3

Current Trends in Digital Cameras and Camera-Phones

KIMIO TATSUNO
Information and Communications Research Unit

1 Introduction

Japan's digital camera industry plays a major role in the currently flourishing digital home appliance business[1, 2]. Supported by the business strategy, "manufacture a product that cannot be copied in a way that cannot be imitated", Japanese companies involved in this field have demonstrated their competitive edge by riding the post-1995 sales surge to a position of global market dominance[3]. In contrast, some overseas companies failed to keep abreast of the innovations in camera technology over the last 10 years. DPA GmbH reported, on May 28, 2005, that AgfaPhoto in Germany had gone bankrupt. Agfa used to be one of the so-called "Big Three" established companies in the photographic film business, along with Fujifilm and Kodak.

The digital camera market in Japan is nearing saturation point, with domestic companies now involved in fierce competition. Kyocera, Olympus and Pentax have been reported as having reduced their scale of production. On the other hand, Canon, Casio, Sony, etc. are growing their market shares and are relentlessly competing for unsaturated international market dominance. Nikon and Canon, both established conventional camera manufacturers, are working to develop the market for advanced digital SLR cameras.

Meanwhile, "camera-phones" equipped with miniature digital camera modules have become a rapidly expanding market category since 2001. Of the 500 million mobile phones manufactured up to the end of fiscal 2004, some 180 million were camera-phones. Japanese companies such as Panasonic, Sony, Sharp and Konica Minolta[4], jointly meet 80% of world demand for the imaging devices and optical modules used in camera-phones, which clearly indicates the competitive strength of Japanese industry in this field.

This article discusses the sources of those companies' international strength in both the technology and marketing of digital cameras. It also explores future trends, as represented by the dynamic development of the camera-phone field. Of particular note is a "tunable-focal-length liquid lens" developed by a French university-originated venture company (Varioptic). This lens is expected to lead to major innovations in the digital cameras installed in camera-phones. Varioptic is collaborating with South Korea's Samsung, the third largest company in the mobile phone business after Nokia and Motorola, and is attracting attention as a good example of industry-university collaboration of the type that the Japanese government is currently seeking to promote.

Ministry of Economy, Trade and Industry (METI) reported in May 2005 that 1,099 venture companies had been established by universities in Japan. The target set in 2001 was surpassed through a three-year collaboration between industry, universities and the government. Now, the primary focus has shifted to "the quality of the venture", or success in operating as a viable business. This report proposes a methodology for promoting business quality in venture companies established by universities, based on accumulated intelligence about the French venture company (Varioptic), how it was established, and the role played by the French government.

2 Development and structure of digital cameras

The prototype of the digital camera was developed out of Sony's analog-type "Mavica" electronic camera (1981), with the first truly digital models being produced by Toshiba and Fujifilm in 1989. These products did not gain immediate acceptance in the marketplace due to their high price and the unavailability of sufficiently well-developed peripherals, i.e. PCs. Stimulated by the strong sales of PCs with the Windows95 operating system, the market developed rapidly following Casio's launch of the first consumer digital camera in 1995. The market expanded further in line with the progress of the Internet.

From today's perspective, the 14-year period from 1981 to 1995 can be regarded as the "lift-off" stage of the digital camera's history. With hindsight, R&D managers at that time should have looked to research engineers with innovative ideas, exercised the patience to wait until peripheral technologies were properly developed, and set their sights beyond immediate, limited sales returns.

The digital camera comprises an imaging device, imaging optics, image processor (DSP), LCD, buffer memory (DRAM), card memory (flash memory), electronic drive circuits, and control mechanics, as shown in Figure 1. Its core component, the imaging device, is constructed using a charge-coupled device (CCD) or a complementary metal oxide semiconductor (CMOS), which converts an optical image to analog electric signals. The analog signals are converted to digital form by the image processor and the buffer memory. The digital signals are stored in the card memory, which incorporates rewritable and non-volatile flash memory.

Another core device is the lens optics, which focuses a picture on the imaging device. The lens optics combines several aspheric lenses in order to correct aberration. The optics requires space to incorporate actuators and related mechanics for zooming, through which the focal length and the length between the lens and the imaging device are adjusted.

