Breakthrough Illusions in the Case of Semiconductor Laser Technology in the U.S. and Japan, 1960-2000

Hiroshi Shimizu
Hitotsubashi University
Institute of Innovation Research
2-1 Naka, Kunitachi
Tokyo 186-8603, JAPAN
Phone:+81-(0)42-580-8433
Fax:+81-(0)42-580-8410
shimizu@iir.hit-u.ac.jp

Abstract

Exploring scientific breakthroughs achieved by U.S. and Japanese firms, this study investigates how firms in those countries developed semiconductor laser technology and shows how they came to be competitive in different fields. Japanese firms achieved many scientific breakthroughs and dominated the mass markets after the 1980s, while their profitability kept declining due to long-term competition in the same product markets. On the other hand, U.S. firms failed to move from scientific breakthroughs to mass production due to scattered R&D efforts into small markets, but they held the lead in niche and custom markets.

JEL Classification Code
N82, N85, O31, O32, O33

Keywords
Semiconductor Lasers, United States, Japan, Technological Development, Scientific Breakthrough

Introduction

How a firm achieves scientific breakthroughs, industrialises them and attains sustainable competitive advantages has become an important issue as the relationship between science and technology becomes more deeply intertwined. This study aims to investigate how U.S. and Japanese firms achieved scientific breakthroughs in semiconductor laser technology and how they industrialised the technology in different fields.

Following Albert Einstein's 1905 theoretical conception of the photoelectric effect, Laser (Light Amplification by Stimulated Emission of Radiation) was conceptually developed in the late 1950s.[1] The first working laser was made by Theodore H. Mainman in 1960.[2] It was called the greatest invention of the century. A laser is an optical source that emits a narrow beam of coherent light. The power in a continuous beam ranges from a fraction of a mill watt to more than a mega watt. Now there are many varieties of lasers; CO_2 laser, YAG laser, He-Ne laser, ruby laser, semiconductor laser, and so on. The range of laser application extends from commercial uses to special military uses.

The semiconductor laser, which is also called the Laser Diode, is a very tiny electronic device. It is used in various application areas such as medical use, light for high-speed cameras, material processing, optical sensors, laser pointers, measurement, optical disks, printers, barcode readers, and optical fibre. The two biggest application areas are optical communication and optical information storage. The semiconductor laser became one of the most important technologies underlying the drastic changes that took place during the last half of the 20th century in information technology, and it has become the most widely used laser since the 1980s.

Reviewing the optoelectronics industry in the U.S. and Japan, the Japan Technology Evaluation Centre (JTEC) found that 'Japan clearly led in consumer optoelectronics, that both countries were competitive in communications and networks, and that the United States held a clear lead in custom optoelectronics.' 'Japan's lead in high-volume consumer optoelectronics and related technologies gave it a dominant share of the overall global optoelectronics market.'[3] In a study of various technology intensive industries in Japan, the Agency of Industrial Science and Technology of Japan

---

1 On the development of the first laser, see Townes, C. H., *How the Laser Happened.*

2 Mainman, T. H., Stimulated Optical Radiation in Ruby.

3 Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report,* p.xv.

(AIST) reported in 1983 that the semiconductor laser is one of the most competitive key industrial technologies in which Japanese firms hold the lead.[4]

Japanese firms became competitive in various areas in the U.S. and advanced European countries from the 1970s to the 1990s. Japanese automobile, consumer electronics, robotics, and semiconductor industries began exporting their products to the U.S. market in the 1970s. There is a vast amount of literature analysing technological development in Japan's technology-intensive industries in comparison with U.S. industries.[5] One of the most famous examples is Ezra Vogel's 1979 book, *Japan as Number One: Lessons for America*, which received widespread attention both in the U.S. and in Japan.

One of the arguments on competition between U.S. and Japanese firms, which is closely related to the central thesis of this paper, is that research and development (R&D) was well-coordinated with manufacturing in Japanese firms, while U.S. firms were unsuccessful in making a smooth transition from R&D to production; thus, they could not industrialise the technological breakthroughs produced in R&D. Examining technology-intensive industries in the U.S., Florida and Kenney pointed out that American firms often failed to capitalise on technological breakthroughs.[6] Immediately after a breakthrough emerged, startups spun off from the parent company to exploit and retain business in small niche markets due to the hyper mobility of high-tech labour and a rich supply of risk capital by venture capitals. Calling this a 'breakthrough illusion', they concluded that big U.S. enterprises failed to move from innovation to mass production. Emphasising that Japanese firms were able to integrate new high technologies to make revolutionary advances in mass-market consumer products, their analysis highlighted the fact that entrepreneurial startups, venture capitals, and high

---

[4] Kogyo Gijutsu In Somubu Gijutsu Chosaka, *Wagakuni Sangyo Gijutsu No Taishitsu to Kadai, [Survey of Japanese Industrial Technology]*, pp.276-277.

[5] It is far beyond the scope of this paper to review the literature on the competitiveness of Japanese firms because this subject has been covered in numerous studies in various fields of research from the 1970s. However, the following are some of the important works discussing Japanese firms in comparison with U.S. firms: Aoki, M., *Information, Incentives, and Bargaining in the Japanese Economy*, Aoki, M. and Dore, R. P., *The Japanese Firm*, Clark, K. B. and Fujimoto, T., *Product Development Performance*, Cusumano, M. A., *The Japanese Automobile Industry*, Finan, W. F., *Matching Japan in Quality*, Lynn, L. H., *How Japan Innovates.*

[6] Florida, R. L. and Kenney, M., *The Breakthrough Illusion.*

labour mobility, all of which have been generally regarded as important institutions for innovation, prevented U.S. firms from moving breakthroughs to mass markets.

While Florida and Kenney focused on U.S. firms that faced serious issues relating to the breakthrough illusion, the central point of this study is to show that Japanese firms were also experiencing a different type of 'breakthrough illusion.' Japanese firms achieved scientific breakthroughs and attained a strong competitive advantage in mass markets, but their profitability kept declining. On the other hand, U.S. firms were losing their leading position in the development of fundamental semiconductor laser technology, as they gained competitiveness in niche and custom markets, which were usually much more profitable than mass markets.

The current study begins with a brief discussion of the historical development of semiconductor laser technology. The next section discusses the findings of a survey of important scientific breakthroughs in papers published in the *Applied Physics Letters*. It is found that many important scientific breakthroughs were achieved by U.S. organisations until the 1980s, while Japanese organisations began to take a lead from the 1980s. The third section examines the central claim of the present study. It is proposed that R&D investment in semiconductor laser technology was scattered and dispersed in various small markets in the U.S. due to the well-developed research networks and high engineer mobility. On the other hand, R&D competition among Japanese firms in the same technological trajectory led them to achieve breakthroughs, but made it difficult for them to generate high profits.

Development of Semiconductor Laser Technology

Four American institutions—General Electric (GE)[7], International Business Machines (IBM)[8], University of Illinois Urbana Champaign (UIUC)[9], and Massachusetts Institute of Technology (MIT)[10] simultaneously but independently developed the first semiconductor lasers in 1962.[11] A research group at GE headed by

---

[7] Hall, R. N., Fenner, G. E., Kingsley, J. D., et al., Coherent Light Emission from GaAs Junctions.

[8] Nathan, M. I., Dumke, W. P., Burns, G., et al., Stimulated Emission of Radiation from GaAs P-N Junctions.

[9] Holonyak, N. J. and Bevacqua, S. S. F., Coherent (Visible) Light Emission from Ga(As1-Xpx) Junctions.

[10] Quist, T. M., Rediker, R. H., Keyes, R. J., et al., Semiconductor Maser of GaAs.

[11] On the invention of the four semiconductor lasers, see Dupuis, R. D., The Diode Laser: The First 30

Robert N. Hall developed the first semiconductor laser on September 16, 1962. Within a month, physicists in the two other institutions independently demonstrated their own versions of the semiconductor laser. The development of the semiconductor laser was amazing and exciting news for physicists who were involved in laser-related R&D.

This invention opened huge possibilities for lasers. Until the semiconductor laser was invented, laser apparatuses were all large-scale. For instance, the ruby laser, which was the first laser in the world, needed a five-meter square amplification apparatus. It also required a significant amount of energy input. However, the invention of the semiconductor laser changed the notion of the laser, since it was a far simpler laser that would eventually fit on a tiny chip and be efficient enough to run with a small battery.

The semiconductor laser was still on a very nascent level, even though it was believed that it would have huge potential. The semiconductor lasers developed in 1962 worked properly only at minus 196 degree Celsius (i.e., liquid nitrogen temperature). Unless the semiconductor laser could work at room temperature, its potential would be fairly limited. Therefore, after the invention of the first semiconductor laser, the focus of R&D in semiconductor laser technology turned to developing a semiconductor laser that could work at room temperature.

