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Innovation Dynamism of Material Technology:
Empirical Analysis of Lithium Ion Battery Industry

By

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08D46044

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Abstract

The main purpose of this study is to reveal the innovation dynamism of material technology, because the development of materials plays a significant role in driving the innovation process. In this study, we focus on Lithium Ion Battery (LIB) as an essential energy device in an information society and analyze the development of materials used in a cathode.

In Chapter I, background of this study is introduced; market trends in the LIB industry, technological structure of LIB, and technological characteristics of materials. Additionally, the relations between previous works and this study, and structure of this dissertation are noted.

In Chapter II, we compare diffusion trajectories of electrode technology in Sony and Panasonic by utilizing patent data, and analyze chronologies of material patents obtained by these firms. On the basis of observation, it was revealed that diffusion trajectories of electrode technology had two waves in both firms. The 2^{nd} wave was initiated by the development of composite materials used in a cathode.

In Chapter III, analyzing the LIB innovation process, we group technologies composing a LIB into 'simple technology' and 'complex technology' by the combination of International Patent Classification (IPC). Based on this model, LIB innovation process in Sony and Panasonic was compared as a model. In conclusion, it was revealed that technologies composing a LIB have diversified from simple technology to complex technology when material technology developed to process, component, and product technologies in both firms. It was also revealed that both simple materials and composite materials traced a similar diversification process in both firms.

In Chapter IV, we analyze trends in the number of patent applications of LIB filed in Japan patent office. It was shown that technologies composing a LIB have diversified from simple technology to complex technology in the LIB industry, and then technology leading the LIB innovation process was replaced from simple technology to complex technology with the development of materials used in a cathode.

In Chapter V, as the total conclusion in this study, it was revealed that technologies composing a LIB have diversified from simple technology to complex technology in the LIB innovation process, and then the combination of IPC has been complicated.

In Chapter VI, R&D management in Panasonic is discussed as addendum. It is considered that 'cross-industrial associations' and 'platform structure' in R&D system can contribute to promote the technological integrations.

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Chapter I

Introduction

1.1 Innovation of material technology in an information society

Innovation is undoubtedly recognized as a significant driving force in sustaining economic growth. As emphasized in numerous studies, innovation of information technology (IT) can dramatically change socioeconomic structures such as people's daily life, organizational activities, and society itself. Service innovations like Google and You Tube were built on the infrastructure of IT, and this IT infrastructure depends on the diffusion of electric device such as cellular phones and laptop PCs.

Most of these electric devices include a battery as a main energy device, and the battery is a key component in the development of functionalities in an electric device. For instance, the development of batteries with high energy density make it possible to expand the functionality of cellular phones for not only talking and e-mail, but also one-seg, music player, TV phone, GPS, movie camera and others. Generally, energy is generated in an electrode, and technological performance of energy devices depends on the material characteristics used in an electrode. Thus, material innovation plays a significant role in driving the development of energy devices and the growth of IT infrastructure.

This fact suggests that material innovation has a strong relationship with the service innovation in an information society. Material innovation has supported service innovation, and service innovation has boosted material innovation. Therefore, it is important to understand the mechanism of material innovation to survive in the world of mega competition.

The development of IT has accelerated the diffusion of digital equipment in the world since the early 1990s. With the diffusion of digital equipment, Lithium Ion Battery (LIB) market also expanded, because the LIB is an essential energy device which can provide higher energy density than other energy devices. Today, many products contain LIB, for example, cellular phones, laptop PCs, and PDAs (personal digital assistant) around the world. LIB was first put into practical use and released to the market by Sony in 1991, and since then Japanese firms have occupied the largest market share for the last 20 years. Therefore, we focus on the LIB innovation process as a model of material innovation, and analyze the development process of material technology used in an electrode in this study.

1.2 Lithium ion battery industry

1.2.1 Technological performance of LIB

Many kinds of digital equipment contain LIB as energy device, and the diffusion of digital equipment has accelerated the expansion of LIB market since the early 1990s. It is because lithium is capable of generating higher energy density than other elements such as nickel, alkaline, and manganese. LIB can be categorized into primary LIB and secondary LIB. Electric power is only discharged in a primary LIB, and it is discharged and recharged in a secondary LIB. The secondary LIB is used in most kinds of digital equipment to recharge energy. Technological characteristics of secondary LIB are summarized like follows.

[Technological characteristics of secondary LIB]

1. Energy density can be generated higher than that of other batteries.
2. Usable duration per charge is longer than that of other batteries.
3. Memory effect is better than that of other batteries in recharging.
4. Charging capacity is hardly deteriorated with the duration of use.
5. Dendrites are hardly precipitated on the electrode.

The material generally used in an anode is carbon, so that lithium has to be used as the main material in a cathode to occur a chemical reaction between cathode and anode. This chemical reaction is considered as the fundamental in the functioning of LIB. The chemical reaction occurs on the electrodes, and then the transfer of lithium-ions on the electrode generates electric power.

The materials generally used in a cathode are lithium-metal oxides; lithium-cobalt oxide ($LiCoO_2$), lithium-nickel oxide ($LiNiO_2$), and lithium-manganese oxide ($LiMn_2O_4$) are especially popular materials, because these materials are superior to other materials in terms of their potential characteristics and cycle characteristics (Ohzuku et al., 1995). These materials have been used in a cathode since the practical use of LIB started in 1991, and the same materials are still being used even now. These materials are essential for generating electric energy, therefore it can be said that the technological functionality of LIB depends on how characteristics of these cathode materials is developed. In this study, since the development of materials plays a significant role in driving the LIB innovation process, we focus on the development of cathode materials as a core technology in LIB.

1.2.2 Trends in LIB market in the world

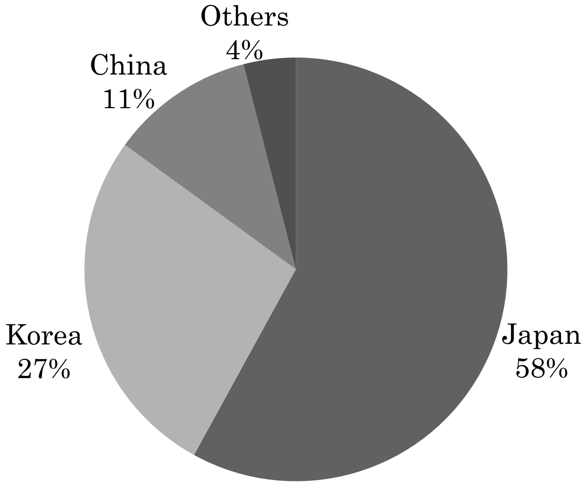


Figure 1-1. World LIB market share in 2008.

Figure 1-1 shows the world market share of the LIB industry in 2008. Data source is the report of "Survey on technological trends in patent applications of LIB industry, 2010" provided by Japan Patent Office (JPO). It is obvious from this figure that Japanese firms occupy the largest LIB market share in the world.

LIB was first manufactured for the market by Sony in 1991 (Nagaura, 1991), and Japanese firms has led the innovation in the LIB industry since then. In fact, Japanese firms occupied more than 90% market share in the 1990s, and they occupied 80% market share in the early 2000. However, market share of Japanese firms decreased to about 60% in 2008. The growth of Chinese firms and Korean firms is considered as the main reason.

In China and Korea, LIB industry is selected as the most important industries, and government invested into firms, universities, and public institutes to encourage researches in the field of LIB. In addition to the increase of market share, the number of patents and academic papers published by these countries are also increased. Therefore, it is important for Japanese firms to make continued innovations and keep the current market share in the LIB industry.

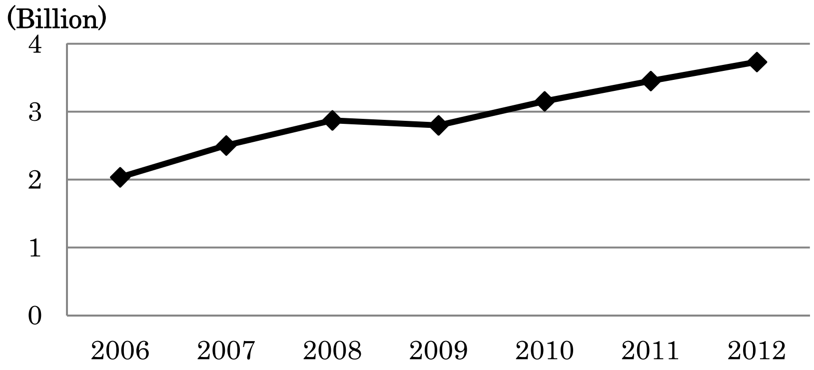


Figure 1-2. Trends in total sales amount of LIB in the world.

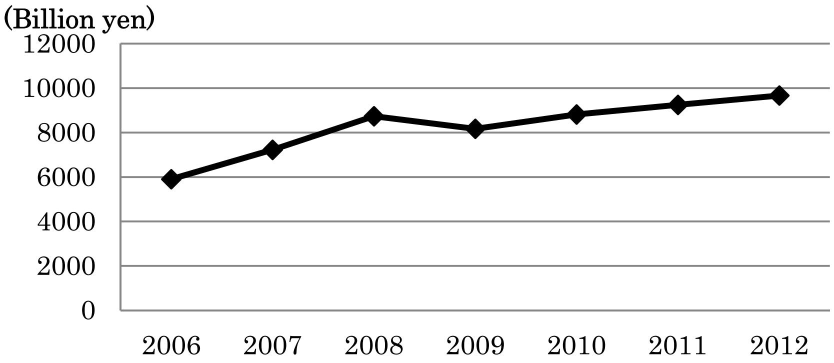


Figure 1-3. Trends in total sales of LIB in the world.

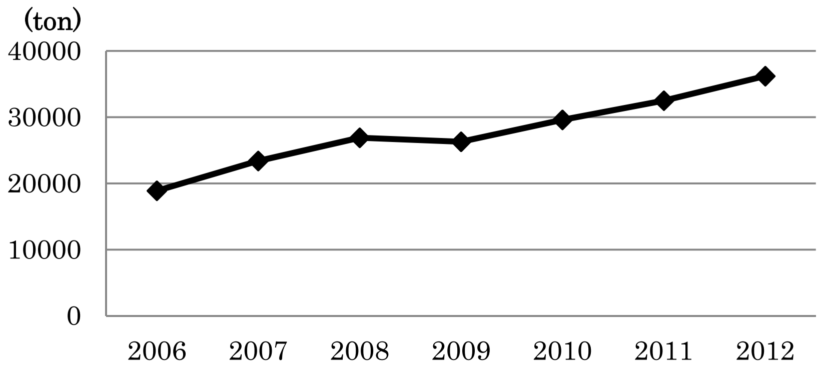


Figure 1-4. Trends in total sales amount of cathode in the world.

Figure 1-2, Figure 1-3, and Figure 1-4 shows trends in total sales amount of LIB in the world, total sales of LIB in the world, and total sales amount of cathode in the world, respectively. Data source is the report of "Survey on technological trends in patent applications of LIB industry, 2010" provided by JPO. These data suggests the possibility of market expansion of the LIB industry in the future.

1.2.3 Trends in domestic LIB market

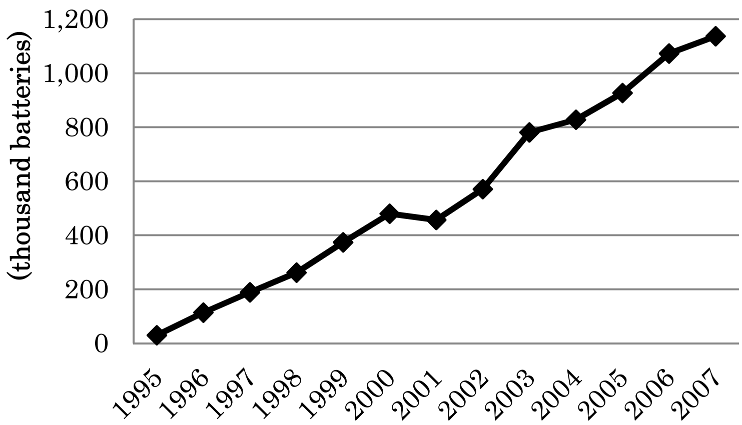


Figure 1-5. Trends in total sales amount of secondary LIB in Japan.

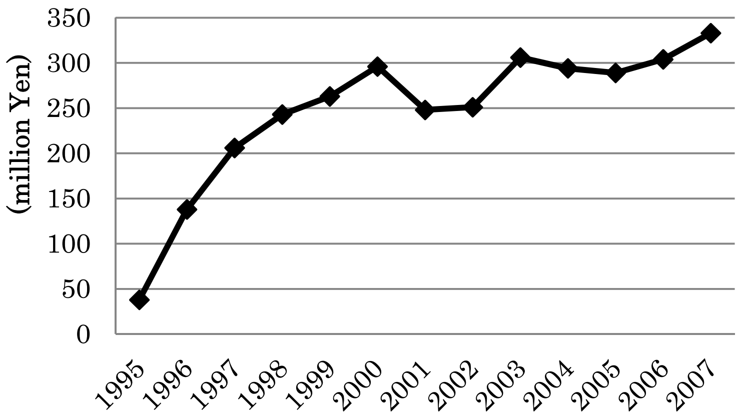


Figure 1-6. Trends in total sales of secondary LIB in Japan.

Japanese firms have occupied the largest LIB market share for the last 20 years. In fact, Japanese firms occupied about 60% world market share of the LIB industry in 2008. Therefore, we focus on firms manufacturing LIB in Japan as a model to analyze the LIB innovation process. Figure 1-5 and Figure 1-6 shows trends in total sales amount and total sales of secondary LIB in the Japanese domestic market, respectively. Data source is the report provided by Battery Association of Japan. These data suggests that total sales amount of secondary LIB has been increasing since the practical use of LIB started in 1991. The increase of total sales of secondary LIB was accelerated in the 1990s, but it has decelerated since 2000.

1.3 Trends in the number of patent applications in the LIB industry

1.3.1 Trends in the number of patent applications in Japan

Before the analysis, it is useful to know trends in the number of patent applications of LIB filed in JPO. Figure 1-7 shows trends in the number of patent applications of LIB which are filed in JPO during 1976-2006. The patent data are obtained by a retrieval of patent data in "Industrial Property Digital Library" provided by National Center for Industrial Property Information and Training in Japan.

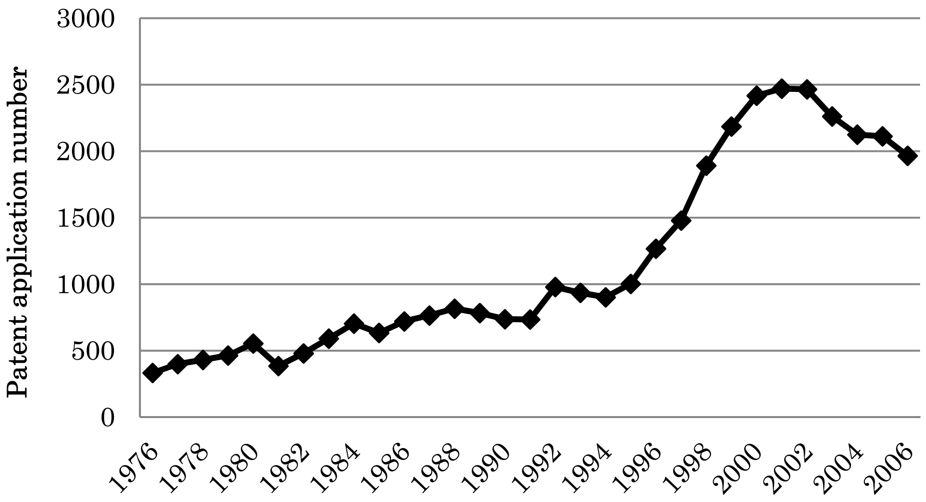


Figure 1-7. Trends in the number of patent applications of LIB in JPO.

Figure 1-7 demonstrates that the number of patent applications of LIB increased rapidly between 1991 and 2002. Patents are selected by using the International Patent Classification (IPC); details are described in Chapter IV. LIB was first manufactured for the market in 1991 by Sony (Nagaura, 1991), and many firms have entered this market since then. It might influence trends that the number of patent applications has begun to decrease since 2002.

One of reasons of these trends in the number of patent applications, it is considered that Japanese firms demonstrated strategic Research and Development (R&D) and filed patents as results of their strategic R&D management. The new functions and capabilities of LIB were developed to differentiate products by encouraging the intensity of R&D competition.

1.3.2 Trends in the number of patents and paper publications in each country

It is also useful to compare the world ranking about the number of patents and papers regarding LIB provided by firms, universities, and public institutes. Data source of Table 1-1, Table 1-2, and Table 1-3 is the report of "Survey on technological trends in patent applications of LIB industry, 2010" provided by JPO.

Table 1-1 shows world ranking about the number of patent applications of LIB in 2009. Table 1-1 demonstrates that four Japanese firms were ranked among the world's top five firms. Panasonic took the first place, and Sony took the second one.

Table 1-2 shows world ranking about the number of researchers who published papers in journals regarding LIB which are selected by committee in JPO; for instance, Power Sources, Journal of the electrochemical society, Electrochemical acta and so on. Table 1-2 demonstrates that one Japanese public institute, National Institute of Advanced Industrial Science and Technology, took the first place. Additionally, two universities, Kyoto university and Tokyo Institute of Technology, took the second and fourth place, respectively.

Table 1-3 shows ranking about the number of patent applications of LIB which were filed in the four world patent offices in 2009; Japan Patent Office (JPO), United State Patent and Trademark Office (USPTO), European Patent Office (EPO), State Intellectual Property Office of China (SIPO). Table 1-3 demonstrates that Sony and Panasonic were ranked among the top three firms in every patent office. Panasonic took the first place in Japan, Europe, and China. This table suggests that Sony and Panasonic have some effective R&D system for leading the innovation. Therefore, we focus on the LIB department in Sony and Panasonic.

These data suggest that Japanese firms conduct strategic R&D management, which contribute to increase the number of patent applications. It also can be said that the level of basic research conducted in Japanese universities and public institutes are much advanced in the world.

In this study, we focus on the Japanese top two leading firms, Sony and Panasonic, and compare the LIB innovation process by analyzing patent data filed by these two firms.

Table 1-1 Rank for world patent application of LIB in 2009.

	Firm	num
1	Panasonic(JP)	2291
2	Sony (JP)	2096
3	Samsung (KR)	1949
4	Sanyo (JP)	1628
5	Mitsubishi chemical(JP)	849

Table 1-2 Rank for the number of LIB researchers in the world in 2009.

	Institute	num
1	National Institute of Advanced Industrial Science and Technology (JP)	368
2	Kyoto university (JP)	280
3	Chinese Academy of Science (CN)	267
4	Tokyo Institute of Technology (JP)	255
5	Argonne National Laboratory (US)	241

Table 1-3 Rank for patent application of LIB in each patent office in 2009.

	JPO	num	USPTO	num	EPO	num	SIPO	num
1	Panasonic(JP)	1144	Samsung(Kr)	415	Panasonic(JP)	176	Panasonic(JP)	295
2	Sony(JP)	1129	Panasonic(JP)	375	Sony(JP)	145	Samsung(KR)	274
3	Sanyo(JP)	880	Sony(JP)	328	LG chem(KR)	107	Sony(JP)	249
4	GS Yuasa(JP)	692	Sanyo(JP)	312	Samsung(Kr)	91	Sanyo(JP)	178
5	Mitsubishi chemical(JP)	616	LG chem(KR)	120	Merck(DE)	78	BYD(CN)	177

Firm or Institute of JP: Japan, KR: Korean, CN: China, US: United State, DE: German

1.4 Technological structure of LIB

1.4.1 Composition of LIB

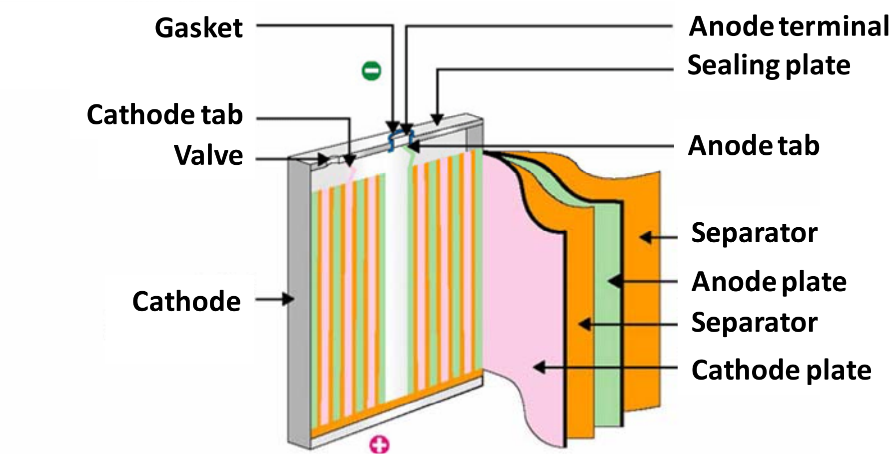


Figure 1-8. Technological structure of LIB.

Figure 1-8 shows the technological structure of LIB. Based on the technological structure, it can be conceptualized that batteries are composed of three technology segments; 'Exterior', 'Structure', and 'Electrode'.

'Exterior' is the technology segment which decides the appearance of a battery such as the shape, weight, and size of LIB; for instance, difference of the shape whether circular LIB or rectangular LIB is distinguished in this segment. 'Structure' is the technology segment which decides the structural details of a battery to recharge electric energy; for instance, difference of the categorization whether primary LIB or secondary LIB is distinguished in this segment. 'Electrode' is the technology segment which decides the details of a cathode and an anode to cause a chemical reaction to generate energy; for instance, difference of the materials used in a cathode is distinguished in this segment.

In these three technology segments, 'Electrode' can be considered as the most important component, because chemical reaction to generate electric power is occurred on the electrode. Then, characteristics of materials used in an electrode have significant influences to generate electric power. Therefore, we mainly discuss how the development of these materials contributes to lead the innovation in the LIB industry.

1.4.2 Composition of electrode

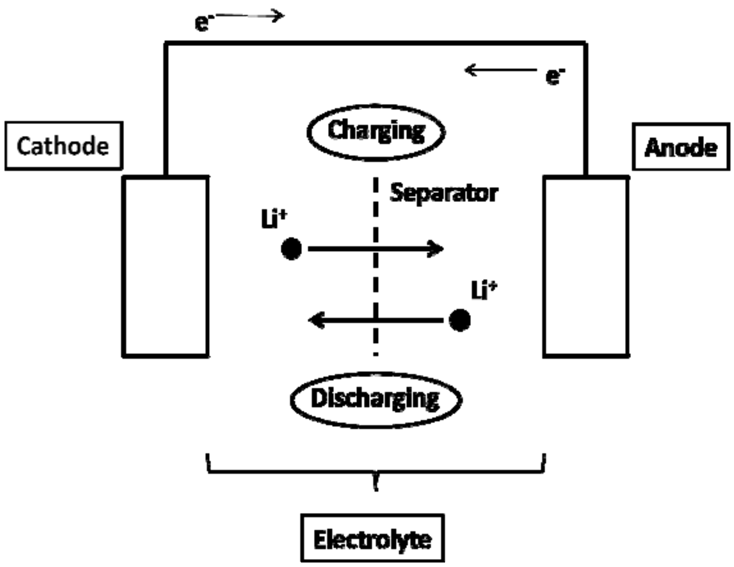


Figure 1-9. Technological structure of an electrode.

Figure 1-9 shows the technological structure of electrode. The chemical reaction occurred on the electrode generates electric power by transferring the lithium-ions between cathode and anode. In recharging, lithium-ions transfer from cathode to anode. In contrast, in discharging, lithium-ions transfer from anode to cathode; for instance, general chemical reaction in recharging can be described as follows.

(Cathode) $LiCoO_2 \rightleftarrows Li_{1-x}CoO_2 + xLi^+ + xe^-$

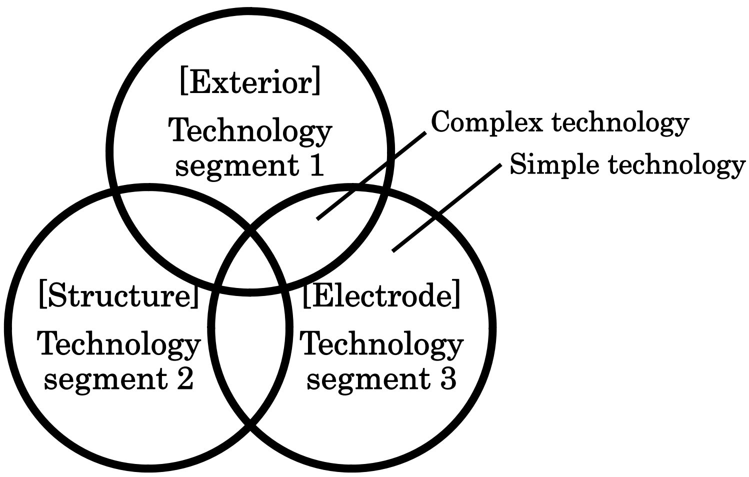
(Anode) $xLi^+ + xe^- + 6C \rightleftarrows Li_xC_6$

In the structure of electrode, the electrolyte is one of the most significant structural differences between LIB and other batteries such as the alkaline battery, nickel battery, and manganese battery. Generally, other batteries contain aqueous solvent as an electrolyte to generate energy, but aqueous solvent is unusable in LIB. It is because lithium easily degrades the aqueous solvent, so that LIB needs to contain organic solvent instead of aqueous solvent as an electrolyte. A drawback of organic solvents, it can easily burn due to the instability of lithium-ion, and causes overheating problems in LIB. Therefore, stabilization materials used in an electrode are essential for LIB to transfer lithium-ions safely.

1.4.3 Conceptual model of technological composition of LIB

It can be conceptualized that batteries are composed of three technology segments; 'Exterior', 'Structure', and 'Electrode'. We divide these three technology segments into two kinds of technological concepts, 'simple technology' and 'complex technology', by using the IPC. We define 'simple technology' as the technology which belongs to only one technology segment, and 'complex technology' as the technology which belongs to two or more technology segments. In this model, technologies composing a LIB can be divided into seven technology groups; three groups are simple technology, and four groups are complex technology. Figure 1-10 shows the conceptual model of grouping three technology segments and the relations with simple technology and complex technology.

In this study, we mainly focus on the development of 'Electrode', because 'Electrode' is a key component to decide the cost, technological functionality such as energy density, and safety of LIB. The development of materials used in an electrode plays an important role in leading the LIB innovation process.



[Simple technology]
'Exterior', 'Structure', 'Electrode'

[Complex technology]
'Exterior and Structure', 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'

Figure 1-10. Conceptual model of grouping technologies composing a battery.

1.5 Development of material technology in LIB

1.5.1 Development of energy density

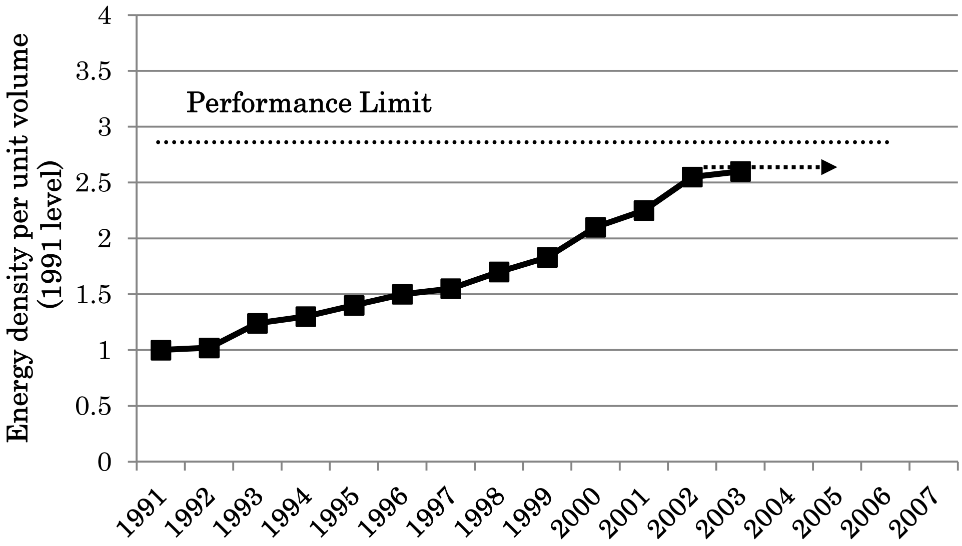


Figure 1-11. Trends in energy density per unit volume of materials (1991 level).
Source: Next generation secondary Lithium Ion Battery, NTS Inc.

Figure 1-11 shows the improvement of energy density of materials used in a cathode. LIB was first manufactured by Sony in 1991, and energy density has been improved since then. In the early 2000s, energy density of LIB has increased about 2.5 times higher than energy density in 1991. It is because higher energy density was required for LIB to satisfy customer's needs with the development of IT and diffusion of digital equipment.

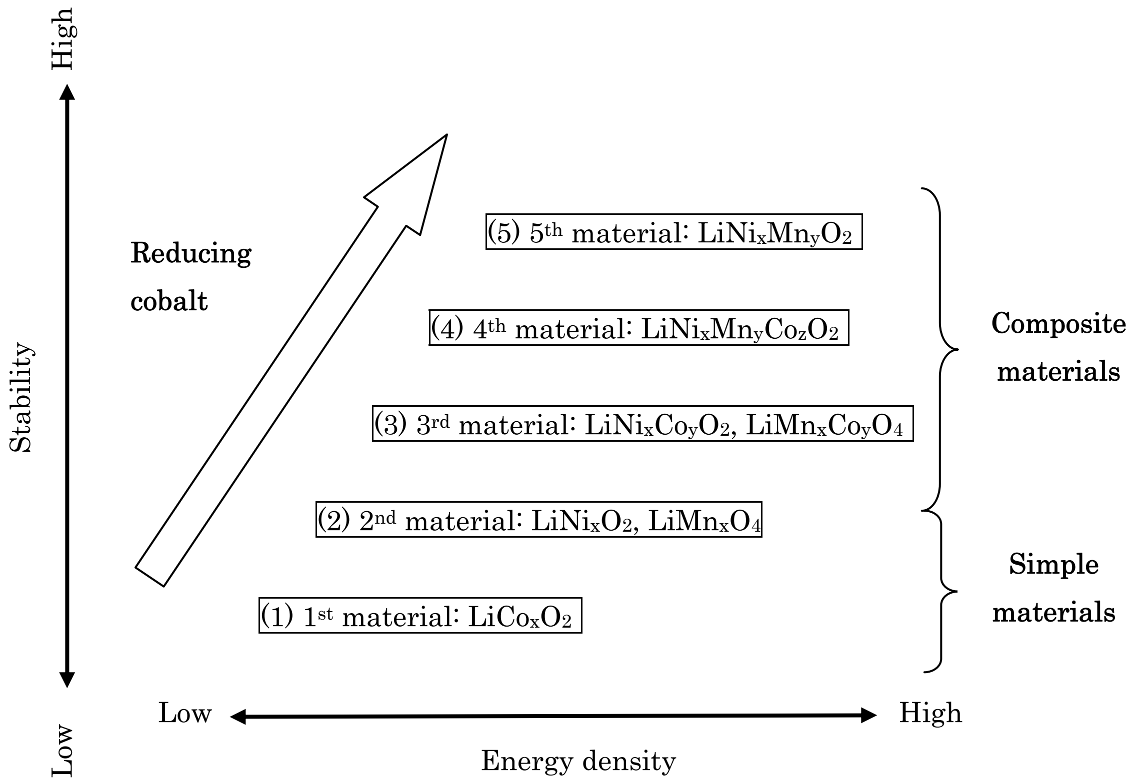
Improvement of energy density per unit volume was accelerated in the 1990s, but it has decelerated since 2000. One of reasons of this deceleration could be that although lithium-cobalt oxide has been used as the main material since the practical use of LIB started in1991, these traditional materials have already reached their performance limit. In addition, essential technologies to make electrodes work such as 'Exterior' and 'Structure' have also been developed to a certain level. It was required for new materials to improve energy density in the next stage.

Therefore, firms could no longer rely on traditional materials to produce electrodes as they did in the 1990s, but had to develop materials with suitable characteristics which could provide higher energy density with lower cost. Composite materials were then developed to lead the improvement of energy density since 2000.

1.5.2 Development of materials used in a cathode

After the practical use of LIB started in 1991, the main purpose of R&D was how technological functionality of electrode could be developed. This functionality of electrode depends on the material characteristics in a cathode and an anode. In a case of cathode, the main goal in the development of materials is how to improve energy density and stability simultaneously with reducing the rate of cobalt (Ohzuku et al., 2007). In this study, we define the development of materials used in a cathode as the following five groups; details are described in Chapter II.

(1) The first material used in a cathode is the lithium-cobalt oxide, which is mainly composed of cobalt. As previously noted, LIB was first manufactured by Sony in 1991, and this material has been used since then. It is because cobalt is known as a material with desirable electric characteristics (Nagaura, 1991; Sekai et al., 1993).
(2) The second material used in a cathode is the lithium-nickel (or manganese) oxide, which is mainly composed of nickel (or manganese). Although cobalt is used in LIB as the desirable material, unavailability of cobalt is pointed as drawbacks. Therefore, these materials were expected to be alternative materials of cobalt, and appeared in the late 1990s (Amatucci et al., 2002; Gummow et al., 1994).
(3) The third material used in a cathode is the lithium-nickel (or manganese)-cobalt oxide, which is mainly composed of nickel (or manganese) and cobalt. The improvement of energy density was accelerated in the 1990s, but it turned to be decelerated after 2000. Then, composite materials in which a portion of cobalt was replaced with nickel (or manganese) were invented to provide higher energy density and constituted with a desirable material structure for heat load in the early 2000s (Armstrong et al., 2002; Ohzuku et al., 1993).
(4) The fourth material used in a cathode is the lithium-nickel-manganese-cobalt oxide, which is mainly composed of nickel, manganese, and cobalt. A portion of cobalt was replaced with both nickel and manganese. This material was diffused rapidly in the late 2000s (Koyama et al., 2004 a, 2004 b; Yoshizawa et al., 2003).
(5) The fifth material used in a cathode is the lithium-nickel-manganese oxide, which is mainly composed of nickel and manganese. This material hasn't put into practical use yet in the LIB industry, but it is expected as the next generation material. It is because it makes electrodes work without cobalt (Gopukumar et al., 2004; Jae-Won et al., 2009; Makimura et al., 2003; Yoncheva et al., 2007, 2009).



(1) 1st material: lithium-cobalt oxide
(2) 2nd material: lithium-nickel (or manganese) oxide
(3) 3rd material: lithium-nickel (or manganese)-cobalt oxide
(4) 4th material: lithium-nickel-manganese-cobalt oxide
(5) 5th material: lithium-nickel-manganese oxide

Figure 1-12. Development of materials used in a cathode.

Based on this material classification, Figure 1-12 shows the development process of materials defined as 1st ~ 5th materials. The main goal in the development of materials is how to invent composite materials with high energy density and stability simultaneously with reducing the rate of cobalt.

In this classification of materials, 1st and 2nd materials can be called ‘simple material’, which is mainly composed of only one element other than lithium and oxygen. In contrast, 3rd, 4th, and 5th materials can be called ‘composite material’, which is mainly composed of two or more elements other than lithium and oxygen.

1.6 Previous works

Many studies demonstrated that technology spillover could play an important role in leading innovations. As Griliches (1979) suggested, the level of productivity achieved by one firm or industry depends on not only its own R&D efforts but also general knowledge spilled over from other firms and industries.

Additionally, many papers discussing the significant role of technology spillover to encourage the development of technologies have been published. For example, technology spillover has influences on R&D strategy (Watanabe et al., 2001). Firms with a well-developed assimilation capacity succeeded in effectively utilizing of technology spillover (Watanabe et al., 2002). The importance of relationships between university and industry in the management of basic researches has been discussed (Audretsch and Lehmann, 2005; Kelly and Nakosteen, 2005; Tanabe and Watanabe, 2005; Millson and Wielmon, 2006). Cross-functional spillover could be a survival strategy for ceramics industry (Ohmura et al., 2005). The differences of firm's size are one of important factors for technology spillovers (Ornaghi, 2006). Furthermore, other studies also demonstrated that technology developments could be attributed to technology spillover (Griliches and Lichtenberg, 1984; Jaffe, 1986; Bernstein and Nadiri, 1988, 1989; Goto and Suzuki, 1989; Kwang and Watanabe, 2001; Nakanishi, 2002; Watanabe and Ane, 2003; Watanabe and Tokumasu, 2003; Nieto and Quevedo, 2005). However, most of these studies mainly discussed mechanism of technology spillover between firms.