3 Analysis of global competitiveness of Japanese digital cameras

3-1 Analysis of the global market for digital cameras

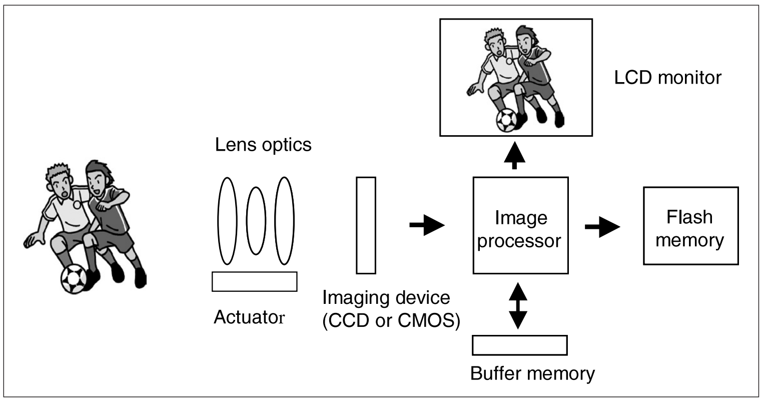
Digital cameras have won widespread acceptance for both business and personal use, due to their usefulness as imaging devices that can be linked with PCs. Sales have grown dynamically (Figure 2), with the ratio of exports to total sales increasing year-on-year (Figure 3)[5].

Digital cameras manufactured in Japan command 80% of the world market (Figure 4), indicating Japanese companies' formidable competitive advantage in this product category.

3-2 Imaging devices

To clarify the source of Japan's global market strength, we show the shipping volume for each pixel number category of imaging devices (CCD or CMOS) in Figure 5[5]. From a baseline of

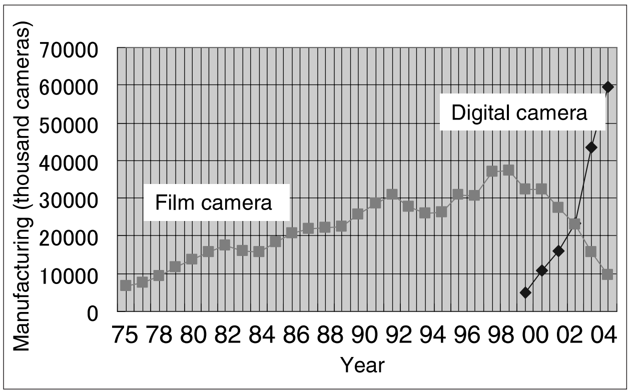
Figure 1 : Basic digital camera construction



imaging devices under 1 M, the pixel number has increased each year, to the stage where the 5-6 M category has dominated the shipping volumes over recent years. The pixel number of the largest sales segment has steadily increased. As digital cameras with larger pixel numbers arrive on the market, consumers tend to select the new models and abandon the smaller pixel number models, which results in increasing price competition in the low-end market. Increases in pixel number lead to expansion of the market, and it is here that Japanese companies driven by advanced R&D manifest their edge over foreign companies. The imaging devices are supplied mainly by Panasonic and Sony, which constantly promote development of the digital camera market, thereby providing an advantage to Japanese camera manufacturers.

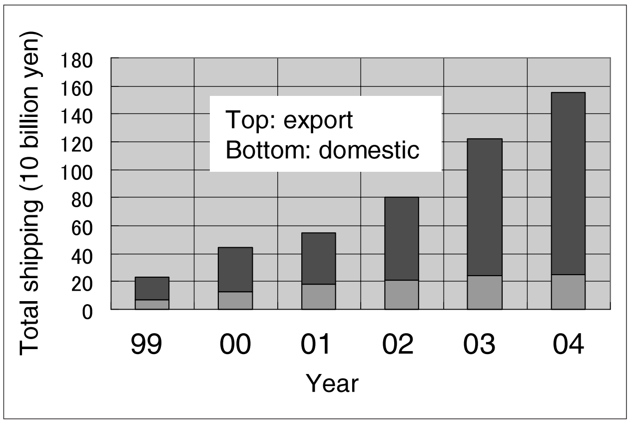
However, when the image is printed up to A4 size, the human eye cannot readily discern the difference between a photograph captured on a 4 M imaging device and one taken by a 7 M camera. It is possible, therefore, that the pixel number for low-end digital cameras will plateau, while professionals and enthusiasts will seek higher resolutions (more than 4 M) in advanced digital SLR cameras, so that they can crop and magnify sections of photographs. It is projected that low-end digital cameras will plunge into cost competition rather than technical competition (i.e. larger pixel numbers), pitting Japanese companies in a fierce price war against South Korean, Taiwanese and Chinese camera manufacturers. Japanese companies will progressively lose their edge in the low-end digital camera market.

