, which reduces the need for accuracy in the mechanical position control of the system. The liquid-immersed lens has long been known for its super high-resolution microscope, but its application to the production exposure system is a historical first. Its applicability to 60nm resolution was confirmed by partial experiment and 45nm to 32nm is possible if mask pattern is simply repetitive.

The second is an exposure system with an electron beam as the source, which has a much shorter wavelength. The electron projection lithograph (EPL) is a typical piece of equipment. This technology irradiates the electron beam (with its wavelength of below 0.1 nm) to a mask pattern and projects the reduced image of the mask pattern onto a wafer. The equipment can expose only a limited area and provides less throughput than optical systems. It has never been mass-produced. However, because it gives better resolution and better focal depth than optical systems, it can be partially used for isolated pattern exposure such as contact holes. It can also be used for the microfabrication of special-purpose LSIs.

On the other hand, a new method called LEEPL (Low-energy electron-beam proximity-projection lithography) is proposed, which positions the mask and the wafer close together and projects the entire image by an electron beam. Its resolution of 65 nm has been confirmed by experiment, and development of a resolution of 45 nm is underway. The cost of the equipment is affordable and higher throughput can be achieved compared with EPL, but it still has a number of problems such as its higher mask cost because it is real-sized.

Figure 2 : Diagram of the optical exposure system



So far, we have briefly reviewed the electron beam lithography system that has been developed to replace the optical lithography system should the latter system reach its limit. However, as its productivity has not improved compared with optical systems, its major role today is for lithography research purposes and fabricating original masks for submicron lithography.

2-3 Next-next-generation EUV/F_2 lithography

As discussed so far, breakthroughs achieved through liquid immersion technology has made a 45-nm ITRS node certain, and even a 32-nm node is possible, but what about beyond these? Next-next -generation lithographic technologies, extreme ultra-violet (EUV) exposure technology and F_2 lithographic technology, are an answer to this question.

EUV technology proposed by Prof. Kinoshita of University of Hyogo, ex-NTT, is an innovative idea from Japan to be proud of. This lithographic technology can use, for example, extreme ultra-violet light (wave length, 13.5 nm) emitted from high-temperature plasma gas generated by the radiation of a high-power laser light to a stream of water ejected from a nozzle in a strong vacuum. Competition among Japan, U.S. and Europe is also fierce in this area. Peculiar to EUV technology is that there is no glass that transmits EUV light. For this reason, a reflective mirror is used, and most of the continuity with the existing optical exposure system will be lost. Hence, the total development costs of the exposure system are estimated to be 43 billion Yen (ca. US $400 million) including basic, measurement, and production technologies. This exceeds the 15 billion Yen for ArF lithography and the 20 billion Yen for F_2 lithography, and this is far more than one company can afford.

Thus, EUV technology in Europe and U.S. is promoted by industry-academy-governme nt collaboration with plenty of funding from, for example, MEDEA+[7] (Microelectronics Development for European Applications +) in Europe, EUV LLC[8] (Limited Liability Company), VNL (Virtual National Lab./Lawrence Berkeley, Lawrence Livermore, Sandia) and ISMT[9] (International SEMsATEC) all in U.S.A. With this background, EUVA[10] (Extreme Ultra Violet Lithography Association) was organized in June 2002 and March 2005 as a consortium through industry-academy-government collaboration with the support of NEDO (New Energy Development Organization) and under the initiative of the Ministry of Economy, Trade and Industry. Amidst international competition, it is developing future technologies including equipment cost reduction. With this situation, Intel announced in autumn 2003 that they would focus on EUV exposure for beyond 32 nm and would skip F_2 lithography. Still, EUV exposure has a number of problems including huge costs, a poor mirror optics record and the necessity for EUV light source development.