As Geroski (1995) suggested, since the process of technology spillover depends on the maturity of technologies, industrial features and technological characteristics should be taken into consideration when we discuss the technology spillover. Therefore, we focus on how such features and characteristics can be reflected into the analysis of technology spillover in this study.

Two-dimensional technology spillover mechanism is introduced, and the role of technology spillover is discussed from two aspects in this study, organizational point of view and technological point of view. Combining these two types of technology spillovers, we classify technology spillover into four types; (1) intra-firm, intra-technology spillover, (2) intra-firm, inter-technology spillover, (3) inter-firm, intra-technology spillover, (4) inter-firm, inter-technology spillover. Based on this model, we discuss the technology spillover not only between firms but also between technologies.

In this study, we focus on the significant role of LIB in an information society, because LIB is used in digital equipments as the main energy device such as cellular phones, laptop PCs, digital cameras and so on. Since Japanese firms has occupied the largest market share and filed the largest number of patent applications in the world since the practical use of LIB started, the LIB industry in Japan can be an excellent case study in analyzing the LIB innovation process.

In a mature economy, new finding of materials plays a significant role in driving innovations. In fact, material technology has supported service and device innovations in incorporating new functions into new devices. It can be said that the functionality in digital equipments depends on the characteristics of cathode materials. For instance, improvement of energy density of cathode materials makes it possible to expand the functionality of cellular phones for not only talking and e-mail but also one-seg, music player, TV phone, GPS, movie camera and others. Therefore, it is important to understand the mechanism of material innovation.

Some papers suggested that technology spillover plays a significant role in driving the development of materials. For instance, the effect of technology spillover in fine ceramics industry was analyzed (Ohmura et al., 2003, 2006). The effect of technology spillover in the nonferrous metal industry was also analyzed (Nakagawa et al., 2007, 2009). We observed the technology spillover effect in the acoustic industry and suggested that the development of material technology was a key to improve the functionalities in a product (Shibata and Saiki, 2009). Thus, on the aspect of technology spillover, the importance of how to innovate materials were discussed so far.

Therefore, we mainly focus on following points in this study.

i) How development of material technology has contributed to drive the diffusion of innovation in the LIB industry in Chapter II.

ii) How development of material technology has contributed to encourage the technology spillover among technologies composing a LIB in Chapter III.

iii) How development of material technology has contributed to advance the diversification of technologies in the LIB innovation process in Chapter IV.

1.7 Structure of the dissertation

In Chapter I, background of this study is introduced; market trends in the LIB industry, technological structure of LIB, technological characteristics of materials, and the relations between previous works and this study are noted.

In Chapter II, trends in diffusion trajectories of electrode technology are analyzed between leading two firms in Japan, Sony and Panasonic. Numerical analysis is conducted by utilizing the bi-logistic function model based on patent data. The development of cathode materials is classified into five groups by the combination of elements, and the timing of when patents of these cathode materials are obtained by these firms is compared.

In Chapter III, based on the results in Chapter II, trends in technology spillover in Sony and Panasonic are analyzed on the aspect of organizational point of view and technological point of view as a case study. The changes of technology spillover structure are compared based on the patents obtained by these firms. In this analysis, we focus on the development process of simple materials and composite materials in these firms by observing the references to patents.

In Chapter IV, based on the results in Chapter III, trends in the diversification process of electrode technology are analyzed by focusing on the combination of IPC of patents filed in JPO. Technologies composing a LIB are grouped into simple technology and complex technology by using the IPC, and technologies composing a LIB are classified into seven technology groups. We compare the number of patent applications among seven technology groups to analyze the contribution of each technology group for innovation, and demonstrate a multiple regression analysis to investigate the most influential technology group leading the LIB innovation process.

In Chapter V, new findings in each chapter are summarized. Finally, as a total conclusion of this study, it is suggested that technologies composing a LIB have diversified with the development of material technology in the LIB innovation process.

In Chapter VI, R&D management in Panasonic is discussed as addendum. It is considered that ‘cross-industrial associations’ and ‘platform structure’ in R&D system can contribute to promote the technological integrations.

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Chapter II
Diffusion of Innovation in the Lithium Ion Battery Industry: Comparative Analysis between Sony and Panasonic

Abstract

In this Chapter II, diffusion of innovation regarding the Lithium Ion Battery (LIB) is analyzed by using patent data. We compare trends in patent applications of electrode technology between Sony and Panasonic. First, diffusion trajectories of electrode technology in Sony and Panasonic are compared. Numerical analysis is conducted by utilizing the bi-logistic function model and patent data which is grouped by International Patent Classification (IPC). Next, we classify the development of materials used in a cathode into five groups, and compare chronologies of material patents obtained by Sony and Panasonic.

On the basis of observation of patent statistics, it was revealed that their diffusion trajectories of electrode technology had two waves, and Panasonic succeeded in prompt undertaking in the 2nd wave on their diffusion trajectory. It was also revealed that Panasonic obtained patents of composite materials earlier than Sony. In conclusion, the results show that Panasonic's prompt undertaking in the 2nd wave earlier than Sony was initiated by the development of composite materials.

Key words

Cathode materials; Diffusion of innovation; International patent classification; Lithium ion battery; Patent.

2.1 Introduction

The development of new technologies is undoubtedly recognized as a significant driving force in sustaining economic growth. As emphasized in numerous studies, the development of information technology (IT) is a driving force transforming the existing socioeconomic structure by permeating people's daily life, organizational activities, and society itself (Ruttan, 2001; Cairncross, 1997).

As introduced in Chapter I, with the development of IT and diffusion of digital equipment, Lithium Ion Battery (LIB) market also expanded, because LIB is required as an essential energy device which can provide high energy density. In the LIB industry, Japanese firms have occupied the largest market share for the last 20 years since the practical use of LIB started in1991. Therefore, we focus on the LIB innovation process of Japanese two leading firms, Sony and Panasonic.

2.1.1 Diffusion of Innovation

Research on the diffusion of innovation has been undertaken in many previous studies. Rogers (1962) attempted to systematize these works in his pioneer work in "Diffusion of Innovations". In his research, Diffusion is defined as "*the process by which an innovation is communicated through certain channels over time among the members of a social system*". It is also suggested that there are four main elements in the diffusion of innovations; innovation features, communication channels, time, and social system. All of Rogers' postulates support the contention that technological functionality can be developed during the diffusion process.

Following this work, it is pointed that adopters who adopt earlier than others are likely to have more gain from the use of products and hence have a greater usage propensity. Additionally, adoption of complex products such as personal computers depends on buyers' ability to develop new knowledge and new patterns of experiences (Mahajan et al., 1990).

Griliches (1957) noted that diffusion process is actually quite similar to the contagion process of epidemic disease, and it can be exhibited as S-shaped growth. Verhulst (1845) first introduced the simple logistic growth function as an epidemic function to model the diffusion process. In a number of previous studies, this logistic growth function has proved to be useful in modeling the wide range of innovation processes, so that this epidemic function is used in analyzing the diffusion process of innovations (Meyer and Ausbel, 1999; Modis, 1992).

Meyer (1994) extended the analysis of this simple logistic growth function to cases where dual processes operate by referring to an example when cars first replaced the population of horses, but then took on a further diffusion trajectory of their own. He postulated bi-logistic function model in an attempt to deal with the diffusion process containing complex growth processes which were not well modeled by the single logistic growth function. The bi-logistic function model is utilized in tracing a diffusion trajectory initiated by two co-existing innovations, and it is generally postulated that growth patterns of successive innovations are sum of successive simple logistic growth function models.

Anderson (1999) demonstrated that technological growth also follows an S-shaped growth curve, and the logistic growth functions are an appropriate approximation to describe the path of evolution by using accumulated patent stock. It is also suggested that the development of functionality plays a significant role in driving the diffusion of innovation.

Additionally, contribution of technology spillover to the technological growth depicted as logistic growth function has been discussed (Watanabe et al., 2003, 2005). It is suggested that technological functionality can be depicted by patent stock which is consists of own technology stock and assimilated technology spillover.

In this chapter, prompted by the foregoing observation of LIB industry, we demonstrate the comparative analysis between Sony and Panasonic. We use patent data as a proxy to evaluate the technological growth, and use the International Patent Classification (IPC) to classify technologies. The difference of business structure between these two firms is introduced in (2.2). The role of this chapter is described in (2.3). Trends in the diffusion trajectories of electrode technology are analyzed by using a bi-logistic function model in (2.4). Patents of cathode materials obtained by these two firms are compared in (2.5). Results are discussed in (2.6). Conclusion in this chapter is remarked in (2.7).

2.2 Comparison of business performance between Sony and Panasonic

2.2.1 Trends in the number of patent applications in the world

Evaluating the strength of R&D in each country, we analyze the number of patent applications of LIB. Table 2-1 shows world ranking about the number of patent applications of LIB in 2009. Table 2-2 shows ranking about the number of patent applications of LIB which were filed in the four world patent offices in 2009; Japan Patent Office (JPO), United State Patent and Trademark Office (USPTO), European Patent Office (EPO), State Intellectual Property Office of China (SIPO). Data source is "Survey on technological trends in patent applications of LIB industry, 2010" provided by JPO.

Table 2-1 demonstrates that four Japanese firms were ranked among the world's top five firms. Panasonic and Sony took the first place and second place, respectively. Table 2-2 demonstrates that Sony and Panasonic were ranked among the top three firms in every patent office. Panasonic took the first place in Japan, Europe, and China. These tables suggest that Sony and Panasonic have some effective R&D management for leading innovation. Therefore, we focus on the growth of Sony and Panasonic.

Table 2-1 Rank for world patent application of LIB in 2009.

	Firm	num
1	Panasonic(JP)	2291
2	Sony (JP)	2096
3	Samsung (KR)	1949
4	Sanyo (JP)	1628
5	Mitsubishi chemical(JP)	849

Table 2-2 Rank for patent application of LIB in each patent office in 2009.

	JPO	num	USPTO	num	EPO	num	SIPO	num
1	Panasonic(JP)	1144	Samsung(Kr)	415	Panasonic(JP)	176	Panasonic(JP)	295
2	Sony(JP)	1129	Panasonic(JP)	375	Sony(JP)	145	Samsung(KR)	274
3	Sanyo(JP)	880	Sony(JP)	328	LG chem(KR)	107	Sony(JP)	249
4	GS Yuasa(JP)	692	Sanyo(JP)	312	Samsung(Kr)	91	Sanyo(JP)	178
5	Mitsubishi chemical(JP)	616	LG chem(KR)	120	Merck(DE)	78	BYD(CN)	177

Firm or Institute of JP: Japan, KR: Korean, CN: China, US: United State, DE: German

2.2.2 Trends in the number of patent applications in Japan

Through the observation of trends in the number of patent applications in the world, it can be said that Sony and Panasonic has led the innovation in the LIB industry. Figure 2-1 shows trends in the number of patent applications of LIB filed in JPO during 1991-2008. Figure 2-2 shows trends in the number of patent applications of LIB filed by Sony and Panasonic during 1991-2008. The data of patent applications are obtained by a retrieval of patent data in "Industrial Property Digital Library" provided by National Center for Industrial Property Information and Training in Japan.

Figure 2-1 demonstrates that the number of patent applications has increased rapidly during 1991-2002. This fact suggests that innovation in the LIB industry occurred during this period. LIB was first manufactured for the market by Sony in 1991 (Nagaura, 1991), and many firms have entered this market since then. It seems that this highly competition leads the decrease of the number of patent applications after 2000. Thus, it is obvious from Figure 2-1 that only one inflection point is included in this figure in the early 2000s. This growth trajectory can be illustrated as the S-curve, which can be exhibited as the simple logistic function model.

Figure 2-2 also demonstrates that the number of patent applications filed by Sony and Panasonic has turned to decrease since 2000. This decline might be caused by the same reason as discussed above. However, as a difference between Figure 2-1 and Figure 2-2, the number of patent applications has turned to increase again since the middle 2000s in Figure 2-2. Thus, it is obvious from Figure 2-2 that Sony and Panasonic has different trends in the number of patent applications from the general trends expressed in Figure 2-1, because two inflection points are included in this figure. First point is the early 2000s, and second point is the middle 2000s. This growth trajectory is considered as the sum of two S-curves. Therefore, we analyze the data of this figure by using the bi-logistic function model in order to divide the LIB innovation process into first wave and second wave.

It could be one of reasons of the strength of Sony and Panasonic that they developed the functionality of LIB in the 1990s and stepped up to the next generation LIB since 2000. Therefore, we focus on the relations between the change of trends in the number of patent applications from first wave to second wave and the development of material technology used in a cathode.

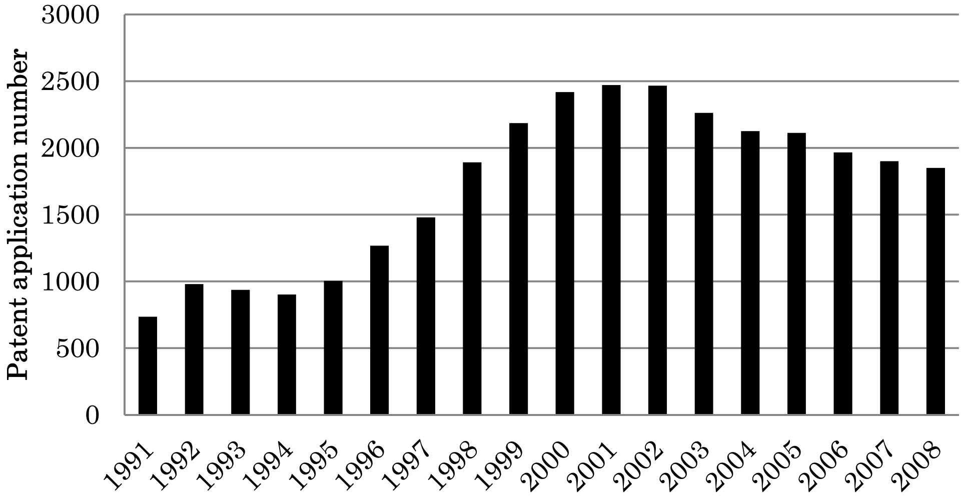


Figure 2-1. Trends in the number of patent applications of LIB in JPO during 1991-2008.

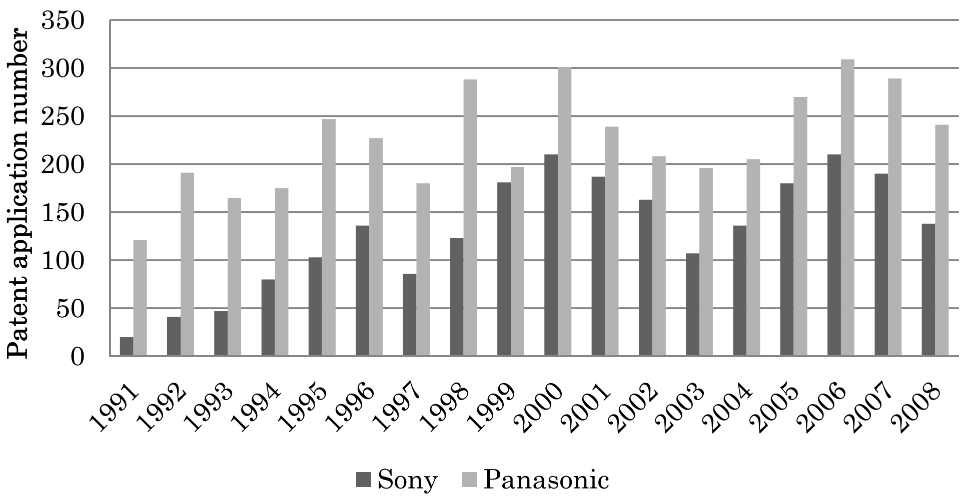


Figure 2-2. Trends in the number of patent applications of LIB filed by Sony and Panasonic during 1991-2008.

2.2.3 Trends in market shares and sales

Before the analysis, we compare the financial data between Sonya and Panasonic. Figure 2-3 shows trends in world market shares of LIB made in Sony and Panasonic. Figure 2-4 shows trends in operating income to sales (OIS) of department to produce LIBs and digital equipments including LIB made in Sony and Panasonic. As the department producing LIBs and digital equipments, 'Electrics department' in Sony and 'Device department' in Panasonic are selected, respectively. Both firms changed the structure of organization and established these new departments in the early 2000 (Annual report in Sony and Panasonic, 2001-2003).

Figure 2-3 demonstrates that Sony has rapidly lost their market share since the practical use of LIB started. As previously noted, LIB was first manufactured by Sony in 1991, so that Sony had the largest market share at the start of the LIB industry. However, many firms entered this market after 1991, and Sony was deprived their market share gradually. In contrast, Panasonic increased their market share steadily. Panasonic entered this market in 1994, and they could have expanded their market share gradually since then. About ten years after the practical use of LIB started, Panasonic could get the almost same market share as Sony and occupy nearly 20% market share in the world.

Figure 2-4 demonstrates that both firms traced a recovery process. Sony fell into red in 2004, but they moved into black in 2007. Panasonic also fell into the red in 2002, but they moved into black in 2003. It means that Panasonic moved into black about four years earlier than Sony. Since both firms restructured their organization around 2000 in order to concentrate on R&D in core competence, we compare the OIS after 2002 in this figure.

It is obvious from these figures that Panasonic increased their market share steadily, therefore it can be said that Panasonic succeeded in making a good progress after they entered the LIB market.

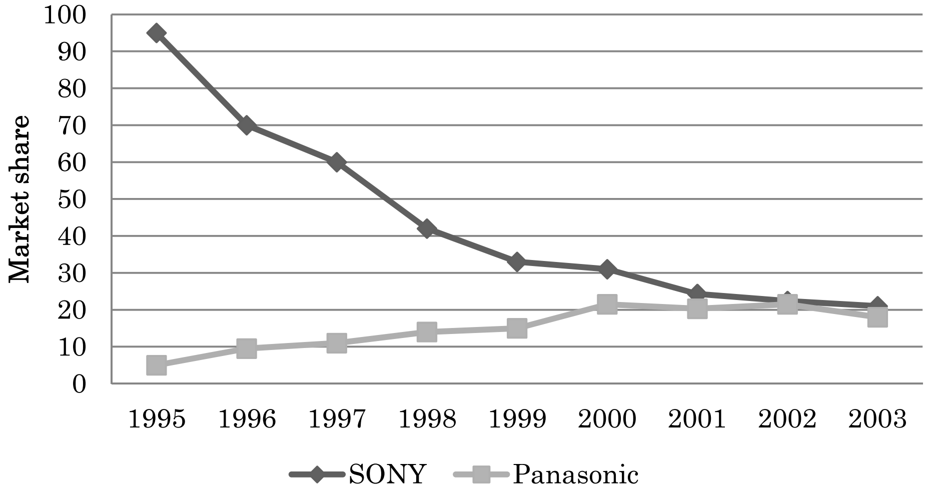


Figure 2-3. Trends in world market share of LIB.

Source: "NIKKEI market share" published by NIKKEI news paper.

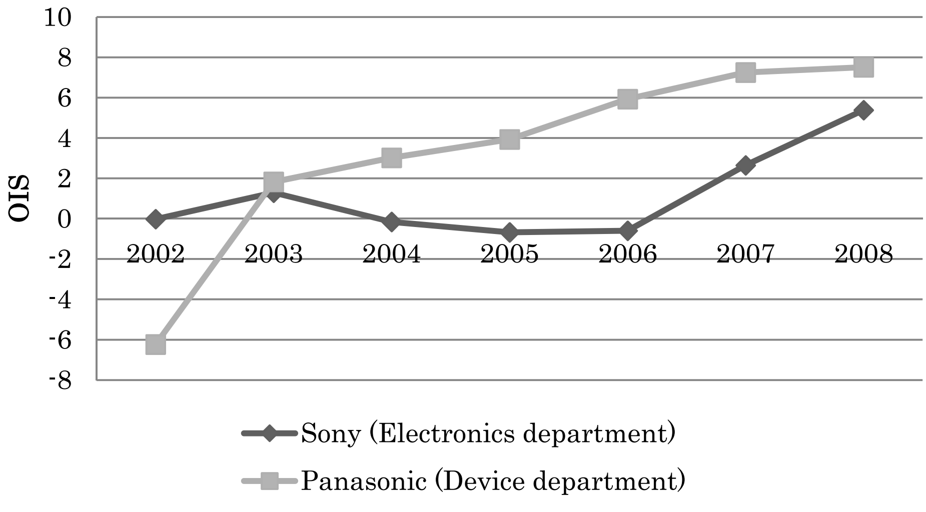


Figure 2-4. Trends in OIS of department regarding LIB.

Source: Annual report in Sony and Panasonic.

2.2.4 Trends in news paper articles

Comparing the LIB innovation process in Sony and Panasonic, we analyze articles regarding LIB on Nikkei newspaper. Nikkei Inc provides a CD-ROM which includes every article appeared on Nikkei news paper. Through this analysis, we investigate how LIB made in Sony and Panasonic are diffused in the market.

In this study, we classify these articles related to their LIB department into four types; (1) Advancement: articles for the increase of production or investment for plant or equipment, (2) Depression: articles for the decrease of production or technical troubles leading the recall of LIB, (3) Innovation: articles for the development of functionalities or the invention of new products, and (4) Enterprise: articles for the collaboration with other firms or restructuring of organization. Table 2-3 shows the total number of each article published from 1991 to 2007. The chronology of each firm's article is attached as Appendix A and Appendix B, respectively.

Table 2-3 Comparison of the number of each article on LIB during 1991-2007.

	(1) Advancement	(2) Depression	(3) Innovation	(4) Enterprise	Total
Sony	5 (19.2%)	12 (46.2%)	5 (19.2%)	4 (15.4%)	26 (100%)
Panasonic	11 (50%)	2 (9.1%)	4 (18.2%)	5 (22.7%)	22 (100%)

Table 2-3 demonstrates that Sony and Panasonic have opposite trend in the case of (1) and (2). In the case of (1), Panasonic has larger amount of articles about LIB than Sony. In contrast, in the case of (2), Sony has larger amount of articles about LIB than Panasonic. In the case of (3) and (4), Sony and Panasonic have almost same amount of articles. These facts suggest that Sony faced many troubles such as recall problems while Panasonic has developed production capability.

According to the articles, Sony faced troubles several times such as overheating and had to recall enormous batteries; for instance, the biggest one was the overheating problem happened in 2006, which led the problems that other firms had to recall their laptop PCs using Sony LIB. It might be one of reasons why Sony loses their LIB market share. In contrast, Panasonic has steadily developed the production capability of LIB and encourage collaboration with other firms. It might be one of reasons why Panasonic increase their LIB market share. The observation of chronology of articles also suggests that Panasonic succeeded in making a good progress in the LIB market.

2.3 Interpretation

In the Chapter I, it is suggested that electrode technology plays an important role in developing the functionality of LIB, because the chemical reaction to generate electric power is occurred on the electrode as the physical fundamental. This chemical reaction depends on the material characteristics used in a cathode.

In the 1990s, simple materials such as lithium-cobalt oxide were mainly used in a cathode (Ohzuku et al., 1995). However, in the 2000s, composite materials were required which could provide higher energy density and constitute a desirable material structure for heat load with less cobalt. In fact, current digital equipments use composite materials such as lithium-nickel-cobalt oxide as a main material, because these materials are superior to other materials in terms of energy density and stability (Ohzuku et al., 2007). Thus, it can be said that the prompt development of material technology is a key to lead the innovation in the LIB industry.

In this chapter, we compare the development process of cathode materials between Sony and Panasonic by using logistic function model. Panasonic entered the LIB market in 1994, and they have maintained a good progress since then. Prompted by the forgoing observations, it seems that prompt development of material technology has encouraged Panasonic's growth. It is because the technological performance of LIB depends on the development of material characteristics. It is considered that Panasonic took the initiative in the LIB industry by the prompt development of material technology, and the timely emergence of composite materials encouraged the growth of LIB department in Panasonic. Therefore, timely undertaking of R&D to develop material technology can be one of Panasonic's strengths.

In the previous works, it is pointed that the early development of functionalities in a product and strategies to create such developments are essential for firms to survive the mega competition. The logistic growth function has proved to be a useful function in modeling an innovation process. Innovation process can be described as S-shaped growth curve, and, and then patent data can be a useful parameter (Anderson, 1999). By using this model, we compare the diffusion trajectories of electrode technology and the chronology of material technology between Sony and Panasonic to analyze the LIB innovation process.

2.4 Analysis of the diffusion of innovation

2.4.1 Methodology to classify technologies

Comparing the LIB innovation process between Sony and Panasonic, we use patent data as an indicator of the innovation. It is demonstrated by numerical analysis that there is a close relationship between R&D and patents (Griliches et al., 1984) and patent can be a useful economic indicator to analyze the innovation. Anderson (1999) also suggested that accumulated patent stock can be an appropriate approximation to describe the evolution of technologies.

As suggested in Chapter I, it can be conceptualized that batteries are composed of three technology segments; 'Exterior' (the shape or the appearance of a battery), 'Structure' (the structural details of a battery), and 'Electrode' (the details of a cathode and an anode to cause a chemical reaction to generate energy).

Generally, every patent application is classified by IPC. According to the IPC, 'Processors or means relating to electric elements such as batteries for the direct conversion of chemical energy into electrical energy' are classified into [H01M]. Therefore, We select technologies regarding LIB from technologies which are classified as this [H01M], and group technologies into three simple technologies and four complex technologies by using the IPC. Finally, technologies composing a LIB can be grouped into seven technology groups like follows. Detail meanings of each IPC are summarized in the Appendix C.

[Simple technology]
We classify technologies composing a LIB into three technology segments; 'Exterior', 'Structure', and 'Electrode'. Technology group which belongs to only one technology segment is defined as 'simple technology'. These technology groups are defined like follows by the sub group level of IPC.

i) Exterior: We classify technologies which belong to only (H01M2) as 'Exterior'.
   We use the following IPC groups to define inventions which belong to 'Exterior'.
   H01M2/00, H01M2/02, H01M2/04, H01M2/06, H01M2/08, H01M2/14, H01M2/16, H01M2/18

ii) Structure: We classify technologies which belong to only (H01M10) as 'Structure'. We use the following IPC groups to define inventions which belong to 'Structure'. H01M10/00, H01M10/36, H01M10/40

iii) Electrode: We classify technologies which belong to only (H01M4) as 'Electrode'. We use the following IPC groups to define inventions which belong to 'Electrode'. H01M4/00, H01M4/02, H01M4/04, H01M4/36, H01M4/38, H01M4/48, H01M4/50, H01M4/52, H01M4/58, H01M4/62, H01M4/64, H01M4/66

[Complex technology]

We classify technologies composing a LIB into three technology segments; 'Exterior', 'Structure', and 'Electrode'. Technology group which belongs to two or more technology segments is defined as 'complex technology', and these are four kinds of combinations of technology segments; 'Exterior and Structure', 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'. These technology groups are defined by the combination of IPC of above simple technology.

Figure 2-5 shows the conceptual model of technologies composing a LIB, which describe the relations among seven technology groups, three simple technologies and four complex technologies. We use the number of patent applications which are classified into simple technology and complex technology by using the IPC to measure the LIB innovation process.

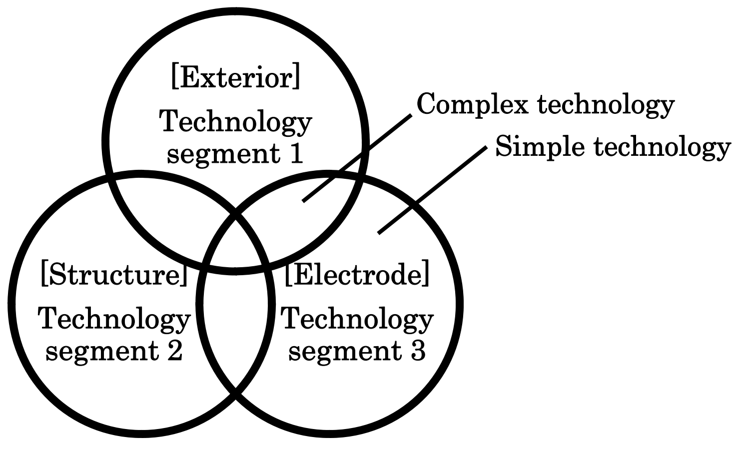


Figure 2-5. Conceptual model of technologies composing a LIB.

2.4.2 Data construction

We compare trends in the number of patent applications in seven technology groups filed by Sony and Panasonic. Table 2-4 shows the results of correlation analysis between the total number of patent applications of LIB filed by these firms and the number of patent applications in each technology group filed by these firms. Figure 2-6 and Figure 2-7 shows trends in the number of patent applications in each technology group filed by Sony and Panasonic.

Table 2-4 The results of correlation analysis among seven technology groups.

	Sony	Panasonic
Exterior	0.61**	0.44
Structure	0.73**	0.45
Electrode	0.44	0.49*
Exterior and Structure	0.72**	0.53*
Exterior and Electrode	0.42	0.28
Structure and Electrode	0.88**	0.64**
Exterior and Structure and Electrode	0.64**	0.62**

* significant at the 5% level ** significant at the 1% level

Table 2-4 demonstrates that correlation coefficient of 'Structure and Electrode' is the highest value in both Sony and Panasonic. Figure 2-6 and Figure 2-7 demonstrates that the number of patent applications grouped as 'Structure and Electrode' is the largest amount of number among the seven technology groups in both Sony and Panasonic. These trends of data suggest that 'Structure and Electrode' is the most influential technology group to drive the LIB innovation process, and it corresponds to the background of the LIB industry noted in Chapter I.

As suggested in Chapter I, electrode technology plays an important role in developing the functionality of LIB after the practical use of LIB started, because it is a key component to decide the cost, technological functionality such as energy density, and safety of LIB. The timely development of materials used in a cathode is important to drive the innovation in the LIB industry. Therefore, we focus on the technology group 'Structure and Electrode' as the most influential technology group in the LIB innovation process.

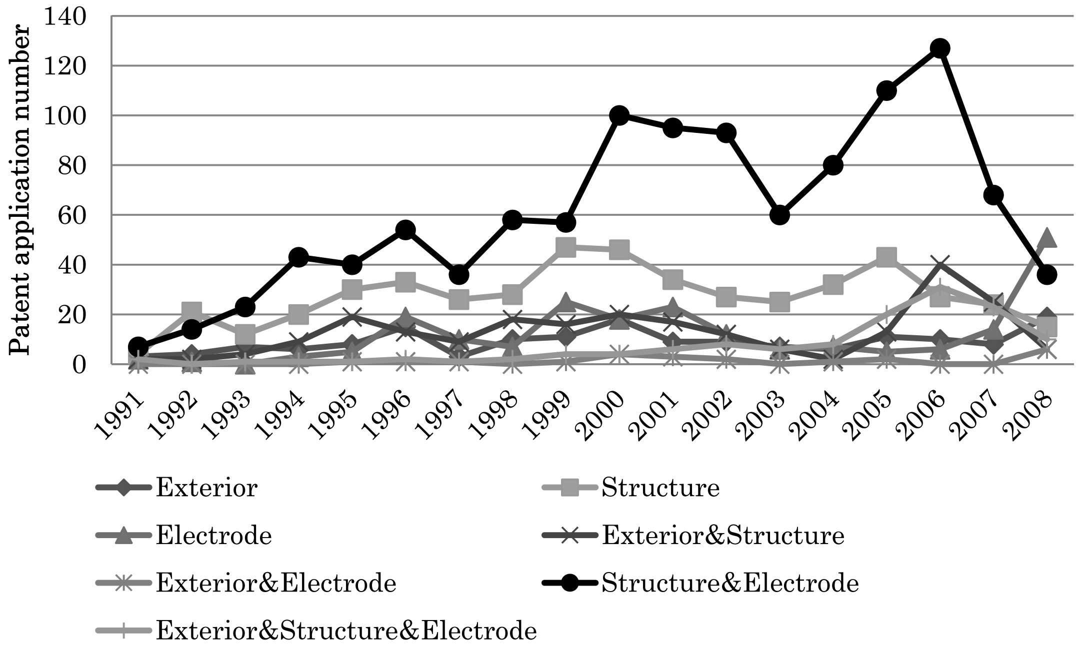


Figure 2-6. Trends in the number of patent applications in Sony.

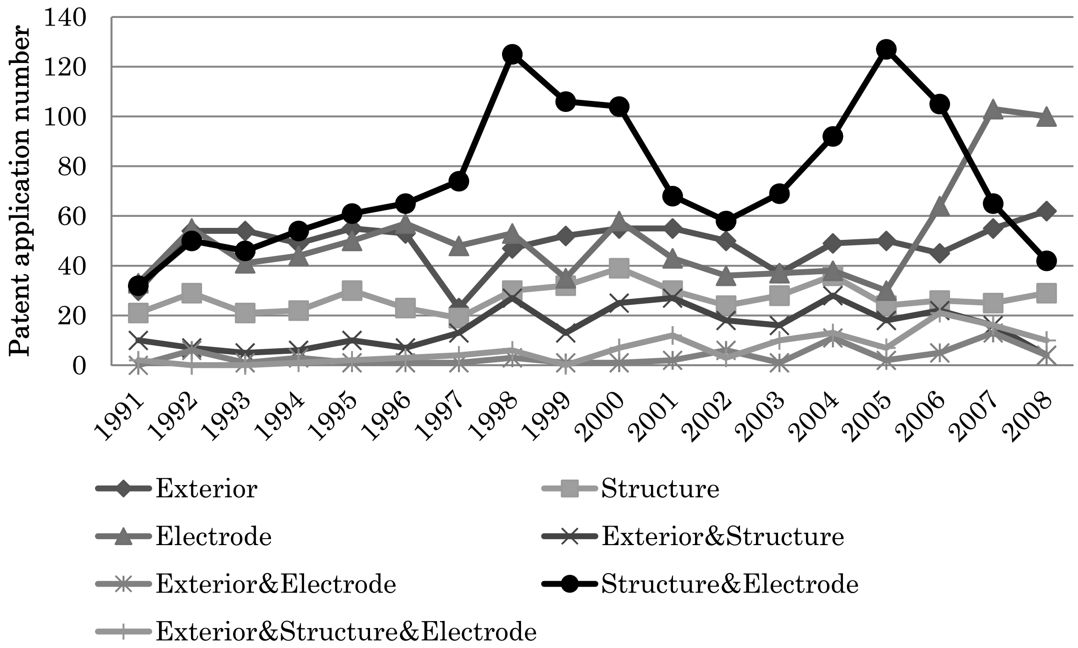


Figure 2-7. Trends in the number of patent applications in Panasonic.

2.4.3 Numerical model of diffusion trajectory

There are many efforts in modeling the diffusion of innovation in previous works. In this study, following two epidemic functions are used for comparative analysis of the diffusion of innovation between Sony and Panasonic.

As Griliches (1957) noted, an epidemic function is useful for analyzing the diffusion and maturity of innovative goods. The epidemic function enumerates the contagion process of an epidemic, and this model provides an analogy of the diffusion and maturity trajectory through the contagion process of innovative goods similar to a medical epidemic. The epidemic function incorporates a negative feedback in an exponential function as follows.

$$\frac{d}{dt}V(t) = aV(t)(1-\frac{V(t)}{N})$$

(2-1)

where '*V(t)*' is the cumulative number of goods. '*N*' is the upper limit of *V(t)*, the carrying capacity. '(1- *V(t)*/*N*)' depicts a negative feedback, and this approaches 1 in the case of the value of *V(t)* is smaller than *N*, and approaches 0 in the case of the value of *V(t)* is larger than *N*, respectively. Therefore, growth ratio (the left hand site of equation (2-1)) increases logistically at the initial stage and stagnates to 0 when *V(t)* approaches to *N*. This trajectory is drawn as S-shaped curve.

Finally, equation (2-2) can be obtained by integrating equation (2-1). Diffusion process of innovative goods can be depicted by the following logistic growth function with its carrying capacity.

$$V(t) = \frac{N}{1+b\exp(-at)}$$

(2-2)

where '*V(t)*' is the cumulative number of innovative goods. '*N*' is carrying capacity. '*a*' is velocity of diffusion. '*b*' is initial stage of diffusion. '*t*' is time trend. The level and timing of inflection in a diffusion trajectory can be identified by taking the first and the second derivative function as illustrated in Figure 2-8.