Figure 2 : Production of digital and film cameras



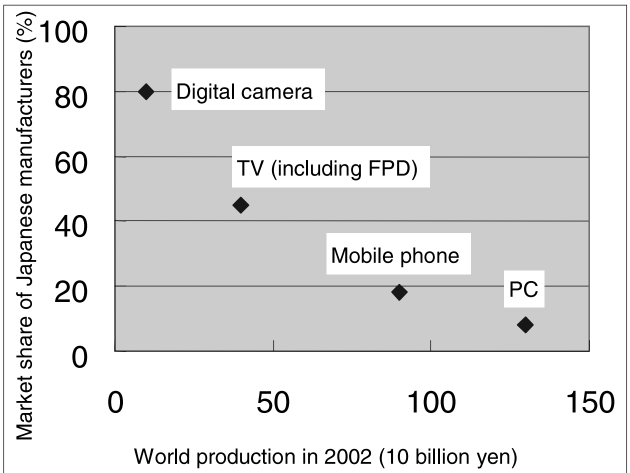
Source: Prepared by STFC based on the Camera & Imaging Products Association report

Figure 3 : Domestic sales and exports of digital cameras



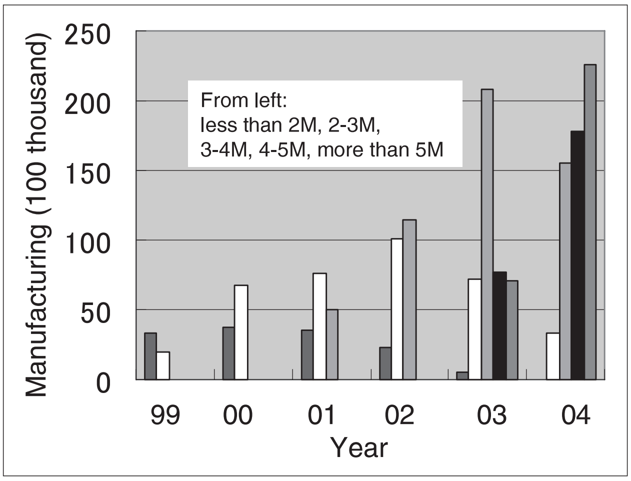
Source: Prepared by STFC based on the Camera & Imaging Products Association report

Figure 4 : World market share of Japanese manufacturers



Source: Prepared by STFC based on reports provided by the Camera & Imaging Products Association [5], Gartner [6], and Japan Electronics and Information Technology Industries Association (JEITA) [7]

Figure 5 : Shipping of imaging devices for each imaging device size (pixels)



Source: Prepared by STFC based on the Camera & Imaging Products Association report

3-3 Optics

Another strength of Japanese companies has been in design and manufacturing of the optics[4]. Many current digital cameras are underpinned by advanced optical design technology, as represented by optical zoom, and advanced manufacturing technology for glass or plastic molded lenses[8] that was developed for optical pick-ups in optical disc drives. The molded lens is designed to be aspheric in order to correct aberration and is manufactured on a large scale using metal molds, which are realized through various types of expertise, including mold-making and lens coating. The business strategy, "manufacture a product that cannot be copied in a way that cannot be imitated", has worked well in this business, helping Japanese companies that are strong in optics and electronics to lead the digital camera market. We considered whether this strength can be maintained in the future, in light of trends in the camera-phone field.

4 Camera-phone trends

4-1 Market trends for camera-phones and technical tasks

The development of the digital camera market is shown schematically in Figure 6. Following the increase in pixels of imaging devices, future progress is projected to diverge along three paths: further increases in pixels; advanced digital SLR cameras equipped with imaging devices of more than 5 million pixels; and camera-phones[9].

The camera-phone has experienced a rapid increase in production, equivalent to that of the digital camera. The past and the future (projected) of the camera-phone market are summarized in Figure 7 [6, 10]. In 2004, 500 million mobile phones had been purchased, including 180 million camera-phones. For 2008, sales of

Figure 6 : Diversifying market for digital cameras

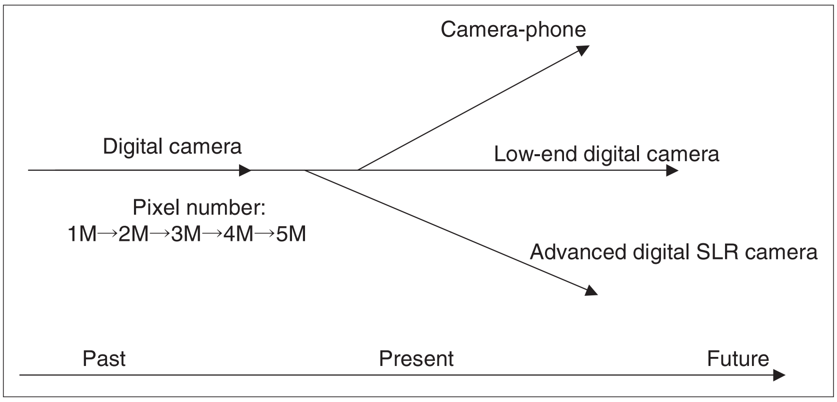
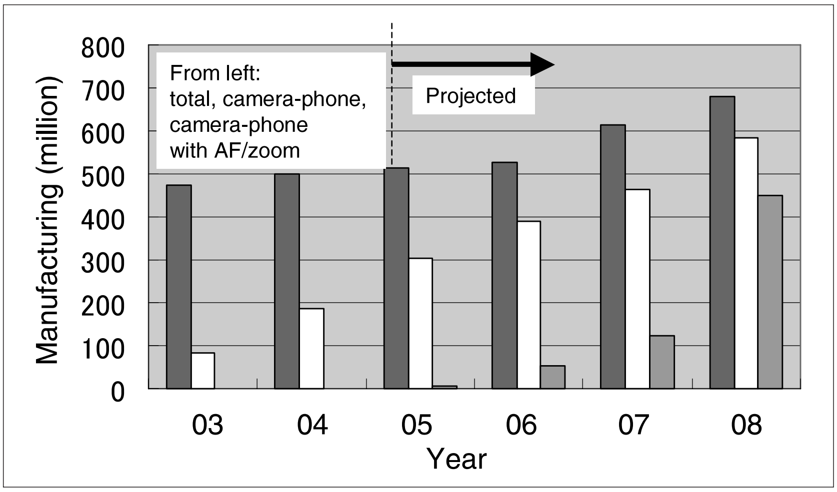