It took eight years for engineers to solve this technological problem. The first semiconductor laser working at room temperature was developed in 1970 by a Bell Laboratory research team.[12] The new semiconductor laser was named Double-Heterostructure Laser (DH). Even though the semiconductor laser developed by Bell was not stable, it was one of the turning points in the technological development of the semiconductor laser, stimulating competition as many firms developed reliable and stable semiconductor lasers that could work at room temperature. The newspapers predicted that this newly invented DH laser would fundamentally transform the field of Optical Engineering in the same way that the transistor changed the face of Electronic Engineering.[13]

Many U.S. electronics, telecommunication, and computing enterprises such as GE, RCA, Bell, and IBM competed to develop semiconductor lasers that could work under stable conditions with a longer lifespan at room temperature. Japanese electronics

---

Days, 40 Years Ago.

[12] Panish, M. B., Hayashi, I. and Sumski, S., Double-Heterostructure Injection Lasers with Room-Temperature Thresholds as Low as 2300 a/Cm.

[13] *Asahishinbun (Asahi Newspaper)*, September 1st, the evening edition. Tsusho-Sangyo-Sho, *Denshi Kogyo Nenkan [Annual Report on the Electronics Industry]*, pp.513-524.

and telecommunication firms such as Hitachi, Toshiba, Mitsubishi Electric, Nippon Electric Company (NEC), Fujitsu, and Nippon Telegraph and Telephone (NTT) became involved in semiconductor laser research from the 1960s as well. Since laser beam amplification was noisy, unstable and the life span of the semiconductor was short in the 1970s, all of the firms were competing to develop stable and long-life semiconductor lasers, which could work at room temperature.

The main application area in the beginning of the 1970s was long-distance telecommunication. At that time, electric wires were used for long-distance telecommunication, but the quality was poor. The main problem was energy loss, and it was necessary to use a relay device, called a repeater, every few kilometres. Too many relay devices produced time lags, background noise and caused lines to be cut-off. Engineers believed that the laser optical fibre would resolve these problems by reducing energy loss. Since it was estimated that the optical fibre would need only one relay device every 180 kilometres, they believed that the optical fibre would enable clear, instant, and stable long-distance telecommunication. It was predicted that optical fibres would take the place of electric wires for long-distance telecommunication if a practical optical fibre and a reliable semiconductor laser could be developed. The Japan Electronic Apparatus Industry Association stated, 'The semiconductor laser attained continuous amplification at room temperature in 1970. It is projected that it will be used in optical telecommunication and data communication soon.'[14]

However, the size of the long-distance telecommunications market was not very large, even though it was an important social infrastructure. Once semiconductor lasers had been set up in the long-distance telecommunication infrastructure, much of the additional demand would be replacement of existing cables. Furthermore, a clear picture of the product markets of the semiconductor laser did not emerge until the late 1970s, even though optical communication (e.g. optical fibre) was regarded as one of the applications of semiconductor lasers. As Hayashi Izuo, one of the Bell Laboratories' engineers who successfully developed semiconductor laser amplification at room temperature in 1970, noted in 1972,

> It is difficult to estimate how the semiconductor laser will be developed. First, it is because we are still uncertain about the technological possibilities. Second, we do not know what kind of product market will be

[14] Nihon Denshi Kikai Kogyo Kai, *Denshi Kogyo 30 Nenshi [a 30 Year History of the Electronics Industry]*, p. 269.

found. Since the invention of the laser, a myriad of dream-like possibilities has been suggested. However, many of them have not been realized yet. Even though many technological problems remain unsolved in semiconductor laser technology, the biggest problem lies in whether appropriate and effective potential uses can be found.[15]

While many firms competed to develop a semiconductor laser for the optical fibre, Stanford University and Minnesota Mining and Manufacturing (3M) started researching laser technology for information storage on photographic videodiscs in 1961.[16] In those days, information was stored in the form of analogue signals. Their aim was to store data in the form of digital signals. Unfortunately, their effort ended in failure because laser technology was still in an immature stage. Even though their research attracted little attention at the time, this was the first attempt to use optoelectronics technology for information storage. Ten years after Stanford and 3M's attempt, some firms began to conduct research on videodisc technology in the early 1970s and developed several videodisc systems based on advances in laser technology. Taking different formats, electronics firms such as Philips, RCA, Mitsubishi Electronics, and Toshiba competed to develop the videodisc.[17]

As firms committed to semiconductor laser R&D, it became clear that the semiconductor laser would eventually be used for optical information storage, such as videodiscs, compact discs and laser discs. Moreover, it was expected that the potential markets for short wavelength semiconductor lasers would be huge because they would be utilized in various application areas such as barcode readers, laser pointers, and laser printers. By the end of the 1970s, it was obvious that the semiconductor laser would involve huge application areas. For example, the *Electronics Industry Year Book of 1979* noted,

It is expected that electronics products such as POS (point of sales)

---

[15] Hayashi, I., Handotai Reza O Omou [Notes on the Semiconductor Laser], p.355.

[16] The photographic videodisc utilises a system in which a signal recorded on the disc is read by the strength of a penetration light from a mercury lamp. Nakajima, H. and Ogawa, H., *Zukai Konpakuto Disuku Dokuhon [Handbook of Compact Disc]*, p. 55.

[17] Nakajima, H. and Ogawa, H., *Zukai Konpakuto Disuku Dokuhon [Handbook of Compact Disc]*Nakajima, H. and Ogawa, H., Zukai Konpakuto Disuku Dokuhon (Handbook of Compact Disc), p. 57.

> system and Video Disc will be widely used in shops and homes. It is projected a huge new market will appear based on the economies of large-scale production, if the semiconductor laser is used in these products. He-Ne laser is currently used in these products. However, firms and research institutions are actively conducting R&D in semiconductor lasers so that it can be used in these products.[18]

Information storage, barcode readers, laser printers were new product markets for the semiconductor laser. As expectations for these markets grew, more firms such as Xerox, Sony, and Sharp began to compete to develop semiconductor lasers both in the U.S. and Japan. The compact disc, which was the first major market for semiconductor lasers, was released in 1982. GaAlAs lasers at a wavelength of 780 nm were used for the compact disc. Semiconductor lasers for barcode readers at a wavelength of 670 nm were developed in 1985. Digital versatile discs using semiconductor lasers at a wavelength of 650 nm, were introduced in Japan in 1996, the U.S. in 1997, Europe in 1998, and Australia in 1999.

Scientific Breakthroughs

The industrialisation of semiconductor lasers took off slowly but surely following the invention of the first semiconductor laser in 1962. After the development of the DH laser in 1970, many firms began to commit to semiconductor laser R&D on a greater scale. Since semiconductor laser technology was deeply intertwined with advanced applied physics, not only firms but academic institutions also conducted fundamental research in semiconductor laser technology.

This section discusses semiconductor laser research that U.S. and Japanese organisations conducted by examining scientific papers on semiconductor lasers published in academic journals. One of the main findings is that many of the important papers were published by Japanese organisations from the 1980s.

Both corporate engineers and academic scientists published their research outcomes in various journals such as *Electronics Letters*, *Journal of Applied Physics*, and *IEE Journal of Quantum Electronics*. This study chooses to examine the *Applied Physics Letters* because it has a wide circulation and a strong international reputation as the top journal in the research of semiconductor lasers. The following tables show the general trends of papers on semiconductor lasers published in the *Applied Physics*

[18] Tsusho-Sangyo-Sho, *Denshi Kogyo Nenkan, [Annual Report on the Electronics Industry]*, p.679.

Letters by organisations in the United States and Japan sorted according to five different phases: 1960-1980, 1981-1985, 1986-1990, 1991-1995, and 1996-2000.

Table 1: Descriptive Statistics of American Organisations

	Total	1960-1980	1981-1985	1986-1990	1991-1995	1996-2000
Number of Organisations	185	26	40	73	104	101
Number of Papers	2035	210	352	562	624	287
Average Number of Citations	26.3	40.73	28.16	23.19	25	22.38
Max Number of Citations	1194	490	306	177	1194	210

Source: The *Applied Physics Letters*, 1960-2000.

Table 2: Descriptive Statistics of Japanese Organisations

	Total	1960-1980	1981-1985	1986-1990	1991-1995	1996-2000
Number of Organisations	70	13	19	26	42	39
Number of Papers	542	54	109	123	158	98
Average Number of Citations	34.02	30.31	35.78	22.01	27.40	59.88
Max Number of Citations	1609	119	1609	165	1363	945

Source: The *Applied Physics Letters*, 1960-2000.