As postulated by previous work (Mahajan et al., 1990), diffusion trajectory shifts from increasing diffusion velocity to decreasing diffusion velocity at the inflection point $t^{\#}$. Furthermore, increasing diffusion velocity shifts from 'increasing faster' to 'increasing slowly' at the earlier inflection point of the first derivative t_1. Decreasing diffusion velocity shifts from 'decreasing slowly' to 'decreasing faster' at the later inflection point of the first derivative t_2. Corresponding to these inflection points, diffusion trajectory can be classified into four stages; (1) Increasing faster ($0 - t_1$), (2) Increasing slowly ($t_1 - t^{\#}$), (3) Decreasing slowly ($t^{\#} - t_2$), (4) Decreasing faster ($t_2 - \infty$). Moreover, it is identified that new functionality emerged in the market at the transition from (1) to (2) by gaining the uses of product and having a greater usage propensity.

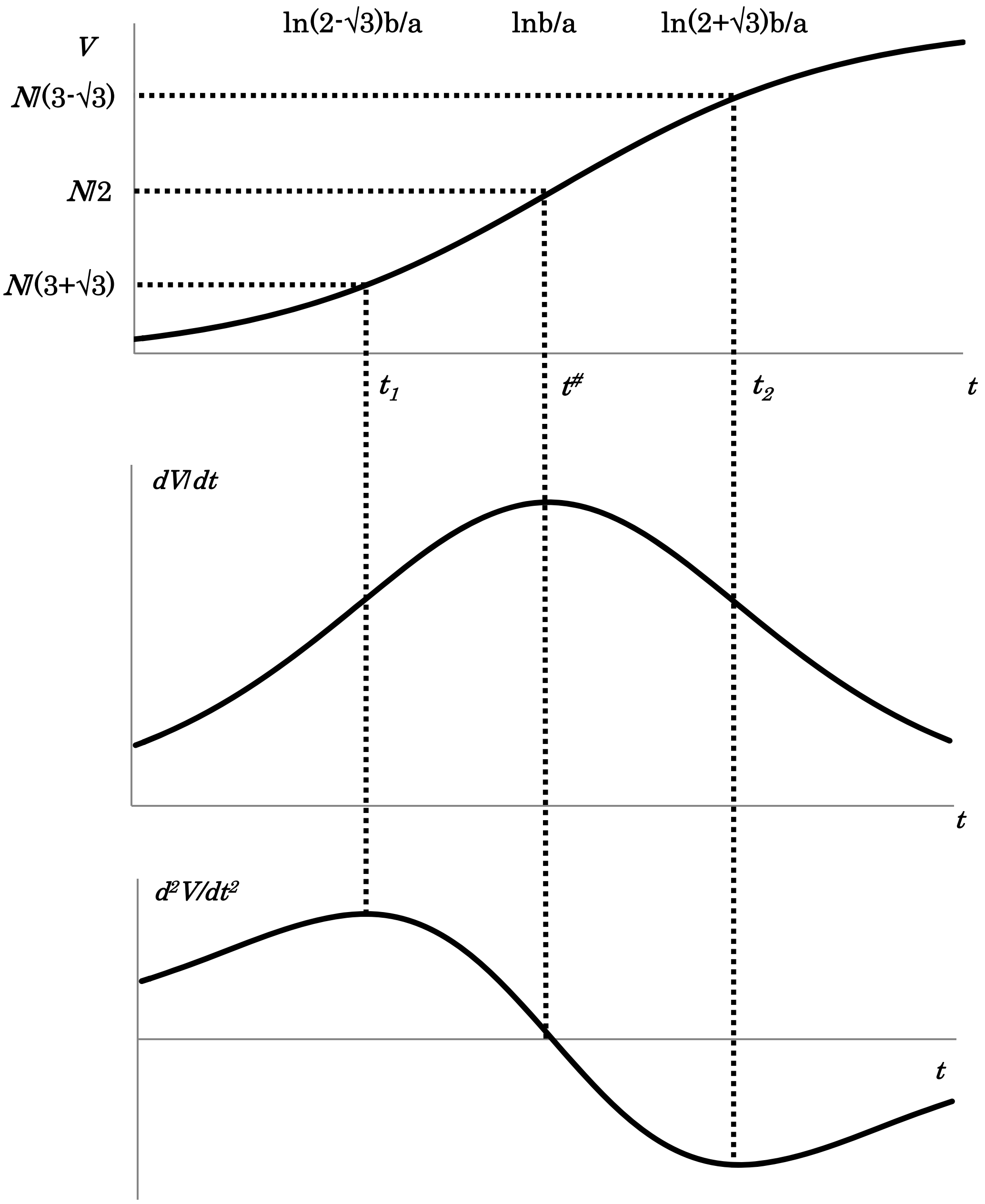
We note that the diffusion trajectory changes from increasing diffusion velocity to decreasing diffusion velocity when the diffusion reaches to the level of $N/2$ at the time $\ln b/a$. In the increasing diffusion velocity, before reaching to the inflection point, the diffusion changes from acceleration to deceleration when it reaches to the level of $N/(3+\sqrt{3})$ at the time $\ln(2-\sqrt{3})b/a$. In the decreasing diffusion velocity, after reaching to the inflection point, the diffusion changes from deceleration to acceleration when it reaches to the level of $N/(3-\sqrt{3})$ at the time $\ln(2+\sqrt{3})b/a$.

As previously introduced, it could be generally postulated that growth patterns of successive innovations are sum of successive simple logistic function models. In this study, the bi-logistic function model postulated by Meyer (1994) is also utilized in tracing a diffusion trajectory initiated by two co-existing innovations. These two co-existing innovation diffusion constituting of V_1 and V_2 can be depicted by the following bi-logistic function model.

$$V(t) = V_1(t) + V_2(t) = \frac{N_1}{1 + b_1\exp(-a_1 t)} + \frac{N_2}{1 + b_2\exp(-a_2 t)} \tag{2-3}$$

where '$V_1(t)$' and '$V_2(t)$' are the cumulative number of innovative goods in each wave. 'N_1' and 'N_2' are carrying capacities in each wave. 'a_1' and 'a_2' are velocity of diffusion in each wave. 'b_1' and 'b_2' are initial stage of diffusion in each wave. 't' is time trend.

We compare the fitness of these two epidemic functions, simple logistic function model and bi-logistic function model, between Sony and Panasonic.



0	→	t_1	→	$t^{\#}$	→	t_2	→	T
Increasing diffusion velocity				Decreasing diffusion velocity				
Increasing faster		Increasing slowly		Decreasing slowly		Decreasing faster		

t_1: inflection point of diffusion velocity in its increasing period

$t^{\#}$: inflection point of diffusion

t_2: inflection point of diffusion velocity in its decreasing period

Figure 2-8. Level and timing of inflection in a diffusion trajectory.

2.4.4 Numerical results of epidemic behavior

Aiming at tracing the LIB innovation process in Sony and Panasonic, numerical analysis is conducted by utilizing the simple logistic function model as depicted in equation (2-2) and the bi-logistic function model as depicted in equation (2-3). Each numerical result is shown in Table 2-5 and Table 2-6, and comparison between each estimate value and actual value is shown in Figure 2-9 and Figure 2-10, respectively.

The results of analysis are summarized in Table 2-5 and Table 2-6, respectively. All t-values and the values of adj. R^2 are statistically significant in Table 2-5 and Table 2-6. These numerical results suggest that both LIB innovation processes of Sony and Panasonic include two waves, V_1 and V_2. In this study, we mainly discuss the results of bi-logistical function model.

As Anderson (1999) suggested, patent data is useful to evaluate the LIB innovation process. In many countries, patent office introduces the 'first-to-file principles' as one of patentability requirements. The 'first-to-file principles' means the system that, if two patent applications claiming same inventions are filed, only earlier patent application is accepted. Therefore, early patent application filing is necessary to have superiorities for other later patent applications.

First, utilizing the estimated bi-logistic function model, we can demonstrate the diffusion trajectory of 'Structure and Electrode' in Sony and Panasonic. These are illustrated in Figure 2-11 and Figure 2-12, respectively. In these figures, it is demonstrated that Sony and Panasonic have similar shape of diffusion trajectories of electrode technology; however, Panasonic realizes the earlier start-up than Sony in both 1st wave and 2nd wave. Additionally, Panasonic can realize higher carrying capacity, N_1 and N_2, than Sony in both 1st wave and 2nd wave.

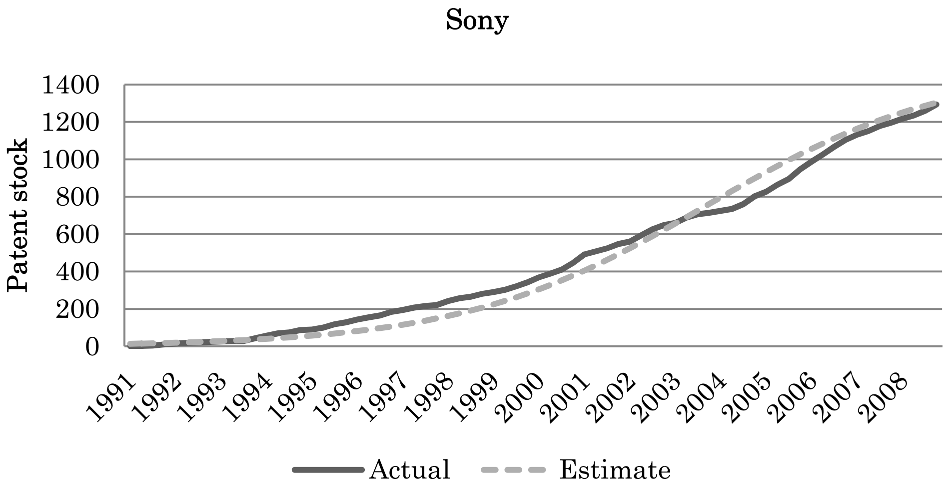
Next, utilizing the estimated bi-logistic function model, we compare the waves, V_1 and V_2, between Sony and Panasonic. These are illustrated in Figure 2-13 and Figure 2-14, respectively. Panasonic realizes the earlier start-up than Sony in both 1st wave and 2nd wave. It is also obvious that the 2nd wave of Sony and Panasonic start in the early 2000s and the late 1990s, respectively. It means that the 2nd wave of Panasonic starts about two years earlier than that of Sony.

Table 2-5 Comparison of the numerical results by the simple logistic function model.

$$V(t) = \frac{N}{1 + b\exp(-at)}$$

	N	a	b	adj. R^2
Sony	1400	0.031	4.81	0.93
		(30.92)	(37.76)	
Panasonic	1600	0.032	3.99	0.90
		(26.08)	(25.47)	

All parenthetic figures are t-values.



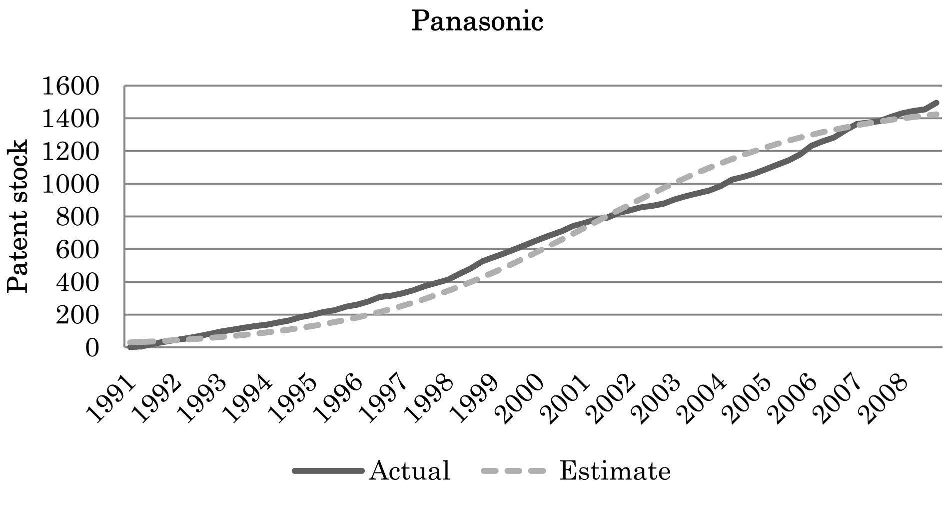


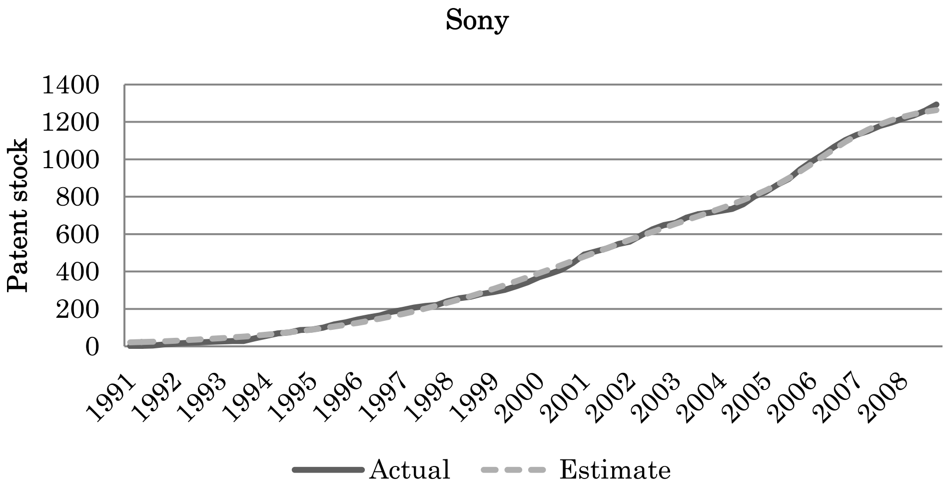
Figure 2-9. Comparison of diffusion trajectories of simple logistic function.

Table 2-6 Comparison of the numerical results by the bi-logistic function model.

$$V(t) = V_1(t) + V_2(t) = \frac{N_1}{1 + b_1 \exp(-a_1 t)} + \frac{N_2}{1 + b_2 \exp(-a_2 t)}$$

	N_1	a_1	b_1	N_2	a_2	b_2	adj. R^2
Sony	935.65	0.032	3.88	387.38	0.109	20.37	0.99
	(19.0)	(26.5)	(63.1)	(8.1)	(7.1)	(7.1)	
Panasonic	1044.39	0.034	3.31	473.64	0.088	15.43	0.99
	(41.0)	(40.9)	(81.6)	(13.4)	(10.1)	(10.1)	

All parenthetic figures are t-value.



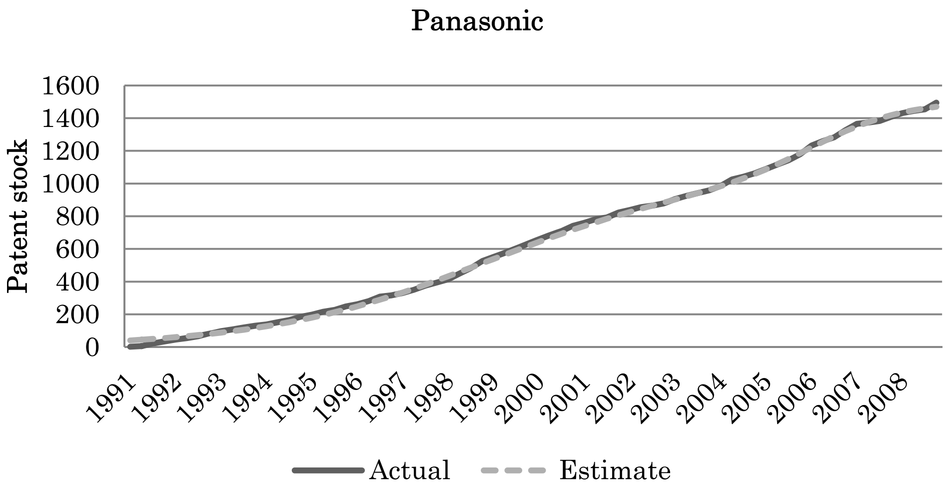


Figure 2-10. Comparison of diffusion trajectories of bi-logistic function.

Sony

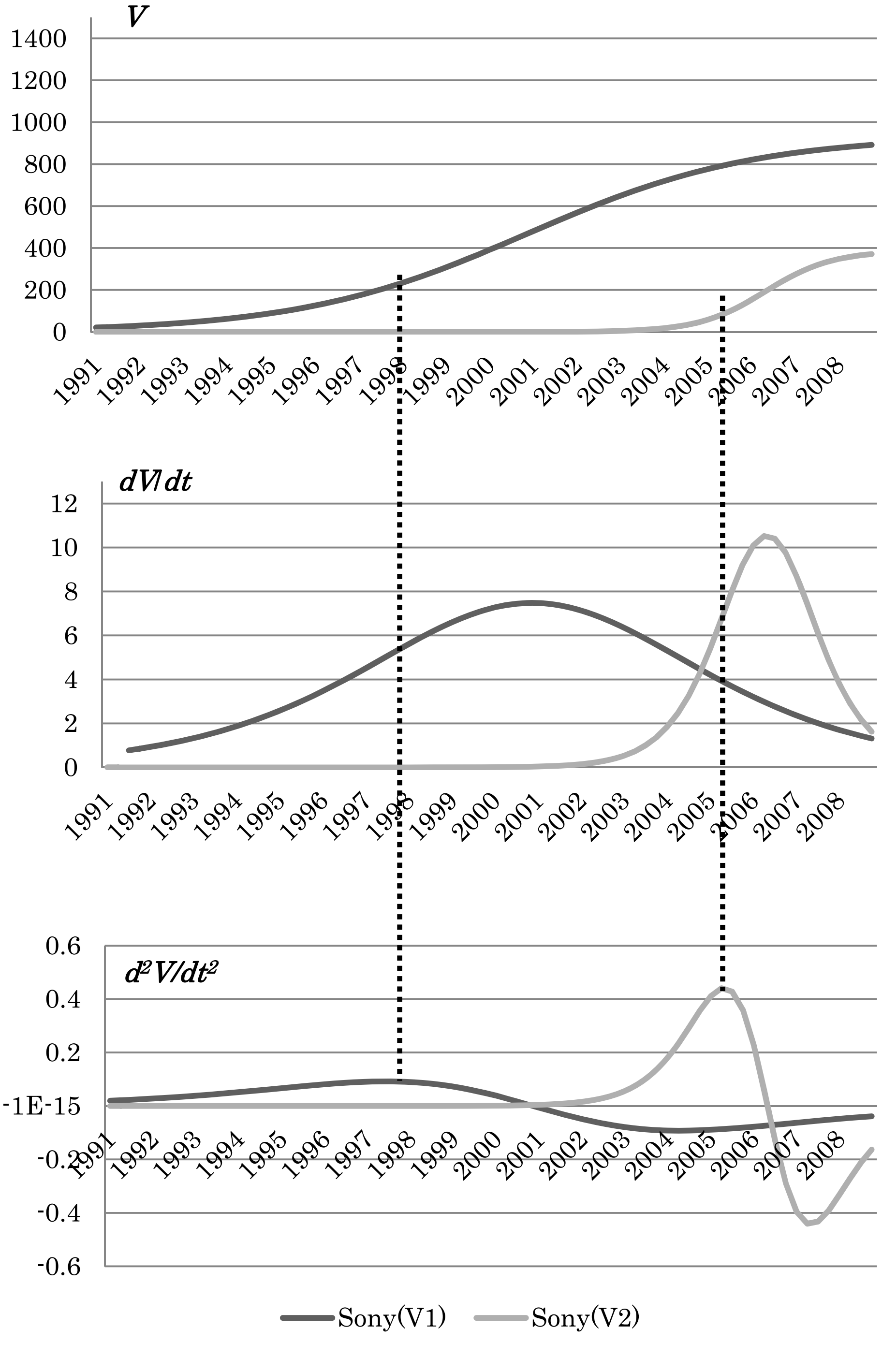


Figure 2-11. Diffusion trajectory of ‘Structure and Electrode’ in Sony.

Panasonic

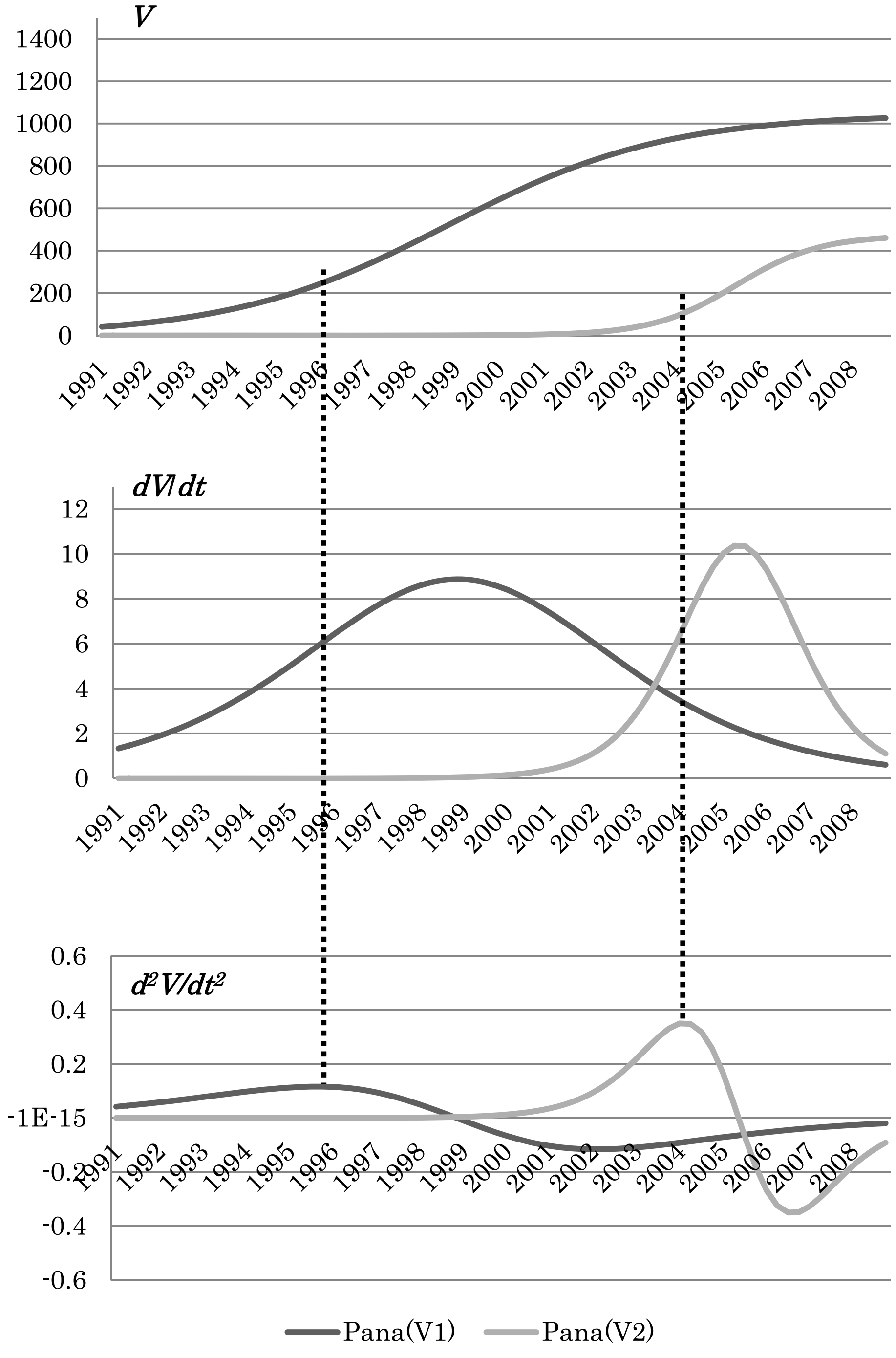


Figure 2-12. Diffusion trajectory of ‘Structure and Electrode’ in Panasonic.

First wave

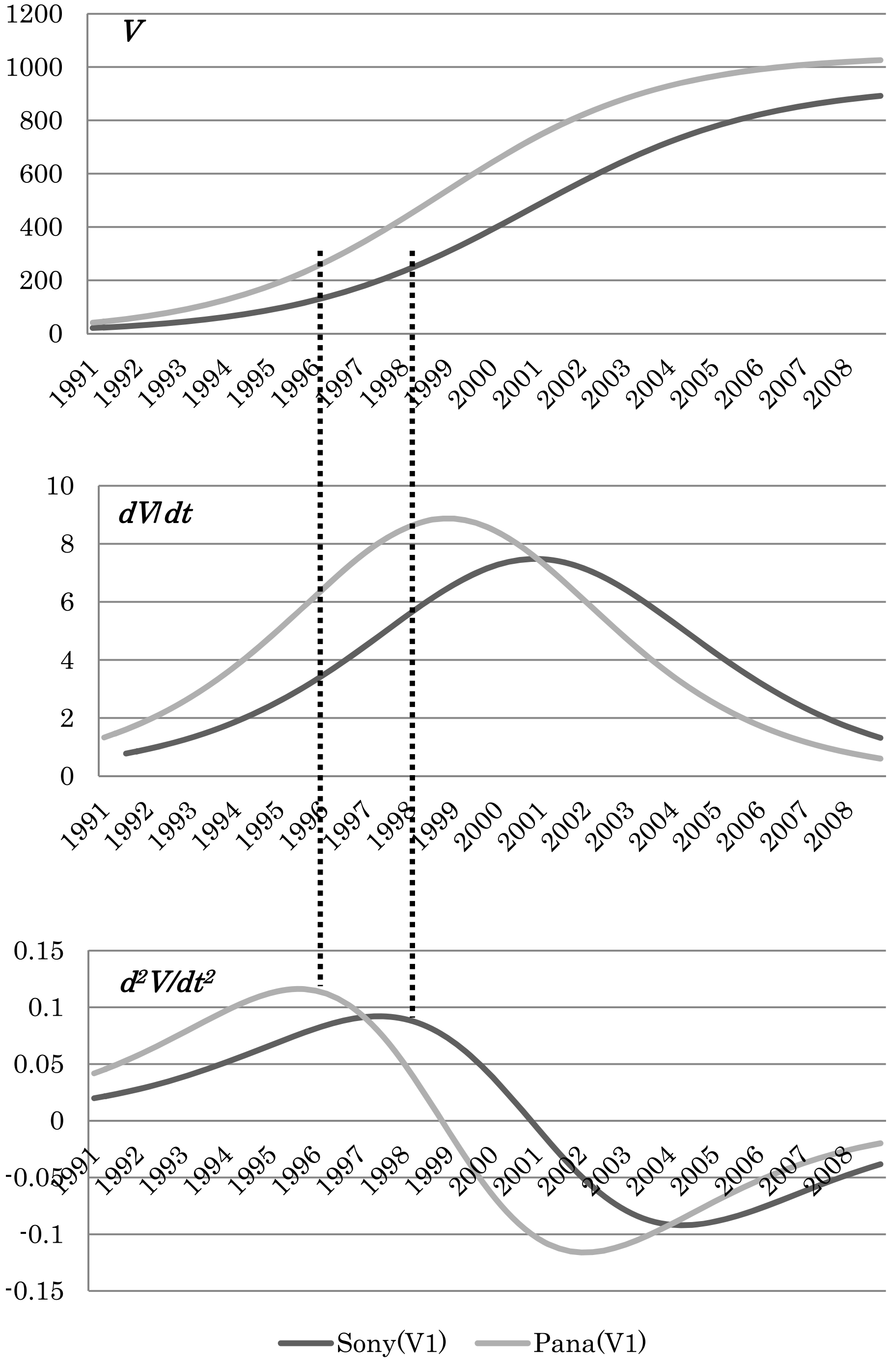


Figure 2-13. Comparison of the 1st wave between Sony and Panasonic.

Second wave

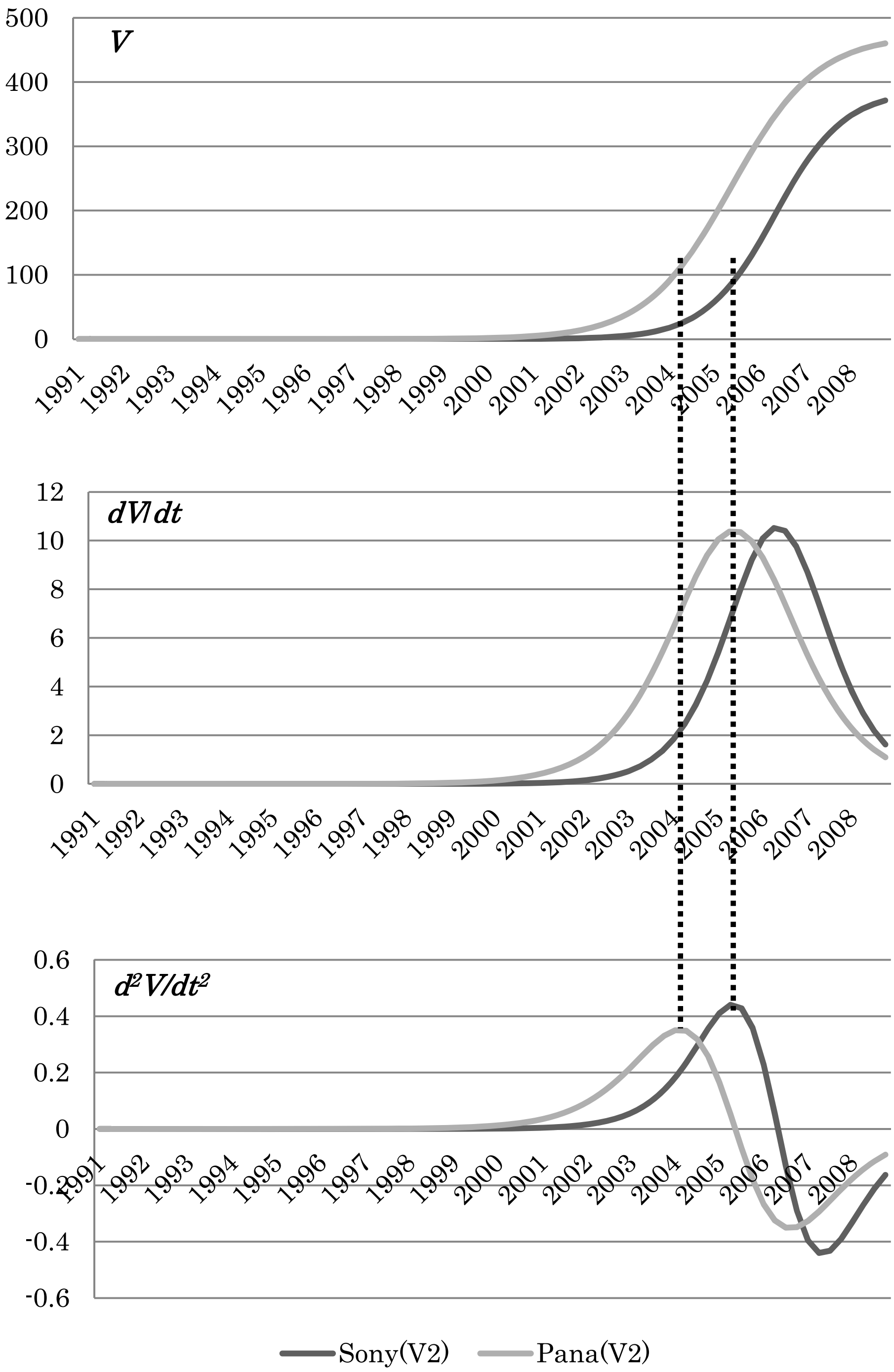


Figure 2-14. Comparison of the 2nd wave between Sony and Panasonic.

2.4.5 Timing of inflection points

As introduced earlier, following Rogers' pioneer work on the innovativeness based on the adopter as the categorization (Rogers, 1962), it is pointed that new functionality emerged in the market at the timing $\ln(2-\sqrt{3})b/a$ (Anderson, 1999; Ouchi et al., 2008). In addition, the development of functionality stagnates at the timing $\ln(2+\sqrt{3})b/a$. Table 2-7 shows inflection points of two waves.

Table 2-7 Inflection points of two waves in the diffusion trajectory.

		Inflection points		
		$t_1 = \ln(2-\sqrt{3})b/a$	$t^{\#} = \ln b/a$	$t_2 = \ln(2+\sqrt{3})b/a$
Sony	1st wave	3rd quarter, 1997	1st quarter, 2001	2nd quarter, 2004
	2nd wave	3rd quarter, 2005	2nd quarter, 2006	3rd quarter, 2007
Panasonic	1st wave	4th quarter, 1995	1st quarter, 1999	1st quarter, 2002
	2nd wave	2nd quarter, 2004	3rd quarter, 2005	4th quarter, 2006

In the case of 1st wave, the wave of Sony and Panasonic reached t_1 in the 3rd quarter of 1997 and the 4th quarter of 1995, respectively. It means that Panasonic reached the inflection point in the 1st wave about two years earlier than Sony. In the case of 2nd wave, the wave of Sony and Panasonic reached t_1 in the 3rd quarter of 2005 and the 2nd quarter of 2004, respectively. It means that Panasonic reached the inflection point in the 2nd wave about one year earlier than Sony. Through the numerical analysis, it was revealed that Panasonic demonstrated earlier start-up and reached the inflection points earlier than Sony in both 1st wave and 2nd wave.

It is considered that the timing of start-up of 2nd wave corresponds to the emergence of composite materials. After simple materials which were used as the main material in the 1990s have reached their technological performance limits, composite materials were invented in order to satisfy demands from market in the early 2000s. It is because composite materials have a desirable material structure to generate higher energy density, and it can reduce the degree of cobalt by replacing cobalt with nickel and manganese. It is assumed that Panasonic noticed this needs from the market in the early stage, and advanced R&D in material technology earlier than Sony. This notice in the early stage supported that Panasonic took the initiative in the prompt development of material technology.

2.5 Analysis of chronology of material patents

2.5.1 Methodology to define patents

We compare material patents obtained by Sony and Panasonic. In addition to the IPC, we use FI (File Index) to define the technology. FI is developed by JPO, and it is used as more precise technological definition than IPC. We can define material characteristics more precisely by using FI.

Figure 2-15 shows the relations between IPC and FI about cathodes. The number of [･] indicates the layer of technology. In this figure, technological classification based on IPC is 1~5 layer; H01M4/00, H01M4/02, H01M4/36, H01M4/48, H01M4/50, H01M4/52, and the one based on FI is 6~7 layer; H01M4/50,101, H01M4/50,102, H01M4/52,101, H01M4/52,102. In this study, we use the most precise technological definition to group cathode materials, H01M4/50,102 and H01M4/52,102.

- H01M4/00 Electrodes
  - H01M4/02･ Electrodes composed of, or comprising, active material
    - H01M4/04･･ Processes of manufacture in general
    - H01M4/36･･ Selection of substances as active materials, active masses, active liquids
      - H01M4/38･･･ of elements or alloys
        - H01M4/40････ Alloys based on alkali metals
      - H01M4/48･･･ of inorganic oxides or hydroxides
        - H01M4/50････ of manganese
          - H01M4/50,101･････ of manganese oxide or hydroxide
            - H01M4/50,102･･････ of composite oxide or hydroxide including manganese to insert light metals
        - H01M4/52････ of nickel, cobalt, or iron
          - H01M4/52,101･････ of nickel, cobalt, or iron oxide or hydroxide
            - H01M4/52,102･･････ of composite oxide or hydroxide including nickel, cobalt, or iron to insert light metals

[layer level]

1 ➡ 2 ➡ 3 ➡ 4 ➡ 5 ➡ 6 ➡ 7

Figure 2-15. Relations between IPC and FI about electrode.

2.5.2 Methodology to group the development of materials

As described in Chapter I, after the practical use of LIB started, technological functionality of electrode plays a significant role in leading the LIB innovation process. This functionality of electrode depends on the development of cathode materials.

As the main technological functionality of cathode materials, improvement of energy density is required to generate higher energy as LIB. The development of IT and the diffusion of digital equipment, especially cellular phones, are considered as the main reason for the demand. In fact, multiple functions of cellular phones are attributed to the improvement of energy density of cathode materials.