Figure 7 : Past and future of the camera-phone market



Source: Prepared by STFC based on reports provided by Gartner [6] and Varioptic [10]

700 million mobile phones are projected, of which more than 90% will be camera-equipped, and 60% will incorporate zoom functions.

Imaging devices installed in mobile phones have fewer pixels than those in digital cameras. Optical modules with 300,000 pixels are manufactured in China, whereas modules with more than 1 million pixels are made in Japan.

Low-end and low-priced imaging devices, whose prices will decrease further as a result of price competition between digital cameras, will be applied to cameras installed in mobile phones. Regardless of increases in pixels, the number of imaging chips obtained from one wafer does not change, which means that, given adequate production yield, the production cost does not increase as the pixel number increases. Therefore, the pixel numbers for camera-phones are rising rapidly, which is attractive to purchasers. Micron Technology, which enjoyed a price edge over Japanese companies in the DRAM market, is attracting attention due to a steady increase in market share for imaging devices following its entry into production of CMOS imaging devices.

However, the optical modules installed in mobile phones need to be much smaller than those used in digital cameras, incorporating auto-focus or zoom mechanisms. A camera-phone equipped with conventional optical ×3 zoom, which was announced by Samsung in May 2005, is shown in Figure 8. The phone is not convenient to carry due to the larger size of the optical system compared to fixed-focal-length optics. The test criteria for a mobile phone (dropping height: 1.8 m, operation: 50,000 times) are more stringent than those for a digital camera. There is a demand for further reduction in component sizes and power consumption as part of the ongoing integration, and multi-functionalization of mobile phones, such as HDD installation and "Super Urban Intelligent Card" (SUICA) compatibility. Some technological breakthrough is needed to satisfy the growing demand for smaller-sized optics and enhanced shockproofing of the zoom mechanics, or to develop innovative replacements for these modules.

Figure 8 : Prototype of a camera-phone with conventional 3x zoom optics

Source: Prepared by STFC based on photo provided by Samsung

4-2 *Emerging technology: Tunable-focal-length liquid lens*

Varioptic[10] and Samsung jointly exhibited an innovative optical module at CeBIT 2005 (Hanover, Germany, March 10-16, 2005), to demonstrate their progress in drastically reducing the size of optics for mobile phones.

The CeBIT 2005 organizing committee noted that only one-quarter of this year's exhibits dealt with hardware, reflecting the declining market trend in that sector. Japanese hardware companies are facing fiercer-than-ever price competition with their East Asian rivals (Korean, Taiwanese, Chinese, etc.) in a smaller overall market. In collaboration with Samsung, the French university-originated venture company Varioptic is seeking to enter the market for mobile phone components, which accounts for a significant proportion of today's hardware market.

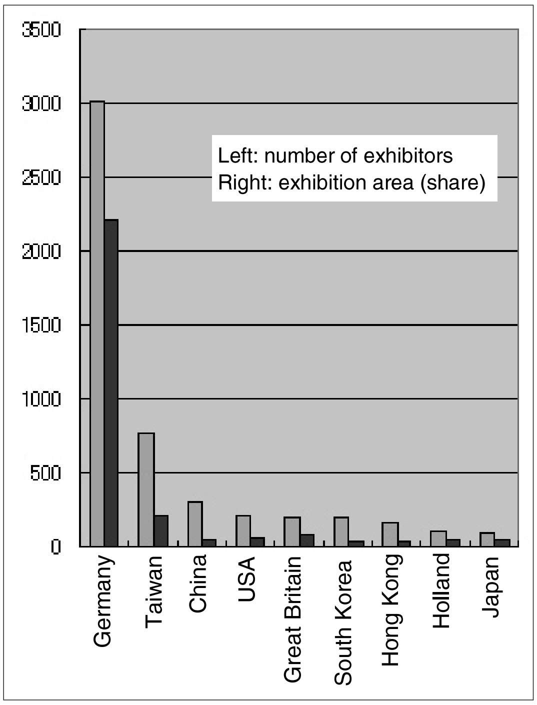
The CeBIT 2005 catchphrase is "Digital Convergence", in which service, software, telecommunications and hardware are integrated around the core of digital technology. The digital technology market is shared equally among the four sectors. As epitomized by the merger of IBM's PC business with Lenovo in China, US companies are moving beyond hardware business into more productive, knowledge-based activities that incorporate IT technology. These moves can be seen as a step toward the post-industrial society.