First, these tables show that the U.S. outnumbered Japan in terms of the number of organisations involved in semiconductor laser research and the number of papers they published. The number of papers both U.S. and Japanese organisations published increased steadily from 1960s until 2000. But both the number of U.S organisations and the number of papers they published are higher than those of Japanese firms in the same time period.

Second, a different picture of semiconductor laser research by U.S. and Japanese organisations emerges if the quality of the papers is compared in terms of the number of times a paper is cited. Japanese organisations obtained a higher average number of citations in most of the time periods examined except for two periods: 1960-1980 and 1986-1990. The difference in the average number of citations in 1986-1990 between the U.S. and Japan was not significant. This implies that the research performance of Japanese organisations in terms of the number of citations started rising from the 1980s. Furthermore, comparing the maximum number of citations of U.S. organisations with that of Japanese organisations, these tables show that both countries produced highly cited papers in each of the five time periods. Japanese organisations produced highly cited papers in the second, fourth and fifth period, while the U.S. organisations produced highly cited papers in the first and third period. The most highly cited paper was produced by a Japanese organisation in the second period from 1981-1985.[19] The following table shows the top ten highly cited papers in the entire period from 1960-2000.

[19] Arakawa, Y. and Sakaki, H., Multidimensional Quantum Well Laser and Temperature Dependence of Its Threshold Current.

Table 3: Top 10 Highly Cited Papers

	Year	Title	Country	Times Cited	Affiliation 1
1	1982	Multidimensional quantum well laser and temperature dependence of its threshold current	Japan	1609	University of Tokyo
2	1994	Candela-class high brightness InGaN/AlGaN double heterostructure blue light emitting diodes	Japan	1363	Nichia Chemical
3	1991	Blue-green laser diodes	US	1194	3M
4	1997	Optically pumped lasing of ZnO at room temperature	Japan	945	Tohoku University
5	1998	Room-temperature ultraviolet laser emission from self-assembled ZnO microcrystallite thin films	Japan	714	Tokyo Institute of Technology
6	1997	Role of self-formed InGaN quantum dots for exciton localization in the purple laser diode emitting at 420 nm	Japan	505	Kyoto University
7	1971	Stimulated emission in a periodic structure	US	490	Bell Laboratories
8	1991	Blue-green injection laser diodes in (Zn,Cd)Se/ZnSe quantum wells	US	454	Brown University
9	1992	Whispering-gallery mode microdisk lasers	US	433	Bell Laboratories
10	1998	InGaN/GaN/AlGaN-based laser diodes with modulation-doped strained-layer superlattices grown on an epitaxially laterally overgrown GaN substrate	Japan	408	Nichia Chemical

Source: *Applied Physics Letters* 1960-2000, Web of Science. The data on the number of citations was obtained in September 2007.

Table 3 shows clearly that many highly cited papers were published by Japanese organisations. All of them except for the paper by the University of Tokyo in 1982, which obtained the highest number of citations, were published in the 1990s. This suggests that Japanese organisations took the lead in semiconductor laser research in the 1990s. Of course, the papers published in the *Applied Physics Letters* do not necessarily represent all of the important breakthroughs. For example, as mentioned above, the first semiconductor laser was invented by four American institutions-GE, IBM, UIUC, and MIT in 1962.[20] The concept of heterojunction structure, which became the fundamental concept of semiconductor lasers, was first introduced by Herbert Kroemer (University of California Santa Barbara) in 1963.[21] The first room temperature operation of the semiconductor laser was achieved by Bell Laboratories.[22] Even though the semiconductor laser developed by Bell was not stable, it was one of the turning points in the technological development of the semiconductor laser, stimulating competition as many firms developed reliable and stable semiconductor lasers that could work at room temperature. However, all these milestones were set in the 1960s and 1970s. As Table 3 shows, after the 1980s, it was Japanese organisations that pulled off most of the breakthroughs.

U.S. Firms: Startups and Networks

As the previous section has shown, U.S. organisations, such as IBM, GE, Bell, UIUC, and MIT, were the leading institutions in semiconductor laser technology until the 1980s.[23] For instance, the first semiconductor lasers were invented by IBM, GE, UIUC and MIT in 1962. UC Santa Barbara introduced the concept of heterojunction structure, which became the fundamental concept of semiconductor laser later in 1963. RCA introduced the first commercial semiconductor lasers in 1969.[24] The first

[20] On the invention of the first semiconductor lasers, see Dupuis, R. D., The Diode Laser: The First 30 Days, 40 Years Ago.

[21] Kroemer, H., A Proposed Class of Heterojunction Injection Lasers.

[22] Panish, M. B., Hayashi, I. and Sumski, S., Double-Heterostructure Injection Lasers with Room-Temperature Thresholds as Low as 2300 a/Cm2.

[23] On the technological development of the laser from 1950-1970, see Bromberg, J. L., *The Laser in America, 1950-1970*.

[24] On semiconductor lasers and RCA, see Kressel, H. and Lento, T. V., *Competing for the Future.*

room-temperature semiconductor laser was developed by the Bell Laboratories in 1970. However, even though a number of U.S. organizations, such as Bell Laboratories and 3M, continued to produce breakthroughs, many of the important scientific papers were published by Japanese organisations after the 1980s, as shown in Table 3 above.

It is from the 1980s that important changes started to take place. As JTEC indicated, numerous entrepreneurial startups emerged in the U.S. optoelectronics industry in the 1980s, which were virtually unheard of in Japan.[25] The monthly report of the Industrial Bank of Japan also reported, ‘Small and middle size business ventures played a central role in the U.S. optoelectronics industry except for a few large scale telecommunications companies and optical fibre manufacturers.’[26] Many technology-intensive start-ups spun off from large parent enterprises such as Bell and Xerox or universities such as UIUC and Caltech that played a leading role in semiconductor laser technology research. For instance, Spectra Diode Laboratories was founded in 1983 as a joint venture between Xerox and Spectra Physics. Spectra Diode developed and manufactured high-power solid-state semiconductor lasers.[27] Lytle, a manufacturer of lasers, was founded in New Jersey in 1986 by an engineer from RCA.[28] Ortel, a manufacturer of optical communication devices[29], was established by researchers from the California Institute of Technology in 1980.[30]

The launching of new startups in the optoelectronics industry in the U.S. encouraged the growth of semiconductor laser research networks.[31] Networking among scientists, engineers, and entrepreneurs came under focus in the 1980s when Silicon

---

[25] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report.*

[26] Nihon Kogyo-Ginko, Hikari Sangyo No Shorai Tenbo [Prospects for the Optoelectronics Industry] p.77.

[27] On Spectra Diode, see Jacobs, R. R. and Scifres, D. R., Recollections on the Founding of Spectra Diode Labs, Inc.

[28] The author contacted one of the founders of Lytel, Professor Dan Botez. He also kindly sent me his Curriculum Vitae.

[29] Ortel is now a division of Emcore, a manufacturer of semiconductors and related devices. ICARUS.

[30] Rogers, M., Ortel, in Three Acts.

[31] For a comparative analysis of inter-organisational research networks between the U.S. and Japan, see Shimizu, H., *Competition, Knowledge Spillover, and Innovation.*

Valley in California attracted wide attention.[32] The role of networking increases as technology becomes more complex, giving rise to uncertainties about demand and competition.[33] A research network is an important means of accessing external complementary knowledge and resources. It plays an important role in leveraging external resources especially for startups because typically they have limited managerial, technological and financial resources. Networking and accessing external complementary knowledge are also important when firms utilize existing technology for a new target.

The following figure is an illustration of inter-organisational collaboration developed by a number of startups based on a survey of co-authored papers on semiconductor laser technology published in the *Applied Physics Letters* from 1960-2000. Collaborative networks can take various forms, from formally contracted and organised research to casual conversations over a pint of beer. The present study uses co-authored papers as a proxy measure of collaborative research among scientists and engineers.[34] It must be noted that this figure does not provide a complete picture of all inter-organisational collaborations in semiconductor laser technology. It is beyond the scope of this paper to illustrate and discuss the entire spectrum of inter-organisational networks that U.S. and Japanese organisations have developed.[35] However, it provides a good indication of how startups developed inter-organisational collaborative networks. The coloured squares denote U.S. startups. The colourless boxes denote academic institutions. The colourless squares signify other organisations such as firms and governmental institutions.