Additionally, as one of the structural characteristics of LIB, organic solvent which can easily burn has to be used as the electrolyte to transfer lithium between cathode and anode. With the improvement of energy density, stability of materials also needs to be developed. It is because cathode materials must withstand heavy heat load when energy is generated on the electrode. The thermotolerance of materials depends on a material structure like simple material and composite material. The material structure of composite material is composed of two or more elements such as nickel-cobalt or manganese-cobalt, in contrast to simple material which is mainly composed of only one element. Therefore, composite materials have a more complicated material structure than simple materials, because nickel atoms or manganese atoms are inserted among the cobalt atoms. While discharging or recharging, lithium-ions hardly move in such a complicated material structure, and it can lead the deceleration of chemical reaction velocity. This deceleration reduces the heat load on cathode materials per unit time, and it contributes to long-lasting materials.

Thus, material innovation in the development of energy density and stability has a significant role in leading the LIB innovation process. In order to satisfy the aforementioned two requirements simultaneously, simple materials needs to be developed into composite materials. It is because these simple materials and composite materials have physically different structures, and appearance of composite materials is essential to improve the stability of cathode materials. Along with the development of these two functionalities of cathode materials, we classify the innovation process of cathode materials into the following five groups (Ohzuku et al., 2007):

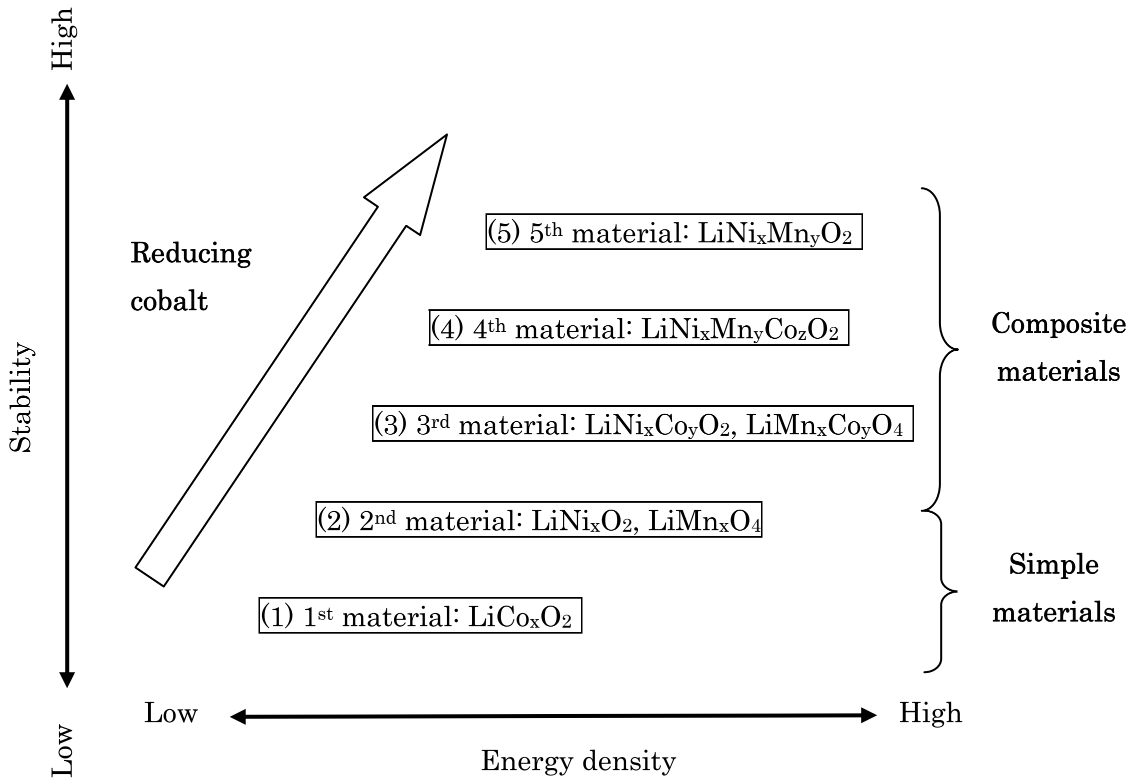
(1) The first material used in LIB is the lithium-cobalt oxide, which is mainly composed of cobalt; for instance, $LiCo_xO_2$ can be classified into this group. We call this material 1st material. As previously noted, LIB was first manufactured by Sony in 1991, and this material has been used since then. It is because cobalt is known as a material having desirable electric characteristics (Nagaura, 1991; Sekai et al., 1993).

(2) The second material used in LIB is the lithium-nickel (or manganese) oxide, which is mainly composed of nickel (or manganese); for instance, $LiNi_xO_2$, $LiMn_xO_4$ can be classified into this group. We call this material 2nd material. Although cobalt was used in LIB as the desirable material at first, cobalt is known as an expensive rare metal because of its unavailability. Therefore, materials like nickel and manganese were expected to be alternative materials of cobalt, so that R&D in these materials was encouraged after the appearance of 1st material in the late 1990s (Amatucci et al., 2002; Gummow et al., 1994).

(3) The third material used in LIB is the lithium-nickel (or manganese)-cobalt oxide, which is mainly composed of nickel (or manganese) and cobalt; for instance, $LiNi_xCo_yO_2$, $LiMn_xCo_yO_4$ can be classified into this group. We call this material 3rd material. The improvement of energy density was accelerated in the 1990s, but the development turned to be decelerated after 2000. One of reasons could be that 1st material and 2nd material reached their performance limit, and new composite materials were required after 2000. Then, composite materials in which a portion of cobalt was replaced with nickel (or manganese) were invented in the early 2000s to provide higher energy density than traditional materials and constituted a desirable material structure for heat load (Armstrong et al., 2002; Ohzuku et al., 1993).

(4) The fourth material used in LIB is the lithium-nickel-manganese-cobalt oxide, which is mainly composed of nickel, manganese, and cobalt; for instance, $LiNi_xMn_yCo_zO_2$ can be classified into this group. We call this material 4th material. A portion of cobalt was replaced with both nickel and manganese. This material was diffused rapidly in the late 2000s (Koyama et al., 2004 a, 2004 b; Yoshizawa et al., 2003).

(5) The fifth material used in LIB is the lithium-nickel-manganese oxide, which is mainly composed of nickel and manganese; for instance, $LiNi_xMn_yO_2$ can be classified into this group. We call this material 5th material. This material hasn't put into practical use yet, but it is expected as the next generation material. Because it makes electrodes work without cobalt (Gopukumar et al., 2004; Jae-Won et al., 2009; Makimura et al., 2003; Yoncheva et al., 2007, 2009).



(1) 1st material: lithium-cobalt oxide
(2) 2nd material: lithium-nickel (or manganese) oxide
(3) 3rd material: lithium-nickel (or manganese)-cobalt oxide
(4) 4th material: lithium-nickel-manganese-cobalt oxide
(5) 5th material: lithium-nickel-manganese oxide

Figure 2-16. Development of materials used in a cathode.

Figure 2-16 shows the development process of materials defined as 1st ~ 5th materials. It describes how cathode materials have been developed over the last 20 years since the practical use of LIB started. In this classification of materials, 1st and 2nd materials can be called 'simple material', which is mainly composed of only one element other than lithium and oxygen. In contrast, 3rd, 4th, and 5th materials can be called 'composite material', which is mainly composed of two or more elements other than lithium and oxygen. The main goal in the development of materials is how to invent composite materials with high energy density and stability simultaneously with reducing the rate of cobalt.

In addition to energy density and stability of materials, how to reduce the degree of cobalt has also been discussed in the development of cathode materials. In the 1990s, cathodes were mainly made from lithium-cobalt oxide with suitable electrical characteristics, and cobalt was considered as the most appropriate material at that time; however, one of drawbacks of using cobalt was its high price. Although LIB with high energy density could be achieved by using cobalt as cathode material, cobalt was an expensive rare metal. If the cobalt content in composite material was increased in order to provide high energy density, these composite materials became more expensive. In order to deal with this contradicted demand, composite materials in which a portion of cobalt was replaced with nickel (or manganese) began to be investigated after 2000. Therefore, a main R&D subject has been to improve the energy density of composite materials to a level as high as cobalt. Composite materials became necessary to reduce the use of cobalt and improve the energy density with new demand for LIB in the 2000s (Lin et al., 2008).

The success of 5th material is expected in the near future due to the unavailability of cobalt. Cobalt is restricted in some regions like the Congo in Africa. The Congo holds the largest cobalt reserves, and it is estimated to represents 50% of the world cobalt reserves. Cobalt is mined and produced in many countries such as Australia, Finland, Canada, and Zambia. Japanese firms have to import cobalt from these producing countries; however, this international trade is influenced by many factors like politics and economics. Thus, it is critical for Japan to ensure a stable supply of energy to advance the development of every product which derives energy from LIB. Therefore, it is valuable to invent new materials which depend less on cobalt to lead innovation for the world's energy.

The LIB industry could no longer rely on lithium-cobalt oxide to produce electrodes as they had been in the early 1990s, and firms had to develop new materials with more suitable characteristics that would satisfy requirements of lowering cost and improving the technological functionality.

Based on the material classification exhibited in Figure 2-16, we analyze patents obtained by Sony and Panasonic and establish the chronology of development of material technology in each firm.

2.5.3 Data construction

In this study, we analyze the LIB innovation process in Sony and Panasonic by using patent data. First, we compared diffusion trajectories of electrode technology in Sony and Panasonic. Numerical analysis was conducted by utilizing the bi-logistic function model and patent data classified into 'Structure and Electrode' defined by IPC. In addition to this numerical analysis, we classify the development of cathode materials into five groups and compare chronologies of material patents obtained by Sony and Panasonic.

Table 2-8 and Table 2-9 show the chronology of material patents obtained by Sony and Panasonic, respectively. In these tables, every patent is extracted which is classified as H01M4/50,102 or H01M4/52,102 and filed by Sony and Panasonic in JPO during 1991-2009.

In these tables, 'Date' indicates the filing date. 'Number' indicates the patent number. 'Chemical formula' indicates the chemical formula described in the main claim of patents. 'Details' indicates the numerical range of composite materials and the combination of added metals. Technological information in 'Details' is collected from patent claims and patent specifications. 'Category' indicates the material classification among (1) ~ (5) which is defined in Figure 2-16. In this 'Category', material technology is classified into five groups on the basis of 'Chemical formula' and 'Details'.

The data of patent applications are obtained by a retrieval of patent data in "Industrial Property Digital Library" provided by National Center for Industrial Property Information and Training in Japan.

Table 2-8 Chronology of material patents obtained by Sony.

No	Date	Number	Chemical formula	Details	Category
1	1998	JP,4161396	Li_xMnO_y	$0.505 \leqq x \leqq 0.525$ $1.96 \leqq y \leqq 2.00$	(2)
2	1998	JP,4161422	$Li_xMn_{2-z}O_4$ $LiMn_{2-y}M_yO_4$	$0 < x \leqq 1.33$ $0 < y < 1$ $0 \leqq z \leqq 0.33$ (M=Ge,Ti,Ni,Zn,Fe)	(2)
3	1999	JP,4244427	$LiMnO_2$		(2)
4	1999	JP,4232277	$LiMn_{1-y}Al_yO_2$	$0.06 \leqq y < 0.25$	(2)
5	1999	JP,4080110	$LiCoO_2$ $LiNiO_2$ $LiNiyCo_{1-y}O_2$ $LiMn_2O_4$	$0 < y < 1$	(1),(2)
6	2000	JP,4501202	$Li_x Mn_2 O_4$	x gets any values	(2)
7	2000	JP,4062856	$LiCoO_2$		(1)
8	2000	JP,4524881	$LiNi_{1-x}M_xO_2$ $Li_yMn_{2-z}M'_zO_4$	$0.01 \leqq x \leqq 0.5$ $0.9 \leqq y \leqq 1.2$ $0.01 \leqq z \leqq 0.5$ (M=Fe,Co,Mn,Cu,Zn, Al etc) (M'=Fe,Co,Ni,Cu,Zn etc)	(3),(2)
9	2000	JP,3982165	$Li_xCo_{1-y}M_yO_2$	$0 < x < 2$ $0 \leqq y < 1$ (M=Ni,Fe,Mn,Cu,Zn,Al,Sn,B, Ga,Cr,V,Ti etc)	(3),(1)
10	2000	JP,4325112	$Li_mCo_xA_yB_zO_2$	$0.9 \leqq x < 1$ $0.001 \leqq y \leqq 0.05$ $0.001 \leqq z \leqq 0.05$ $0.5 \leqq m \leqq 1$ (A=Al,Cr,V,Mn,Fe. B=Mg,Ca)	(3),(1)
11	2001	JP,4210892	$Li_xMn_{2-y}Ma_yO_4$ $LiNi_{1-z}Mb_zO_2$	$0.9 \leqq x \leqq 2$ $0.01 \leqq y \leqq 0.5$ $01 \leqq z \leqq 0.5$ (Ma=Co,Cu,Zn,Sn,Cr,V etc) (Mb=Fe,Co,Mn,Cu,Zn,Al etc)	(3),(2)

12	2001	JP,4404179	$Li_xNi_{1-y-z}Mn_yMI_zO_2$	0.9≦x＜1.1 0.25≦y≦0.45 0.01≦z≦0.30 (M=Li,Ni,Mn,Mg,Ti,V,Cr,Fe,Co,Al,Ga etc)	(5),(4)
13	2002	JP,4032744	$Li_xNi_{1-y-z}Mn_yM_zO_2$	0.9≦x＜1.1 0.05≦y≦0.50 0.01≦z≦0.30 (M=Li,Ni,Mn,Mg,Ti,V,Cr,Fe,Co,Al,Ga etc)	(5),(4)
14	2002	JP,4221932	$Li_xMn_{2-y}M'_yO_4$	0.9≦x 0.01≦y≦0.5 (M'=Fe,Co,Ni,Cu,Zn,Al,Sn,Cr,V,Ti,Mg etc)	(3),(2)
15	2002	JP,4224987	$LiNiO_2$ $Li_xNi_yCo_{1-y}O_2$	0＜x＜1 0.7＜y＜1.0	(3),(2)
16	2002	JP,4447831	Composite material with Ni, Co, Mn	0.5≦x≦0.6 y=0.2 0.2≦z≦0.3 x+y＋z=1 (x=Ni, y=Co, z=Mn,Ti)	(4),(3)
17	2002	JP,4192574	$Li_xMn_{2-y}M_yO_4$	0.9≦x 0.01≦y≦0.5 (M=Fe,Co,Ni,Cu,Zn,Al,Sn,Cr,B,Ti,Cr etc)	(3),(2)
18	2003	JP,4106651	$Li_aMn_bCr_cAl_{1-b-c}O_d$	1.2＜a＜1.6 0＜b 0＜c 0.5＜b＋c＜1 1.8＜d＜2.5	(2)
19	2003	JP,4061648	$LiNi_{1-x}M_xO_2$	0.1≦x≦0.5 (M=Fe,Co,Mn,Cu,Zn,Cr,V,Ti,Al, Sn,Ga,Sr etc)	(5),(3)
20	2004	JP,4237074	$LiNi_{1-x}M_xO_2$	0.2≦x≦0.5 (M=Fe,Co,Mn,Cu,Zn,Cr,V,Ti,Al, Sn,Ga,Sr etc)	(5),(3)

21	2004	JP,4172423	$Li_xNi_{1-y-z}Co_yMn_zO_2$	$0.05 \leqq x \leqq 1.15$ $0.15 \leqq y+z \leqq 0.70$ $0.05 \leqq z \leqq 0.40$	(4)
22	2004	JP,4192869	$LiCoO_2$		(1)
23	2005	JP,4483618	$Li_4Mn_5O_{12}$		(2)
24	2005	JP,4482822	$Li_aCo_xMI_yMII_zO_2$	$0.9 \leqq a \leqq 1.1$ $0.9 \leqq x < 1$ $0.001 \leqq y \leqq 0.05$ $0.001 \leqq z \leqq 0.05$ $x+y+z=1$ (MI=Al,Cr,V,Mn,Fe) (MII=Mg,Ca etc)	(4),(3)
25	2006	JP,4240060	$Li_xCo_aM1_bM2_cO_2$	$0.9 \leqq x \leqq 1.1$ $0.9 \leqq a < 1$ $0.001 \leqq b \leqq 0.05$ $0.001 \leqq c \leqq 0.05$ $a+b+c=1$ (M1=Al,Cr,V,Mn,Fe) (M2=Mg,Ca etc)	(3)
26	2006	JP,4306697	$Li_xCo_{1-y}M_yO_{b-a}X_a$	$0.2 < x \leqq 1.2$ $0 \leqq y \leqq 0.1$ $1.8 \leqq b \leqq 2.2$ $0 \leqq a \leqq 1.0$ (M=B,Mg,Al,Si,P,S,Ti,Cr,Mn ,Fe,Co,Ni,Cu,Zn,Ga,Y,Zr,Mo etc. X is halogen)	(3)
27	2006	JP,4311438	$Li_{1+x}Co_{1-y}M_yO_{2-z}$	$-0.10 \leqq x \leqq 0.10$ $0 \leqq y < 0.50$ $-0.10 \leqq z \leqq 0.20$ (M=Mg,Al,B,Ti,V,Cr,Mn,Fe, Ni,Cu,Zn etc)	(3)

(1) 1st material: lithium-cobalt oxide

(2) 2nd material: lithium-nickel (or manganese) oxide

(3) 3rd material: lithium-nickel (or manganese)-cobalt oxide

(4) 4th material: lithium-nickel-manganese-cobalt oxide

(5) 5th material: lithium-nickel-manganese oxide

Table 2-9 Chronology of material patents obtained by Panasonic.

No	Date	Number	Chemical formula	Details	Category
1	1998	JP,3986148	$Li_xNi_yCo_zO_2$	$0.90 \leqq x \leqq 1.05$ $0.7 \leqq y \leqq 0.9$ $y+z=1$	(3)
2	1998	JP,3985323	$Li_xM_yNi_{1-y}O_2$	$0.5 \leqq x \leqq 1.10$ $0 \leqq y \leqq 1$ (M=Fe,Cu,Mg,Co,Mn etc)	(3),(2)
3	1998	JP,4055241	$LiNi_xM_{1-x}O_2$	$0.5 \leqq x \leqq 1$ (M=Co,Mn,Cr,Fe,V,Al)	(3),(2)
4	1998	JP,4106741	A_2MX_4	(X=F,Cl,O,S etc) (A=Li) (M=Ni,Na,K,Ca,Ti,Zn, Sr etc.)	(2),(1)
5	1998	JP,4092779	Li_xMnO_4	$0.54 \leqq x \leqq 0.59$	(2)
6	1999	JP,4186291	$LiMn_2O_4$		(2)
7	1999	JP,4453122	$LiMn_2O_4$ etc		(2)
8	2000	JP,4330758	$LiMn_2O_4$ etc		(2)
9	2001	JP,4510331	$Li[Li_x(Ni_{1/3}Mn_{1/3}Co_{1/3})_{1-x}]O_2$	$0 \leqq x \leqq 0.3$	(4)
10	2001	JP,4080337	$Li[Li_x(Ni_{1/2}Mn_{1/2})_{1-x}]O_2$	$0 \leqq x \leqq 0.3$	(5)
11	2002	JP,4153700	$Li_a(Co_{1-x-y}Mg_xM_y)_bO_c$	$0 \leqq a \leqq 1.05$ $0.005 \leqq x \leqq 0.15$ $0 \leqq y \leqq 0.25$ $0.85 \leqq b \leqq 1.1$ $1.8 \leqq c \leqq 2.1$ (M=Ni,Mn,Al)	(3),(1)
12	2002	JP,4056271	$Li_xMn_yO_z$ $Li_xMn_yNi_mO_z$		(3),(2)
13	2002	JP,4197237	$Li_{2\pm\alpha}[Me]_4O_{8-x}$	$0 \leqq \alpha < 0.4$ $0 \leqq x < 1.3$ (Me=Mn,Ni,Cr,Fe,Co, Cu)	(5)

14	2002	JP,4259847	$Li[M_x(Ni_\delta Mn_\gamma)_{1-x}]O_2$	$-0.1 \leqq x \leqq 0.3$ $-0.1 \leqq y \leqq 0.5$ $\delta=0.5\pm0.1$ $\gamma=0.5\pm0.1$ (M=Co etc)	(5),(4)
15	2002	JP,4150343	$Li_a(Co_{1-x-y}Mg_xM_y)_bO_c$	$0 \leqq a \leqq 1.05$ $0.005 \leqq x \leqq 0.025$ $0 \leqq y \leqq 0.25$ $0.85 \leqq b \leqq 1.1$ $1.8 \leqq c \leqq 2.1$ (M=Ni,Mn,Al)	(3)
16	2003	JP,4274801	$Li_zCo_{1-x-y}Mg_xM_yO_2$	$0.97 \leqq 1/z \leqq 1$ $0.005 \leqq x \leqq 0.1$ $0.001 \leqq y \leqq 0.03$ (M=Al,Ti,Sr, Mn etc)	(3),(1)
17	2003	JP,4271448	$Li_zCo_{1-x-y}Mg_xM_yO_2$	$0 \leqq z \leqq 1.03$ $0.005 \leqq x \leqq 0.1$ $0.001 \leqq y \leqq 0.03$ (M=Al,Ti,Sr, Mn,Ni etc)	(3),(1)
18	2003	JP,4300827	$LiMg_xCo_{1-x}O_2$	$0 \leqq x < 1$	(3)
19	2003	JP,4313096	$Li_a(Co_{1-x-y}Mg_xM_y)_bO_c$	$0 \leqq a \leqq 1.05$ $0.01 \leqq x \leqq 0.2$ $0 \leqq y \leqq 0.02$ $0.85 \leqq b \leqq 1.1$ $1.8 \leqq c \leqq 2.1$ (M=Al,Mn,Zr, In,Sn)	(3),(1)
20	2003	JP,3994078	$Li_xNi_yCo_zO_2$	$0.90 \leqq x \leqq 1.05$ $0.7 \leqq y \leqq 0.9$ $y+z=1$	(3)
21	2003	JP,4554911	$Li_{1\pm x}Ni_{1/2}Co_{1/2}O_2$	$x \leqq 0.1$	(3)

22	2004	JP,4549689	$Li_a(Co_{1-x-y}Mg_xAl_y)_bM_zO_c$	0＜a≦1.05 0.005≦x≦0.15 0.0001≦y≦0.01 0.0002≦z≦0.008 0.85≦b≦1.1 1.8≦c≦2.1 (M＝Na,K etc)	(3)
23	2006	JP,4541324	$LiNi_{1-a-b-c-d}Co_aAl_bM^1{}_cM^2{}_dO_2$	0.05≦a≦0.35 0.005≦b≦0.1 0.0001≦c≦0.05 0.0001≦d≦0.05 (M^1=Mn,Ti,Y,Nb,Mo,W) (M^2=Mg,Ca,Sr,Ba)	(5),(4)
24	2007	JP,4047372	$LiCoO_2$ $LiNiO_2$ $LiMn_2O_4$		(1),(2)
25	2009	JP,4440339	$Li_{1-x}Na_xNi_{1-y}Me_yO_2$	0＜x≦0.05 0≦y≦0.34 (Me=Co,Mn,Fe,Cu,Al,Mg,Ti,Zr,Ce)	(3)

(1) 1st material: lithium-cobalt oxide

(2) 2nd material: lithium-nickel (or manganese) oxide

(3) 3rd material: lithium-nickel (or manganese)-cobalt oxide

(4) 4th material: lithium-nickel-manganese-cobalt oxide

(5) 5th material: lithium-nickel-manganese oxide

2.5.4 The results of analysis

In the case of LIB industry, it is useful to observe the timing of when R&D in material technology was switched from simple materials to composite materials. In order to investigate this, we compared the timing of when patents of composite materials were filed by Sony and Panasonic. As previously explained, 'first-to-file principles' was introduced by JPO, therefore early filing of patent application is necessary to have superiorities for other later patent applications.

In the case of Sony, Table 2-8 demonstrates that the first patent of composite material was filed in 2000. While most patents of 1^{st} and 2^{nd} materials were filed before 2000, patents of 3^{rd}, 4^{th}, and 5^{th} materials were filed after 2000. Thus, R&D was switched to the composite materials after 2000. Additionally, we discuss the trends in chronology with the numerical results from a bi-logistic function model. According to Figure 2-14, it appears that the 2^{nd} wave of Sony started in around 2000. This emergence of composite materials corresponds to the start-up of 2^{nd} wave in Sony.

In the case of Panasonic, Table 2-9 demonstrates that the first patent of composite material was filed in 1998. It suggests that R&D in Panasonic was switched from patents of 1^{st} and 2^{nd} materials to patents of 3^{rd}, 4^{th}, and 5^{th} materials about two years earlier than Sony. It can be said that the 2^{nd} wave of Panasonic started in around 1998 by referring Figure 2-14. This emergence of composite materials corresponds to the start-up of 2^{nd} wave in Panasonic.

After the practical use of LIB started, both Sony and Panasonic were competing to invent new materials. The results of chronological analysis of material patents suggested that the start-up of 2^{nd} wave corresponds to the emergence of composite materials in both firms. Additionally, it was also revealed that the number of patents of simple materials has decreased and that of composite materials has increased since 2000. It is assumed that the emergence of composite material leveraged the shift from 1^{st} wave to 2^{nd} wave.

Thus, based on the results of numerical analysis and chronological analysis, it can be said that Panasonic demonstrated earlier development of material technology than Sony. Panasonic's prompt undertaking in the 2^{nd} wave in the diffusion trajectory of electrode technology was initiated by the development of composite materials.

2.5.5 Trends in the number of patent applications of primary battery

In addition to the discussion of secondary LIB, it is useful to know trends in the primary LIB. Generally, LIB can be classified into two types, primary battery and secondary battery. Primary battery can only discharge energy, and secondary battery can both discharge and recharge energy. In the LIB industry, firms mainly produce secondary LIB in these days, because secondary LIB is used in almost all digital equipments like cellular phones and laptop PCs.

These two kinds of battery can be classified by IPC. Primary battery is classified as H01M6, and secondary battery is classified as H01M10. We compare patent applications of LIB which belongs to H01M6 filed by Sony and Panasonic during 1991-2008. Figure 2-17 shows trends in the number of patent applications of the primary LIB to compare trends between Sony and Panasonic. The data of patent applications are obtained by a retrieval of patent data in "Industrial Property Digital Library".

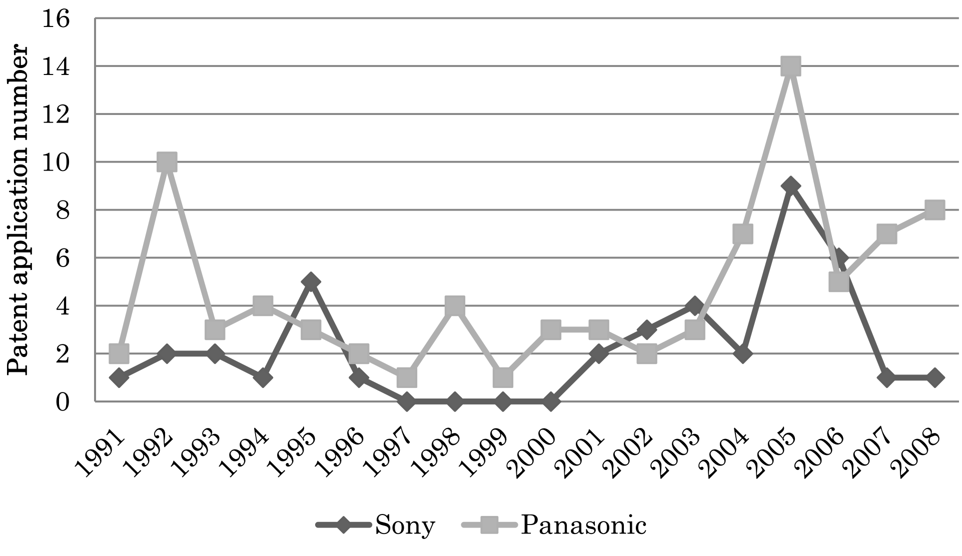


Figure 2-17. Trends in the number of patent applications of primary LIB.

Figure 2-17 demonstrates that Panasonic has larger amount of patent applications of primary LIB than that of Sony. This fact suggests that Panasonic has large number of patent applications in not only secondary LIB but also primary LIB. Sony first manufactured LIB, but Panasonic also has continued R&D in material technology to manufacture both primary LIB and secondary LIB.

2.6 Discussion

It is useful to discuss what Panasonic did between 4th quarter, 1995 (t_1 of 1st wave) and 2nd quarter, 2004 (t_1 of 2nd wave). It could be considered that timely invention of composite materials encouraged the Panasonic's earlier start-up on the diffusion trajectory of electrode technology. According to the NIKKEI news paper (Appendix A, B), one of differences between Sony and Panasonic was the collaborative R&D with different industries. In 2000, president of Panasonic stated to advance cross-industrial associations to survive the global competition.

Mr. Kunio Nakamura was elected as the president of Panasonic in June 2000. Nakamura has implemented the restructuring of organization under the theme of 'Destruction and Creation' since the appointment as president. In fact, Nakamura announced that cross-industrial association was the key to survive the global competition, and has encouraged collaborative R&D with other firms and universities since 2000. It is assumed that such collaborative R&D would help the development of material technology in Panasonic.

The importance of such open innovations is pointed in many previous works (Chesbrough et al., 2002, 2003, 2006; Grove, 1996; Millson and Wielmon, 2006). Additionally, many previous works demonstrated that technology spillover plays an important role in innovation (Watanabe et al., 2002, 2003; Verspagen and Loo, 1999; Cohen and Levinthal 1989, 1990). The importance of relationships between university-industry has been discussed (Audretsch and Lehmann, 2005; Kelly and Nakosteen, 2005; Tanabe and Watanabe, 2005). In fact, in 2001 and in 2006, Japanese government started the second and third "Science and Technology basic plans" to encourage academia-industry cooperation. It seems that cross-industrial associations could contribute the development of material technology in Panasonic.

Based on the foregoing observation, it could be considered that Panasonic has encouraged the cross-industrial associations since 2000, and it contributed to the rapid growth of diffusion trajectory of electrode technology. In collaborative R&D, it could provide opportunities for inventors to gather knowledge relating to material technology widely from outside and exchange knowledge to expand the opportunities of research. Then, knowledge relating to material technology spilled into Panasonic, and it could account for the prompt development of composite materials.

2.7 Conclusion

In conclusion, it was revealed that Panasonic succeeded in prompt undertaking in the 2nd wave on the diffusion trajectory of electrode technology earlier than Sony. Additionally, it was also revealed that Panasonic obtained the patents of composite materials earlier than Sony. It can be said that Panasonic's prompt undertaking in the 2nd wave in the diffusion trajectory was initiated by the development of composite materials.

Appendix A. Articles about LIB of Sony

Date	Main articles	Classification of articles
1995.11.05	Fire trouble was happened in Sony's factory	2
1996.03.10	Sony increased production of LIB (7.5 million batteries/ month)	1
1996.12.12	Sony increased production of LIB (15 million batteries/ month)	1
1997.10.25	Sony recalled 15 million batteries	2
1998.12.05	Sony established factory in Mexico to provide LIB to North America	4
1999.12.12	Sony and Fuji Electronics	4
2000.03.01	Sony recalled battery pack	1
2000.06.09	Sony starts producing super-thin batteries in Mexico	3
2000.09.08	Sony starts producing LIB for cellular phones	3
2001.07.04	Defects were found, and 560 thousand LIB are recalled	2
2001.07.05	Sony posted 2 million Yen to recall the battery	2
2003.10.07	Sony states to increase the production of LIB by 20-30% per month	1
2004.03.02	Sony starts selling LIB with 5% lower prices than current products	3
2004.05.14	Sony consolidated its subsidiaries producing LIB	4
2004.06.24	Sony invests in China to encourage the local producing capability	1
2004.12.10	Sony invented the LIB for cellular phones with great capacity	3
2005.02.16	Sony invented the long-lasting LIB with high capacity	3
2006.08.17	The trouble about LIB overheating was happened	2
2006.09.20	DELL recalled 4.2 million laptop PCs including Sony battery, and Apple recalled 1.8 million ones	2
2006.10.06	HITACHI recalled 16 thousand laptop PCs including Sony Battery	2
2006.10.14	SHARP stated to recall 28 thousand laptop PCs including Sony battery	2
2006.10.17	Fujitsu (338 thousand), Lenovo (526 thousand) also recall Sony battery	2
2006.10.20	Sony stated the 78% decrease of operating income	2
2006.10.24	Sony stated to recall the 250 thousand own laptop PCs (VAIO)	2
2006.10.25	The vice president in Sony made an apology about LIB problem	2
2006.12.01	The president in Sony stated to encourage the review of organization.	4

Appendix B. Articles about LIB of Panasonic

Date	Main articles	Classification of articles
1994.03.08	Panasonic enter the LIB market	1
1994.06.16	Panasonic encourages producing capability (2 million /month)	1
1994.11.11	Panasonic starts producing batteries in Mexico	1
1996.03.23	Panasonic starts producing LIB in Indonesia	1
1996.03.27	Panasonic increased production of LIB (20 million batteries/ month)	1
1996.04.02	Panasonic and Philips do collaborative R&D for automotive LIB	4
1996.04.18	Panasonic improved a low service temperature limit of LIB	3
1996.05.21	Panasonic and TOYOTA established new factory	1
1996.10.16	Panasonic provides batteries to NISSAN	4
1996.12.12	Panasonic and TOYOTA starts to invent automotive LIB	3
1996.12.17	Panasonic provides batteries to Ford	4
1997.01.30	Panasonic invested 130 billion Yen to increase the production of LIB	1
1997.05.14	Panasonic starts producing LIB in wakayama prefecture	1
1998.06.26	Panasonic starts producing LIB for laptop PCs (1 million/month)	3
1998.09.04	Panasonic invented LIB 0.5mm thick	3
1998.10.14	Panasonic EV energy increase the production of automotive LIB	1
1999.10.28	Panasonic starts to sale the LIB	1
2000.07.14	President of Panasonic states that cross-industrial association is essential strategy to survive the global competition.	4
2001.01.05	Panasonic encourages the producing capability (20 million/month)	1
2002.09.28	Panasonic encourages the review of organization.	4
2006.09.05	Panasonic recalls 6 thousand laptop PCs	2
2006.12.18	Panasonic invented new LIB to prevent overheating trouble	2

Appendix C. List of IPC

[H01M2/00] Constructional details or processes of manufacture, of the non-active parts

[H01M2/02・] Cases, jackets, or wrappings

[H01M2/04・・] Lids or covers

[H01M2/06・・] Arrangements for introducing electric connectors into or through cases

[H01M2/08・・] Sealing materials

[H01M2/14・] Separators; Membranes; Diaphragms; Spacing elements

[H01M2/16・・] characterized by the material

[H01M2/18・・] characterized by the shape

[H01M10/00] Secondary cells; Manufacture thereof

[H01M10/36・] Accumulators not provided for in groups 10/06 to 10/34

[H01M10/40・・] with organic electrolytes

[H01M4/00] Electrodes (electrodes for electrolytic processes C25)

[H01M4/02・] Electrodes composed of, or comprising, active material

[H01M4/04・・] Processes of manufacture in general

[H01M4/36・・] Selection of substances as active materials, active masses, active liquids

[H01M4/38・・・] of elements or alloys

[H01M4/40・・・・] Alloys based on alkali metals

[H01M4/48・・・] of inorganic oxides or hydroxides

[H01M4/50・・・・] of manganese

[H01M4/52・・・・] of nickel, cobalt, or iron

[H01M4/58・・・] of inorganic compounds other than oxides or hydroxides

[H01M4/62・・] Selection of inactive substances as ingredients for active masses

[H01M4/64・・] Carriers or collectors

[H01M4/66・・・] Selection of materials

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Chapter III
Technology Spillover in Innovation of Material Technology: A Case Study of Lithium Ion Battery in Sony and Panasonic

Abstract

In this Chapter III, in order to analyze the innovation process of materials used in Lithium Ion Battery (LIB), we compare the changes of technology spillover structure of two leading firms in Japan, Sony and Panasonic. Technology spillover structure is classified into four types on the aspect of organizational view and technological view. Based on this technology spillover structure, diversification process of simple materials and composite materials is compared between Sony and Panasonic.