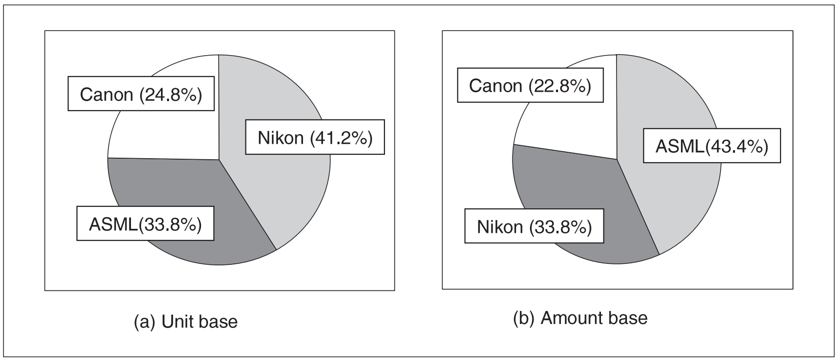
On the other hand, there are also problems with F_2 lithography, such as production technology for the large crystal growth of CaF_2 (Calcium Fluoride) for lenses. However, it may have an advantage over EUV because it is an extension of the existing optical system that has produced fruitful results as an exposure system. To reinforce this view, ASML delivered an experimental F_2 exposure system in April 2003, priced at over 12 billion Yen to InterUniversities MicroElectronic Center (IMEC[11]) in Europe for the early identification of technical hurdles in production. Zeiss in Germany, a well-established optical technology company in the world, is responsible for the ASML optical system. In Japan, F_2 lithographic technology is driven in the "Asuka Project" of Selete[12] to be completed in March 2006. Whether to pursue F_2 or EUV beyond this needs a high level of decision as it is very complicated, not only in its technology, but also in its development time and the huge amount required for investment.

3 Share of the worldwide market and the international competitiveness of Japanese companies

In worldwide market share of semiconductor products, it has been almost ten years since a Japanese company lost the No. 1 position. However, thanks to the strong digital consumer product and mobile product market, and perhaps due to corporate reorganization, Renesas Technology (consolidated semiconductor company of Hitachi and Mitsubishi) attained the No. 3 position in sales, if nominally, next to Intel and Samsung. This raised the intention of Japanese electronic companies to invest capital for semiconductor and LCD products. This is a good chance for Japanese companies to retrieve international competitiveness in semiconductor microfabrication equipment. We now consider the market share of semiconductor microfabrication equipment and the international competitiveness of Japanese companies, which is the subject of this report.

The international market share of semiconductor exposure equipment is shown in Figure 3. The market is oligopolized by three companies, Nikon and Canon, the world's preeminent optical makers in Japan, and ASML (in the Philips group in the Netherlands) carrying Zeiss optics with a long history in optical technologies. In Figure 3, (a) is the unit base and (b) is the amount base. Nikon has the best sales by unit, but ASML has the best sales by amount. So far in the semiconductor manufacturing equipment market, Japanese companies have taken a strong world both in

Figure 3 : Market Share of Optical Exposure Systems in 2003



Source: Prepared by the author based on data from Press Journal Ltd.

technology and business. Recently, however, on the business side, ASML sometimes beats Japanese companies, emphasizing customer service and supplying easy-to-use products to the market. This causes great problems for Japanese companies. Customers choose ASML products even though the price is higher. Through the process of acquiring and improving international competitiveness, Japanese companies are expected to offer better customer services that emphasize usability and maintenance.

In U.S.A, optical makers like Kodak and Perkin-Elmer did good business in optical equipment such as cameras, instruments and others in the past, but they have lost their competitive edge today. For some time, SVGL was active in optical exposure systems, but they were acquired by ASML several years ago. As seen here, the lithography system industry in U.S. is losing its energy. However, universities in U.S. are still energetically researching and developing, and are responsive to front-line technical issues, as is seen with liquid immersion breakthroughs. What made this happen?

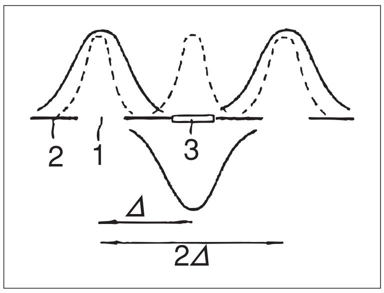
4 Technical advantage of Japanese companies and the success of universities in U.S.