---

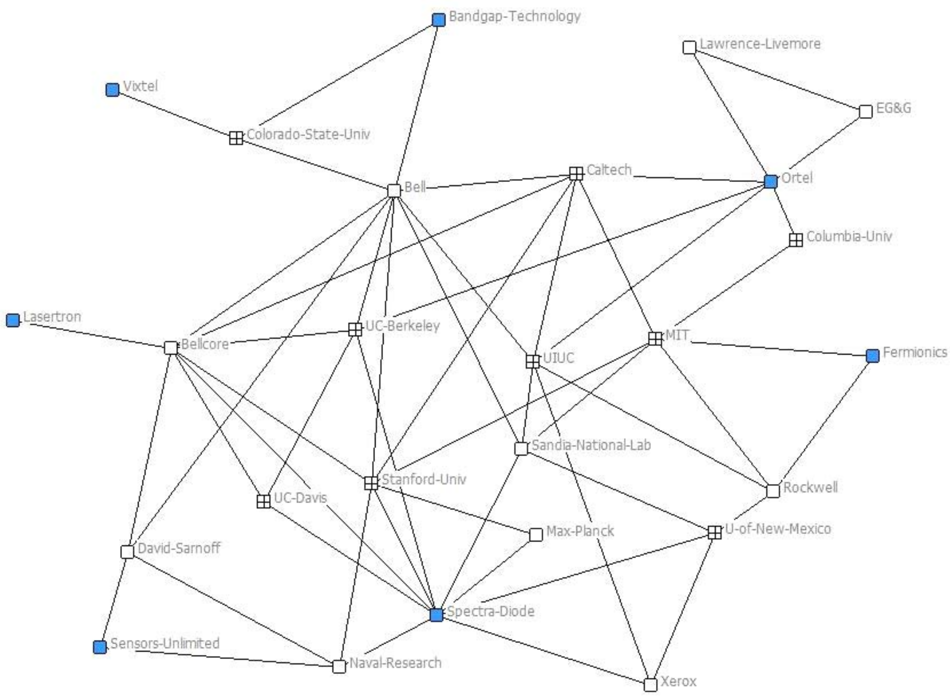
[32] For example, Freiberger, P. and Swaine, M., *Fire in the Valley,* Saxenian, A., *Regional Advantage.*

[33] Burgers, W. P., Hill, C. W. L. and Kim, C. W., *A Theory of Global Strategic Alliances*.

[34] It must be noted however that co-authored papers do not cover all collaborative research among practitioners. In particular, it is difficult to capture informal research networks, many of which do not have a visible presence in academic journals. However, a study of co-authored papers allows for the systematic investigation of collaboration across industries. Furthermore, it must be noted that this figure does not illustrate all the inter-organisational collaborations in semiconductor laser technology.

[35] For a complete illustration of inter-organisational networks, see Shimizu, H. and Hirao, T., Collaborative Research Networks in Semiconductor Laser Technology, 1960-2000.

Figure 1: Research Networks of Startups



Starups

Firms and Governmental Institutions

Academic Institutions

Source: The *Applied Physics Letters*, 1960-2000.

This figure shows how U.S. startups collaborated with universities and big enterprises. For instance, Spectra Diode collaborated with many academic institutions, such as University of California (UC) Berkeley, UC Davis, Stanford University, and University of New Mexico. Apart from academic institutions, it also collaborated with big enterprises, such as the Bellcore and Xerox. Ortel collaborated with four universities, such as Caltech, Columbia University, UC Berkley, and UIUC, and became one of the first optoelectronic companies that went public in 1994.

The spin-off engineers played an important role in these venture businesses. For example, Dan Botez, who received a Ph.D in semiconductor laser and LPE technology in 1976 from UC Berkeley, and became a highly cited engineer in semiconductor laser technology, began his engineering career at IBM in 1976.[36] In 1977,

[36] The author contacted Professor Dan Botez. He also kindly sent me his Curriculum Vitae. The description of his career is based on the CV.

he moved to the David Sarnoff Research Centre at RCA,, and developed novel semiconductor lasers, two of which became commercial products. In 1984, he left RCA and founded Lytle Inc. in New Jersey. In 1986, Botez joined TRW Inc. where he continued his research in high-power semiconductor lasers. In 1998, he founded Alfalight, a designer and manufacturer of high-power semiconductor lasers for the industrial, defence, and telecommunication markets. Ortel, Lytle, Alfalight, and Spectra Diode were all launched by spin-off engineers. These engineers used advanced and important tacit knowledge that they acquired while working in big enterprises or universities to venture into new businesses.

The startups were generally less integrated and focused their businesses in very specific markets.[37] They accessed external complementary knowledge through well-developed research networks and utilized the semiconductor laser technology for untapped markets. For instance, numerous small startups such as Lasertron, Sensors Unlimited, Spectra Diode, and Ortel launched into business to manufacture highly specialised lasers, modulators, or detector devices, all of which cater to the needs of niche and custom markets. According to the JTEC,

> These small businesses, which generally specialize in the manufacture of photonic components, are rarely positioned to compete head-to-head with the larger, systems-oriented companies; instead, they tend to specialize by filling narrow niches. As companies become established, the niches expand with the manufacture of additional specialized, unique devices produced to fill the needs of particular subsets of customers.[57]

Startups spun off from large enterprises or universities, which were committed to the fundamental research of semiconductor laser technology. R&D efforts were eventually scattered across niche or highly customized markets. The following figure plots the number of patents in fundamental technology of semiconductor lasers obtained by U.S. and Japanese organisations from the U.S. patent office from 1975 to 2000. This figure

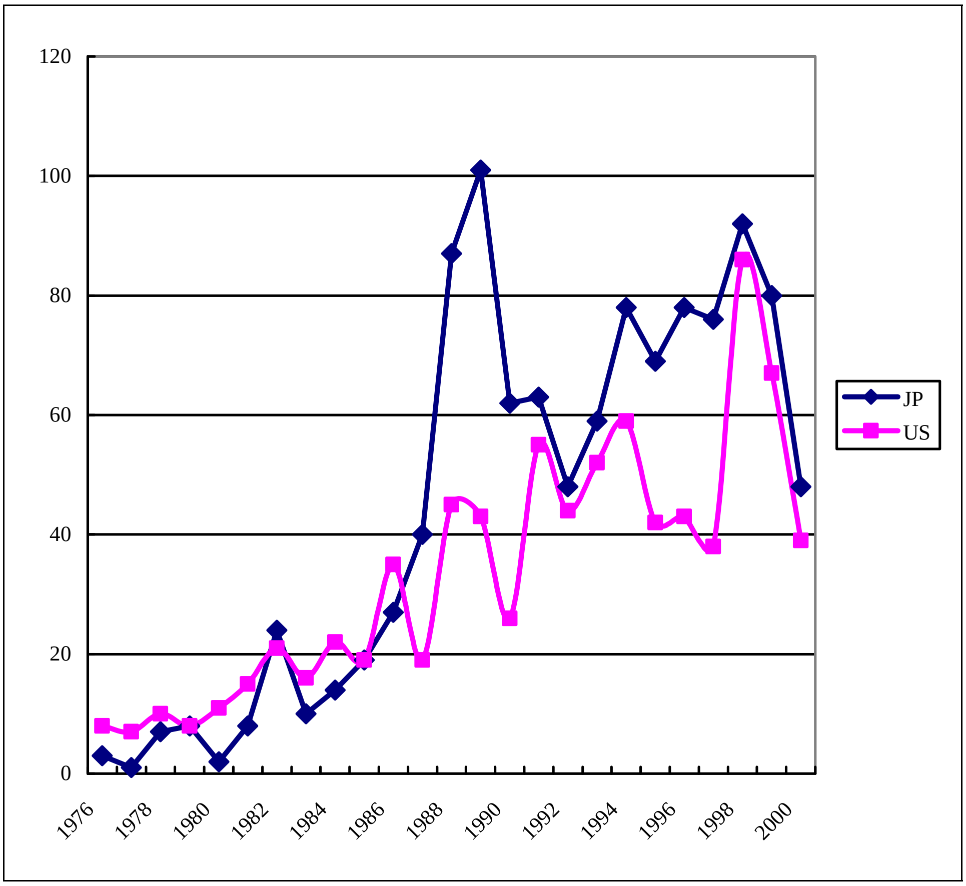
---

[37] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report.*

[57] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report*, p. xvii.

uses two 7th International Patent Classes, H01 S3/18 and H01 S3/19[38], which were regarded as fundamental technology of semiconductor lasers.[39] It shows that the number of patents that U.S. organisations obtained in these patent classes was larger than that of Japanese organisations until the mid-1980s. The number of patents U.S. organisations obtained did not show a significant increase after the mid-1980s except for a sudden rise in 1998. However, Japanese organisations, mainly electronics firms such as Toshiba, Hitachi, NEC, Sharp, Sony, took the lead in terms of the number of patents from the late 1980s.

Figure 2: Semiconductor Laser Patents by U.S. and Japanese Organisations



Source: The U.S. Patent Office, 1976-2000.