In conclusion, it was revealed that simple materials and composite materials followed the same growth trajectory, which could be described as inter-technology spillover; diffusion of technologies from material technology to process, component, and product technologies. It was also revealed that this LIB innovation process was reconstructed when physical structure of materials was innovated from simple materials to composite materials. In conclusion, the changes of technology spillover structure played a significant role in driving the development of material technology.

Keywords

Cathode; Cobalt; Lithium ion battery; Patent; Patent strategy; Technology spillover.

3.1 Introduction

In a mature economy, material technology plays a significant role in driving the innovation process. Improvement of material technology, especially materials used in a cathode of Lithium Ion Battery (LIB), is essential for digital equipments such as cellular phones, laptop PCs in these days. Such materials have been innovated with the contribution of knowledge creation, and significant role of knowledge management in R&D has been discussed so far.

In the case of LIB, as suggested in Chapter II, LIB firms could no longer rely on simple material, which is mainly composed of one element, to produce electrode as they did in the 1990s, but had to develop materials with suitable characteristics which could provide higher energy density with lower cost. Composite material, which is composed of two or more elements, was then invented to realize higher technological performance in the early 2000s.

3.1.1 Knowledge management

The importance of how to create knowledge in R&D has long been discussed among academics. Nonaka (1990, 1991) suggested that knowledge can be important sources of competitive advantage for firms and knowledge creation can be critical for innovation. Nonaka (1994) noted that firms should not only possess information efficiently but also create knowledge to respond to changes in business environment. This knowledge creation can be one of important firm's strategies, and how to manage knowledge is discussed so far.

In previous works, many papers are discussing the importance of knowledge management. For instance, process of accessing, sharing and integrating knowledge (Grant and Baden, 2004; Grant, 1997), knowledge-based view of the firm (Grant, 1996 a, b), organizational knowledge creation (Nonaka, 1994), wellsprings of knowledge (Leonard-Barton, 1992, 1995), intellectual capital (Stewart, 1997), working knowledge (Davenport and Prusak, 1998), knowledge workers (Fuller, 2001), and community of practice (Brown and Duguid, 1991), gives us useful suggestions of how to create new knowledge.

In many cases, innovation would not be created by an individual person but a collective work of a group or a team, so that "organizational knowledge creation" is proposed which is defined as "*the process of making available and amplifying knowledge created by individuals as well as crystallizing and connecting it with an organizational knowledge system*" (Nonaka et al., 2006).

As an academic work, although some papers discuss the individual tacit knowledge (Gourlay, 2004; Tsoukas, 2003) and the quality of individual tacit knowledge (Noh et al, 2000; Sanders, 2004), group tacit knowledge is recently focused on as one of organizational knowledge creation models (Cook and Brown, 1999; Zarraga and Bonache, 2005). It is because group tacit knowledge is socially complex and difficult to imitate, and therefore it can constitute a part of a firm's intangible resources that give rise to competitive advantage (Leidner, 2000). The quality of group tacit knowledge is also remarked recently, and it is suggested that it can be a resource that organizations can rely on when they confront with unexpected and unfamiliar situations (Erden, von Krough, and Nonaka, 2008). The importance of information systems to combine individual knowledge in an organization is also implied (von Krough, 2009). Thus, methods of how to manage knowledge in an organization have been discussed.

3.1.2 Technology spillover

In order to propose effective knowledge management for R&D, many papers demonstrated that knowledge flow among technologies, technology spillover, could play an important role in leading the innovation. For example, technology spillover can make an impact on R&D strategy (Watanabe et al., 2001). Firms with a well-developed assimilation capacity succeeded in effectively utilizing technology spillover resulting in a very productive R&D structure (Watanabe et al., 2002). Cross-functional spillover could be a survival strategy for ceramics industry (Ohmura et al., 2003; Ohmura and Watanabe, 2005). The differences of firm's size are one of important factors for technology spillovers (Ornaghi, 2006). Furthermore, other studies also demonstrated that technology developments could be attributed to technology spillover (Griliches and Lichtenberg, 1984; Jaffe, 1986; Bernstein and Nadiri, 1988, 1989; Goto and Suzuki, 1989; Kwang and Watanabe, 2001; Nakanishi, 2002; Watanabe and Ane, 2003; Watanabe and Tokumasu, 2003; Nieto and Quevedo, 2005). Most of these studies show the mechanism of technology spillover in the innovation process.

Additionally, some papers suggested that technology spillover plays a significant role in developing materials. For instance, the effect of technology spillover in the fine ceramics industry is analyzed (Ohmura et al., 2003, 2006). The effect of technology spillover in the nonferrous metal industry is also analyzed (Nakagawa et al., 2007, 2009). We also analyzed the technology spillover effect in the acoustic industry, and suggested that the development of material technology is a key to improve the functionalities in a product (Shibata and Saiki, 2009). Thus, on the aspect of technology spillover, the importance of how to innovate materials are discussed so far.

In this study, we mainly focus on the development of cathode materials used in LIB, and discuss the differences of LIB innovation process between Sony and Panasonic. Then, we introduce the concept of technology spillover structure which is classified into four types on the aspect of organizational point of view and technological point of view.

In this chapter, two-dimensional model of technology spillover is introduced in (3.2). Hypothetical view is described in (3.3). The technology spillover in material technology is analyzed in (3.4). The results are discussed in (3.5). Conclusion in this chapter is remarked in (3.6).

3.2 Two-dimensional model of technology spillover

Technology spillover structure can be discussed from an organizational point of view and a technological point of view.

From the organizational point of view, technologies can spillover within a firm, and between firms. These types of technology spillovers are defined as 'intra-firm technology spillover' and 'inter-firm technology spillover'; for instance, technology spillover within Panasonic is an 'intra-firm technology spillover', and spillover between Panasonic and other firms is an 'inter-firm technology spillover'.

On the other hand, on the technological point of view, technologies can spillover within a technological field, and between technological fields; for instance, technology spillover within material technology used in a cathode of LIB is an 'intra-technology spillover', and spillover between material technology and product technology is an 'inter-technology spillover'.

Combining these two types of technology spillovers, technology spillovers are classified into four types; (1) intra-firm, intra-technology spillover, (2) intra-firm, inter-technology spillover, (3) inter-firm, intra-technology spillover, (4) inter-firm, inter-technology spillover. Table 3-1 shows the two-dimensional model of technology spillover structure, and we analyze trends in the technology spillovers by using this model.

The change of technology spillover structure with economic paradigm shift, from intra-technology spillover to inter-technology spillover, was discussed by analyzing the development of materials in the nonferrous metal industry (Nakagawa et al., 2009).

Table 3-1 Two-dimensional model of technology spillover.

(i)	Intra-firm, intra-technology spillover	- within a firm - within a technological field
(ii)	Intra-firm, inter-technology spillover	- within a firm - between technological fields
(iii)	Inter-firm, intra-technology spillover	- between firms - within a technological field
(iv)	Inter-firm, inter- technology spillover	- between firms - between technological fields

3.3 Hypothetical view

In the Chapter I, we suggest that material technology played an important role in developing the functionality of LIB. It was required for new materials to provide higher energy density and constitute a desirable material structure for heat load with less cobalt Thus, it can be said that the prompt development of material technology is a key to lead the innovation in the LIB industry.

Additionally, in the Chapter II, it was revealed that Panasonic succeeded in prompt undertaking of the diffusion trajectory of electrode technology in both 1st wave and 2nd wave, and Panasonic obtained patents of composite materials earlier than Sony. On the basis patent statistics, we concluded that Panasonic's prompt undertaking of electrode technology earlier than Sony was initiated by the development of composite materials.

Panasonic encouraged cross-industrial associations after 2000, and it provided opportunities for researchers to exchange knowledge relating to material technology. This collaborative R&D would contribute to promote inter-firm technology spillover, and technology spillover between industries. In addition to this, Panasonic introduced the 'platform structure' to utilize specific knowledge of core technologies in the development of products (Shinozaki, 2002). In this R&D system, researchers moved from basic research center to advanced research center to transfer knowledge, and it would contribute to advance the inter-technology spillover. Thus, Panasonic shifted the technology spillover from intra-firm to inter-firm technology spillover, and from intra-technology spillover to inter-technology spillover.

It could be considered that knowledge of material technology was diffused not only within material technology but also between material technology and other technologies to facilitate the development of material technology such as process, component, and product technologies. We call these technologies 'complementary technology'. After material technology has been developed, it would be diffused to complementary technologies. Therefore, the hypothesis can be expressed as follows.

[Hypothesis]
Knowledge of material technology was diffused to complementary technology in the LIB innovation process.

3.4. Analysis of technology spillover in material technology

3.4.1 Methodology to define patents and materials

We compare trends in the number of joint patent applications filed by Sony and Panasonic, and analyze the relations among researchers in these firms who invented materials used in a cathode.

In previous studies, in order to analyze the technology spillover, patent data has been recognized as a useful indicator to evaluate the technological innovation quantitatively (Griliches, 1990). Patents can be good examples to investigate technology spillover, because patents describe technological contents, references to technologies, and relations among inventors. Technology spillover paths can be identified by tracking the date of application, inventors, and technological description. Therefore, we use patent data to investigate the LIB innovation process.

As introduced in Chapter II, FI (File Index) is used to define technologies. FI was developed by Japan Patent Office (JPO), and it was used as more precise technological definition of patent than IPC. It is possible to define material characteristics more precisely by using FI. In this study, we use the most precise technological definition to group cathode materials, H01M4/50,102 and H01M4/52,102.

The definition of these FI, H01M4/50,102 and H01M4/52,102, are as follows.

- H01M4/50,102: Selection of substances of composite oxide or hydroxide including manganese to insert light metals
- H01M4/52,102: Selection of substances of nickel, cobalt, or iron of composite oxide or hydroxide including nickel, cobalt, or iron to insert light metals

The data of patents are obtained by a retrieval of patent data in "Industrial Property Digital Library" provided by National Center for Industrial Property Information and Training in Japan.

As introduced in Chapter II, material innovation in the development of energy density and stability has a significant role in leading the LIB innovation process. Additionally, materials which can reduce the degree of cobalt also have been discussed. In order to satisfy these requirements simultaneously, simple materials need to be developed into composite materials. (Ohzuku et al., 2007). In this study, we define the development of materials used in a cathode as the following five groups (Table 3-2).

Table 3-2 The development of material technology used in a cathode.

(1) 1st material lithium-cobalt oxide
(2) 2nd material lithium-nickel (or manganese) oxide
(3) 3rd material lithium-nickel (or manganese)-cobalt oxide
(4) 4th material lithium-nickel-manganese-cobalt oxide
(5) 5th material lithium-nickel-manganese oxide

Examples of each material can be expressed as follows.

(1) The 1st material used in LIB is the lithium-cobalt oxide, which is mainly composed of cobalt; for instance, $LiCo_xO_2$ can be classified into this group.

(2) The 2nd material used in LIB is the lithium-nickel (or manganese) oxide, which is mainly composed of nickel (or manganese); for instance, $LiNi_xO_2$, $LiMn_xO_4$ can be classified into this group.

(3) The 3rd material used in LIB is the lithium-nickel (or manganese)-cobalt oxide, which is mainly composed of nickel (or manganese) and cobalt; for instance, $LiNi_xCo_yO_2$, $LiMn_xCo_yO_4$ can be classified into this group.

(4) The 4th material used in LIB is the lithium-nickel-manganese-cobalt oxide, which is mainly composed of nickel, manganese, and cobalt; for instance, $LiNi_xMn_yCo_zO_2$ can be classified into this group.

(5) The 5th material used in LIB is the lithium-nickel-manganese oxide, which is mainly composed of nickel and manganese; for instance, $LiNi_xMn_yO_2$ can be classified into this group (Makimura and Ohzuku, 2003).

3.4.2 Data construction about inventors of material technology

In order to compare trends between the number of joint patent applications and the inventors, Table 3-3 and Table 3-4 show the chronology about material patents obtained by Sony and Panasonic and every inventor relating to these patents. In these tables, every patent is extracted which is classified as H01M4/50,102 or H01M4/52,102 and filed by Sony and Panasonic in JPO during 1991-2009.

In these tables, 'Date' indicates the filing date of patent. 'Number' indicates the patent number. 'Co-applicant' indicates the applicant of joint application other than Sony or Panasonic. 'Inventor' indicates researcher who is the inventor of patents. In the 'Inventor', 'S_n' and 'P_n' mean researchers in Sony and Panasonic, respectively. 'M_n', 'T_n', 'I_n', 'U_n', and 'E_n' mean researchers in Mitsui Chemical, Tanaka Chemical, Independent inventor, Osaka City University, and Energy Company, respectively. 'Category' indicates the classification of materials according to the Table 3-2.

In the case of Panasonic, some researchers moved from Panasonic to Energy Company. As previously noted, Panasonic introduced 'platform structure', and researchers moved from basic research center in Panasonic to advanced research center in Energy Company; 'Energy Company' is the group company of Panasonic treating energy devices. Such researchers are expressed as '$E_n(P_n)$'.

It is obvious by referring Table 3-3 and Table 3-4 that Sony obtained 27 patents of cathode materials by 43 inventors in Sony during 1998-2006, and only one patent was obtained with other firm as joint application. In contrast, Panasonic obtained 25 patents by 31 inventors in Panasonic during 1998-2009, and 9 patents were obtained with other firms, universities, and independent inventors as joint applications.

Table 3-3 Chronology about patents of cathode materials obtained by Sony.

No	Date	Number	Co-applicant	Inventor	Category
1	1998.01.29	JP,4161396	None	S1,S2,S3	(2)
2	1998.08.26	JP,4161422	None	S4	(2)
3	1999.02.24	JP,4244427	None	S5,S6,S7	(2)
4	1999.06.04	JP,4232277	None	S5	(2)
5	1999.07.09	JP,4080110	Mitsui Chemical	S8,M1	(1),(2)
6	2000.01.20	JP,4501202	None	S4,S9,S10, S11	(2)
7	2000.04.12	JP,4062856	None	S12,S13	(1)
8	2000.08.14	JP,4524881	None	S14,S15	(3),(2)
9	2000.10.05	JP,3982165	None	S16,S17,S18	(3),(1)
10	2000.12.28	JP,4325112	None	S19,S20,S21	(3),(1)
11	2001.03.01	JP,4210892	None	S14,S15,S21,S22,S23,S24	(3),(2)
12	2001.12.06	JP,4404179	None	S20,S21	(5),(4)
13	2002.01.08	JP,4032744	None	S20,S21	(5),(4)
14	2002.01.21	JP,4221932	None	S21,S25	(3),(2)
15	2002.05.29	JP,4224987	None	S26	(3),(2)
16	2002.10.18	JP,4447831	None	S20,S21	(4),(3)
17	2002.11.28	JP,4192574	None	S27	(3),(2)
18	2003.04.03	JP,4106651	None	S7	(2)
19	2003.04.11	JP,4061648	None	S20,S21	(5),(3)
20	2004.02.16	JP,4237074	None	S20	(5),(3)
21	2004.05.26	JP,4172423	None	S20,S21,S28	(4)
22	2004.09.10	JP,4192869	None	S29,S30	(1)
23	2005.02.17	JP,4483618	None	S31	(2)
24	2005.12.07	JP,4482822	None	S21,S28,S32,S33	(4),(3)
25	2006.05.26	JP,4240060	None	S21,S28,S32,S34,S35	(3)
26	2006.06.16	JP,4306697	None	S36,S37,S38,S39,S40	(3)
27	2006.11.28	JP,4311438	None	S41,S42,S43	(3)

S_n: Researchers in Sony

M_n: Researchers in Mitsui Chemical

Table 3-4 Chronology about patents of cathode materials obtained by Panasonic.

No	Date	Number	Co-applicant	Inventor	Category
1	1998.02.04	JP,3986148	Tanaka Chemical	P1, P2, P3, T1, T2, T3	(3)
2	1998.02.06	JP,3985323	None	P3, P4	(3),(2)
3	1998.04.23	JP,4055241	None	P2, P3, P5, P6, P7	(3),(2)
4	1998.05.28	JP,4106741	None	P8, P9, P10	(2),(1)
5	1998.06.09	JP,4092779	None	P9, P11, P12	(2)
6	1999.01.21	JP,4186291	None	P9, P11, P13, P14, P15	(2)
7	1999.06.23	JP,4453122	None	P9, P11, P13, P16	(2)
8	2000.03.29	JP,4330758	Independent Inventor	I1	(2)
9	2001.06.27	JP,4510331	Osaka City University	P11, P17, U1	(4)
10	2001.11.07	JP,4080337	Osaka City University	P11, P17, U1	(5)
11	2002.01.23	JP,4153700	None	P17, P18, P19, P20, P21, P22	(3),(1)
12	2002.03.19	JP,4056271	Independent Inventor	I1, I2	(3),(2)
13	2002.04.30	JP,4197237	Osaka City University	P11, P17, P23, U1	(5)
14	2002.10.17	JP,4259847	Osaka City University	P11, P17, U1	(5),(4)
15	2002.11.25	JP,4150343	None	P24, P25, P26, P27	(3)
16	2003.01.09	JP,4274801	None	P11, P17	(3),(1)
17	2003.01.16	JP,4271448	None	P11, P17	(3),(1)
18	2003.03.06	JP,4300827	None	E1, E2, E3, E4, E5	(3)
19	2003.06.09	JP,4313096	None	P2, P3, T1, T4, T5	(3),(1)
20	2003.09.19	JP,3994078	Tanaka Chemical	P2, P3, T1, T4, T5	(3)
21	2003.11.07	JP,4554911	Osaka City University	E11(P17), E6, U1	(3)
22	2004.02.06	JP,4549689	None	E12(P2), E13(P24), E14(P26), E7, E8	(3)
23	2006.06.09	JP,4541324	None	E15(P11), E9, E16(P16), E10	(5),(4)
24	2007.04.05	JP,4047372	None	P28, P29	(1),(2)
25	2009.05.13	JP,4440339	None	P17, P30, P31	(3)

P_n: Researchers in Panasonic

T_n: Researchers in Tanaka Chemical

I_n: Researchers as Independent inventor

U_n: Researchers in Osaka City University

E_n: Researchers in Energy Company

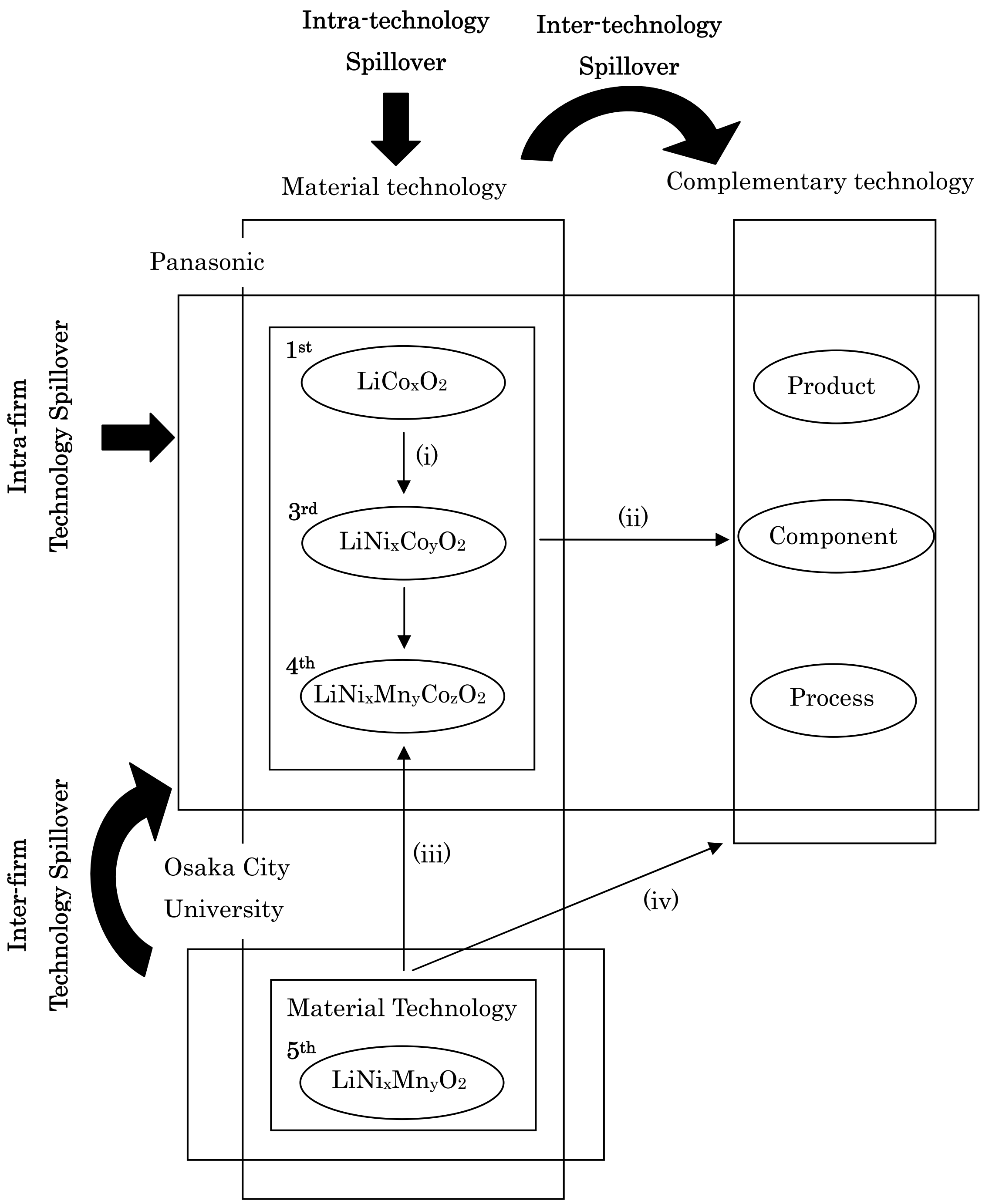
3.4.3 Methodology to analyze technology spillover

As previously introduced, we use two-dimensional technology spillover model to investigate the knowledge flow. As Beneito (2006) suggested, technology spillover structures reflect strategic options in firm's technology developments, because collaborative R&D activities play a different role from in-house R&D. In order to compare trends in changes of technology spillover with the development of material technology between Sony and Panasonic, we have to define the technology spillover structure in the case of the LIB industry.

In a previous work, we introduced the concept of technological classification like 'basic technology' and 'complementary technology' in acoustic industry. 'Basic technology' was defined as the technology which demonstrates the fundamental physical laws as a core technology, and 'complementary technology' was defined as the technology which facilitates the work of basic technologies in a product. In conclusion, we suggest that technology spillover diffused from basic technology to complementary technology with the development of materials (Shibata and Saiki, 2009).

In this study, we introduced the concept of technological classification like 'material technology' and 'complementary technology' in the LIB industry. 'Material technology' is defined as the development of materials used in a cathode as a core technology, and 'complementary technology' is defined as the technology which facilitates the work of material technology such as process, component, and product technologies. In the case of LIB, the development of complementary technology has a strong relationship with the development of material technology, because complementary technology should be developed on the basis of technological characteristics of material technology. Therefore, it is considered that knowledge is diffused from material technology to complementary technology. Based on this technological classification, we investigate the diffusion process of technologies in LIB.

Technology spillover in Panasonic can be described as Figure 3-1 as an example. In this figure, vertical line separate technologies into material technology and complementary technology, and it can distinguish the intra- or inter-technology spillover. In contrast, horizontal line separate technologies into sole patent application and joint patent application with Osaka City University, and it can distinguish the intra- or inter-firm technology spillover.



(i) Intra-firm, intra-technology spillover
(ii) Intra-firm, inter-technology spillover
(iii) Inter-firm, intra-technology spillover
(iv) Inter-firm, inter-technology spillover

Figure 3-1. Schematic diagram of technology spillovers.

Technology spillover expressed in Figure 3-1 has the following meanings.

(i) Intra-firm, intra-technology spillover

This type of spillover occurs within a firm, and within a technological field. Figure 3-1 illustrates the development process of material technology in Panasonic. This figure illustrates the process where 1st material (ex. $LiCo_xO_2$) is developed to 3rd material (ex. $LiNi_xCo_yO_2$), and this 3rd material is developed to 4th material (ex. $LiNi_xMn_yCo_zO_2$).

(ii) Intra-firm, inter-technology spillover

This type of spillover occurs within a firm, and between technological fields. Figure 3-1 illustrates the diffusion of material technology in Panasonic. This figure illustrates the process where materials are utilized in the development of process, component, and product technologies.

(iii) Inter-firm, intra-technology spillover

This type of spillover occurs between firms, and within a technological field. Figure 3-1 illustrates the development process of material technology in the collaborative R&D between Panasonic and Osaka City University. This figure illustrates the process where 5th material (ex. $LiNi_xMn_yO_2$) is invented in the collaborative R&D in material technology.

(iv) Inter-firm, inter-technology spillover

This type of spillover occurs between firms, and between technological fields. Figure 3-1 illustrates the diffusion of material technology in the collaborative R&D between Panasonic and Osaka City University. This figure illustrates the process where 5th material is utilized in the development of process, component, and product technologies in the collaborative R&D.

The importance of close relationships to perform the collaborative R&D between university-industry and government-industry has been discussed (Audretsch and Lehmann, 2005; Kelly and Nakosteen, 2005; Tanabe and Watanabe, 2005; Millson and Wielmon, 2006). In 2001 and 2006, Japanese government started the second and third "Science and Technology basic plans", in which government encouraged academic-industry cooperation. It is expected that these national policies supported the integrations between Panasonic and Osaka City University.

3.4.4 Data construction about technology spillover structure

In a previous work, it was suggested that technologies are transferred by some core researchers. In the case of material industry, researchers who conducted research on two or more materials delivered among materials as technology spillover (Ohmura and Watanabe, 2006).

As previously noted, 5th material is expected as the new generation material which can provide higher energy density than other materials without cobalt. Since cobalt is one of expensive rare metals, it has a significant meaning to the invention of 5th material in obtaining patents. Therefore, we focus on core researchers who contribute to the invention of 5th material, and further analyze how these core researchers invented the 5th materials.

Based on the chronology in Table 3-3 and Table 3-4, we can define the core researchers in Sony and Panasonic who invented 5th materials. In the case of Sony, it seems that 'S21' has led the invention of 5th materials such as 'JP,4404179', 'JP,4032744', and 'JP,4061648'. In the case of Panasonic, it seems that 'P11' has led the invention of 5th materials such as 'JP,4080337', 'JP,4197237', 'JP,4259847', and 'JP,4541324'. Thus, inventions of 5th materials filed by Sony and Panasonic would be attributed to the contribution by these two core researches, respectively.

Table 3-5 and Table 3-6 show all patents filed by 'S21' and 'P11' as core researchers in Sony and Panasonic. Patent publications are extracted which are classified as H01M4/50,102 and H01M4/52,102 by FI and filed by 'S21' and 'P11' during 2004-2008, because patent applications filed in this period have not been decided yet whether these are accepted as patents or not. Based on patent data on these tables, we analyze trends in the changes of technology spillover in Sony and Panasonic, respectively. These technology spillovers are grouped depending on the existence of co-applicants and the technological contents in patent claims.

In these tables, 'Date' indicates the filing date of patents and patent publications. 'Number' indicates the patent number and patent publication number. 'Co-applicant' indicates the applicant of joint application other than Sony or Panasonic. 'Invention' indicates the technological content of patents and patent publications. 'Spillover type' indicates the groups of technology spillover illustrated in Figure 3-1.

Table 3-5 Trends in the changes of technology spillover structure in Sony.

No	Date	Number	Co-applicant	Invention	Spillover type
1	1988	JP,2897217	None	Materials and LIB	(i)
2	1990	JP,3049727	None	Materials and LIB	(i)
3	1990	JP,3469836	None	Materials and LIB	(i)
4	1991	JP,3160920	None	Materials and LIB	(i)
5	1991	JP,3200867	None	Materials and LIB	(i)
6	1991	JP,3010781	None	Materials and LIB	(i)
7	1991	JP,3103899	None	Materials and LIB	(i)
8	1991	JP,3010783	None	Materials and LIB	(i)
9	1991	JP,3303319	None	Materials of cathode and anode	(ii)
10	1991	JP,3318941	None	Manufacturing	(ii)
11	1992	JP,3355644	None	Manufacturing	(ii)
12	1994	JP,3421877	None	Materials of cathode and anode	(ii)
13	1994	JP,3451763	None	Manufacturing	(ii)
14	1995	JP,3543437	None	Materials and LIB	(i)
15	1997	JP,3769871	None	Manufacturing	(ii)
16	1997	JP,3633223	None	Manufacturing	(ii)
17	1998	JP,4437239	None	Materials of anode	(ii)
18	2000	JP,4325112	None	Materials of cathode and anode	(ii)
19	2001	JP,4210892	None	Materials and LIB	(i)
20	2001	JP,4404179	None	Materials and LIB	(i)
21	2002	JP,4032744	None	Materials and LIB	(i)
22	2002	JP,4221932	None	Materials and electrolyte	(ii)
23	2002	JP,4058680	None	Manufacturing	(ii)
24	2002	JP,4333103	None	Manufacturing	(ii)
25	2002	JP,4447831	None	Materials and LIB	(i)
26	2002	JP,4281329	None	Structure of LIB	(ii)
27	2003	JP,4061648	None	Materials and LIB	(i)
28	2003	JP,4061586	None	Materials and LIB	(i)
29	2004	JP,4172423	None	Materials and LIB	(i)
30	2005	JP,4482822	None	Materials and LIB	(i)

31	2006	JP,4240060	None	Materials and LIB	(i)
32	2007	JPA,2008-234872	None	Materials and LIB	(i)
33	2007	JPA,2008-282667	None	Materials and LIB	(i)
34	2008	JPA,2010-129471	None	Materials and LIB	(i)

JP: Japan patent number, JPA: Japan patent publication number

Table 3-5 demonstrates that 'S21' is the inventor in 31 patents and 3 patent publications of cathode materials during 1988-2008, and no patents were filed with other firms or universities as joint application. In the case of Sony, each technology spillover shows following distinctive characteristics.

(i) Intra-firm, intra-technology spillover

In all periods, this type of technology spillover could be most frequently observed in R&D in cathode materials. All patents of cathode materials were filed as sole patent application, and patents filed as joint patent applications with other firms couldn't be found. Therefore, it seems that Sony developed 5th materials with their own efforts, and filed patents of these composite materials as sole patent application.

(ii) Intra-firm, inter-technology spillover

In the late 1990s and the early 2000s, this type of technology spillover was observed. It seems that, after the development of material technology, R&D expanded to the invention of complementary technology to facilitate the work of materials. Then, technology spillover occurred between material technology and complementary technology.

(iii) Inter-firm, intra-technology spillover

No joint patent applications were found in R&D, so that this type of technology spillover couldn't be observed.

(iv) Inter-technology, inter- technology spillover.

No joint patent applications were found in R&D, so that this type of technology spillover couldn't be observed.

Table 3-6 Trends in the changes of technology spillover in Panasonic.

No	Date	Number	Co-applicant	Invention	Spillover type
1	1995	JP,3329124	None	Manufacturing	(ii)
2	1995	JP,3331824	None	Materials and LIB	(i)
3	1995	JP,3229531	None	Materials and LIB	(i)
4	1998	JP,4366724	None	Materials and LIB	(i)
5	1998	JP,4066509	None	Manufacturing	(ii)
6	1998	JP,3468099	None	Manufacturing	(ii)
7	1998	JP,4092779	None	Manufacturing	(ii)
8	1998	JP,3468106	None	Manufacturing	(ii)
9	1998	JP,4085479	None	Anode and LIB	(ii)
10	1998	JP,4185191	Mitsui Mining & Smelting Co	Manufacturing	(iv)
11	1998	JP,3528615	None	Manufacturing	(ii)
12	1999	JP,4186291	None	Manufacturing	(ii)
13	1999	JP,4453122	None	Materials of cathode and anode	(ii)
14	2000	JP,3890185	Osaka City University Tanaka Chemical	Materials and its manufacturing	(iii)
15	2001	JP,4510331	Osaka City University	Materials and LIB	(iii)
16	2001	JP,3827545	Osaka City University	Manufacturing	(iv)
17	2001	JP,4080337	Osaka City University	Materials and LIB	(iii)
18	2001	JP,3782058	None	Materials and LIB	(i)
19	2002	JP,4197237	Osaka City University	Manufacturing	(iv)
20	2002	JP,4259847	Osaka City University	Materials and LIB	(iii)
21	2002	JP,3654592	None	Materials of cathode and electrolyte	(ii)
22	2002	JP,3844733	None	Materials and LIB	(iii)
23	2003	JP,4274801	None	Manufacturing	(iv)
24	2003	JP,4271448	None	Materials and LIB	(iii)
25	2003	JP,3637344	None	Manufacturing	(iv)
26	2003	JP,4060782	None	Battery pack and electric devices	(ii)
27	2003	JP,4112478	None	Battery Pack and charging devices	(ii)
28	2006	JP,4541324	None	Materials and LIB	(i)

29	2007	JPA,2007-234607	Osaka City University	Materials and LIB	(iii)
30	2007	JPA,2008-034369	None	Materials and LIB	(i)
31	2007	JPA,2008-078146	Osaka City University	Materials and LIB	(iii)
32	2007	JPA,2008-084871	Osaka City University	Manufacturing	(iv)
33	2007	JPA,2008-071763	Osaka City University	Manufacturing	(iv)
34	2008	JPA,2008-288213	None	Materials and LIB	(i)
35	2008	JPA,2008-293997	Osaka City University	Manufacturing	(iv)

JP: Japan patent number, JPA: Japan patent publication number

Table 3-6 demonstrates that 'P11' is the inventor in 28 patents and 7 patent publications of cathode materials during 1995-2008, and 12 patents were filed with other firms or universities as joint patent application. In the case of Panasonic, each technology spillover shows following distinctive characteristics.

(i) Intra-firm, intra-technology spillover

In all periods, this type of technology spillover could be frequently observed in R&D in cathode materials.

(ii) Intra-firm, inter-technology spillover

In the late 1990s, this type of technology spillover was observed. It seems that complementary technology needed to be developed to facilitate the work of simple materials, and Panasonic developed it with their own efforts.

(iii) Inter-firm, intra-technology spillover

In the early 2000s, this type of technology spillover was observed. Since Panasonic filed patents of 5^{th} materials which was invented in the collaborative R&D with Osaka City University, most patents regarding 5^{th} materials were filed as joint patent application. Then, technology spillover occurred between Panasonic and Osaka City University to develop 5^{th} materials in the collaborative R&D.

(iv) Inter-technology, inter- technology spillover

In the late 2000s, this type of technology spillover was observed. After the invention of 5^{th} materials, R&D in the field of collaborative R&D with Osaka City University expanded to not only material technology but complementary technology to facilitate the effective work of new materials. Then, technology spillover occurred between material technology and complementary technology.

3.4.5 The results of analysis

On the basis of the observation of Table 3-5 and Table 3-6, it can be said that trends in technology spillover are different between Sony and Panasonic. Figure 3-2 and Figure 3-3 illustrate the differences of trends in Sony and Panasonic as matrix; material technology or complementary technology, sole application or joint application.

In the case of Sony, Figure 3-2 demonstrates that the technology spillover was changed from (i), to (ii), to (i), to (ii). It suggests that technology spillover existed only within a firm, but it was changed from intra- to inter-technology spillover.

First, Sony manufactured LIB and developed cathode materials from their own R&D. In 1990s, simple materials such as 1st and 2nd materials were mainly invented. Second, after materials were developed to a certain level in the late 1990s, then complementary technology was developed to improve the working of cathode materials. It seems that researchers transferred knowledge about material characteristics of simple materials to invent suitable components. Third, composite materials were required to provide higher energy density without cobalt in the early 2000s, and then Sony invented 5th materials with their own efforts. Finally, Sony invented complementary technology using 5th materials only from researchers inside Sony.

In the case of Panasonic, Figure 3-3 demonstrates that the technology spillover is changed from (i), to (ii), to (iii), to (iv). It suggests that technology spillover is changed from (i) to (iv) in the diagonal of the matrix, and it shows a shift from intra- to inter-firm technology spillover, and from intra- to inter-technology spillover

In the 1990s, Panasonic followed a similar trajectory to that of Sony. First, when they entered the LIB market in 1994, Panasonic also developed simple materials such as 1st and 2nd materials with their own efforts. Second, complementary technology was developed in the late 1990s. Third, composite materials were required in the early 2000s, and then Panasonic started the collaborative R&D with Osaka City University and invented 5th materials earlier than Sony. Finally, after 5th materials were developed to a certain level, the inventor moved from Panasonic to Energy Company, and then complementary technology was invented to facilitate the effective use of 5th materials in the late 2000s. The R&D system in Panasonic and their 'platform structure' might have contributed to provide such opportunities.