So far, a roadmap of semiconductor microfabrication technologies and corresponding lithographic solutions has been explained, and semiconductor devices and the market share of microfabrication equipment has been reviewed. We will next analyze the international competitiveness of Japan in the semiconductor industry using two representative cases. The first case is an ultra resolution technology in which Japanese companies have been especially strong, from basic technology, to application through industry, to industry collaboration between optical and electronics companies. The second case is the success of U.S. universities that triggered the breakthrough in liquid immersion technology.

4-1 Industry to industry collaboration on ultra resolution technologies in Japan

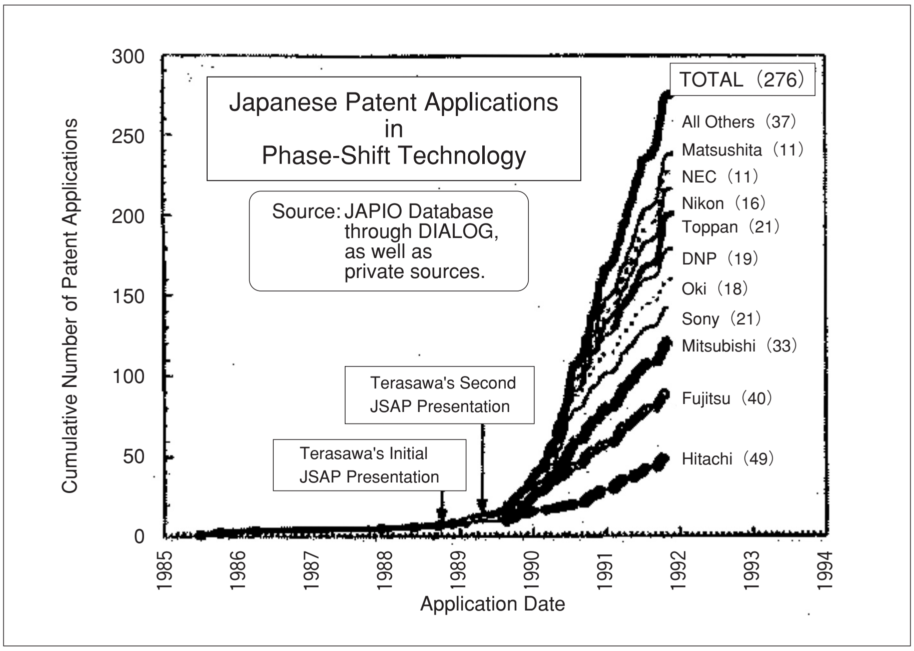
According to Equation (1) in Chapter 2, the minimum line width of semiconductor microfabrication can be made smaller by reducing the K-factor, even if the wavelength of the light source and the numerical aperture are kept the same. Resolution enhancement technology (RET) is a technology based on this idea, and the phase-shift technology shown in Figure 4 is representative of it. It shifts the phase of adjacent patterns on the mask by 180 degrees to divide electric field intensity into two. This is to improve the lithographic resolution by almost 200%. The basic idea was invented by Mr. Masato Shibuya,

Figure 4 : Principle of the phase-shift method



Shift phases of adjacent patterns on the mask by 180 degrees for a resolution improvement of about twice

Figure 5 : Trends in of number of patents related to the phase-shift mask, i.e., a champion of RET (Resolution enhancement technology)



Source: Presentation materials by F. Schellenberg at Microlithography2004

then working for Nikon, and now Prof. of Tokyo Polytechnic University, and the patent application was made by Nikon[13]. After this, Dr. M.D. Levenson at IBM independently proved its effect, and a group working under Dr. Shinji Okazaki of Hitachi opened the way to actual application.

Figure 5, with the vertical axis showing the number of patents for the phase-shift mask, shows that Japanese companies led in this area. The chart was presented by Mr. Frank Schellenberg of Mentor Graphics, an authority on lithographic technology, in his keynote speech entitled "Resolution Enhancement Technology: the Past, the Present, and Extensions"[14] at Microlithography 2004 mentioned above. Phase-shift can be applied only to repetitive patterns, and it is difficult to use for isolated patterns such as contact holes, but it is a general technology compatible with KrF, ArF and the F_2 exposure system since it does not limit the wavelength of the light source.