U.S. firms retreated from fierce R&D competition in fundamental

---

[38] H01 S3/18 covers semiconductor lasers, structure or shape of the active region. H01 S3/19 covers semiconductor lasers, structure or shape of the active region comprising PN junctions.

[39] Tokkyocho, *Korede Wakaru Handotai Reza [Handbook of the Semiconductor Laser]*.

semiconductor laser technology, and focused on utilizing the semiconductor laser to launch new businesses in untapped niche markets. Exploring the technological development of various lasers in the U.S. in the early phase of semiconductor laser technology from 1950 to 1970, Bromberg showed that U.S. firms shifted from long-term programs to more profitable short-term programs after 1968.[40] Since semiconductor lasers were regarded as an important breakthrough that could have huge potential[41], large U.S. firms, such as GE, Bell, and RCA, were still conducting R&D in semiconductor laser until the mid-1980s. However, while the Japanese electronics industry was growing in the 1970s and 1980s, American electronics firms were facing unfavourable conditions for R&D investment.[42] Due to intense competition from foreign rivals beginning in the late 1970s,the market share of U.S. electronics in the global market fell from 71% in 1960 to 27% in 1986, while that of Japan rose from 8% to 35%.[43] American electronics firms tried to restructure their over diversified businesses to focus on the profitable divisions. Only those firms that managed to unbundle their unprofitable businesses could maintain their position in worldwide markets. When John Francis "Jack" Welch Jr. became Chairman and Chief Executive Officer of GE in 1981, he tried to restructure its businesses to generate more profits, and introduced a strategy that demanded each of its divisions to aim to take the number one or two position in the market. In his book, he calls this policy 'fix it, sell it, or close it'.[32] While Japanese electronics firms were growing, U.S. electronics firms relinquished unprofitable business divisions and focused their managerial resources in areas in which their divisions had already emerged as profitable.

Japanese Firms: Competition in the Same Markets

As described above, Japanese organisations started making major breakthroughs from the 1980s. However, this does not necessarily mean that Japanese firms were leading in scientific research because many of the organisations that

---

[40] Bromberg, J. L., *The Laser in America, 1950-1970.*

[41] For example, Wolff, M. F., Will Diode Laser Obsolete Earlier Lasers?, Tsusho Sangyo Sho, *Denshi Kogyo Nenkan [Annual Report on the Electronics Industry]*

[42] Curtis, P. J., *The Fall of the U.S. Consumer Electronics Industry.*

[43] Chandler, A. D., The Competitive Performance of U.S. Industrial Enterprises since the Second World War.

[32] For the 'fix it, sell it, or close it' policy, see Welch, J. and Byrne, J. A., *Jack*, pp.106-110.

published important papers were academic institutions such as University of Tokyo, and Tokyo Institute of Technology. However, taking a closer look at academic papers reveals that Japanese firms took the lead in achieving breakthroughs when they began to develop short wavelength semiconductor lasers.

While many entrepreneurial startups emerged in the optoelectronics industry in the U.S. and targeted the niche and custom markets from the 1980s, such startups were virtually non-existent in Japan as JTEC reported.[44] Big enterprises such as Toshiba, Hitachi, and Sony played a dominant role in the research of semiconductor laser technology. They developed semiconductor lasers for the growing mass markets such as compact discs, digital versatile discs, barcode readers, and laser printers. It is clearly indicated in their corporate technical journals that the primary R&D goal was to provide semiconductor lasers to in-house assembly lines for those final products.[43]

As many firms competed in the same product markets, breakthroughs emerged in the same trajectory. Using a scientific paradigm analogy introduced by Kuhn, Dosi defined technological trajectory as the direction of technological advance within a technological paradigm.[45] Technological paradigm is defined as 'an outlook, a set of procedures, a definition of the relevant problems, and of the specific knowledge related to their solution.'[46] In tracing the development of the semiconductor laser, many articles in academic and technical journals reported that the main focus was to develop semiconductor lasers that could emit at a short wavelength[47] Based on a review of papers published in academic journals to compare their reported wavelength. Figure 3 below illustrates the technological trajectory of semiconductor lasers.

---

[44] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report,* p.xvii.

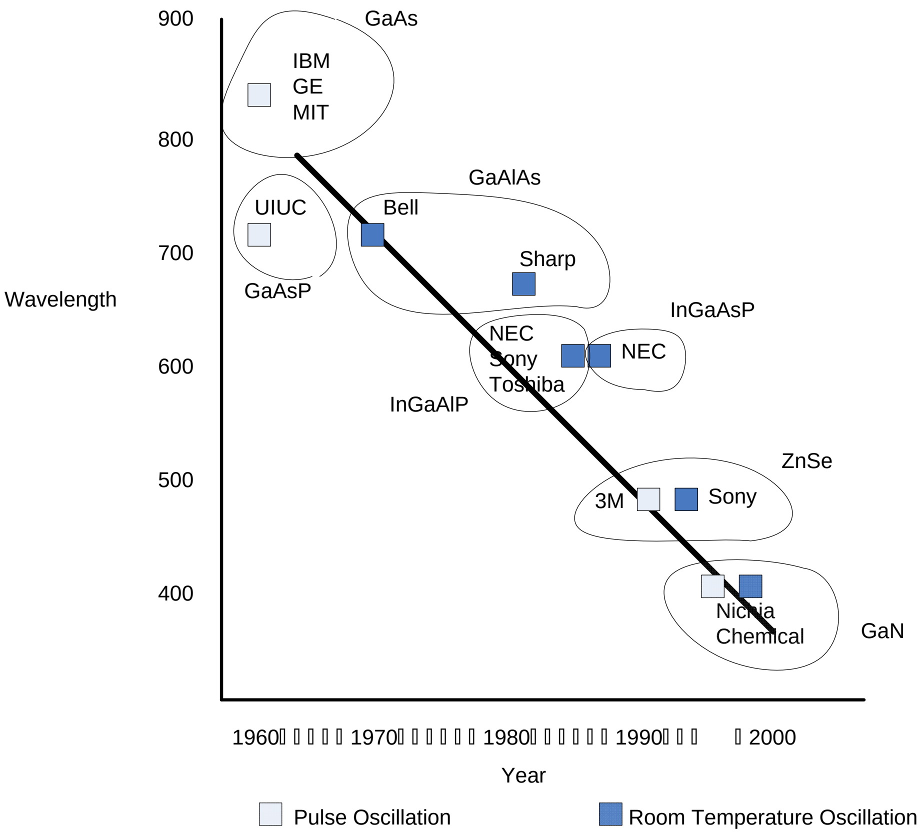
[43] Much of the research in the corporate technical journals indicated that the firms researched and developed the semiconductor laser primarily to satisfy their in-house demand. For example, Kondo, M., Mokume, K., Kashima, S., et al., Konpakuto Dhisuku Pureyayo MPL-2 gata Hikari Pikkuappu [MLP-2 Optical Pick Up for Compact Disc Player], Aiki, K. Kajimura, T., Chinone, N., Laser Diodes for Optical Information Processing Systems.

[45] Dosi, G., Technological Paradigms and Technological Trajectories, Kuhn, T. S., *The Structure of Scientific Revolutions.*

[46] Dosi, G., Technological Paradigms and Technological Trajectories.

[47] Hatakoshi, G., Visible Semiconductor Lasers, Tokkyocho, *Korede Wakaru Handotai Reza [Handbook of the Semiconductor Laser].*

Figure 3: Technological Trajectory of Semiconductor Lasers



Source: Hatakoshi, Visible Semiconductor Lasers

The white squares represent semiconductor laser pulse oscillation. The blue squares signify continuous wave (CW) oscillation at room temperature. Usually pulse oscillation semiconductor lasers were developed first. But if a semiconductor laser can only operate on pulse oscillation, its application will be seriously limited. Therefore, engineers tried to develop CW oscillation at room temperature next after developing pulse oscillation.

As Figure 3 illustrates, U.S. organisations such as IBM, GE, MIT, UIUC, and Bell were achieving breakthroughs by 1970. Japanese organisations made no significant breakthroughs in this early phase of semiconductor laser technology development. However, Japanese firms began to make breakthroughs with the development of shorter wavelength semiconductor lasers from the 1980s. The recording density of an optical disc depends on the size of the laser beam spot. Because the diameter of the beam spot is proportional to the wavelength of light, the recording density is inversely proportional to the square of the wavelength.[48] Therefore it was necessary for Japanese firms to develop shorter wavelength semiconductor lasers because their target was the rapidly growing information storage markets. Japanese engineers experimented with different materials and developed manufacturing technologies in order to develop short wavelength semiconductor lasers. For instance, Sharp achieved room-temperature CW operation at a wavelength below 700nm using AlGaAs double heterojunction lasers in 1982.[49] Sony developed room-temperature CW InGaAlP double heterostructure lasers, whose emission wavelength was 671 nm in 1985.[50] Nichia Chemical built room-temperature CW InGaN multi-quantum-well structure lasers in 1996.[51] Not many breakthroughs made by U.S. firms appear in the technological trajectory because R&D investment in semiconductor laser technology was scattered and dispersed in various small markets in the U.S. due to the well-developed research networks and high engineer mobility, which allowed firms to access external complementary knowledge when targeting profitable niche markets.