At CeBIT 2005, 6,270 companies (compared to 6,109 in 2004) occupied exhibition booths, covering 308,881 m^2 (312,539 m2 in 2004) of exhibition space, and 480,000 participants (510,000 in 2004) visited over the 7 days, which indicates the gigantic scale of the convention. Figure 9 summarizes the number of companies from each country that exhibited at CeBIT 2005, and illustrates the expanded representation by East Asian countries.

Panasonic promoted its digital camera equipped with an Optical Image Stabilizer (OIS) in the extensive area dedicated to digital home appliances at CeBIT 2005, although it did not show any new technology. On the other hand, Samsung exhibited a prototype camera-phone equipped with the above-mentioned Varioptic-developed tunable-focal-length liquid lens, which is tuned by applying voltage. An advance on the camera-phone shown in Figure 8, the prototype incorporates a zoom function without any enlargement in overall size. The license fee reportedly is 1.2 million euros.

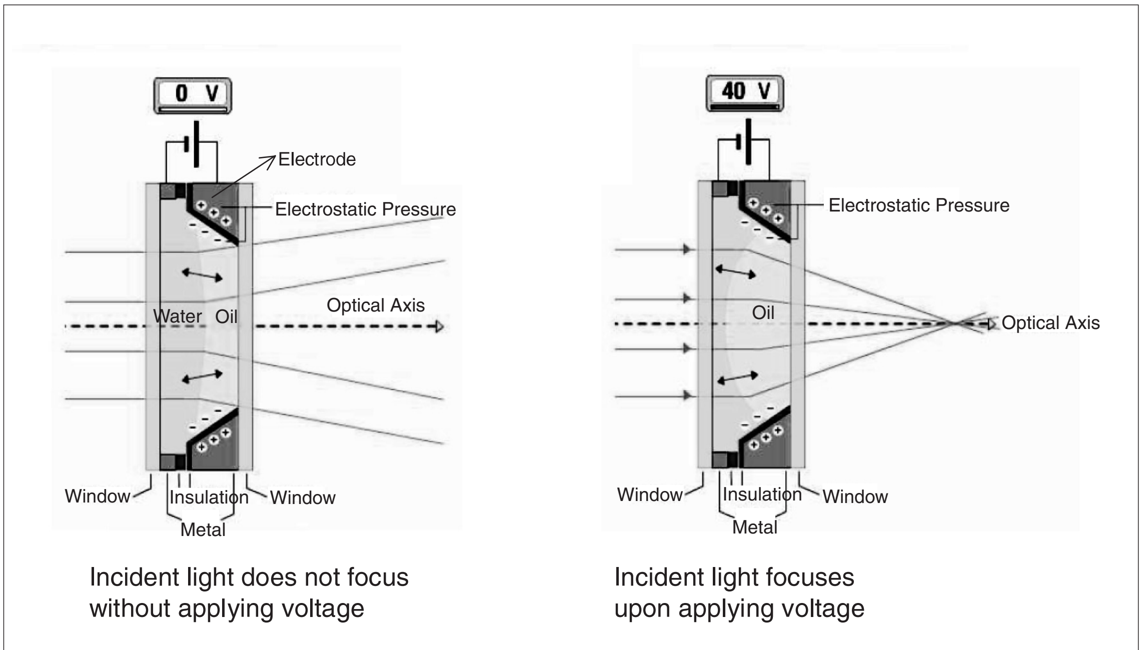
Figure 10 shows the basic design of Varioptic's tunable-focal-length liquid lens, in which the optics is constructed using water and an oil-drop lens. Forming a sphere surface through surface tension, the oil-drop functions as a lens. The lens system is designed to be achromatic, incorporating convex and concave lenses (made of plastic or glass) in order to avoid chromatic or spherical aberration. With no voltage applied, light does not form an image after passing through the lens, as shown in Figure 10 (left figure). When 40 V is applied, the lens curvature increases (diopter, the inverse of focal length, increases) and forms an image after passing through the lens, as shown in Figure 10 (right figure). This system has both focal length tuning and focusing. Further, zooming is realized using two units of this system in place of the mechanics