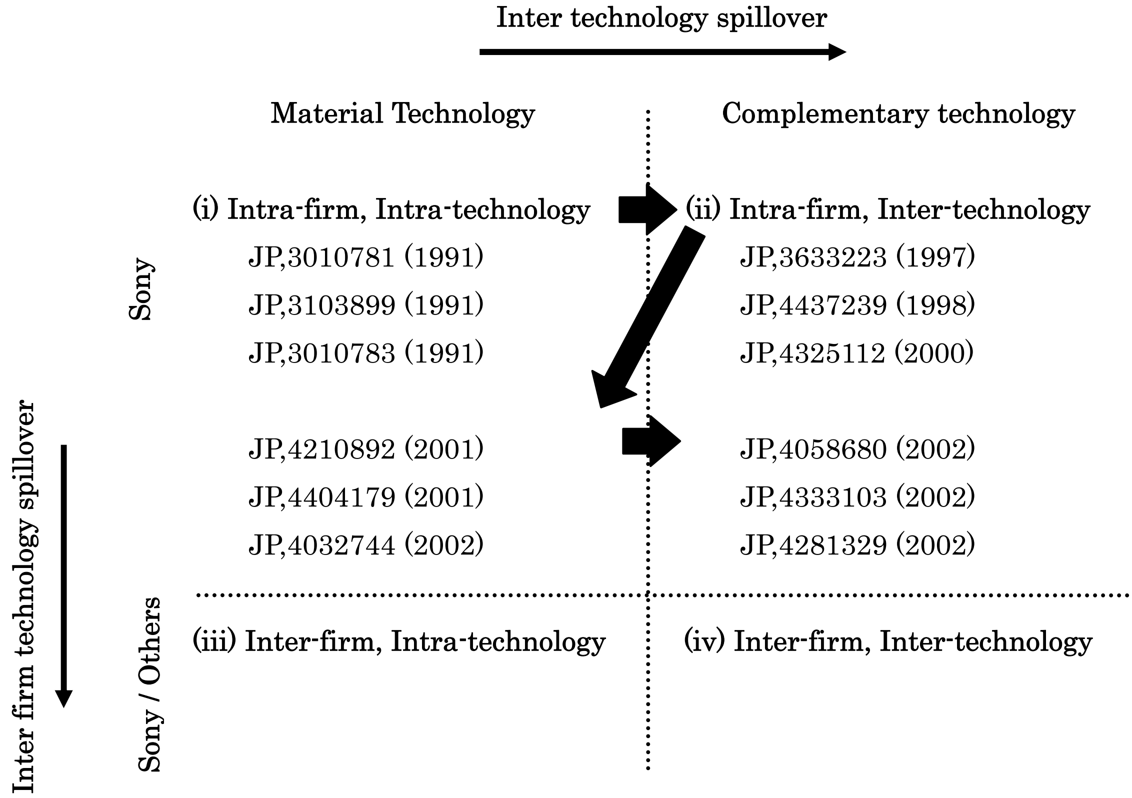


Figure 3-2. Matrix of technology spillovers in Sony.

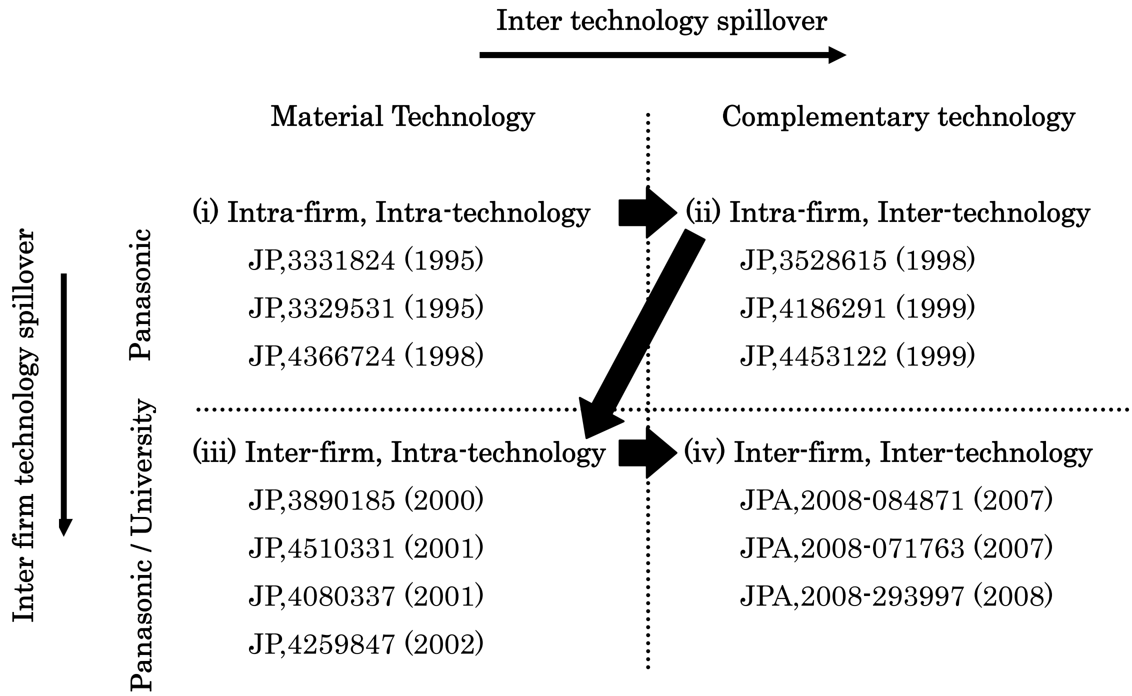


Figure 3-3. Matrix of technology spillovers in Panasonic.

3.4.6 Patent strategy of material technology

In previous works, the importance of patent strategy has been discussed. For instance, management of intangible resources is reported (Hall, 1992; Young et al., 2008). The measurement of patent portfolio size and its quality is discussed (Lichtenthaler, 2009; Gann Xu, 2009). The numbers of patent applications and citations can be a factor to evaluate patents (Blind et al, 2009). Patent management in biotechnology industry is discussed (Thumm, 2001; Calabrese et al, 2000). Patent management in Japanese firms is also noted (Sasaki, 2004).

We also demonstrated the importance of patent strategy for the innovation, and discussed the changes of patent strategy before and after the restructuring of organization by focusing on the merger and acquisition (M&A) in pharmaceutical industry. Intellectual Property (IP) management in M&A cases of Japanese pharmaceutical firms were investigated. We used the rate of Rate For Examination (RFE), the duration of RFE, and the rate of granted as indices of IP management, which can describe the selectivity in filing patent applications and in filing RFE. The ways of managing IP protection of the firms depend on IP management department, and these indices would be useful to analyze the strategies of IP management in M&A. The management would be blended among two or more firms before M&A with less difficulty if they are similar in their IP management. Thus, it is advisable for IP department of pharmaceutical firms in M&A to obtain information of IP management using indices stated above in advance (Shibata, Takahashi, and Saiki, 2010).

In this work, we investigated following two things based on the analysis of relations between patent strategy and restructuring of organization in two cases of M&A of pharmaceutical firms, Daiichi-Sankyo and Astellas.

i) The ways of managing IP protection of the firms before M&A are different with each other or similar in each IP management indices.
ii) The ways of managing information on IP rights in the new-drug firms before M&A could be blended with little difficulties because of their similarity with one another.

Thus, it is important to provide suitable IP management in each industry. It is also important to understand IP management in the case of material technology

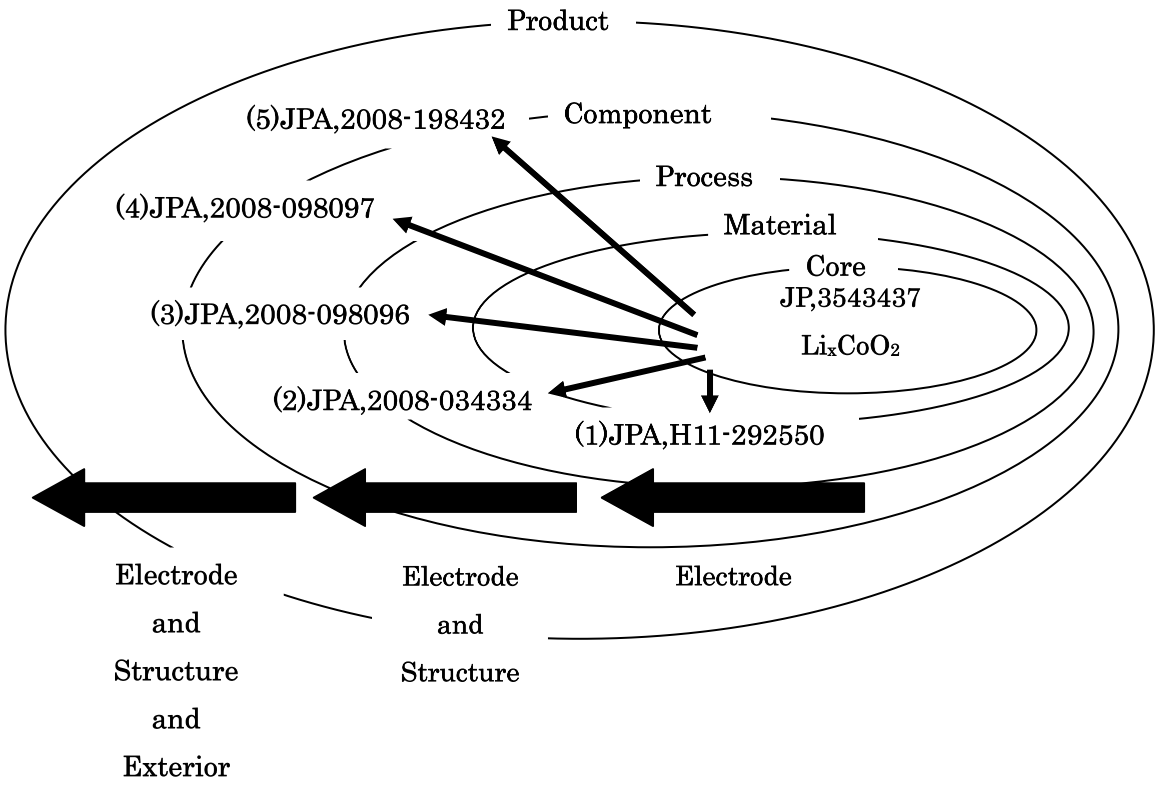
Both Figure 3-2 and Figure 3-3 suggests that simple materials and composite materials followed the same growth trajectory, which could be described as technology spillover from material technology to complementary technology. This growth trajectory of material technology could be traced by analyzing references to patents and the combination of IPC. Figure 3-4 shows the diversification process of simple materials in Sony, because Sony first invented the simple material and produced LIB. Figure 3-5 shows the diversification process of composite materials in Panasonic, because Panasonic filed and obtained patents of composite materials earlier than Sony.

Figure 3-4 demonstrates the process where the 1st material obtained by Sony as core material in 1995, 'JP,3543437', diffused to complementary technologies. Figure 3-5 also demonstrates the process where the 5th material first obtained by Panasonic as core material in 2000, 'JP,3890185', diffused in the same trajectory. For instance, after material technology was developed into 5th material, references to patents were diffused from material technology to process, component, and product technologies. Thus, based on the analysis of references to patents, it can be said that the technologies composing a LIB have diversified with the development of material technology in the LIB innovation process. 'JP,3543437' and 'JP,3890185' were the sole material patents which is referred patents in Figure 3-4 and 3-5 (Appendix C and Appendix D shows the index of material patents referred by patents in Figure 3-4 and Figure 3-5).

With the diversification of technology, the combination of IPC has been complicated in both the diversification process of simple materials and composite materials. As noted in Chapter II, 'Electrode' is defined as H01M4, 'Structure' as H01M10, and 'Exterior' as H01M2. Figure 3-4 and Figure 3-5 demonstrate that, in both simple materials and composite materials, technology groups shifted from simple technology to complex technology in the LIB innovation process. When physical structure of materials was innovated from simple materials to composite materials, then this diversification process was reconstructed.

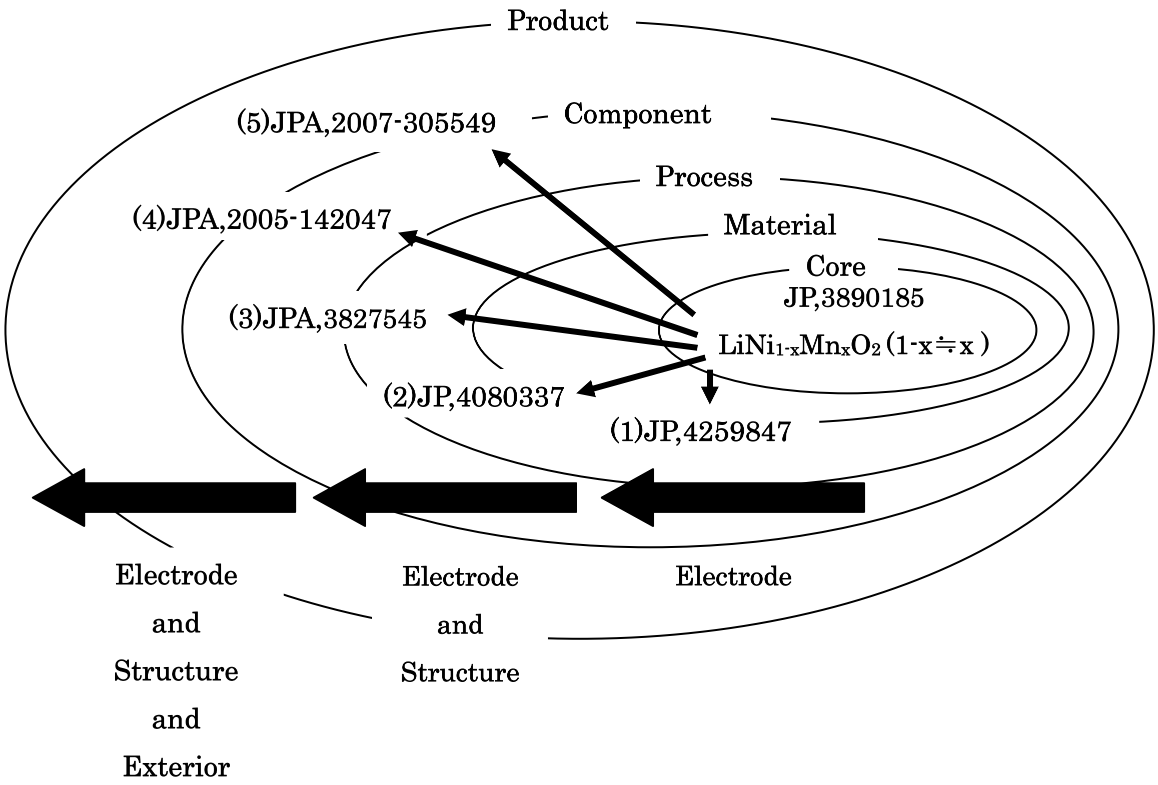
Thus, both simple materials and composite materials followed the same trajectory from material technology to process, component, and product technologies. Both materials followed the same changes of technology group defined by IPC from simple technology to complex technology in the LIB innovation process.

Hypothesis is verified



Patent	Exterior	Structure	Electrode
(1) JPA,H11-292550			H01M 4/02 H01M 4/58
(2) JPA,2008-034334		H01M 10/40	H01M 4/02 H01M 4/38 H01M 4/58
(3) JPA,2008-098096	H01M 2/12 H01M 2/16 H01M 2/34	H01M 10/40	H01M 4/02 H01M 4/58
(4) JPA,2008-098097	H01M 2/16 H01M 2/34	H01M 10/40	H01M 4/02 H01M 4/58
(5) JPA,2008-198432	H01M 2/16	H01M 10/40	H01M 4/02 H01M 4/58

Figure 3-4. Patent map of diffusion process regarding simple material.



Patent	Exterior	Structure	Electrode
(1) JP,4259847			H01M 4/50 H01M 4/52
(2) JP,4080337			H01M 4/50 H01M 4/52
(3) JP,3827545		H01M 10/40	H01M 4/02 H01M 4/58
(4) JPA,2005-142047	H01M 2/16	H01M 10/40	H01M 4/02 H01M 4/58 H01M 4/66
(5) JPA,2007-305549	H01M 2/16	H01M 10/40	H01M 4/02 H01M 4/58 H01M 4/66

Figure 3-5. Patent map of diffusion process regarding composite material.

3.5 Discussion

As the innovation dynamism of material technology in the LIB industry, the results demonstrate that technology spillover structure was changed from intra-technology to inter-technology spillover.

First, intra-technology spillover, technology spillover within material technology, was encouraged. As previously noted, technological functionality of LIB was attributed to the development of materials with high energy density and stability. It could be considered that material technology was based on explicit knowledge, because it can be conceptualized by chemical rules such as chemical formula, chemical equation, and chemical laws. In the LIB industry, innovation was created from the conceptualization of core material and derivative materials. Thus, intra-technology spillover facilitated the development of materials at the start of innovation.

Next, inter-technology spillover, technology spillover between material technology and complementary technology, was encouraged as an integration of technologies. In both simple materials and composite materials, the innovation process traced a similar path. After the development of material technology, knowledge regarding materials needed to be transferred to complementary technologies to reflect specific characteristics of materials into a product. It could be considered that complementary technology had a strong relationship with tacit knowledge; for instance, methods of how to manufacture products would be based on the experiences, skills, and know-how from a firm's own facilities and equipments. Integration of these technologies was then required to manufacture innovative products. Thus, inter-technology spillover facilitated the manufacturing of products in the LIB innovation process.

For example, Panasonic has advanced cross-industrial associations since 2000 and increased the collaborative R&D. In addition to this, Panasonic introduced 'platform structure' in their R&D and promoted the horizontal integration between core technologies and strategic products. It seems that these projects contributed to encourage technology spillover, not only within Panasonic but also between Panasonic and other entities, additionally not only within a basic technology but also between basic technology and advanced technology. This change of the technology spillover structure from intra-technology to inter-technology spillover can be one of reasons for Panasonic's success.

3.6 Conclusion

In conclusion, it was revealed that simple materials and composite materials followed the same growth trajectory, which could be described as inter-technology spillover; diffusion of technologies from material technology to process, component, and product technologies. Then, both materials followed the same changes of technology group defined by IPC from simple technology to complex technology in the LIB innovation process. It was also revealed that this LIB innovation process was reconstructed when physical structure of materials was innovated from simple materials to composite materials.

Appendix A. Index of material patents obtained by Sony.

Date	Number	Name
1988.07.27	JP,2897217	Organic electrolyte secondary battery
1990.04.07	JP,3049727	Non-aqueous electrolyte secondary battery
1990.04.07	JP,3469836	Non-aqueous electrolyte secondary battery
1991.02.05	JP,3160920	Non-aqueous electrolyte secondary battery
1991.04.26	JP,3200867	Non-aqueous electrolyte secondary battery
1991.04.26	JP,3010781	Non-aqueous electrolyte secondary battery
1991.05.02	JP,3103899	Non-aqueous electrolyte secondary battery
1991.05.02	JP,3010783	Non-aqueous electrolyte secondary battery
1991.11.30	JP,3303319	Non-aqueous electrolyte secondary battery
1991.12.28	JP,3318941	Manufacture of Positive electrode material
1992.04.03	JP,3355644	Non-aqueous electrolyte secondary battery
1994.08.31	JP,3421877	Non-aqueous electrolyte secondary battery
1994.11.29	JP,3451763	Manufacture of positive electrode active material
1995.07.24	JP,3543437	Manufacture of positive electrode active material and non-aqueous electrolyte secondary battery
1997.04.25	JP,3769871	Production of positive electrode active material
1997.08.07	JP,3633223	Manufacture of positive electrode active material, and non-aqueous electrolyte secondary battery
1998.01.29	JP,4161396	Non-aqueous electrolyte secondary battery
1998.08.11	JP,4437239	Non-aqueous electrolyte secondary battery
1998.08.26	JP,4161422	Non-aqueous electrolyte secondary battery
1999.02.24	JP,4244427	Non-aqueous electrolyte battery
1999.06.04	JP,4232277	Non-aqueous electrolyte battery
1999.07.09	JP,4080110	Non-aqueous electrolyte battery
2000.01.20	JP,4501202	Secondary battery
2000.04.12	JP,4062856	Positive electrode activator and non-aqueous electrolyte secondary cell
2000.08.14	JP,4524881	Secondary battery
2000.10.05	JP,3982165	Solid electrolyte battery
2000.12.28	JP,4325112	Positive-electrode active material and non-aqueous electrolyte secondary battery
2001.03.01	JP,4210892	Secondary battery
2001.12.06	JP,4404179	Positive electrode active material and secondary battery using it

2002.01.08	JP,4032744	Positive electrode active material and non-aqueous electrolyte secondary battery
2002.01.21	JP,4221932	Non-aqueous electrolyte battery
2002.05.29	JP,4224987	Non-aqueous electrolyte battery
2002.08.13	JP,4058680	Positive electrode active material, its manufacturing method and non-aqueous electrolyte secondary battery
2002.10.18	JP,4447831	Positive electrode activator and non-aqueous electrolyte secondary battery
2002.08.27	JP,4333103	Non-aqueous electrolyte battery and method for manufacturing the same
2002.11.08	JP,4281329	Non-aqueous electrolyte battery
2002.11.28	JP,4192574	Electrode for non-aqueous electrolyte secondary battery, and non-aqueous electrolyte secondary battery
2003.04.03	JP,4106651	Positive electrode material, its manufacturing method, and battery using it
2003.04.11	JP,4061586	Anode active material and non-aqueous electrolyte secondary battery using it
2003.04.11	JP,4061648	Positive active material and non-aqueous electrolyte secondary battery using it
2004.02.16	JP,4237074	Positive electrode active material and non-aqueous electrolyte secondary battery
2004.05.26	JP,4172423	Cathode activator and non-aqueous electrolyte secondary battery
2004.09.10	JP,4192869	Thin card battery
2005.02.17	JP,4483618	Battery
2005.12.07	JP,4482822	Positive active material and battery
2006.05.26	JP,4240060	Cathode active material and battery
2006.06.16	JP,4306697	Positive electrode active material and its manufacturing method, positive electrode, its manufacturing method, and secondary battery
2006.11.28	JP,4311438	Positive electrode active material, non-aqueous electrolyte secondary battery using this, and manufacturing method of positive electrode active material

2006.08.31	JPA,2006-236349	Battery
2006.10.16	JPA,2008-098096	Secondary Battery
2006.10.16	JPA,2008-098097	Secondary Battery
2007.02.09	JPA,2008-198432	Battery
2007.03.16	JPA,2008-234872	Positive electrode active material and battery
2007.05.10	JPA,2008-282667	Positive active material for lithium ion secondary battery using organic electrolyte
2008.11.28	JPA,2010-129471	Cathode active material and non-aqueous electrolyte battery

JP: Japan patent number, JPA: Japan patent publication number

Appendix B. Index of material patents obtained by Panasonic.

Date	Number	Name
1995.03.03	JP,3329124	Manufacture of positive electrode active material for non-aqueous electrolytic secondary battery
1995.07.31	JP,3331824	Non-aqueous electrolyte secondary battery
1995.12.27	JP,3229531	Non-aqueous electrolyte secondary battery
1998.02.04	JP,3986148	Nickel-cobalt hydroxide for active material of non-aqueous electrolyte battery
1998.02.06	JP,3985323	Sealed non-aqueous electrolyte secondary battery
1998.03.02	JP,4366724	Non-aqueous electrolyte secondary battery
1998.04.23	JP,4055241	Non-aqueous electrolyte secondary battery
1998.05.13	JP,4066509	Lead-acid battery and its manufacture
1998.05.28	JP,4106741	Non-aqueous electrolyte secondary battery
1998.05.29	JP,3468099	Manufacture of positive active material for lithium secondary battery
1998.06.09	JP,4092779	Manufacture of positive electrode active material for non-aqueous electrolyte secondary battery
1998.07.08	JP,3468106	Manufacture of positive active material for lithium secondary battery
1998.07.31	JP,4085479	Non-aqueous electrolyte secondary battery
1998.07.31	JP,4185191	Manufacture of spinel type lithium manganese
1998.08.05	JP,3528615	Manufacture of positive electrode active material for lithium secondary battery
1999.01.21	JP,4186291	Positive electrode active material for non-aqueous electrolyte secondary battery and its manufacture
1999.06.23	JP,4453122	Non-aqueous electrolyte secondary battery
2000.03.29	JP,4330758	Electrode material for non-aqueous electrolytic secondary battery and battery using the same
2000.07.27	JP,3890185	Positive electrode active material and non-aqueous electrolyte secondary battery using the same
2001.06.27	JP,4510331	Positive electrode active material and non-aqueous electrolyte secondary battery containing the same
2001.09.13	JP,3827545	Positive electrode active material, method of manufacture, and non-aqueous electrolyte secondary battery

2001.11.07	JP,4080337	Positive electrode active material and non-aqueous electrolyte secondary battery
2001.12.03	JP,3782058	Positive electrode active material for non-aqueous electrolyte secondary battery and non-aqueous electrolyte secondary battery
2002.01.23	JP,4153700	Non-aqueous electrolyte secondary battery
2002.03.19	JP,4056271	Manufacturing method of electrode material, electrode material and non-aqueous electrolyte battery
2002.04.30	JP,4197237	Positive electrode active material, its manufacturing method and non-aqueous electrolyte secondary battery
2002.10.17	JP,4259847	Positive electrode active material and non-aqueous electrolyte secondary battery containing the same
2002.10.25	JP,3654592	Lithium ion secondary battery
2002.11.25	JP,4150343	Lithium ion battery
2002.12.26	JP,3844733	Non-aqueous electrolyte secondary battery
2003.01.09	JP,4274801	Manufacturing method of positive electrode active material for non-aqueous electrolyte secondary battery
2003.01.16	JP,4271448	Positive electrode active material for non-aqueous electrolyte secondary battery
2003.03.06	JP,4300827	Non-aqueous electrolyte secondary battery
2003.05.02	JP,3637344	Positive electrode activator for non-aqueous electrolyte secondary battery, and manufacturing method of the same
2003.06.09	JP,4313096	Cathode and lithium-ion secondary battery using it
2003.09.19	JP,3994078	Method of manufacturing lithium compound nickel-cobalt oxide for non-aqueous electrolyte battery active material
2003.11.07	JP,4554911	Non-aqueous electrolyte secondary battery
2003.11.13	JP,4060782	Battery pack and electric device
2003.11.14	JP,4112478	Battery pack charger
2004.02.06	JP,4549689	Lithium-ion secondary battery
2006.06.09	JP,4541324	Non-aqueous electrolyte secondary battery
2006.06.09	JP,4541324	Non-aqueous electrolyte secondary battery

2007.04.05	JP,4047372	Positive electrode active material, its manufacturing method and non-aqueous electrolyte secondary battery
2009.05.13	JP,4440339	Electrode for non-aqueous electrolyte secondary battery
2003.11.07	JPA,2005-142047	Non-aqueous electrolyte secondary battery
2006.05.15	JPA,2007-305549	Cathode active substance, its manufacturing method and non-aqueous electrolyte secondary battery
2007.04.26	JPA,2007-234607	Positive electrode active material and non-aqueous electrolyte secondary battery having it
2007.06.21	JPA,2008-034369	Positive electrode active material for non-aqueous electrolyte secondary battery and non-aqueous electrolyte secondary battery
2007.10.22	JPA,2008-078146	Cathode active material and non-aqueous electrolyte secondary battery containing this
2007.10.22	JPA,2008-084871	Method for producing positive-electrode active material
2007.10.22	JPA,2008-071763	Chemical conversion method and manufacturing method of non-aqueous electrolyte secondary battery
2008.07.14	JPA,2008-288213	Positive electrode active material for non-aqueous electrolyte secondary battery and the non-aqueous electrolyte secondary battery
2008.08.06	JPA,2008-293997	Positive electrode active material and non-aqueous electrolytic secondary battery

JP: Japan patent number, JPA: Japan patent publication number

Appendix C. Index of material patents referred by patents in Figure 3-4.

Patent	Number	Name
JPA,H11-292550	JPA,H8-319120	Lithium double oxide, its production and lithium secondary battery
	JPA,H9-35715	Manufacture of positive electrode active material and nonaqueous electrolyte secondary battery
	JPA,H8-180863	Manufacture of positive electrode material for lithium secondary battery
JPA,2008-034334	JPA,2002-175836	Nonaqueous electrolyte battery
	JPA,2005-285492	Nonaqueous electrolyte solution and lithium secondary battery using it
	WO03/019713	Battery
JPA,2008-098096	WO03/019713	Battery
	JPA,H7-302614	Nonaqueous electrolyte secondary battery
JPA,2008-098097	WO03/019713	Battery
	JPA,H7-302614	Nonaqueous electrolyte secondary battery
JPA,2008-198432	WO03/019713	Battery

JPA: Japan patent publication number, WO: International patent publication number

Appendix D. Index of material patents referred by patents in Figure 3-5.

Patent	Number	Name
JP,3980185	JPA,H8-171910	Manufacture of positive electrode active material for lithium secondary battery
	JPA,H9-129230	Nonaqueous electrolytic battery and manufacture of positive active material
	JPA,H10-69910	Lithium nickel composite oxide, manufacture thereof, and positive electrode active substance for secondary battery
	JPA,H8-171910	Manufacture of positive electrode active material for lithium secondary battery
	JPA,S60-257072	Lithium secondary battery
	JPA,S60-41773	Organic electrolyte battery
	JPA,S60-247265	Two-color electrophotographic printing method
	JPA,S61-165957	Nonaqueous battery
	JPA,S61-214376	Lithium organic secondary battery
	JPA,S61-161673	Secondary battery
	JPA,H3-59963	Lithium secondary battery
	JPA,S60-79677	Electrolyte for lithium secondary battery
	JPA,H9-204932	Electrolyte for lithium secondary battery, and lithium secondary battery
	JPA,H9-204932	Electrolyte for lithium secondary battery, and lithium secondary battery
	US,5393622	Process for production of positive electrode active material
	US,5370948	Process for production of positive electrode active material for nonaqueous electrolyte lithium secondary cell
	US,5264201	Lithiated nickel dioxide and secondary cells prepared therefrom
	US,5629110	Method for producing cathode active material for non-aqueous electrolyte secondary battery
	US,5985237	Process for producing lithium manganese oxide suitable for use as cathode material of

		lithium ion secondary batteries
	US,4002492	Rechargeable lithium-aluminum anode
JP,4259847	JPA,H4-267053	Lithium secondary battery
	JPA,H10-69910	Lithium nickel composite oxide, Manufacture thereof, and positive electrode active substance for secondary battery
	JPA,2000-77071	Nonaqueous electrolyte secondary battery
	JPA,2001-202959	Active material for positive electrode of nonaqueous electrolyte secondary battery and its producing method
	JPA,2000-77071	Nonaqueous electrolyte secondary battery
	JPA,H8-171910	Manufacture of positive electrode active material for lithium secondary battery
	JPA,H9-129230	Nonaqueous electrolytic battery and manufacture of positive active material
	JPA,H10-69910	Lithium nickel composite oxide, manufacture thereof, and positive electrode active substance for secondary battery
	JPA,2002-42813	Positive electrode active material and non-aqueous electrolyte secondary battery using the same
	US,5393622	Process for production of positive electrode active material
	US,5370948	Process for production of positive electrode active material for nonaqueous electrolyte lithium secondary cell
	US,5264201	Lithiated nickel dioxide and secondary cells prepared therefrom
	US,5629110	Method for producing cathode active material for non-aqueous electrolyte secondary battery
	US,5985237	Process for producing lithium manganese oxide suitable for use as cathode material of lithium ion secondary batteries
JP,4080337	JPA,H8-171910	Manufacture of positive electrode active material for lithium secondary battery

	JPA,H9-129230	Nonaqueous electrolytic battery and manufacture of positive active material
	JPA,H10-69910	Lithium nickel composite oxide, manufacture thereof, and positive electrode active substance for secondary battery
	JPA,H4-267053	Lithium secondary battery
	JPA,H8-171910	Manufacture of positive electrode active material for lithium secondary battery
	JPA,S60-257072	Lithium secondary battery
	JPA,2002-42813	Positive electrode active material and non-aqueous electrolyte secondary battery using the same
	US,5393622	Process for production of positive electrode active material
	US,5370948	Process for production of positive electrode active material for nonaqueous electrolyte lithium secondary cell
	US,5264201	Lithiated nickel dioxide and secondary cells prepared therefrom
	US,5629110	Method for producing cathode active material for non-aqueous electrolyte secondary battery
	US,5985237	Process for producing lithium manganese oxide suitable for use as cathode material of lithium ion secondary batteries
	US,4002492	Rechargeable lithium-aluminum anode
JP,3827545	JPA,H8-171910	Manufacture of positive electrode active material for lithium secondary battery
	JPA,H9-129230	Nonaqueous electrolytic battery and manufacture of positive active material
	JPA,H10-69910	Lithium nickel composite oxide, manufacture thereof, and positive electrode active substance for secondary battery
	JPA,2002-42813	Positive electrode active material and non-aqueous electrolyte secondary battery using the same

	JPA,2003-017052	Positive electrode active material and non-aqueous electrolyte secondary battery containing the same
	US,5393622	Process for production of positive electrode active material
	US,5370948	Process for production of positive electrode active material for nonaqueous electrolyte lithium secondary cell
	US,5264201	Lithiated nickel dioxide and secondary cells prepared therefrom
	US,5629110	Method for producing cathode active material for non-aqueous electrolyte secondary battery
	US,5985237	Process for producing lithium manganese oxide suitable for use as cathode material of lithium ion secondary batteries
JPA,2005-142047	JPA,H07-320784	Nonaqeous electrolytic lithium secondary battery
	JPA,H10-027609	Secondary battery with nonaqueous electrolyte
	JPA,H07-335261	Lithium secondary battery
	JPA,H10-027626	Lithium secondary battery
	JPA,H10-069922	Non-aqueous electrolyte lithium secondary battery
	JPA,2001-210324	Lithium secondary battery
	JPA,2001-243952	Lithium secondary battery
	JPA,H09-171824	Nonaqueous electrolyte secondary battery
	JPA,H10-208744	Battery
JPA,2007-305549	JPA,H11-072544	Method and device for monitoring remaining capacity of secondary cell
	JPA,2000-348725	Lithium ion secondary battery
	JPA,H11-321951	Aerosol injection device
	JPA,H9-147867	High voltage intercalation compound for Lithium battery
	JPA,H7-320784	Nonaqeous electrolytic lithium secondary battery

JPA,H7-335261	Lithium secondary battery
JPA,H10-27609	Secondary battery with nonaqueous electrolyte
JPA,H10-27626	Lithium secondary battery
JPA,H10-27627	Lithium secondary battery
JPA,2001-243952	Lithium secondary battery
JPA,2001-210324	Lithium secondary battery

JP: Japan patent number, JPA: Japan patent publication number, US: United State patent number

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Chapter IV
Trends in Diversification of Technologies: Empirical Analysis of Lithium Ion Battery Industry in Japan

Abstract

In this Chapter IV, we investigate trends in the diversification process of technologies composing a Lithium Ion Battery (LIB) by demonstrating the multiple regression analysis. The number of patent applications of LIB filed in Japan patent office is utilized as a proxy to evaluate the development of technologies. We group LIB into two groups by using the International Patent Classification (IPC), 'simple technology' and 'complex technology'. Simple technology is the technology which belongs to one technology segment, and complex technology is the technology which belongs to two or more technology segments.

In conclusion, it was revealed that technologies relating to electrode technology have diversified from simple technology to complex technology in the LIB innovation process. Especially, complex technology relating to electrode technology has increased after the practical use of LIB started, and it played a significant role in leading the LIB innovation process.

Keywords

Innovation; International Patent Classification; Lithium Ion Battery; Patent

4.1 Introduction

It is important for firms to continuously develop inventions and technologies, and produce new valuable products which can show their innovation capability. The R&D efforts of firms leading the innovation are essential for firm's growth and the growth of society itself.