Japanese firms competed to develop a shorter wavelength laser, which could handle high volume information storage, and captured a significant market share in this sector, as indicated in the JTEC report.[53] Their R&D efforts were concentrated mainly on developing short wavelength semiconductor lasers for information storage markets. A Japanese engineer, Izuo Hayashi, who developed the first room-temperature semiconductor laser at Bell Laboratories, noted that R&D competition among Japanese firms contributed to the development of semiconductor lasers.[52] The AIST also reported that competition among Japanese firms played an important role in gaining a

---

[48] Tamargo, M. C., Ii-Vi Semiconductor Materials and Their Applications.

[49] Yamamoto, S., Hayashi, H., Hayakawa, T., et al., *Room-Temperature CW Operation in the Visible Spectral Range of 680–700 nm by AlGaAs Double Heterojunction Lasers.*

[50] Ikeda, M., Mori, Y., Sato, H., et al., Room-Temperature Continuous-Wave Operation of an AlGaInP Double Heterostructure Laser Grown by Atmospheric Pressure Metalorganic Chemical Vapor Deposition.

[51] Nakamura, S., Senoh, M., Nagahama, S.-i., et al., InGaN-Based Multi-Quantum-Well-Structure Laser Diodes, Nakamura, S., Senoh, M., Nagahama, S., et al., Room-Temperature Continuous-Wave Operation of InGaN Multi-Quantum-Well Structure Laser Diode

[53] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report*, pp.6-9.

[52] Hayashi, I., A Retrospective: 50 Years of Research: Following the Heart.

competitive advantage in high volume consumer electronic semiconductor laser products such as optical information storage products, which were the biggest market in the optoelectronics industry.[53]

Why did Japanese firms not retreat from the unrelenting competition and target niche markets as many U.S. firms did? One of the reasons lies in the fact that Japanese electronics firms were enjoying a favorable economic climate for R&D investment, while American electronics firms were facing a decline from the mid1970s.[54] In 1972, the R&D component in the U.S. was 2.32% of the GDP, while that of Japan was 1.86.[55] In 1982, the same figure for the U.S. was 2.48%, while that of Japan had increased to 2.38%. From 1972, R&D investment in Japan increased steadily until it reached 3.02% in 1996, while in the U.S. it reached 2.55% and has never gone beyond 3%. R&D investment in microelectronics technology in the late 1970s and 1980s led to new growth industries in consumer electronics and computers, and to higher productivity in pre-established industries. Under such favourable economic conditions, Japanese electronics firms targeted mass markets that were growing rapidly. Because the semiconductor laser was regarded as the most important key component in the development of optoelectronics products, it was necessary to source it internally for Japanese firms that internalized the final product manufacturing process in order to have a secure and reliable laser supply.[56]

The macroeconomic climate was one of the reasons that allowed Japanese firms to compete in the same product markets. But it was not the only reason why Japanese firms did not differentiate their R&D target and focus on untapped niche markets. As the JTEC reported, entrepreneurial startups were virtually non-existent in the Japanese optoelectronics industry. Compared to the U.S., the inter-organisational research networks in Japan were not as well-developed.[57] The less developed research

---

[53] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report,* pp.6-9.

[54] Chandler, A. D., The Competitive Performance of U.S. Industrial Enterprises since the Second World War.

[55] Kagaku Gijutsu Cho Kagaku Gijutsu Seisaku Kenkyusho, *Kagaku Gijutsu Shihyo [Science and Technology Index]),* p.277.

[56] This point is confirmed in interviews with Japanese engineers who were involved in semiconductor laser R&D. For details of the interviews, see Shimizu, *Competition, Knowledge Spillover, and Innovation*, p.187 and pp.239-242.

[57] On the research networks in Japan, see Shimizu, *Competition, Knowledge Spillover, and*

networks prevented engineers from accessing external complementary knowledge, which play an important role in the lateral utilisation of existing technology for new targets.

Moreover, engineer mobility, which plays a key role for a firm in acquiring external knowledge, was also very low in Japan compared to the U.S. As past research on the Japanese labour market has shown,[58] it was quite rare for star engineers to transfer from one company to another in Japan in the semiconductor laser industry. The following table shows the mobility of the top fifty highly cited engineers in semiconductor laser technology in U.S. and Japan based institutions from 1960 to 1990 and their affiliations. If an engineer changed his/her affiliation once (e.g. from the Bell Laboratories to UC Berkeley) from 1960 to 1990, a value of two is assigned to the engineer's affiliation. If an engineer did not change his/her affiliation at all in this time period, a value of one is assigned. This table clearly shows that the mobility of highly cited engineers was higher in the U.S. than Japan.[59] The average number of affiliations held indicates that Japanese star engineers tended not to change their affiliation.[60] The low mobility of star engineers blocked Japanese firms from acquiring external knowledge, which would play an important role in the lateral utilisation of the technology in new fields. Thus, many Japanese firms were channelled to compete in the

---

Innovation, pp.106-116, Shimizu, H. and Hirao, T., Collaborative Research Networks in Semiconductor Laser Technology, 1960-2000.

[58] Japanese employees had little incentive to leave their firms in the middle of their careers under the lifetime employment system and seniority-based wages. For example, Hazama, H., *The History of Labour Management in Japan,* Ariga, K., Brunello, G. and Ohkusa, Y., *Internal Labor Markets in Japan.*

[59] This finding is compatible with the findings on hyper mobility of high-tech labor in California observed by Florida and Kenney. Florida, R. L. and Kenney, M., *The Breakthrough Illusion*, pp.79-83.

[60] Only one exception was Hayashi Izuo. He began his professional career in the Department of Science and Technology at the University of Tokyo in 1946 and became a visiting scholar at MIT in 1963. He moved to Bell Laboratories in 1964 and developed the first semiconductor laser that worked at room temperature in 1970, which was one of the important breakthroughs in this field. He moved to the Central Research Division of NEC from 1971 to 1982. He was appointed as technical director of the OMCS project from 1982-1987. For his career, see, Ito, R., Dai 1 Kai Oyo Butsuri Gakkai Gyoseki Jushosha Shokai [Profile of the Japan Society of Applied Physics Prizewinners], pp.384-385.

same technological trajectory due to the less developed research networks and low engineer mobility.

Table 4: Mobility of Top Fifty Engineers

	Engineers in U.S. Organisations	Engineers in JPN Organisations
Number of observations	50	50
Average number of affiliations held by engineer	2.1	1.1
Variance	1.69	0.09
Median	2	1
Maximum	5	2

Source: *Web of Science. Scitation.*

Japanese firms gained a competitive edge in high-volume markets and cornered a huge share of the market.[61] However, it does not necessarily mean that the profitability of Japanese firms was high. Many firms such as Hitachi, Toshiba, Mitsubishi Electric, Matsushita, NEC, Fujitsu, Sony, Sharp, and Sanyo competed to develop reliable and long-lasting lasers for an optical information storage market undergoing a high-volume expansion. Severe R&D competition over the long-term in the same markets lowered their profitability. As a number of firms competed in the same technological area for an extended period of time, the aggregate amount of R&D investment in the area gradually grew larger. The increase in R&D investment enhanced the potential for making technological breakthroughs on the one hand but lowered the profitability of Japanese firms on the other. Since the semiconductor laser is one of the components of the final products and firms diversified into a wide range of products, it is difficult to determine the profitability of semiconductor lasers separately from other businesses.[62] However, it has been pointed out in the Japanese literature that the

[61] Forrest, S. R., Coldren, L. A., Esener, S. C., et al., *JTEC Panel on Optoelectronics in Japan and the United States Final Report.* Wood, S. C. and Brown, G. S., *Commercializing Nascent Technology: The Case of Laser Diodes at Sony.*

[62] The overall operating earning rate of big Japanese electronics firms, Hitachi, Toshiba, Mitsubishi Electric, Fujitsu, NEC, Sony, Matsushita Electric, Sharp, and Sanyo, declined from 6% to 2% from the mid-1980s to the 1990s. *Nikkei Needs*. Ortel, one of the startups in the optoelectronics industry, posted a higher operating earning rate at 28% in 1994, 36% in 1995,

profitability of the Japanese electronics industry has been steadily declining from the 1980s.[63] This was also pointed out in interviews conducted with engineers in the current study. To quote one of the interviewees, 'The price of semiconductor lasers is steadily decreasing. But we have to develop new generation semiconductor lasers for compact discs, barcode readers, DVDs, and blue ray discs for example.'[64]