Figure 9 : Exhibitors from each country at CeBIT 2005



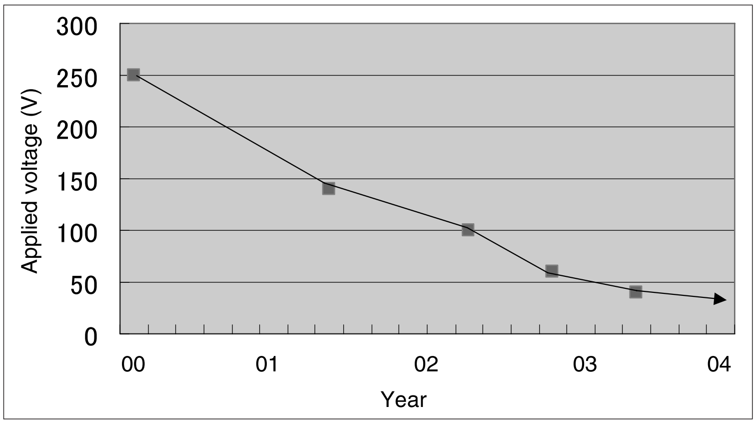
Source: Prepared by STFC based on brochures provided by CeBIT organizers

Figure 10 : Principle of the tunable-focal-length lens



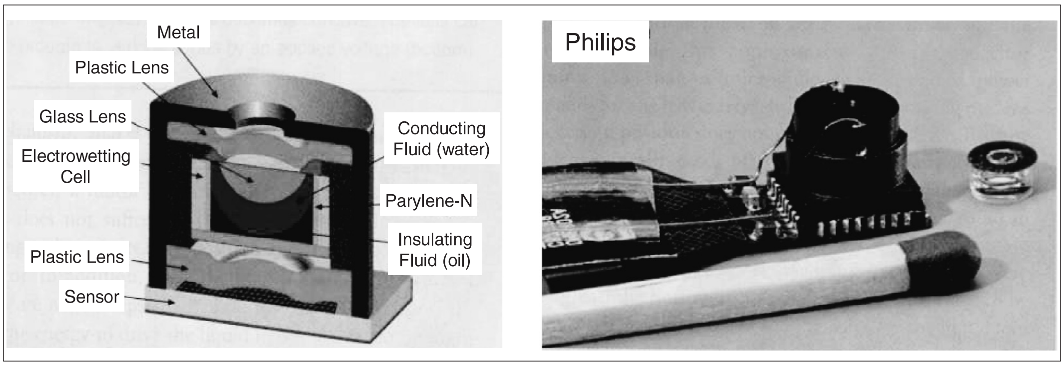
Source: Prepared by STFC based on brochures provided by Varioptic

Figure 11 : History of applied-voltage reduction (25 diopter)



Source: Prepared by STFC based on brochures provided by Varioptic

Figure 12 : Tunable-focal-length liquid lens developed by Philips



Source: Prepared by STFC based on brochures provided by Philips

and the driving motor.

In the initial phase of development, the voltage applied had to be as high as 250 V in order to obtain 25 diopter (focal length: 40 mm), which is the criterion for a camera lens. However, as shown in Figure 11, Varioptic engineers succeeded after 5 years of development in reducing the voltage to lower than 40 V, at which point commercial application of this technology became realistic. Given its advantages in terms of cost, shockproofing, power consumption, rapid response, size, etc., the tunable-focal-length liquid lens is attracting considerable attention as a potential optical module for use in camera-phones.

Philips, the Dutch consumer electronics giant, has been developing a liquid lens for camera-phones[11]. Although Varioptic claims that it obtained its patent ahead of Philips, the latter exhibited a competitive prototype, as shown in Figure 12. Philips is said to be moving toward mass production, although it has not officially announced an application field for its liquid lens.

Venture companies have an edge at start-up, whereas large companies have an advantage at the commercialization stage, namely, reliability/quality control and mass-production. Varioptic is believed to be limiting its activity to development of a prototype, and then licensing the technology to large companies, such as Samsung, for mass-production. Both companies are being watched to see where they move next in this field.

5 History of camera technology innovation in France, and Varioptic

The history of the camera began not with Kodak in the US or Agfa-Gevaert in Germany, but in France with the device invented in 1839 by Louis Daguerre (French painter, 1799-1851)[12]. Gradually, the basic technology proliferated to Germany and the US. In the US, the camera rapidly gained popularity following the invention of the roll-film camera by Kodak in 1888[13].

Today, France has virtually no camera industry. So, although camera technology was originally invented in France, the camera industry actually developed in the US. This is somewhat analogous to the transistor: invented in the US, but then developed industrially by Japanese manufacturers.

This lack of an active camera industry means that French innovation in camera technology takes place only in universities. In the same way, innovation in lithography took place in a US university due to the uncompetitive nature of that country's stepper lithography industry. Researchers at MIT pioneered immersion lithography, coming up with a technological breakthrough that would characterize the next three generations of technology as described in International Technology Road Map for Semiconductors (ITRS) (Source: Science and Technology Trends, May 2004[14]).