In summary, ultra resolution technology that was a breakthrough in optical lithography, is a good example of a technology developed by Japanese companies ahead of the rest of the world, then raised by American companies and put into practical use by the Japanese companies that predominated other countries. It should be acknowledged that technologies from Japanese companies contributed not only to production technologies and yield improvement, but also to solutions to fundamental technical issues. At Microlithography2004, a new award was established using the name of Zernike, who won the Noble prize in 1953 for his phase contrast microscope. Mr. B.J. Lin received the award this year for his driving liquid immersion technology discussed in the next section. Accomplishments in RET technology will be strong candidates for the next award.

4-2 Breakthroughs from liquid immersion and the technical sense of MIT

As reviewed, Japanese engineers have generally led the optical lithography with ultra resolution technology as a typical example. However, there are too many technical options[3,5] for next-generation lithographic solutions, as stated in Chapter 2 of this article, and it is unclear which technology should be the main solution. A concern of exposure system manufacturers both at home and abroad has been that they have been unable to narrow down the options, making development investment too large and irretrievable.

In this situation, at Microlithography2004[6] held in February this year in Silicon Valley (Santa Clara), Nikon, ASML and Canon each made separate presentations on the production usage of ArF liquid immersion technology as a breakthrough to a 65-nm node and beyond. They all confirmed this technology to be their first choice. A technology development race has already started for rollout by the end of this year or by early next year. Further competition for purchase orders from customers aiming for the top market share has also kicked off. For this, resources are being focused on and selected. That is, engineers engaged in the development of other lithographic technologies have been transferred to the development of the liquid-immersed ArF stepper.

We will now see how this noteworthy breakthrough technology attracted the limelight as a technology of choice for the next generation. As is clear from Abbe's equation (1), liquid immersion technology is so well known that it appears in school textbooks as enhancing microscope resolution. In fact, the invention of the liquid recycling lithography as announced this time can be traced back to a patent applied for early in the 1980s by Mr. Akihiro Takanashi of Hitachi[15]. At that time, however, RET technology, such as the phase-shift above, had much higher priority in development than other options for next-generation technologies. Thus, liquid immersion technology remained frozen for some time. RET itself seems to be lacking innovative ideas in technology recently.

With this background, Dr. Rothschild and others of MIT Lincoln Laboratory announced an experiment on liquid immersion lithography using F_2 lasers with a wavelength of 157 nm in 2001[16]. Mr. B. J. Lin, who moved to TSMC in Taiwan after IBM, and others then established a perspective through theoretical investigation in which a 45-nm node can be supported by liquid immersion lithography. They stressed that the technology should be promoted for production use. At Microlithography2003, Dr. Soichi Owa and others of Nikon presented an idea called "local fill," a new handling technology of liquid immersion, and showed that it can be applied to production equipment. This accelerated development works at all vendors including ASML and Canon, including simulation of liquid immersion and production experiments. All three companies are in fierce competition for productization to ship the first model by the end of this year or early next year. Considering this history, it is unclear how accurately the engineering team at MIT foresaw the future of the technology, but it is certain that they were very responsive to requirements from the frontier of optical lithography and that they triggered a breakthrough in liquid immersion technology.

5 Issues of industry-academy collaboration in Japan and how to proceed

5-1 *Issues of industry-academy collaboration in Japan*

The development of liquid immersion technology that became a breakthrough in lithographic solutions was triggered by Prof. Rothschild of Lincoln Laboratory, Massachusetts Institute of Technology (MIT). His laboratory received funding from DARPA (No. F19628-00-C-0002) to pursue the ultimate limits of optical lithography, and contributed to the development of leading technologies, such as exposure experiments using an F_2 (157nm) laser. In other words, they ran experiments at the same level of as the development group in the industry, and they clearly understood frontline technical issues. It is not surprising that they triggered this breakthrough. As is seen in this example, universities in U.S. are much more responsive to technical issues at the forefront of the industry than universities in Japan[17]. This enables them to make breakthroughs and to breed venture companies that are rooted in real business.