As suggested in Chapter III, changes of technology spillover structure played a significant role in driving the development of material technology in the LIB innovation process. In this process, simple materials and composite materials followed the same growth trajectory. It is inter-technology spillover; diffusion of technologies from material technology to process, component, and product technologies.

4.1.1 Knowledge spillover

A lot of papers have been published discussing the usefulness of knowledge spillover as one of the foremost factors in encouraging the development of technologies. As Griliches (1979) mentioned, the level of productivity achieved by one firm or industry depends on not only its own R&D efforts but also general knowledge spilled over from other firms and industries. In previous studies, patent data has been recognized as a useful indicator in evaluating the technological innovation quantitatively (Griliches, 1990). In many papers, relations between innovation and knowledge spillover are discussed by using patent data.

Many previous papers have mainly discussed the knowledge spillover at the level of countries, industries, or firms. For instance, how the spillover effect among different foreign countries affects domestic productivity has been discussed (Branstetter, 2001; Eaton and Kortum, 1999; Keller, 2002). The importance of knowledge spillover between industries has also been discussed (Scherer, 1984; Griliches and Lichtenberg, 1984; Goto and Suzuki, 1989). The importance to control the industrial characteristics has been reported so far (Bernstein and Nadiri, 1988; Bernstein, 1997; Terero, 2001).

We find three main points of view in previous papers in relations to knowledge spillover. The first point is technological affinity. It is comparatively easy to obtain knowledge from other firms which are working in a similar technology field, because it is assumed that these firms possess similar technological facilities and experiences. Companies working in a similar technology field are able to raise R&D productivity by referring to other firms' R&D result (Jaffe, 1986; Lee, 2006). The second point concerns geographical distance between firms. Geographical distances relate to the ease of communication with other firms. Companies, which are located in a region close to one another, can easily make contact, so that they have the advantage of prompt information exchanges (Jaffe et al., 1993; Tappeiner et al., 2008). The third feature is cultural differences. It is relatively easy for firms to cooperate with another firm which shares similar cultures concerning management principles, business structure, and language. A mutual understanding of culture could be a key for promotion of knowledge spillover. In this study, we focus on the technological affinity in analyzing knowledge spillover among technologies composing a product (Shibata and Saiki, 2010).

Geroski (1995) reported that knowledge spillover effect depends on the maturity of technologies. Therefore, industrial characteristics and technological characteristics should be taken into consideration when knowledge spillover is discussed. Recent papers have focused on this point and discussed the existence of technology spillover.

Some papers suggested that technology spillover played a significant role in leading the development of material technology. For instance, the effect of technology spillover in fine ceramics industry was analyzed (Ohmura et al., 2003, 2006). The effect of technology spillover in the nonferrous metal industry was also analyzed (Nakagawa et al., 2007, 2008, 2009). We also analyzed the technology spillover effect in the acoustic industry, and suggested that the development of material technology is a key to improve the functionality of products (Shibata and Saiki, 2009). Thus, on the aspect of technology spillover, the importance of how to innovate materials have been discussed so far.

In this chapter, the back ground of the LIB industry is introduced in (4.2). Hypothetical view is described in (4.3). The trends in diversification of technologies composing a LIB are analyzed in (4.4). The results are discussed in (4.5). Conclusion in this chapter is remarked in (4.6).

4.1.2 Diversification of technology in acoustic industry

In previous work, we focused on the innovation process in the acoustic industry and analyzed the role of technology spillover based on the empirical observation of patent statistics. Especially, speaker is the main electric device in the acoustic industry. We defined 'basic technology', technology which demonstrates the fundamental physical laws as a core technology, and 'complementary technology', technology which facilitates the work of basic technology, respectively. The International Patent Classification (IPC) was used to group technologies. In the case of speaker technology, transducers (H04R9, H04R17) were defined as basic technology, because dynamo-electrical system was based on the Fleming's rules. Additionally, 'Component' (H04R1), 'Circuit' (H04R3), and 'Diaphragm' (H04R7) were defined as complementary technology. Figure 4-1 shows the relations among these IPC, and details are described in Appendix A.

In speaker technology, it could be said that development of material technology played an important role in leading the innovation process. In all periods, main demands from markets were miniaturization and improving the frequency characteristics of a speaker; however, these demands were structurally contradicted. It is because large panel was required to create good sounds with large volume in a diaphragm. The key to satisfy both of these contradicted demands was the material characteristics used in a diaphragm. Thus, the development of material technology is a key factor to improve the functionality of a speaker in the acoustic industry.

Based on the analysis of patent statistics, it was revealed that there were two stages in the innovation process in the speaker industry. Technology spillover mainly occurred between basic technology and complementary technology, but structure of technology spillover has changed in the innovation process. First, technology spillover occurred between basic technology and 'Diaphragm', and next technology spillover occurred between 'Diaphragm' and 'Component'. It is considered that the development of materials used in a diaphragm was a key to change the structure of technology spillover in the innovation process. First, knowledge of fundamental physical laws spilled over from basic technology to 'Diaphragm' to encourage the development of materials used in a diaphragm. Second, knowledge of materials used in a diaphragm spilled over to 'Component' to facilitate the effective work of new materials. As a result, it can be said that the development of materials was a key to encourage the technology spillover in the innovation process (Shibata and Saiki, 2009).

- Speaker
  - Basic Technology: 9/00. 9/02. 9/02,101. 9/02,102. 9/02,103. 9/04,102. 9/04,103. 9/04,104. 9/04,105. 9/06. 9/10. 9/18. 17/00. 17/10.
  - Complementary technology
    - Components
      - Structural details: 1/00. 1/00,310. 1/00,311. 1/00,317. 1/00,318. 1/02. 1/02,101. 1/02,102. 1/02,103. 1/02,104. 1/02,105. 1/06. 1/06,310. 1/12. 1/42. 1/44. 1/44,310.
      - Frequency characteristics: 1/20. 1/20,310. 1/22. 1/22,310. 1/24. 1/26. 1/28. 1/28,310. 1/30. 1/32. 1/32,310. 1/34. 1/34,310. 1/36. 1/38. 1/40. 1/40,310.
      - Human interfaces: 1/10. 1/10,101. 1/10,102. 1/10,103. 1/10,104.
    - Circuits: 3/00. 3/00,101. 3/00, 310. 3/02. 3/04. 3/04,101. 3/04,102. 3/12. 3/14
    - Diaphragms: 7/00. 7/02. 7/04. 7/06. 7/08. 7/10. 7/12. 7/14. 7/16. 7/18. 7/20. 7/22. 7/24. 7/26

Figure 4-1. Composition of IPC relating to speaker technologies.

In this chapter, we will focus on more microscopic technological level of technology segments composing a product by using the IPC in the analysis of technology spillover. The IPC is used for the classification of patents, and this classification depends on the technological difference which the inventions pertain to. In this study, we discuss the technology spillover among technology groups composing a LIB.

4.2 Two periods in the LIB innovation process

Figure 4-2 shows trends in the number of patent applications of LIB which were filed and disclosed in the Japan Patent Office (JPO). Patents of LIB are selected by main group of IPC; details are described in (4.4.1).

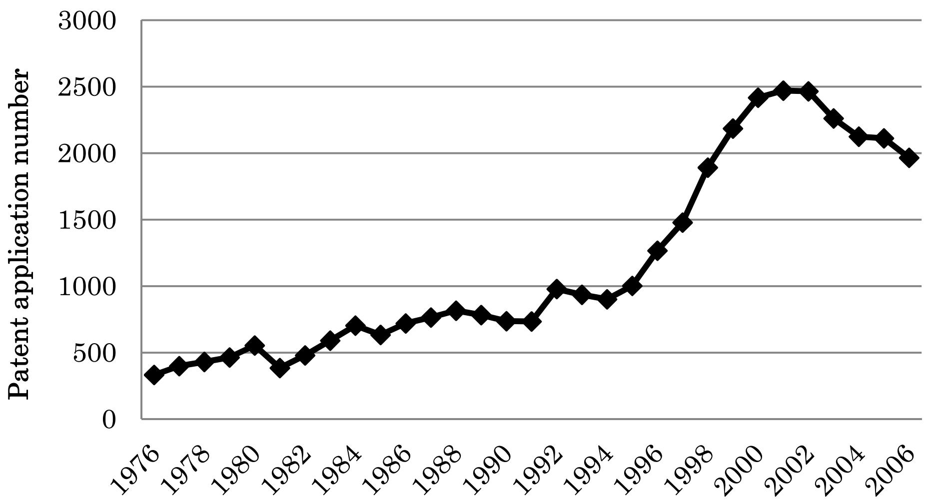

Figure 4-2. Trends in patent applications of LIB in JPO.

Figure 4-2 demonstrates that the number of patent applications has increased rapidly from 1991 to 2002. LIB was first manufactured for the market by Sony in 1991 (Nagaura, 1991), and many firms have entered this market since then. As a result, the number of patent applications began to decrease after 2002.

We can identify two periods in this LIB innovation process. We call them '1st period' and '2nd period'. The 1st period is defined as the period from 1979 to 1990, and it means 12 years before the practical use of LIB started. Practical use means the timing of when LIB was released to the market. The 2nd period is defined as the period from 1991 to 2002, and it means 12 years after the practical use of LIB started.

In this study, we compare trends in the number of patent applications of LIB that were filed between these two periods to analyze the changes of technological compositions of LIB, and discuss how main R&D field was changed before and after the practical use of LIB started.

4.3 Hypothetical view

In the Chapter I, it is suggested that new materials better than lithium-cobalt oxide was developed in the 1990s in order to satisfy requirements from market. Although properties of manganese and nickel were different from those of cobalt, the development of composite materials was requested to satisfy needs from market. Therefore, composite materials such as lithium-manganese-cobalt oxide were invented as new materials (Makimura et al., 2003).

In the Chapter III, it was revealed that technology spillover structure changed from intra-technology to inter-technology spillover. Technology spillover occurred from material technology to process, component, and product technologies. Technological functionality of LIB was innovated by the development of material technology, and then technology spillover played a significant role in the diffusion of technology.

In order to lead the LIB innovation process, 'Electrode' made of new materials has to be diffused to constitutional technologies like 'Exterior' and 'Structure'. Technology spillover has to occur between 'Electrode' and 'Exterior', or between 'Electrode' and 'Structure', to obtain the optimal structural contents. It is because the metal constituents with different properties require an applicable LIB constitution suitable for their properties; for instance, new materials used in an electrode need applicable LIB constitutions like size, weight, and shape to match its characteristics.

It could be considered that the collaboration of two or more technologies involving 'Electrode' is required in the 2nd period; for instance, 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'. These technologies are classified as complex technology. The collaborations among technologies would be inspired in the LIB innovation process, and then technologies have diversified with the increase of complex technology. It can be postulated that the changes from simple technology to complex technology have been caused by the development of composite materials for electrode technology, and then technology spillover contributed to diffuse the material technology. Therefore, the hypothesis can be expressed as follows.

[Hypothesis]
Technology leading the LIB innovation process was replaced from simple technology to complex technology.

4.4 Analysis of trends in diversification of technologies

4.4.1 Methodology to classify technologies

In previous works, quite strong relationships between R&D and the number of patent applications have been suggested (Griliches et al., 1984), and so that patent statistics could be a useful economic indicator in illuminating the process of innovation.

In this study, we introduce the concept of 'Innovation Process' and 'Technology Knowledge' as proxy variables like follows by using the number of patent applications as an indicator. 'Innovation Process' indicates the total number of patent applications regarding LIB. 'Technology Knowledge' is classified into simple technology and complex technology, and these indicates that the number of patent applications given the specific IPC of simple technology or complex technology.

[Innovation Process]
The total number of patent applications relating to LIB.

[Technology Knowledge]
The number of patent applications relating to either simple technology or complex technology defined by IPC.

When patents are filed to obtain rights for inventions, patent office gives IPC depending on the technological categorization of patents. It is considered that the number of patents defined by IPC could be a proxy to evaluate the volume of technological ideas disclosed in patents. Therefore, we can discuss which kinds of 'Technology Knowledge' most contribute to encourage 'Innovation Process' by performing the empirical analysis.

As suggested in Chapter II, it can be conceptualized that batteries were composed of three technology segments; 'Exterior' (the shape or the appearance of a battery), 'Structure' (the structural details of a battery), and 'Electrode' (the details of a cathode and an anode to cause a chemical reaction to generate energy). According to the IPC, batteries are classified into [H01M]. We select technologies regarding LIB from technologies which are classified as this [H01M], and group technologies by IPC into three simple technologies and four complex technologies. Finally, technologies can be grouped into seven technology groups like follows.

[Simple technology]

We classify technologies composing a LIB into three technology segments; 'Exterior', 'Structure', and 'Electrode'. Technology group which belongs to only one technology segment is defined as 'simple technology'. These technology groups are defined like follows by the sub group level of IPC.

i) Exterior: We classify technologies which belong to only (H01M2) as 'Exterior'.
   We use the following IPC groups to define inventions which belong to 'Exterior'.
   H01M2/00, H01M2/02, H01M2/04, H01M2/06, H01M2/08, H01M2/14, H01M2/16, H01M2/18

ii) Structure: We classify technologies which belong to only (H01M10) as 'Structure'.
   We use the following IPC groups to define inventions which belong to 'Structure'.
   H01M10/00, H01M10/36, H01M10/40

iii) Electrode: We classify technologies which belong to only (H01M4) as 'Electrode'.
   We use the following IPC groups to define inventions which belong to 'Electrode'.
   H01M4/00, H01M4/02, H01M4/04, H01M4/36, H01M4/38, H01M4/48, H01M4/50, H01M4/52, H01M4/58, H01M4/62, H01M4/64, H01M4/66

[Complex technology]

We classify technologies composing a LIB into three technology segments; 'Exterior', 'Structure', and 'Electrode'. Technology group which belongs to two or more technology segments is defined as 'complex technology', and these are four kinds of combinations of technology segments; 'Exterior and Structure', 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'. These technology groups are defined by the combination of IPC of above simple technology.

In these seven technology groups, there are one simple technology and three complex technologies relating to electrode technology; 'Electrode', 'Exterior and Electrode', 'Structure and Electrode', and 'Exterior and Structure and Electrode'. In order to analyze trends in the diversification of technologies composing a LIB, we focus on the relations between these simple technology and complex technology relating to electrode technology.

4.4.2 Data construction

We construct data to compare trends in the number of patent applications in seven technology groups which are disclosed in JPO during 1976-2006. The data of patent applications are obtained by a retrieval of patent data in "Industrial Property Digital Library" provided by National Center for Industrial Property Information and Training in Japan.

We compare trends in the number of patent applications in seven technology groups filed in JPO during 1st period and 2nd period. Table 4-1 shows the results of correlation analysis between the total number of patent applications of LIB and the number of patent applications in each technology group.

Table 4-1 The results of correlation analysis among seven technology groups.

	1st period	2nd period
Exterior	0.12	0.97**
Structure	0.89**	0.93**
Electrode	0.95**	0.83**
Exterior and Structure	0.64	0.97**
Exterior and Electrode	0.41	0.97**
Structure and Electrode	0.91**	0.99**
Exterior and Structure and Electrode	0.20	0.97**

* significant at the 5% level ** significant at the 1% level

In the seven technology groups, we focus on the technology groups relating to electrode technology as a core technology in LIB. Table 4-1 demonstrates that correlation coefficient of 'Electrode' as simple technology is the highest value in the 1st period, but it turns to be the lowest value in the 2nd period. In contrast, the values of correlation coefficient of complex technologies relating to electrode technology increase from 1st period to 2nd period, and the values are higher than that of 'Electrode' as simple technology in the 2nd period; complex technologies relating to electrode technology indicates 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'. Thus, this result demonstrates that the high correlation coefficients are changed from simple technology to complex technology in the LIB innovation process with the development of material technology.

Figure 4-3 shows trends in shares about the number of patent applications of each simple technology in the total patent applications of LIB; simple technology indicates ‘Exterior’, ‘Structure’, and ‘Electrode’. Figure 4-4 shows trends in shares about the number of patent applications of each complex technology in the total patent applications of LIB; complex technology indicates ‘Exterior and Structure’, ‘Exterior and Electrode’, ‘Structure and Electrode’, ‘Exterior and Structure and Electrode’.

Figure 4-3 and Figure 4-4 obviously demonstrate that the shares of simple technology have decreased and the shares of complex technology have increased through all periods. Especially, the share of ‘Structure and Electrode’ was increasing dramatically during the 2nd period.

In the 1st period, large shares of ‘Technology Knowledge’ were occupied by simple technology by referring to Figure 4-3, in contrast shares of complex technology were small by referring Figure 4-4. Thus, shares of ‘Technology Knowledge’ were concentrated on a few technology groups in the 1st period. In the 2nd period, shares of each ‘Technology Knowledge’, simple technology and complex technology, were getting closer. It is obvious by referring figures that this trend was attributed to the decrease of simple technology and the increase of complex technology in the 2nd period. It means that the combination of IPC to define technologies composing a LIB has been complicated.

As suggested in the Chapter II, the number of patent applications grouped as ‘Structure and Electrode’ has led the LIB innovation process in Sony and Panasonic with the development of material technology. The results in Figure 4-3 and Figure 4-4 correspond to the trends in this previous chapter. After the practical use of LIB started, the development of ‘Electrode’ played an important role in leading the LIB innovation process, because chemical reaction to generate electric power is occurred on the electrode.

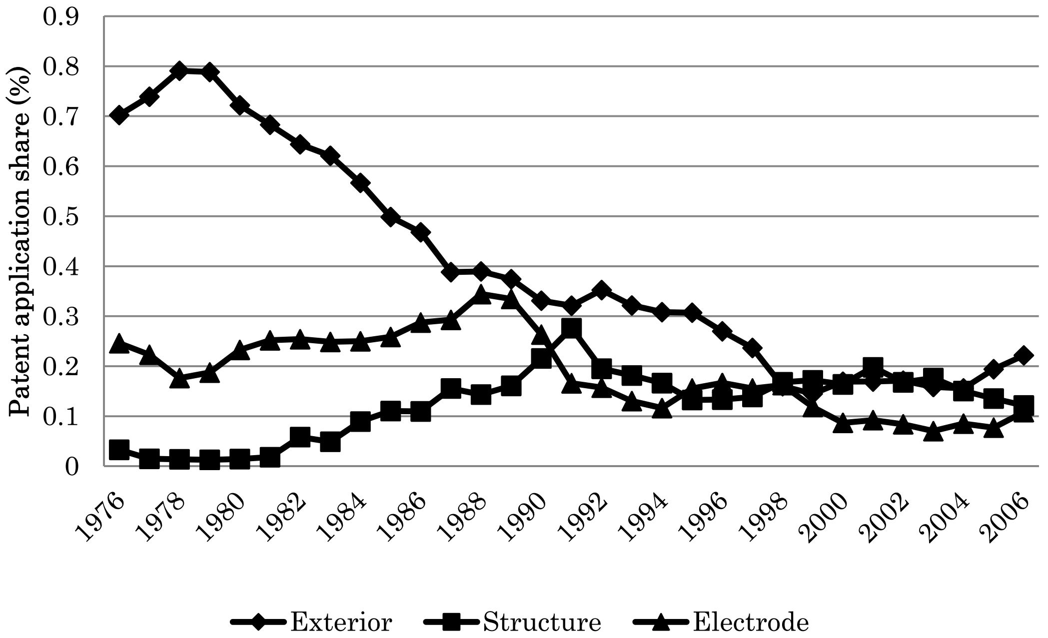

Figure 4-3. Trends in patent application shares of each simple technology.

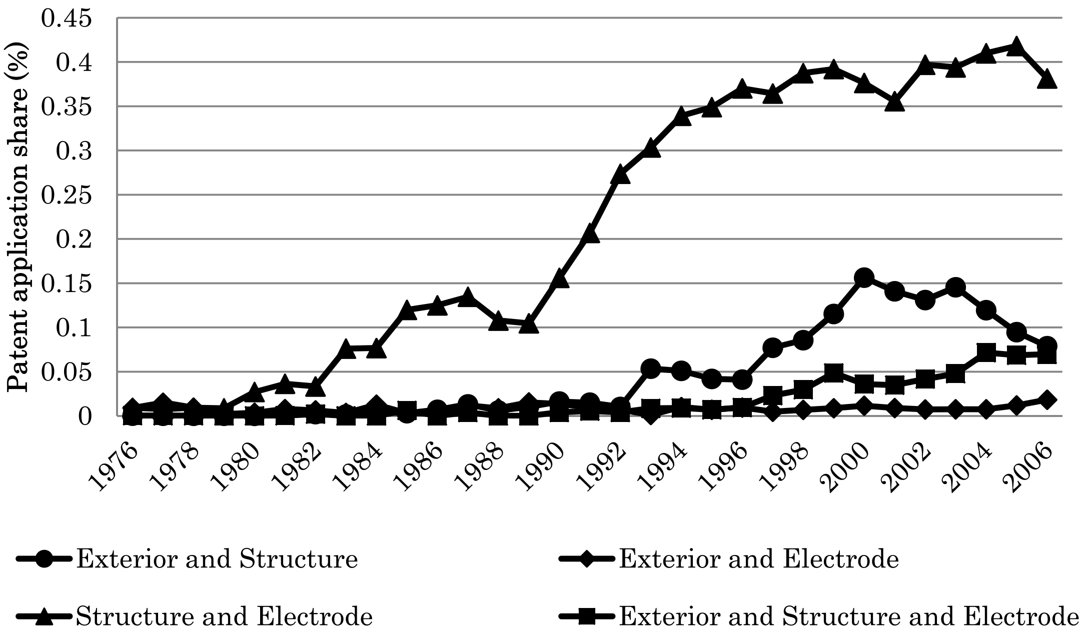

Figure 4-4. Trends in patent application shares of each complex technology.

4.4.3 Numerical model to analyze diversification of technologies

To analyze the diversification process of technologies composing a LIB from simple technology to complex technology, we perform the multiple regression analysis. As previously noted, complex technology is defined as the combination of two or more simple technologies. It is considered that technology spillover occurred among simple technologies, and it inspired the growth of complex technology.

In order to analyze the contributions of simple technology and complex technology for the innovation during the 1st period and the 2nd period, the relations between 'Innovation Process' of LIB and 'Technology Knowledge' of simple technology and complex technology can be described as in the equation (4-1).

$$P = F\ (T_{simp}, T_{comp}) \tag{4-1}$$

where 'P' indicates 'Innovation Process', and it is measured by the total number of patent applications relating to LIB. 'T_{simp}' indicates 'Technology Knowledge' of simple technology, and it is measured by the number of patent applications given IPC of one technology segment. 'T_{comp}' indicates 'Technology Knowledge' of complex technology, and it is measured by the number of patent applications given IPC of two or more technology segments.

In order to analyze the contribution of technology groups relating to electrode technology for the innovation, we select simple technology and complex technology relating to electrode technology as a core technology in LIB. (4-1) can be rewritten as the equation (4-2).

$$P = F\ (T'_{simp}, T'_{comp}) \tag{4-2}$$

where 'T'_{simp}' indicates 'Technology Knowledge' of simple technology relating to electrode technology, and it is measured by the number of patent applications given IPC of 'Electrode'. 'T'_{comp}' indicates 'Technology Knowledge' of complex technology relating to electrode technology, and it is measured by the number of patent applications given IPC of 'Exterior and Electrode', or 'Structure and Electrode', or 'Exterior and Structure and Electrode'.

In the equation (4-2), difference of the 1st period and the 2nd period can be distinguished by substituting a dummy variable. Finally, (4-2) can be rewritten as linear function like equation (4-3).

$$\ln P = A + (1-D)(\gamma_{s1} \ln T'_{simp(1)} + \gamma_{c1} \ln T'_{comp(1)}) + D(\gamma_{s2} \ln T'_{simp(2)} + \gamma_{c2} \ln T'_{comp(2)}) \tag{4-3}$$

where, 'A' indicates a constant value. 'D' indicates a dummy variable; D=0 in the 1st period, and D=1 in the 2nd period. '$T'_{simp(1)}$' and '$T'_{comp(1)}$' indicates 'Technology Knowledge' of simple technology and complex technology relating to electrode technology in the 1st period, respectively. '$T'_{simp(2)}$' and '$T'_{comp(2)}$' indicates 'Technology Knowledge' of simple technology and complex technology relating to electrode technology in the 2nd period, respectively. 'γ_{s1}', 'γ_{c1}', 'γ_{s2}' and 'γ_{c2}' are coefficient values, respectively.

By performing the multiple regression analysis in (4-3), we can analyze which factors, simple technology or complex technology, contributed to lead the LIB innovation process in each period.

4.4.4 Numerical results of multiple regression analysis

In order to analyze how 'Technology Knowledge' has led 'Innovation Process' through 1st period and 2nd period, we focus on the trends in the number of patent application of simple technology and complex technology relating to electrode technology.

Figure 4-5 shows trends in the number of patent applications of simple technology relating to electrode technology such as 'Electrode', and the sum of the number of patent applications of complex technology relating to electrode technology such as 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'.

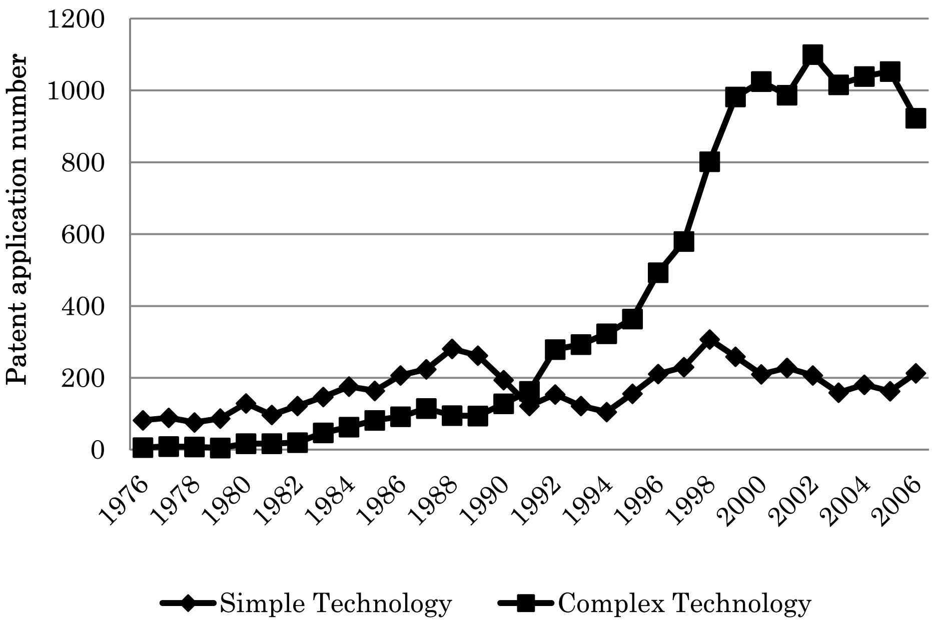

Figure 4-5. Trends in the diversification of electrode technology.

Figure 4-5 demonstrates that the number of patent applications of simple technology has not increased through 1st period and 2nd period. In contrast, that of complex technology has increased dramatically in the 2nd period, and it exceeded that of simple technology after 1991. As previously noted, LIB was first manufactured by Sony in 1991. The timing of when the number of patent applications of complex technology exceeded that of simple technology corresponds to the timing of when LIB was first manufactured. It seems that the increase of 'Structure and Electrode' as complex technology was inspired by the growth of 'Electrode' as simple technology.

Table 4-2 shows the results of multiple regression analysis by the equation (4-3). In this analysis, patent data is divided into two terms of the year.

Table 4-2 The results of the multiple regression analysis.

Period	D	γ_{s1}	γ_{c1}	γ_{s2}	γ_{c2}	adj. R^2	DW
1st period	0	0.65	0.11			0.98	1.22
		(13.6)	(3.72)				
2nd period	1			0.06	0.70		
				(1.28)	(16.9)		

All parenthetic figures are t-values.

Table 4-2 demonstrates that contribution ratio of complex technology in the 2nd period dramatically increased compared to the 1st period. On the other hand, the contribution ratio of simple technology decreased, and the value of complex technology exceeded the value of simple technology in the 2nd period. These results suggest that simple technology more contributed to the increase of 'Innovation Process' than complex technology did in the 1st period, in contrast complex technology more contributed than simple technology did in the 2nd period.

It could be considered that 'Technology Knowledge' of electrode technology might not spilled over so much in the 1st period, because the electrode technology had a little development before the practical use of LIB started. Therefore, complex technology had little influence to 'Innovation Process'. In contrast, complex technology was created by the technology spillover among simple technologies in the 2nd period, especially the technology spillover from 'Electrode' to other technology groups like 'Exterior' and 'Structure'. It seems that the increase of complex technology was demonstrated in the development of electrode technology. Thus, technology leading the LIB innovation process was replaced from simple technology to complex technology.

These facts suggest that Japanese LIB industry has continuously made R&D efforts to deal with the diversification of technologies. Since technological diversification could promote the innovation (Lichtenhthaler, 2005; Garcia-Vega, 2006; Watanabe et al., 2005), this strategy played a significant role in leading the innovation in the LIB industry.

Hypothesis is verified.

4.5 Discussion

In this chapter, we grouped technologies composing a LIB into simple technology and complex technology by using the IPC, and analyzed the LIB innovation process based on patent data. Through this analysis, it was revealed that technology leading the LIB innovation process was replaced from simple technology to complex technology.

It was shown that the LIB innovation process was divided into two periods. In the 1st period, before the practical use of LIB started, the number of patent applications was mainly concentrated on the 'Electrode' as simple technology. However, in the 2nd period, after the practical use of LIB started, that of complex technology has increased such as 'Exterior and Electrode', 'Structure and Electrode', 'Exterior and Structure and Electrode'. It was revealed that the combination of IPC to define inventions has been complicated after the practical use of LIB started by the increase of complex technology through all periods.

In the Chapter III, we concluded that innovation process in the LIB industry was started from the new findings of material technology, and innovation was encouraged with the diversification of technologies. Technology spillover occurred from 'Electrode' to 'Structure' and 'Exterior', and it has led the growth of complex technology like 'Structure and Electrode' and 'Exterior and Structure and Electrode'. Numerical results in this Chapter IV correspond to the results in this Chapter III.

On the basis of intensive empirical observation of patent statistics, it could be considered that diversification of technology from simple technology to complex technology was driving the LIB innovation process, and it was originated by the development of material technology. In the LIB innovation process, material technology would spill over to the constitutional technologies like 'Structure' and 'Exterior' to design the appropriate size, weight, shape and structural details with the aim of better product function. Technology spillover occurred from material technology to complementary technology in order to diffuse material technology to process, component, and product technologies for LIB production. Thus, technologies composing a LIB have diversified with the development of material technology.

Finally, it can be concluded that the diversification of technology played an important role in leading the LIB innovation process.

4.6 Conclusion

In conclusion, it was revealed that technologies relating to electrode technology have diversified from simple technology to complex technology in the LIB innovation process. Especially, complex technology relating to electrode technology has increased after the practical use of LIB started, and it played a significant role in leading the LIB innovation process. Based on this conclusion, we could introduce the significant effect of technology spillover among simple technologies.

Appendix A. List of IPC

[H04R1/00] Details of transducers
[H04R1/00,310・] Speaker
[H04R1/00,311・・] Waterproof structure
[H04R1/00,317・・] by using bone conduction
[H04R1/00,318・・] support board or suspender
[H04R1/02・] Casings; Cabinets; Mountings therein
[H04R1/02,101・・] Speaker cabinets
[H04R1/02,102・・] Speaker cases applied to specific thing
[H04R1/02,103・・・] for using with other equipments
[H04R1/02,104・・] front panel of speaker
[H04R1/02,105・・] Attachment tools for speaker
[H04R1/06・] Arranging circuit leads; Relieving strain on circuit leads
[H04R1/06,310・・] Speaker
[H04R1/10・] Earpieces; Attachments therefor
[H04R1/10,101・・] Headphone and appendage
[H04R1/10,102・・・] Pad
[H04R1/10,103・・・] Attachment tool
[H04R1/10,104・・] Earphone and appendage
[H01R1/12・] Sanitary or hygienic devices for mouthpieces or earpieces
[H04R1/20・] Arrangements for obtaining desired frequency or directional characteristics
[H04R1/20,310・・] Speaker
[H04R1/22・・] for obtaining desired frequency characteristic only
[H04R1/22,310・・・] Speaker
[H04R1/24・・・] Structural combinations of separate transducers or of parts of the same transducer and responsive respectively to two or more frequency ranges
[H04R1/26・・・] Spatial arrangement of separate transducers responsive to two or more frequency ranges
[H04R1/28・・・] Transducer mountings or enclosures designed for specific frequency response; Transducer enclosures modified by provision of mechanical or acoustic impedances,
[H04R1/28,310・・・・] Speaker
[H04R1/30・・・] Combinations of transducers with horns
[H04R1/32・・] for obtaining desired directional characteristic only

[H04R1/32,310・・・] Speaker

[H04R1/34・・・] by using a single transducer with sound reflecting, diffracting, directing or guiding means

[H04R1/34,310・・・・] Speaker

[H04R1/36・・・・] by using a single aperture of dimensions not greater than the shortest operating wavelength

[H04R1/38・・・・] in which sound waves act upon both sides of a diaphragm and incorporating acoustic phase-shifting means

[H04R1/40・・・] by combining a number of identical transducers

[H04R1/40,310・・・・] Speaker

[H01R1/42・] Combinations of transducers with fluid-pressure or other non-electrical amplifying means

[H01R1/44・] Special adaptations for subaqueous use

[H01R1/44,310・・] Speaker

[H04R3/00] Circuits for transducers

[H04R3/00,101・] Protection circuit

[H04R3/00,310・] Speaker

[H04R3/02・] for preventing acoustic reaction

[H04R3/04・] for correcting frequency response

[H04R3/04,101・・] by using a negative feedback circuit

[H04R3/04,102・・] for transducers of moving-coil, piezo-electric transducers, and other transducers

[H04R3/12・] for distributing signals to two or more loud-speakers

[H04R3/14・・] Cross-over networks

[H04R7/00] Diaphragms for electromechanical transducers; Cones

[H04R7/02・] characterized by the construction

[H04R7/04・・] Plane diaphragms

[H04R7/06・・・] comprising a plurality of sections or layers

[H04R7/08・・・・] comprising superposed layers separated by air or other fluid

[H04R7/10・・・・] comprising superposed layers in contact

[H04R7/12・・] Non-planar diaphragms or cones

[H04R7/14・・・] corrugated, pleated, or ribbed

[H04R7/16・] Mounting or tensioning of diaphragms or cones

[H04R7/18・・] at the periphery

[H04R7/20・・・] Securing diaphragm or cone resiliently to support by flexible material, springs, cords, or strands

[H04R7/22･･･] Clamping rim of diaphragm or cone against seating

[H04R7/24･･] Tensioning by means acting directly on free portion of diaphragm or cone

[H04R7/26･] Damping by means acting directly on free portion of diaphragm or cone

[H04R9/00] Transducers of moving-coil, moving-strip, or moving-wire type

[H04R9/02･] Details

[H04R9/02,101･･] Frame; appendage

[H04R9/02,102･･] Magnetic circuit

[H04R9/02,103･･] Damper

[H04R9/04･･] Construction, mounting, or centering of coil

[H04R9/04,102･･･] Coil

[H04R9/04,103･･･] Lead wire; Connection between coil and lead wire

[H04R9/04,104･･･] Bobbin

[H04R9/04,105･･･ ･] Bobbin and other components

[H04R9/06･] Loud-speakers

[H04R9/10･] Telephone receivers

[H04R9/18･] Resonant transducers, i.e. adapted to produce maximum output at a predetermined frequency

[H04R17/00] Piezo-electric transducers; Electrostrictive transducers

[H04R17/10･] Resonant transducers

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Chapter V
Conclusion

5.1 General summary

In this study, we focus on the development of material technologies used in a cathode of LIB to analyze the innovation dynamism of material technology.

In the Chapter I, based on the observation of market data and previous works, the significant role of material technology used in a cathode was suggested.

In the Chapter II, it was revealed that Panasonic's prompt undertaking in the 2^{nd} wave in the diffusion trajectory of electrode technology earlier than Sony was initiated by the development of composite materials. In fact, it was also revealed that Panasonic obtained patents of composite materials earlier than Sony. Based on this conclusion, we could suggest the significant role of composite materials to lead the LIB innovation process.