Conclusions

This study discusses how semiconductor laser technology was developed in the U.S. and Japan by examining papers on semiconductor lasers published in the *Applied Physics Letters*. The first semiconductor lasers were invented by U.S. institutions in 1962. Bell Laboratories developed the first room temperature operation semiconductor lasers in 1970. U.S. organisations were the leaders in the early phase of technological development. The aim of all firms in the industry was to develop fundamental technology of semiconductor lasers for optical fiber and information storage. Inter-organisational collaborative networks, which allowed firms to access external complementary knowledge, were developed in the U.S. from the 1980s. As the networks grew, numerous startups targeting niche and custom markets spun off from big enterprises or universities. As Florida and Kenney pointed out, startups applied semiconductor laser technology in untapped markets by making use of well-developed research networks and the hyper mobility of engineers. The development of semiconductor lasers in the technological trajectory illustrated in Figure 3 eventually slowed down in the U.S. due to the dispersed and scattered R&D efforts into small niche markets. Markets with the highest volume were eventually dominated by Japanese firms that continued to compete in the same technological areas. However, while fierce competition in the same technological trajectory led Japanese firms to achieve breakthroughs, it also made it difficult for them to generate high returns over the long-term.

These findings imply that if many firms avoided competing in a certain

---

and 10% in 1996. *Ortel Annual Reports Form 10-K*, 1996.

[63] Mishina, K., *Senryaku Fuzen No Ronri [the Logic of Strategy Failure]*, Nobeoka, K., *Kachidukuri No Gijutsukeiei [Value Creation in the Management of Technology]*, Sakakibara, K., *Inobeshon No Shuekika [Profiting from Technological Innovations]*

[64] Interview with Dr. Hatakoshi Genichi, who was involved in semiconductor laser R&D at Toshiba, conducted by the author on 18 December 2008.

technological field and targeted different small markets, technological development would be retarded. Hayek regarded competition as a discovery procedure and emphasised the efficiency of information transaction in a market economy.[65] An individual firm does not own enough knowledge about the whole economy and does not necessarily know what the best technology is and what kind of product mix is suitable for the market. Through competition, firms gain knowledge about what is the most useful production system, which is the most satisfying product mix, and what kind of organisation is suitable for their business strategy. If many firms are competing in the same technological area for a certain period of time, this discovery procedure is enhanced.

Technology-intensive startups in the U.S. tended to target unexploited product markets and establish a unique position with a different product mix and technological choice from competitors; in contrast, Japanese firms tended to compete in the same product mix with the same technological choices as competitors. A questionnaire survey that the AIST conducted found that a number of firms competed in the same sort of product market, thus stimulating technological change of semiconductor lasers and industrial development.[66] This pattern of competitive strategy has been discussed in the existing English and Japanese literature on the competitive strategy of Japanese firms.[67] It has been argued that Japanese firms tended to make similar technological choices and compete in similar product markets.

Much of the existing literature on the competitive strategy of firms has taken a negative view of this pattern of competition. For example, Kim and Mauborgne indicated the need for firms to exist apart from markets that have a high concentration of rival competitors and to explore untapped product markets, called 'blue oceans.'[68] Introducing the industrial organisation framework in a firm's competitive strategy, Porter argued that it is essential for firms to assume a unique position in the product

---

65 Hayek, Competition as a Discovery Procedure, Hayek, The Meaning of Competition.

66 Kogyo Gijutsu In Somubu Gijutsu Chosaka, *Wagakuni Sangyo Gijutsu No Taishitsu to Kadai, [Survey of Japanese Industrial Technology],* pp.276-277.

67 For instance, Gregory, G., *Japanese Electronics Technology*, Okimoto, D. I. E., *Competitive Edge*. Asaba, S., *Nihon Kigyo No Kyoso Genri [Competitive Theory of Japanese Firms: An Empirical Study of the Isomorphic Behaviour of the Firm]*, Shintaku, J., *Nihon Kigyo No Kyoso Senryaku [Competitive Strategy of Japanese Firms]*.

68 Kim, W. C. and Mauborgne, R. E., *Blue Ocean Strategy*.

market in order to gain sustainable competitive advantages.[69] In his account, strategy rests on choosing a unique position by offering a different mix of value from competitors. Directing his attention to Japanese firms, Porter also pointed out, 'instead of choosing distinctive ways of competing, tailoring activities, and making trade-offs, Japanese companies tend to proliferate products and features, serve all market segments, sell through multiple channels, and emulate one another's production approaches.'[70] Porter maintained that this strategy without significant differences in activities is a classic strategic mistake. While the 'competitive forces' theory espoused by Porter takes a negative view of this pattern of competition in Japan[71], the competing pattern of Japanese firms served an important function in accumulating technological capabilities and inducing technological developments because this competition pattern encourages a high level of knowledge creation and exchange among competitors.

Second, the pattern of competition among Japanese firms did not necessarily increase their profitability due to strong competition in the same markets. Experiencing fierce competition in technological development, a firm has to spend a huge amount of resources in R&D to develop innovative products and to compete with its rivals. If firms in the industry cannot develop innovation and differentiate their products, price competition will be very severe, which will eventually lower profitability. It has been argued that Japanese firms pursue growth and market share at the expense of profitability and dividends.[72] While competition enhances technological development, intense competition over the long-term reduces profitability. It was a rational strategy for U.S. firms to channel their resources to untapped markets, which were usually more profitable than the product markets in which many firms were already engaged in fierce competition. It has been suggested that U.S. and Japanese firms faced different types of 'breakthrough illusions.' On the one hand, U.S. firms achieved important scientific breakthroughs in fundamental semiconductor laser technology but did not fully move from breakthroughs in R&D to mass production, a phenomenon which Florida and Kenney called 'the breakthrough illusion.' Startups play an important role in our society in developing new untouched markets and fulfilling untapped demand. With the support of well-developed research networks, high engineer mobility, and a sufficient supply of

---

[69] Porter, M. E., *Competitive Strategy*, Porter, M. E., What Is Strategy?

[70] Porter, M. E., Takeuchi, H. and Sakakibara, M., *Can Japan Compete?*, p.91.

[71] For a comparison of the 'competitive forces' theory with the resource- based view, see Teece, Pisano & Shuen, Dynamic Capabilities and Strategic Management.

[72] Blinder, A., *International Perspective,* Wolferen, K. V., *The Enigma of Japanese Power.*

venture capital, they explored untouched markets and allocated their resources to those markets in the U.S. However, this eventually slowed down the technological development of semiconductor lasers in the U.S., even though the startups earned higher profits than they would have been able to if they had competed in the same technological areas. On the other hand, Japanese firms faced a different type of 'breakthrough illusion' in that they did not fully profit from their breakthroughs due to fierce competition in the same product market, but the concentration of R&D efforts in the same market contributed to the enhancement of technological development in the semiconductor laser industry.

References

Ariga, K., Brunello, G. and Ohkusa, Y. (2000) *Internal Labor Markets in Japan* (Cambridge: Cambridge University Press).

Asaba, S. (2002) *Nihon Kigyo No Kyoso Genri: Doshitsuteki Kodo No Jissho Bunseki, [Competitive Theory of Japanese Firms: Empirical Study of Isomorphic Behaviour of the Firm]* (Tokyo: Toyo Keizai Shinpo Sha).

Blinder, A. (1992) International Perspective: Trading with Japan: Why the U.S. Loses-Even on a Level Playing Field *Business Economics*, 27: 25-29

Borgatti, S. P., Everett, M. G. and Freeman, L. C. (1999) *Ucinet 6.0 Version 1.00* (Natick: Analytic Technologies).

Bromberg, J. L. (1991) *The Laser in America, 1950-1970* (Cambridge: MIT Press).

Burgers, W. P., Hill, C. W. L. and Kim, C. W. (1993) A Theory of Global Strategic Alliances: The Case of the Global Auto Industry *Strategic Management Journal*, 14: 419-32

Chandler, A. D. (1994) The Competitive Performance of U.S. Industrial Enterprises since the Second World War *Business History Review*, 68: 1-72

Curtis, P. J. (1994) *The Fall of the U.S. Consumer Electronics Industry: An American Trade Tragedy* (Westport; London: Quorum Books).