Please note that we are not discussing pure research activities such as on elementary particles, but how to proceed with application research activities, like MIT in the case above, conducted by university production technology groups. Universities in Japan usually have a lot of so-called "basic research for the future" even if it is application research in reality and has strong potential. They also tend to set their target off the mainstream, which is contrary to the aim of basic research. It would be useful to calculate the number of articles whose topics ended up only in publication rather than application. For example, at Microlithography2004[6] where mainstream technology is discussed, universities in U.S. contributed 25 articles, while there were only a few from Japanese universities. In addition, as is seen from the examples at MIT and Rochester University at Microlithography2004[6], their data collection methods and simulation results were very close to those used in the industry, which indicates the quality of their work and their contribution to mainstream technology. On the other hand, presentations by universities from Japan are, in most cases, limited to the presentation of ideas and concepts only using charts, and data is limited only to photos. At society meetings of optical disk technology in the past, the author sometimes felt irritated by certain presentations where the nature of the technology could have been presented more clearly using signal-to-noise ratios and efficiency information in addition to photographs.

What prevents Japanese universities from entering the mainstream of the technology? One reason may be that some universities do not have sufficient research equipment. To collect data like signal-to-noise ratios and efficiency data requires reasonably expensive equipment that some universities cannot afford. It is a concern that universities have not completely grasped leading-edge technical information about mainstream technology, including the design methods of state-of-the-art devices or expertise in measuring methods. As it is easiest and quickest for universities to learn these methods from the industry, it would be convenient if this information can be disclosed by the industry.

However, there is the a barrier of corporate confidentiality. Maintaining confidentiality in the industry is reasonable, but the limitations of working by oneself are now being questioned, and technology itself will be stifled if corporations focus on confidentiality and on the enclosure of technical information. To allow corporations to disclose their information to universities without anxiety, we need a system where the rights of the corporation are guaranteed even after the corporation discloses technical information to universities, and where corporations feel comfortable about information exchange with universities.

By closing a legal contract on confidentiality as equal partners (e.g., Nondisclosure Agreement (NDA) or Exclusive Agreement (EA)) between a university and a corporation, we need to change the relationship between both parties to obtain a win-win result through technology exchange. It has been pointed out that confidential information may be carried by students to other companies for whom they will work after graduation. However, this can be avoided if the NDA binds students engaged in collaborative work between universities and the industry.

The discussion so far indicates that there are at least two issues, other than funding, in investigating how university-industry collaboration should be managed in application university technology groups. One is the issue of patent filing for which the university TLO is usually responsible, and the other is how to manage research and development activities that result in inventions.

5-2 Status of TLOs of Japanese universities and ILP of MIT

Technology Licensing Organizations (TLO)[18] in universities in Japan is to manage intellectual property (IP) such as patents, related to the industry-academy collaboration above. The main mission of the TLO is to file patents for work undertaken by university researchers, to transfer technology to corporations, and to allocate funds for the next research project. In other words, the TLO is a legal entity, something like the Patent Department of universities that gathers and assesses the results of study by university researchers, register their patents and transfers the technology to corporations. The legal background of the TLO is “Law for Technology Transfer from Universities and Others” (a.k.a. the TLO law) which came into in effect in August 1988. A total of 36 TLOs have been founded and approved today in Japan.

In contrast, industry-academy collaboration in U.S. has a long history. In MIT[19], for example, an organization called ILP[20] (Industrial Liaison Program) was formed in 1948 in addition to TLOs. While the TLOs above handle intellectual property protection, the ILP handles leading-edge technical issues and constitutes a part of the Innovation Value Chain with more than 50 years of experience. The Innovation Value Chain is a chain of value created from technical innovation to investment return, or a productive chain of basic research - application research - productization - business - research investment. Last year, 645 companies invested in MIT, with 21 companies investing over $1M and 139 companies investing between $100K and $1M. MIT graduates had founded more than 4,000 companies by 1997, created 1,100 thousand jobs and achieved about 2,500 billion Yen in sales[20]. Revenue from patents in all of North America including MIT in 2002 amounted to about 145.3 billion Yen[21].