Dr. Bruno Berge, who held a teaching position in a university and a research position at the French National Center for Scientific Research, invented the unique tunable-focal-length liquid lens[15], even though the original lens required further development in terms of quality (less thermal dependency) and reduction of fabrication cost. The lens could become competitive through further miniaturization of conventional mechanical optics, or through a high-quality 5 M pixel picture obtained by combining a 15 M pixel imaging device (current device is 5 M pixels) and ×3 digital zoom.

This technology could find specialized applications, such as in the optical head of a gastroscope, even if the liquid lens should fail to enter the mass market of a camera-phone due to complicated mass production or a high manufacturing cost. This implies that Japanese university researchers engaged in applied optics are deprived of the opportunity to demonstrate their potential despite their being better informed as to the development of digital cameras and gastroscopes.

Varioptic was established in 2002 at Lyon-Gerland Technopole[16], Lyon, France, by Dr. Bruno Berge. Supported by the French innovation law[20] enacted in 1999, Varioptic has been funded by the National Agency for the Valuation of Research (ANVAR), Créalys, University of Joseph Fourier, Région Rhône-Alpes, Rhône-Alpes Entreprendre, and the Ministere de la Recherche.

According to Dr. Berge, the tunable-focal-length lens is based on 10 years' research activity at Université Joseph Fourier/Grenoble I and Ecole Normale Supérieure de Lyon. Research began in 1990 and the main patent was filed in 1999 (WIPO: 99018456), even though the camera-phone had not yet been developed. Since 2002, the research has been funded by the government. Dr. Berge could be regarded as a "stubborn researcher", having dedicated himself to basic research on "electrowetting" mainly derived by his scientific interest as a motivation. Incidentally, the first paper published by Dr. Niels Bohr (Nobel Prize Laureate, Danish theoretical physicist) was titled "Surface tension measurement of liquids"[17]. The research on "electrowetting" is considered to be very basic research work. Dr. Berge extended his expertise in and understanding of "electrowetting" during the lead-time, whereby he successfully established a "competitive core of research" by studying the mechanism of "electrowetting".

6 Proposal for industry-university collaboration in Japan

University-originated venture companies are discussed based on the case of Varioptic. Universities in Japan have established 1,099 venture companies, as shown in Figure 13 (Source: METI, May 2005[18]). This is a result of a 3-year program involving industry, universities and the government, which targeted establishment of 1,000 companies. METI commented that, in the process of moving from startup to growth, the venture companies were expected to stimulate the economy by transforming their orientation from one of quantity to one of quality[18].

When Varioptic, a venture company established in France, is reviewed from the viewpoint of quality, it demonstrates that a quality-oriented venture has the potential to evolve from its university base, even in a field dominated by foreign companies, particularly in the current globalized economic environment. This can be applied to industry-university collaboration and is epitomized by immersion lithography, mentioned above, which was a technical breakthrough in steppers for semiconductor manufacturing. That breakthrough was achieved by researchers at MIT[14] in the US, which does not have a competitive industry in this field.

A venture company that obtains patents has the potential to contribute significantly to improving the quality of a university-originated venture, given a "competitive core strength" underpinned by long R&D experience, as shown in the case of Varioptic.

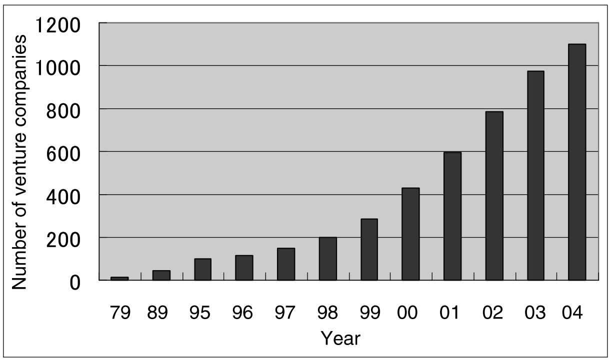
Japanese government institutes that fund research and university institutes that manage research need to take the long view, exercise patience and not raise their expectations too high when promoting core competitiveness. They should manage research in a manner that considers the personalities and independence of researchers, accompanied by assessment of research validity, particularly in the early stages.

7 Conclusion

As shown in such technological breakthroughs as immersion lithography for steppers[14] and the tunable-focal-length liquid lens, the material used for optics has extended from glass through plastics to liquid. Given the difficulties of handling, manufacturing cost and temperature dependency, it stands to reason that industry would be reluctant to invest in a program to develop the liquid lens, although an idea patent is conceivable whereby the technology is patented at the concept stage. In fact, Hitachi filed a patent related to immersion lithography in the 1980s[14]. Canon also filed a patent related to the liquid lens.