In the Chapter III, it was revealed that simple materials and composite materials followed the same growth trajectory, which was described as inter-technology spillover; diffusion of technologies from material technology to process, component, and product technologies. In both Sony and Panasonic, simple materials and composite materials followed the same change of technology group defined by IPC from simple technology to complex technology. The LIB innovation process was reconstructed when physical structure of materials was innovated from simple materials to composite materials. Thus, it could be suggested that technology spillover played a significant role in the LIB innovation process.

In the Chapter IV, it was revealed that technologies relating to electrode technology have diversified from simple technology to complex technology in the LIB innovation process. Technology leading the LIB innovation process was replaced from simple technology to complex technology with the development of materials used in a cathode. Then, technology spillover occurred from 'Electrode' to 'Structure' and 'Exterior', and it has led the growth of complex technology like 'Structure and Electrode' and 'Exterior and Structure and Electrode'. The significant role of diversification of technologies composing a LIB could be suggested.

Based on the general summary in each previous chapter, we propose the innovation dynamism of material technology in this Chapter 5.

5.2 Innovation dynamism of material technology

Finally, based on the conclusion in each chapter, we can conclude that the innovation dynamism of material technology in the LIB industry appears as follows.

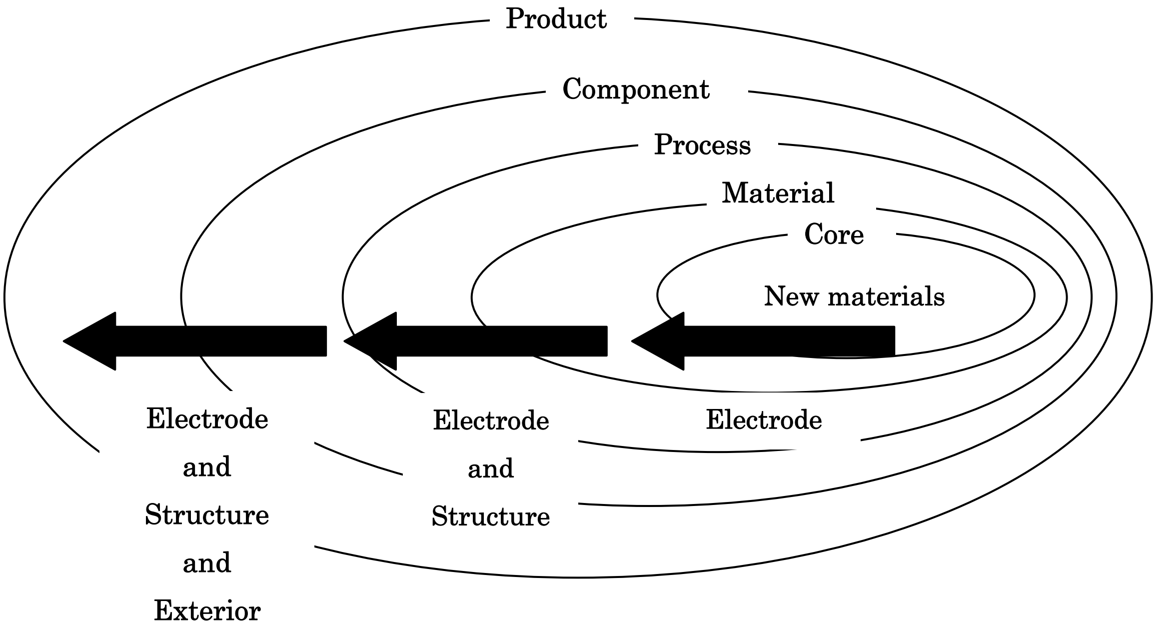


Figure 5-1. Innovation dynamism of material technology.

i) Technology spillover structure changed from intra-technology spillover to inter-technology spillover in the LIB innovation process. First, core material technology was diffused within material technology. Second, core material technology was diffused to process, component, and product technologies.

ii) Both simple materials and composite materials followed the same changes of technology group defined by IPC from simple technology to complex technology. With the diversification of technology, the combination of IPC has been complicated. Technology leading the LIB innovation process was replaced from simple technology to complex technology with the development of materials.

iii) This LIB innovation process was reconstructed when physical structure of materials was innovated from simple materials to composite materials. Diffusion of innovation was attributed to the development of cathode materials.

5.3 Implication

It is useful to understand how results of this research can contribute to R&D in firms. As one example, this result makes it possible to evaluate the maturity level of material technology in the LIB innovation process.

Technologies composing a LIB was developed on the basis of material technology in the LIB innovation process (Material → Compartment → Product); for instance, material characteristics were developed by changing the mole ratio of elements, changing added materials, or changing the manufacturing process. In this study, it was revealed that this LIB innovation process was reconstructed when physical structure of materials was innovated to the next stage; for instance, since LIB was first manufactured from simple materials in 1991, LIB innovation process was created on the basis of simple materials in 1990s. In the 2000s, since composite materials with superior physical structure than simple materials started to be diffused, LIB innovation process was reconstructed on the basis of composite materials. The LIB innovation process traced a similar path in both the 1990s and the 2000s.

In this research, we focused on the relation between the development of materials and the technology groups defined by IPC. As a result, it was revealed that the combination of IPC has diversified ('Electrode' → 'Structure and Electrode' → 'Exterior and Structure and Electrode') with the development of materials in the LIB innovation process (Material → Compartment → Product). This result demonstrates that the development of materials can be evaluated by the combination of IPC; for instance, material technology ('Material') corresponds to simple technology ('Electrode'), and complementary technology ('Compartment' and 'Product') corresponds to complex technology ('Structure and Electrode', 'Exterior and Structure and Electrode'). Thus, by observing the combination of IPC, it is possible to select essential materials which can be the roots to create the next LIB innovation process.

This result is useful for R&D managers, material engineers, and intellectual property lawyers to research material patents obtained by other firms; for instance, Panasonic filed about 4000 patents relating to LIB during 1991-2008. Researching patents defined as the technology group of 'Electrode', we can select only 40 patents as essential materials among the 4000 patents filed by Panasonic.

5.4 New findings in each chapter

In this study, following new things were found in each chapter.

Chapter II

i) Panasonic demonstrated timely start-up of the diffusion trajectory of electrode technology earlier than Sony in both 1^{st} wave and 2^{nd} wave.

ii) Panasonic filed and obtained patents of composite materials such as 3^{rd}, 4^{th}, and 5^{th} materials earlier than Sony.

iii) Panasonic's prompt undertaking in the 2^{nd} wave was initiated by the development of composite materials.

Chapter III

i) In both Sony and Panasonic, technologies have diversified from material technology to process, component, and product technologies.

ii) In both Sony and Panasonic, both simple materials and composite materials followed the same changes of technology group defined by IPC from simple technology to complex technology.

iii) In both Sony and Panasonic, the LIB innovation process was reconstructed when physical structure of materials was innovated from simple materials to composite materials.

Chapter IV

i) Technologies relating to electrode technology have diversified from simple technology to complex technology in the LIB innovation process.

ii) Complex technology relating to electrode technology has dramatically increased after the practical use of LIB started.

iii) Technology leading the LIB innovation process was replaced from simple technology to complex technology with the development of materials.

5.5 Future works

In this study, we analyzed a significant role of material technology in the LIB industry as a model on the basis of patent data. In future works, it will be helpful to analyze material technology from different point of view like follows.

i) It is useful to compare innovation dynamism of material technology between different energy devices; for instance, comparing the innovation process between LIB and solar battery, or LIB and fuel battery. Through this comparison, we can propose more flexible innovation dynamism of material technology.

ii) It is also useful to discuss the difference of innovation dynamism between Japanese firms and foreign firms; for instance, comparing R&D management between Japanese firms and Korean firms, or Japanese firms and Chinese firms. Through this discussion, we can realize why Korean firms and Chinese firms can make such rapid progress in the LIB industry.

iii) Additionally, it is necessary to consider how the material innovation influences innovations in other industries; for instance, analyzing how material innovation contributes to the development of service innovation such as Google or You tube in the diffusion of digital equipment. Through this analysis, we can understand the process of how the development of material technology in the LIB industry can create and lead the innovation in other industries.

Chapter VI
Addendum:
A case study of R&D management of material technology in Panasonic

6.1 Historical view in reforms at Panasonic

As one example of R&D management in Panasonic, it is useful to discuss the relations between 'Nakamura Reform' and the results of Chapter III.

In the 1990s, Panasonic expanded their market share by riding the wave of rapid economic growth, and then they relied on mass production and high volume sales through the business department system that divided products into technological categories. This organizational structure has an advantage that business department system is able to optimize the overall business process of development, manufacturing, and sales. This fact suggests that Panasonic adopted a diversification strategy in order to increase the variety of products, and enhance their positions in the market.

However, following things would be considered as the disadvantages of this organizational structure; high cost is required due to duplication of business divisions; gaps in awareness among employees in different divisions; lack of speed and sharing of information due to vertical layers of management. As a result, Panasonic faced difficulties to follow the changes of the environments caused by the diversity of demands from markets and the development of digital equipments. Finally, Panasonic recorded the largest profit loss in their history in fiscal 2001 (Kodama, 2007).

Restructuring the organizational structure, Mr. Kunio Nakamura was elected as the president of Panasonic in June 2000. Since the appointment as president, Nakamura has implemented the restructuring of organizational structure under the theme of 'Destruction and Creation'. In order to make the organization to be a flat structure, this restructuring changed pyramid organization of the old business departments from 13-layer structure to 4-layer structure. Although Panasonic recorded the largest profit loss in fiscal 2001, it has realized a sudden V-shaped recovery in business results after Panasonic instituted drastic structural reforms.

When Nakamura was elected as the president, he announced 'Great Leap 21 Plan' on 9 January, 2004. This is the mid-term management plan for the next three years starting from fiscal 2004. For instance, Panasonic invented 'V products' in this plan which has three features; Black-box technology, environmental considerations, and universal design. Thus, restructuring of organization provided fields for workers to create new ideas and products in Panasonic.

In the 'Nakamura Reform', many projects and strategies were demonstrated such as the introduction of cell production system, modularization design concepts, and balancing the quality and cost. In this study, we especially focus on the following three strategies relating to R&D management (Shinozaki, 2002).

First, the 'alliance strategy' was encouraged as one of these policies. Project team specialized for alliance was established in Panasonic to select the best partner for alliance. In this strategy, Panasonic classified business segments into two segments according to whether they need alliance or not. With the introduction of this new strategy in 2000, Panasonic changed R&D management from diversification strategy in the 1990s to 'selection and concentration'. Panasonic encouraged the 'alliance strategy' to survive the global competition.

Second, Nakamura undertook the restructuring of R&D system, and introduced 'platform structure' as new R&D system. In this system, platform was classified into two types, 'platform for the core technology' and 'platform for the strategic products'. The main purpose of this restructuring R&D system was promoting the horizontal integration between these two platforms, and crystallizing the individual knowledge accumulated in Panasonic group. In this structure, basic researches were mainly performed R&D in the basic research center in Panasonic. With the development of these basic researches, technologies were transferred from basic research center to each advanced research center in the Panasonic group. In the case of LIB, technology was transferred from basic research center in Panasonic to advanced research center in Energy Company.

Third, 'black-boxing strategy' was also advanced. The main purpose of this strategy was inventing products which other firms hardly imitate. In this strategy, development of technology which was based on tacit knowledge was encouraged such as process technology for producing products. In parallel with this, obtaining intellectual property rights such as patents and trademarks was also advanced.

We discuss the process in which knowledge possessed by researchers and inventors was shared, assessed, and integrated across organizational boundaries in order to create new knowledge in Panasonic.

6.2 Trends in the number of joint patent applications with universities

It is useful to know trends in the number of patent applications filed as joint patent application between firms and universities. In previous works, the importance of relationships between university-industry in the management of basic research has been discussed. In fact, in 2001 and in 2006, Japanese government started the second and third “Science and Technology basic plans” to encourage academia-industry cooperation.

Figure 6-1 shows trends in the number of joint patent applications between Sony and universities, and Panasonic and universities. The data of patents are obtained by a retrieval of patent data in “Industrial Property Digital Library” provided by National Center for Industrial Property Information and Training in Japan.

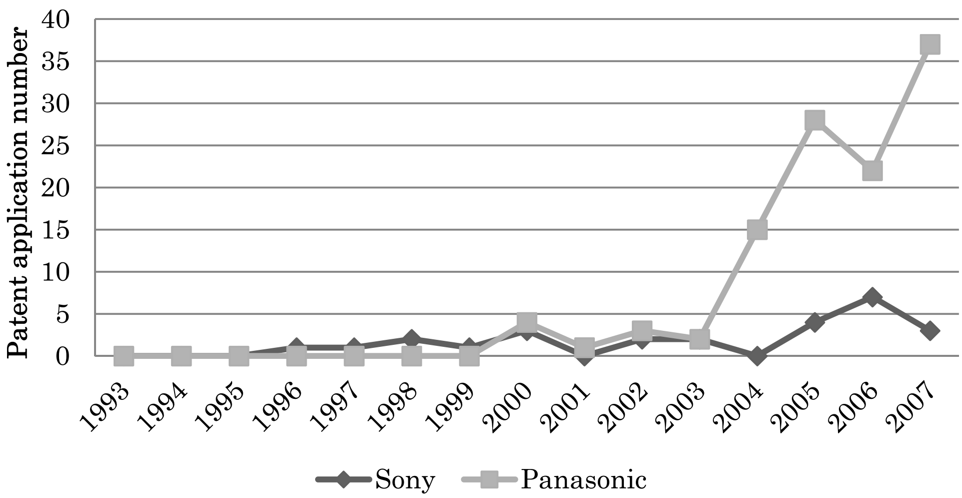


Figure 6-1. Trends in the number of joint patent applications with universities.

Figure 6-1 demonstrates that Panasonic increased the number of joint patent applications with universities after 2003. It seems that ‘Nakamura Reform’ contributed to encourage the collaborative R&D between academia-industry in Panasonic, and increased the number of joint patent application with universities. It is considered that this collaborative R&D would contribute to the development of material technology in LIB as well.

6.3 Trends in the number of joint patent applications of LIB

In the history of Panasonic, 2000 year can be the useful boundary, because this is the year that Nakamura was appointed as a president and started the 'Nakamura Reform'. Based on the Table 3-3 and Table 3-4 in Chapter III, Table 6-1 shows the number of sole patent applications and that of joint patent applications of cathode materials in the 1990s and in the 2000s.

Table 6-1 Trends in the number of joint patent applications.

	In 1990s	In 2000s
Sony	Sole application (4 patents)	Sole application (22 patents)
	Joint application (1 patent)	Joint application (0 patent)
Panasonic	Sole application (6 patents)	Sole application (10 patents)
	Joint application (1 patent)	Joint application (8 patent)

Table 6-1 demonstrates that Sony and Panasonic have different trends in the number of joint patent applications of cathode materials. In the 1990s and 2000s, Sony mainly filed patents as sole application. In contrast, Panasonic mainly filed patents as sole application in the 1990s, and then few patents were filed as joint application. However, the number of patents filed as joint application was turned to increase after 2000. It is assumed that collaborative R&D contributed to the early development of composite materials in Panasonic. In fact, according to the Table 3-3 and Table 3-4 in Chapter III, the first patent classified as 3rd material, JP,3986148, was obtained as joint application with 'Tanaka Chemical'. In addition to this, the first patent classified as 4th and 5th materials, JP,4510331 and JP,4080337, was obtained as joint application with 'Osaka City University'.

As one of reasons of the good progress of material technology in Panasonic, it could be considered that Nakamura encouraged cross-industrial associations and alliance strategies in 'Nakamura Reform' after 2000. In this strategy, Nakamura advanced to expand the range of alliance for not only within same industry but between various industries, not only with familiar firms but with competitive firms, and not only with firms but with universities and public research institutes. With the increase of collaborative R&D, the number of joint patent applications between Panasonic and other entities like firms, universities, and public institutes was increased as well.

6.4 Trends in the relations among inventors

In 'Nakamura Reform', Panasonic advanced the collaborative R&D with outside researchers and increased the number of joint patent applications. In order to analyze the relations between development of cathode materials and inside researchers in Sony and Panasonic, we compare the combination of inventors listed in Table 3-3 and Table 3-4 in Chapter III. In Figure 6-2 and Figure 6-3, patents and inventors in Table 3-3 and Table 3-4 are connected with arrows to visualize the relations among inside researchers who invent material technology in Sony and Panasonic, respectively.

In the case of Sony, it is obvious from Table 3-3 that Sony obtained only one patent filed as joint patent application. Figure 6-2 demonstrates the less relation among inside researchers in Sony than relations in Panasonic. There are 43 inventors of cathode materials in Sony; however, 34 inventors among them related to only one patent. Inventors who related to two or more patents were 9. It means that almost 20% inventors contributed to obtain more than two patents. It seems that almost no patents filed as joint application, and researchers in Sony performed the R&D in cathode materials independently.

In the case of Panasonic, it is obvious from Table 3-4 that Panasonic obtained 9 patents filed as joint patent application with other entities such as other firms, universities. Figure 6-3 demonstrates that relations among inside researchers in Panasonic were more complicated than that of Sony. There are 31 inventors of cathode materials in Panasonic, and 22 inventors among them related to only one patent. Inventors who related to two or more than patent were 9. It means that almost 30% inventors contributed to obtain more than two patents. It seems that cathode materials were invented by utilizing knowledge of outside researchers in other entities, and crystallizing individual knowledge of inside researchers in Panasonic.

Through the comparison between the results of Figure 6-2 and Figure 6-3, it is obvious that Panasonic encouraged the collaborative R&D with outside entities and integrated individual knowledge of material technology among researchers. Thus, relations among researchers in Panasonic were more complicated than that of Sony. This fact suggests that R&D management in Panasonic contributed to advance the collaboration among researchers.

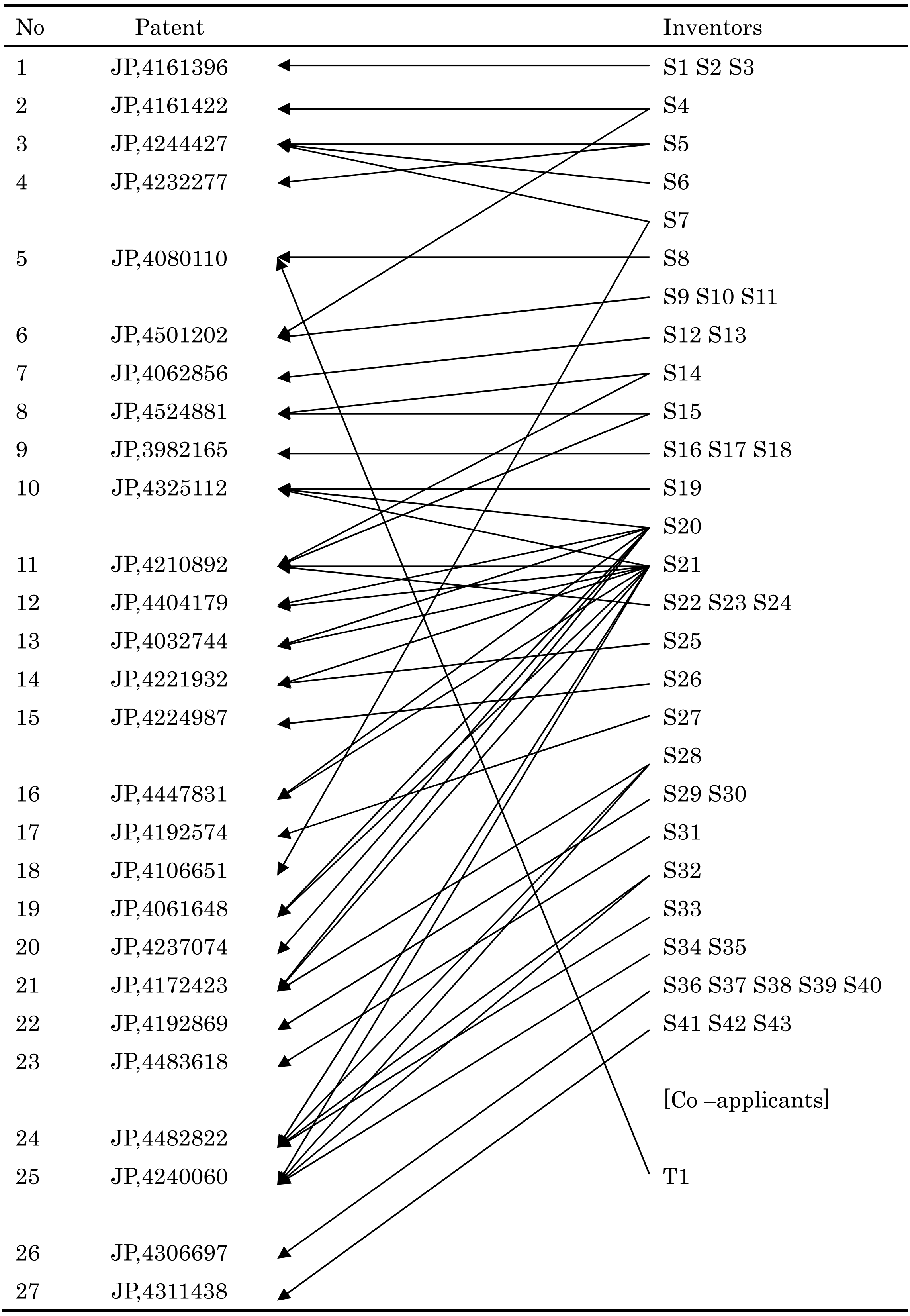


Figure 6-2. Relations between inventors and patents in Sony.

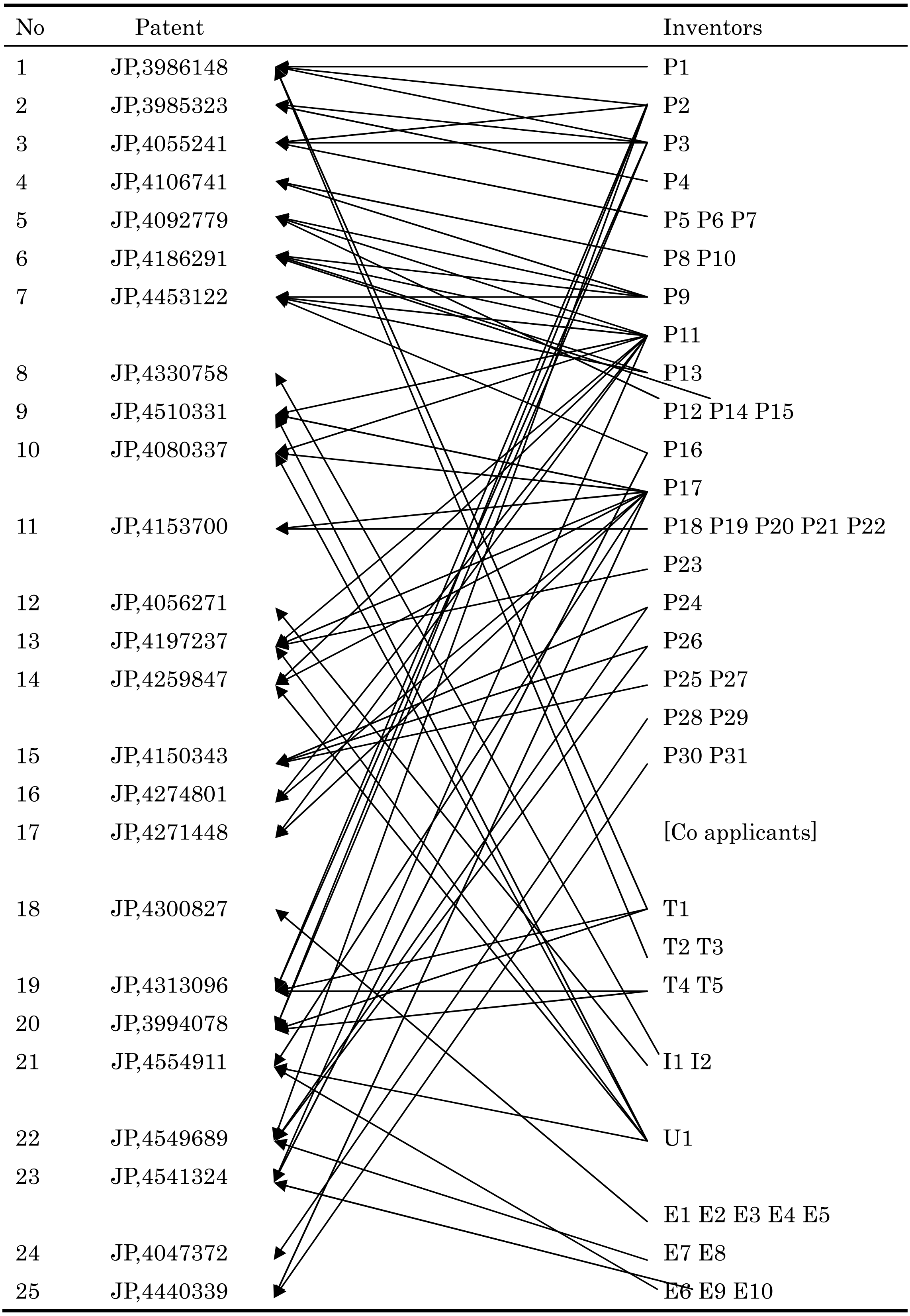


Figure 6-3. Relations between inventors and patents in Panasonic.

6.5 Trends in the move of inventors in Panasonic

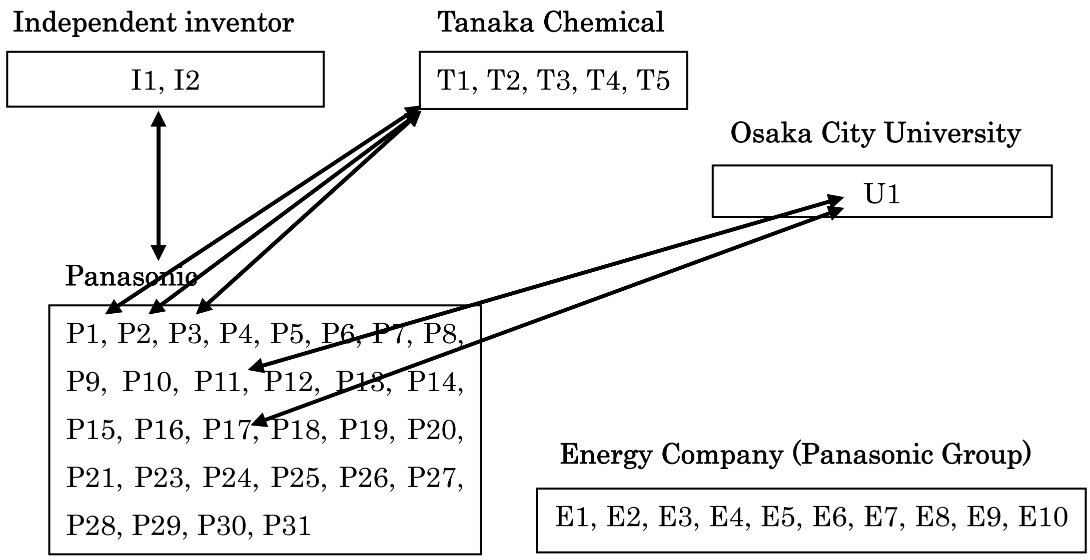
As previously noted, Panasonic encouraged the collaborative R&D after 2000. Furthermore, according to the Table 3-4, it was also revealed that some researchers moved from basic research center in Panasonic to advanced research center in Energy Company. Energy Company is one of Panasonic group companies, which mainly treats energy devices. It seems that this move of researchers was attributed to the Panasonic's new R&D system, 'platform structure', in order to promote the knowledge integrations.

As previously noted, Nakamura introduced 'platform structure' in their R&D management as 'Nakamura Reform', and promoted the horizontal integration between core technology and strategic products in Panasonic. It seems that basic researches in every technology field were performed in the basic research center in Panasonic. In the 'platform structure', after these basic researches reached a workable level, researchers moved from basic research center to each advanced research center in the Panasonic group. In the case of LIB, researchers moved from Panasonic to Energy Company. Figure 6-4 shows these moves of researchers in Panasonic.

Figure 6-4 demonstrates that technology spillover in Panasonic was composed of two steps. First, Panasonic encouraged the collaborative R&D with other entities in the cross-industrial associations, and obtained knowledge, skills, and ideas from outside widely. This type of technology spillover between firms could be recognized as inter-firm technology spillover. Since R&D in material technology was considered as basic researches, the collaborative R&D was demonstrated in the basic research center in Panasonic in the early 2000s.

Second, after basic researches developed to a practical level, researchers moved to the advanced research center in Energy Company. It is assumed that main purpose of this move was promoting the horizontal integration in Panasonic group, and transferred knowledge of material technology to share it among researchers in Energy Company to produce strategic products. This type of technology spillover between technologies could be recognized as inter-technology spillover. Thus, Panasonic encouraged the utilization of two kinds of technology spillovers, inter-firm technology spillover and inter-technology spillover.

[1st stage ~inter-firm technology spillover~]



[2nd stage ~inter-technology spillover~]

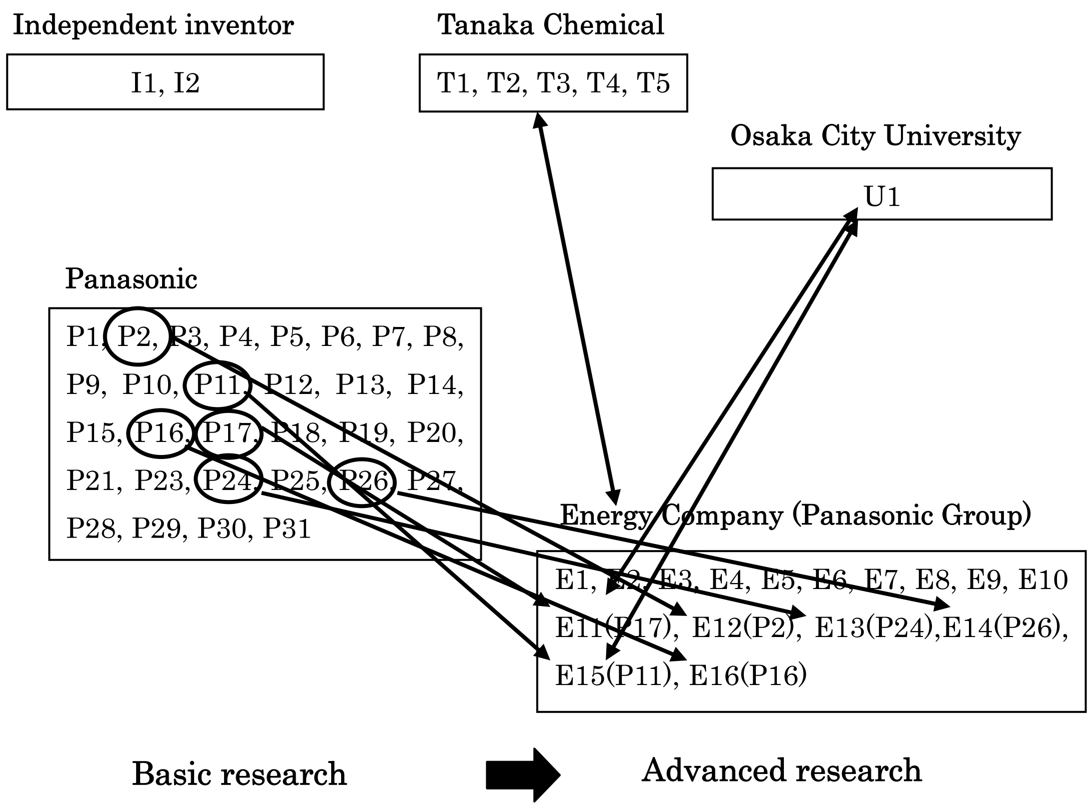


Figure 6-4. Two stages of technology spillover in Panasonic.

6.6 R&D management in Panasonic

In R&D management of material technology in Panasonic, the results demonstrate that technology spillover structure was changed from intra-firm to inter-firm technology spillover, and from intra-technology to inter-technology spillover.

In the 1990s, when Panasonic entered the LIB market, intra-firm technology spillover was dominated. It is considered that materials were critical for innovation, so that firms hardly disclosed their manufacturing process of materials. Additionally, firms might not need external learning for material technology in this period, because material innovation was conducted from the development of their own technology such as simple materials. Thus, intra-firm technology spillover facilitated the development of cathode materials in the 1990s.

In the 2000s, the technology spillover structure has changed according to the 'Nakamura Reform'. This change has extended to the boundary of spillovers from intra-firm to inter-firms, from intra-technology to inter-technology.

First, inter-firm technology spillover was encouraged in their R&D management. In fact, after Nakamura announced encouraging cross-industrial associations, Panasonic and Osaka City University filed their first joint patent application in 2001. Next, inter-technology spillover was encouraged as the diffusion of technologies in their R&D management. After the development of material technology, knowledge of new materials was transferred to develop complementary technology by moving researchers from basic research to advanced research. This material innovation could be a symbolic case of academic-industry collaboration in Japan.

It is considered that Panasonic obtained knowledge of material technology from university, and next knowledge was transferred to develop complementary technology. It is likely that there existed bilateral causality between academic research and practical research, so that intensive collaborative R&D contributed to invent the composite materials. It can be said that strategic R&D management in Panasonic has led the technology spillover to diffuse the knowledge of material technology, and this technology spillover played a significant role to develop the material technology in the LIB innovation process.

6.7 R&D management of material technology

Based on the observation of R&D management in Panasonic, following 3 steps R&D management of material technology can be proposed as one example.

In stage 1, intra-firm technology spillover leads an innovation. When firms enter the material industry, they need to prepare infrastructures to create materials such as facilities, equipments, and tools to produce materials. Additionally, knowledge, not only material technology but also know-how, experiences, skills for their facilities, also needs to be accumulated. After the development of materials, complementary technology is also developed to facilitate the effective work of materials. It seems that the R&D in material technology is started from the firm's own effort, and little collaborative R&D is performed with other entities. In this step, the basic infrastructure to create materials is established.

In stage 2, inter-firm, intra-technology spillover leads an innovation. Firms are required to develop the technological characteristics of materials in the advancement of the performance of a product. In order to develop materials, collaborative R&D is encouraged to provide opportunities for inside researchers in a firm to exchange information with outside researchers. It seems that collaborative R&D is demonstrated among researchers in the field of material technology to develop the functionality of core technology. In this step, horizontal integration between organizations, for instance between university and firm, is promoted. Additionally, vertical integration within material technology, for instance between simple materials and composite materials, is promoted.

In stage 3, inter-firm, inter-technology spillover leads an innovation. In order to put new materials into practical use, it is required for firms to diffuse knowledge of material technology to process, component, and product technologies. Then, researchers in the collaborative R&D need to move to participate in the advanced research. In this step, horizontal integration between organizations is promoted. Additionally, horizontal integration between technologies, for instance between material technology and product technology, is promoted.

Figure 6-5 shows the relations of R&D management and innovation of material technology on the aspect of technology spillover.

	Dynamism of R&D management		Dynamism of Innovation
	Organizational view	Technological view	Material technology
Stage 3	**Inter-firm** ● Horizontal integration between organizations is encouraged. ● Collaborative R&D is performed between basic research and advanced research. ● Inside core researchers move to attend advanced research.	**Inter-technology** ● Horizontal integration between material technology and complementary technology is encouraged. ● Knowledge about materials obtained from outside needs to be shared and integrated with knowledge about manufacturing for the practical use of materials.	**Diffusion of material technology**  Material technology is diffused to process, components, and products.
Stage 2	**Inter-firm** ● Horizontal integration between organizations is encouraged. ● Collaborative R&D is performed between researchers of material technology.	**Intra-technology** ● Vertical integration within material technology is encouraged. ● Knowledge about materials obtained from outside and one accumulated in inside need to be crystallized to develop materials.	**Development of material technology**  Material technology is developed in collaborative R&D.
Stage 1	**Intra-firm** ● R&D for the creation of new materials is started from the firm's own effort at first. ● Little collaborative R&D are performed at the start.	**Inter-technology and Intra-technology** ● The basic infrastructure to create materials is established, and knowledge starts to be accumulated in a firm. ● Both of material and complementary technologies are invented in own R&D.	**Creation of material technology**  Material technology is created as a core technology in a firm.

Figure 6-5. R&D management of material technology.

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