Revenue from patent licensing through TLOs in Japan is increasing, but the cumulative amount by 2003 was only 1.4 billion Yen[22]. It is necessary to take into account here that the full start of TLOs is very recent and that there are still a number of management issues regarding revenue from patents. Some people have considered obtaining patent revenue from basic research, but in reality, little basic research reaches production level. Even if the research does reach production level, it usually takes 20 to 30 years, and basic patents expire when the product is on the market.

For this reason, patent applications from universities should be made not only for basic technologies but also for application technologies during the productization stage for continuous and exhaustive coverage in related areas. This strategy would be unrealistic without collaboration with corporations that have sufficient experience and a proven record in achieving patent revenue. In addition, patent maintenance costs are fairly high, which calls for a strict screening process on whether right to patents already applied for should be retained or not. These are patent-related technical issues to improve efficiency in acquiring patent rights from invention. We now consider a much more important issue, i.e., how to manage research and development work that will produce inventions, and propose a solution considering issues in the industry-academy collaboration discussed above.

5-3 How to make industry-academy collaboration more efficient

The solution is first that researchers in the production application area in universities visit the development organizations of corporations and share frontline technical issues in development with corporate engineers. The intellectual property management and protection issues that always emerge in these cases can be handled through the TLOs established in universities and governmental research centers. The main mission of TLOs today is to protect the rights of universities; failure to do so will hinder progress.

Thus, the second solution is to redefine the mission of TLOs, which is not only to protect the profits of the university, but also to consider how to protect the profits of the corporation and to establish a legally contracted relationship as equal partners between the corporation and the university. Otherwise, corporations will not be any closer to universities than today, and no further collaboration between industry and universities will take place. The third solution is that corporations should disclose technical issues in frontline development to universities under the joint supervision of the IP department of the corporation and the TLO of the university, with the expectation that excellent research staff of the university be used.

If these three solutions are combined and promoted, both parties can engage in technology exchange with peace of mind since technology disclosure will not damage the IPs of each party. There will be deeper, more extensive discussion between the researchers and engineers of each party than at society meetings or conferences, and scientific knowledge and technologies will be stimulated more with the aim of making progress in technology.

Business potential that requires a higher level of judgment, it can be decided comprehensively at a meeting by management level people from each party. In summary, for each key target project, universities and corporations first agree on the “give and take” rule based on a legally equal contractual relationship. Then, based on this rule, a project team is organized by researchers and engineers with experience in developing leading-edge technologies and products. The team should pursue development steps to attain the goal of productization. This will produce world-class industry-academy collaboration on research and development. This type of process has already been realized in industry-industry collaboration between corporations and has achieved a number of promising results.

5-4 Participation in the international Innovation Value Chain

Finally, we will cover research that funds industry-academy collaboration in U.S. and Europe. In the area of semiconductor microfabrication, a consortium called ISMT[9] (International SEMATEC)plays an important role in U.S. ISMT makes investments for research and development far more than Japan in many universities including MIT, Rochester University, New Mexico University, and others. As seen at a meeting hosted by ISMT in January 2004 to report the accomplishments of each project from spring 2002 to the end of 2003, they regularly present and review the work conducted in each project. In Europe, there is IMEC[11] mentioned above, in Leuven, Belgium, as a base for industry-academy collaboration for the semiconductor industry.

Considering moves in U.S. and Europe, we need to promote healthy, productive industry-academy collaboration in Japan. That is, we should accumulate experience in managing the collaboration between corporations and universities in Japan based on the equal, “give and take” relationship rather than “ruler and ruled” relationship, and similar to the legally contractual relationships normally seen in U.S. and Europe. If we continuously succeed over time, we will then be able to extend the relationship to overseas universities and corporations for technology collaboration based on the “give and take” rule. Universities in Japan may mature to cover an area of the international Innovation Value Chain where the technology levels of each country are intermixed. This will result in a situation in which Japanese university production technology groups have attractive potential so that companies like Intel are interested in funding their research and development activities.