Before the technology could be applied to the advanced aberration-corrected lens, it had to be preceded by a profound understanding of the physics of the system, such as "electrowetting", because an idea without such understanding could not work. Driven by the self-motivated intellectual curiosity of researchers, university research plays an important role, with the researchers expected to spearhead the trend of core research.

Figure 13 : Number of venture companies established by universities



Source: Prepared by STFC based on reports provided by the Ministry of Economy, Trade and Industry

The digital camera market has become saturated, while the market for camera-phones is obviously expanding. Business opportunities arise at the intersection of market trends and technological seeds. It should be noted that Philips, an established giant in the Netherlands, is also developing the tunable-focal-length liquid lens, building on the collaboration between Varioptic and Samsung.

Having fostered a number of venture company start-ups over the last few years, industry-university collaboration is now at a stage where it can become productive. Well-trained, experienced engineers state flatly, "Poorly completed research is a joke." Working in an environment that fosters the taking of research risks, university researchers are encouraged to take business risks, to undertake their own core research and to forecast business and technology trends. As demonstrated by Varioptic, a quality-oriented venture company has a chance to emerge, even in a field dominated by foreign companies, in the current globalized economic environment.

Taking into account the personalities and independence of researchers, government institutes that fund research and university institutes that manage research should possess the management expertise to foster impressive, large-scale, but admittedly risky, innovation by adopting a patient approach.

Acknowledgments

The author wishes to acknowledge the valuable viewpoints and information kindly provided by Dr. Hiroshi Ooki (Nikon Corp.), Dr. Hiroshi Miyamae (Konica-Minolta Holdings, Inc.), Dr. Yuji Komatsu (Sony Corp.), Dr. N. Cavasin (Waseda University), Dr. Shingo Hamada (NISTEP, MEXT), Dr. Yukinori Nakano (Kwansei Gakuin University), Dr. Atsushi Ogasawara (AIST), and Dr. Tatemi Ido (Hitachi, Ltd.).

References

[1] Abe, Tadahiko. Growth strategy of digital home appliances. Research Report, Economy Research Institute, Fuji Research Institute Corporation. No. 212, November 2004. (Japanese)

[2] Yamada, Hajime. Technology Management. NTT Publishing Co., Ltd. (Japanese)

[3] Special issue: Future trends and application technology of a digital camera system. Optical and electro-optical engineering contact. Vol. 40, January 2002. (Japanese)

[4] Saito, Tadashi and Yamaguchi, Susumu. Development of 1.3 M micro camera unit with a macro mode. Konica Minolta Technology Report. Vol. 2, pp. 157-160, 2005. (Japanese)

[5] Camera & Imaging Products Association. Camera Industry in Japan - CIPA Report 2005. (Japanese)

[6] http://www.gartner.co.jp/press/index.html (July 5, 2005)

[7] http://www.jeita.or.jp (July 5, 2005)

[8] Ogura,Iwao. Camera development story in Japan. Asahi Sensho 684, Asahi Shimbun Company. (Japanese)

[9] Special issue: Current and future trends in camera phones. Optical and electro-optical engineering contact. Vol. 40, January 2002. (Japanese)

[10] http://www.varioptic.com/en/technology.php (July 5, 2005)

[11] Hendriks, B. et al., Proceedings of ICO 2004, Tokyo, July 12, 2004, pp. 11-12.

[12] Mitsui, Keishi and Tokyo Metropolitan Museum of Photography Ed. Introduction to history of photography. Shinchosha Co. (Japanese)

[13] http://wwwjp.kodak.com/JP/ja/corp/7a140000.shtml (July 5, 2005)

[14] Tatsuno, Kimio. Recent Trends in Semiconductor Microfabrication Equipment Technology - Proposals for Industry-Academy Collaboration on Research and Development in Japan. Science and Technology Trends — Quarterly Review. No. 13, October 2004.

[15] http://www.spm.cnrs-dir.fr/encre/encre_03/CDR/CVs/ (July 5, 2005)

[16] http://www.lyongerland.com (July 5, 2005)

[17] Academia-Industry Cooperation Promotion Division, METI, News Release, April 25, 2005. (Japanese)

[18] Kamefuchi, Susumu. Books. Iwanami Shoten, May 2005. (Japanese)

[19] NISTEP. Survey for evaluating the accomplishment of the master plan. Report No. 83.

[20] http://www.lexpressmagazine.com/reussir/dossier/creation/dossier.asp?ida=430024

Kimio TATSUNO, Ph.D.
Head of Information and Communications Research Unit, Science and Technology Foresight Center

D. Eng. He was formerly involved in the R&D on optical disks, fiber-optic communication, and diode laser-related instruments at the Central Research Laboratory, Hitachi Ltd. Currently, he proposes government policies from the viewpoint of industry-university collaboration, standardization, and technology innovation, and studies science and technology trends at NISTEP.
Membership: JSAP, IEICE, OSA.

(Original Japanese version: published in July 2005)