Dosi, G. (1982) Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change *Research Policy*, 11: 147-62

Florida, R. L. and Kenney, M. (1990) *The Breakthrough Illusion: Corporate America's Failure to Move from Innovation to Mass Production* (New York: Basic Books).

Forrest, S. R., Coldren, L. A., Esener, S. C., et al. (1996) *JTEC Panel on Optoelectronics in Japan and the United States Final Report* (Baltimore: Japanese

Technology Evaluation Center/ International Technology Research Institute).
Freiberger, P. and Swaine, M. (2000) *Fire in the Valley: The Making of the Personal Computer* (New York; London: McGraw-Hill).
Gregory, G. (1986) *Japanese Electronics Technology: Enterprise and Innovation* (Chichester: Wiley).
Hatakoshi, G. (1997) Visible Semiconductor Lasers *The Journal of The Institute of Electronics Information and Communication Engineers* 80: 692-96
Hayashi, I. (2001) A Retrospective: 50 Years of Research- Following the Heart *Oyo Buturi*, 70: 1043-45
Hayek, F. A. V. (1948) The Meaning of Competition. In: Hayek, F. A. V., eds. *Individualism and Economic Order* (Chicago: University of Chicago Press), pp.92-106
Hayek, F. A. V. (2002) Competition as a Discovery Procedure *The Quarterly Journal of Austrian Economics*, 5: 9-23
Hazama, H. (1997) *The History of Labour Management in Japan* (Basingstoke: Macmillan).
Ikeda, M., Mori, Y., Sato, H., et al. (1985) Room-Temperature Continuous-Wave Operation of an Algainp Double Heterostructure Laser Grown by Atmospheric Pressure Metalorganic Chemical Vapor Deposition *Applied Physics Letters*, 47: 1027-28
Ito, R. (2001) Dai 1 Kai Oyo Butsuri Gakkai Gyoseki Jushosha Shokai (the Profile of Japan Society of Applied Physics Prizewinners) *Oyo Butsuri*, 70: 384-85
Itoh, H. (1994) Japanese Human Resource Management from the Viewpoint of Incentive Theory. In: Aoki, M. and Dore, R. P., eds. *The Japanese Firm: The Sources of Competitive Strength* (Oxford: Oxford University Press), pp.233-64
Jacobs, R. R. and Scifres, D. R. (2000) Recollections on the Founding of Spectra Diode Labs, Inc. *IEEE Journal of Selected Topics in Quantum Electronics*, 6: 1228-30
Kagaku Gijutsu Cho Kagaku Gijutsu Seisaku Kenkyusho. (2004) *Kagaku Gijutsu Shihyo: Nihon no Kagaku Gijutsu Katsudo no Taikeiteki Bunseki [Science and Technology Index: Systematic Analysis of Japan's Science and Technology Activities]* (Tokyo: Kokuritsu Insatsu Kyoku).
Kim, W. C. and Mauborgne, R. E. (2005) *Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant* (Boston: Harvard Business School).
Kogyo Gijutsu In Somubu Gijutsu Chosaka. (1983) *Wagakuni Sangyo Gijutsu No Taishitsu to Kadai, [Survey of Japanese Industrial Technology]* (Tokyo: Tsusho Sangyo Chosakai).
Kressel, H. and Lento, T. V. (2007) *Competing for the Future: How Digital Innovations*

Are Changing the World (Cambridge: Cambridge University Press).
Kroemer, H. (1963) A Proposed Class of Heterojunction Injection Lasers *Proceeding IEEE*, 51: 1782-83
Kuhn, T. S. (1970) *The Structure of Scientific Revolutions* (Chicago: University of Chicago Press).
Mainman, T. H. (1960) Stimulated Optical Radiation in Ruby *Nature*, 187: 493-94
Mishina, K. (2004) *Senryaku Fuzen No Ronri: Manseitekina Teishueki No Yamai Kara Do Nukedasuka [the Logic of Strategy Failure]* (Tokyo: Toyokeizai Shimposha).
Nakajima, H. and Ogawa, H. (1988) *Zukai Konpakuto Disuku Dokuhon [Handbook of Compact Disc]* (Tokyo: Omusha).
Nakamura, S., Senoh, M., Nagahama, S.-i., et al. (1996) InGaN-Based Multi-Quantum-Well-Structure Laser Diodes *Japanese Journal of Applied Physics*, 35: 74-76
Nakamura, S., Senoh, M., Nagahama, S.-i., et al. (1996) Room-Temperature Continuous-Wave Operation of InGaN Multi-Quantum-Well Structure Laser Diodes *Applied Physics Letters*, 69: 4056-58
Nihon Kogyo-Ginko. (1990) Hikari Sangyo No Shorai Tenbo [the Prospects for the Optoelectronics Industry] *Kogin Chosa* 250 no.6.
Nobeoka, K. (2008) Kachidukuri No Gijutsukeiei: Imiteki Kachi No Sozo to Manejimento [Value Creation of Management of Technology] *Hitotsubashi University Institute of Innovation Research Working Paper*, WP#08-05.
Okimoto, D. I., Sugano, T. and Weinstein, F. B. (1984) *Competitive Edge: The Semiconductor Industry in the U.S. And Japan* (Stanford: Stanford University Press).
Panish, M. B., Hayashi, I. and Sumski, S. (1970) Double-Heterostructure Injection Lasers with Room-Temperature Thresholds as Low as 2300 a/Cm2 *Applied Physics Letters*, 16: 326-27
Porter, M. E. (1980) *Competitive Strategy: Techniques for Analyzing Industries and Competitors* (New York: Free Press).
Porter, M. E. (1985) *Competitive Advantage: Creating and Sustaining Superior Performance* (New York; London: Free Press; Collier Macmillan).
Porter, M. E. (1996) What Is Strategy? *Harvard Business Review*, November-December: 61-78
Porter, M. E., Takeuchi, H. and Sakakibara, M. (2000) *Can Japan Compete?* (Cambridge: Basic Books/Perseus Publication).
Rogers, M. (2001) Ortel, in Three Acts *Caltech News*, 35: 5
Sakakibara, K. (2005) *Inobeshon No Shuekika: Gijutsukeiei No Kadai to Bunseki*

[Profiting from Technological Innovations] (Tokyo: Yuhikaku).
Saxenian, A. (1994) *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge; London: Harvard University Press).
Saxenian, A. (2002) *Local and Global Networks of Immigrant Professionals in Silicon Valley* (San Francisco: Public Policy Institute of California).
Shimizu, H. (2007) *Competition, Knowledge Spillover, and Innovation: Technological Development of Semiconductor Lasers, 1960-1990*. PhD thesis, London School of Economics and Political Science.
Shimizu, H. and Hirao, T. (2008) Collaborative Research Networks in Semiconductor Laser Technology, 1960-2000: A Comparative Perspective on Networks and Breakthroughs in the United States and Japan *Business and Economic History On-Line*, 6: 1-24
Shintaku, J. (1994) *Nihon Kigyo No Kyoso Senryaku [Competitive Strategy of Japanese Firms]* (Tokyo: Yuhikaku).
Tamargo, M. C. (2002) *II-VI Semiconductor Materials and Their Applications* (New York: Taylor & Francis).
Teece, D. J., Pisano, G. and Shuen, A. (2000) Dynamic Capabilities and Strategic Management. In: Dosi, G., Nelson, R. R. and Winter, S. G., eds. *The Nature and Dynamics of Organizational Capabilities* (Oxford: Oxford University Press), pp.334-62.
Tokkyocho. (1999) *Korede Wakaru Handotai Reza: Motto Tsukao Motto Ikaso Konna Gijyutsu [Handbook of Semiconductor Laser]* (Tokyo: Hatsumei kyokai).
Tsusho Sangyo Sho. (1979) *Denshi Kogyo Nenkan [Annual Report on the Electronic Industry]* (Tokyo: Denpa Shimbunsha).
Vogel, E. F. (1979) *Japan as Number One: Lessons for America* (Cambridge: Harvard University Press).
Welch, J. and Byrne, J. A. (2001) *Jack: Straight from the Gut* (New York: Warner Books).
Wolferen, K. V. (1989) *The Enigma of Japanese Power: People and Politics in a Stateless Nation* (London: Macmillan).
Wolff, M. F. (1962) Will Diode Laser Obsolete Earlier Lasers? *Electronics*, 35: 14-15
Wood, S. C. and Brown, G. S. (1998) Commercializing Nascent Technology: The Case of Laser Diodes at Sony *Journal of Product Innovation Management*, 15: 167-83
Yamamoto, S., Hayashi, H., Hayakawa, T., et al. (1982) Room-Temperature CW Operation in the Visible Spectral Range of 680–700 Nm by AlGaAs Double Heterojunction Lasers *Applied Physics Letters*, 41: 796-98