In particular, attention should be paid to how the above issues can be handled by the corporations, universities and governmental organizations involved in EUVA technology and F_2 lithography, who are expected to provide technological innovation for the next generation.

6 Conclusion

In first half of this report, Chapters 2 and 3, we reviewed recent semiconductor devices, technological trends in semiconductor microfabrication equipment and the international market share that should indicate the international competitiveness of Japanese companies; this is the background to this report. In the second half, Chapters 4 and 5, starting with the technology trends discussed in the first half of this report, we reviewed how to run industry-industry collaboration in Japan and in industry-academy collaboration in U.S. This highlighted the issues subsequently covered in this report. Finally, we made proposals to take us one step further toward better industry-academy collaboration on research and development work in Japan. In these proposals, we should:

(1) Consider the liquid immersion technology that made a breakthrough in lithographic solutions, the university in U.S. (MIT) that triggered development, even though the lithographic industry in U.S. had lost its international competitiveness. This was possible because universities in U.S. tried to identify issues and trends in frontline development work conducted by corporations worldwide and were sufficiently responsive to these issues.

(2) In other words, development fields in corporations worldwide is a crossroads of the needs of the market and the seeds of scientific knowledge, and they set technology trends while tackling frontline technical issues that become the source of new invention and discovery. Thus, university researchers involved in application research in Japan should be

engaged more deeply than ever in sharing technical issues with corporate engineers.

Here, the management and protection of IP is always an important issue. In this regard, TLOs that have been already established in universities and governmental institutions should build legally equal partnerships considering the protection of the corporation's rights as well as the rights of the university. Otherwise, corporations will not be any to universities or disclose detailed technical information. This will result in lack of progress in industry-university collaboration. In addition, corporations should disclose technical issues in frontline development to universities under the joint supervision of the IP department of the corporation and the TLO of the university, with the expectation that excellent research staff of the universities be used.

We also need to consider patent strategies to improve the efficiency of obtaining patent rights for inventions that the TLO already has. University researchers involved in industry-academy collaboration should not only aim for fundamental patents that would bring huge returns with the lowest potential for success, but should also steadily and exhaustively apply for patents for existing technologies with corporate engineers, so that there is extensive patent coverage. In addition, as patent maintenance costs are high, a strict screening process should be used for patents already applied for by the cooperation with the corporate IP department.

(3) Under agreement on the "give and take" rule between corporations and universities based on a legally equal contractual relationship that includes patented technologies, a project team should be organized by researchers and engineers with experience in developing leading-edge technologies or and. The team should pursue development steps to attain the goal of productization. This will create world-class industry-academy collaboration on research and development. This process has already been realized in corporation-corporation collaboration, and there have already been a number of accomplishments.

From this point of view, attention should be paid to the progress of EUVA, the next-next-generation lithography consortium and F_2 lithography in which universities are already participating, where industry-academy collaboration including TLOs will be tested on how well they are working. If we steadily pursue industry-university collaboration based on the equal "give and take" relationship contract common worldwide, then universities in Japan will be able to cover some aspect of the international Innovation Value Chain.

Finally, we reconfirm the scope of this article. As subtitled, this article discusses industry-university collaboration where researchers in application research groups in universities work together with researchers of corporations on joint development programs. We have investigated how to make this more effective.

Issues on industry-academy collaboration originate after the industrial revolution when contact frequency between industry and education increased. On the other hand, intellectual activity began way before the industrial revolution. People from older societies were intellectually curious, stimulated not by industry or by government, but directly by nature and society, and they voluntarily created and systemized intelligence. These people and those who need information joined to form the origin of universities. This leads us to the question of the original mission of universities along with traditions in knowledge and education. The question concerns the nature of universities, and the question is not simple enough to be answered only from the viewpoint of industry-academy collaboration. The question requires serious discussion based on facts traced back to the beginning of the university, to the industrial revolution, to the Renaissance, and to ancient Greece and the four great civilizations of the world, Egypt, Mesopotamia, Indus and China, or even the origin of humankind.

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