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How Do Firms Compete When Faced with Architectural Changes?: Lessons from the Optical Storage Media Industry

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Abstract: This study explores how firms respond to changes in product or process architecture. Product or process architecture is the design rules of a system which can be described as the pattern of interrelations between components. Firms must prepare adequate knowledge in a specific architectural condition, so changes of architecture cause serious managerial problems for firms, called modularity traps (or integrity traps). A case study of the optical storage media industry gives some hints for overcoming such traps. First, firms have to alter their strategies and business domains when architectural conditions are changing. That is, in a modularity condition firms have to specialize, and in an integrity condition firms have to coordinate some activities. Second, and more importantly, firms have to retain their component and system knowledge, in order to maintain competitiveness both in specialized activities and in integrated activities.

Keywords: product architecture, modularity trap, architectural knowledge, vertical integration, optical storage media, CD, DVD

1. Architectural change causes serious managerial problems

‘Vertical integration to horizontal specialization’ has been one of the characteristics of industrial competition since the 1990s. Many firms thought about ‘outsourcing’ and ‘refocusing’, to improve competitive performances. In fact, in electronics industries, traditional vertically integrated firms lost competitiveness and networks of specialized firms took over them (Sturgeon, 2002). In computer industry, specialized firms such as Intel or Microsoft who can make each component of a computer, replaced integrated firms such as IBM (Grove, 1995). In semiconductor business, instead of vertical integration, specialization in design (fab-less) and that in manufacturing (foundry) became the dominant form of organization.

Those changes were caused by modularity. Modularity is the decoupled condition of product or process architecture. When architecture changes towards modularity, each component or each business activity can be done independently, and firms can get competitive advantage by focusing their resources on specific business areas. Modularity is the essentials of the trends towards specialization in these days.

But architecture not only goes modular but also goes integral. When architecture return from modular to integral, specialized firms, who gained competitiveness in modularity, do not respond to integrity and lose competitiveness. Kusunoki and Chesbrough, 2001 called this problem as ‘modularity trap.’

Then, how do firms respond to such two-way architectural changes? When architecture changes to modular, firms should specialize. But, specialization disables a firm to respond to reintegration. To think about this dilemmatic problem, we analyze optical storage media industry.

2. What is architecture?: Literature review

2.1. Architectural perspective of the product and process

Architecture is one of the perspectives of artificial systems. ‘Artificial’ means human-made, and ‘system’ means composed of more than one component. So an artificial system is a thing that consists of some components made by humans. It includes not only concrete objects, such as automobiles or mobile phones, but also immaterial properties such as economic system or human relations (Simon, 1996).

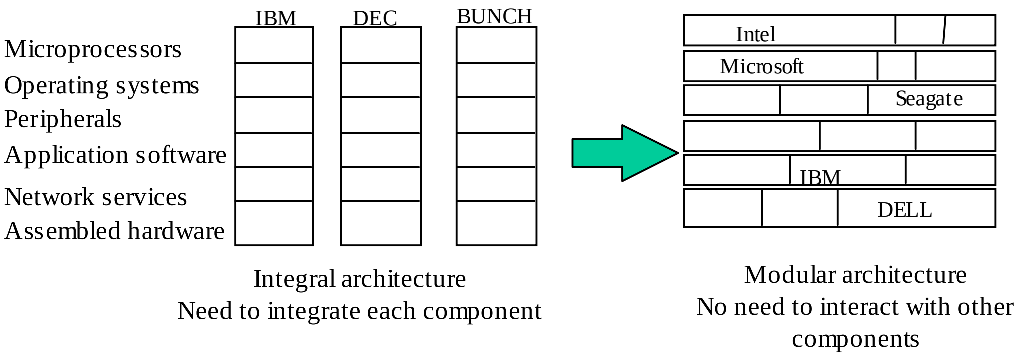
‘Architecture’ as a characteristic of a system can be described as the pattern of interrelations between components (Baldwin & Clark, 2000). We can distinguish the architecture of systems into two types by the strength of the interdependence of their components: integral and modular. A modular architecture specifies independence (a decoupled structure) of each component. An integral architecture specifies interdependence (a tightly coupled structure) of each component (Ulrich, 1995). The automobile, the quality of which is realized by integrating numerous parts, is a typical integral architecture product. On the other hand, the personal computer (PC), whose components, such as the MPU, DRAM, or HDD, are developed and produced independently, is a typical modular architecture product.

Firms must have adequate knowledge and capabilities for their confronting product or process

Figure 1. Relationships between knowledge and architecture

		type of architecture: integral	type of architecture: modular
type of knowledge	knowledge about system capability for integration or coordination	good	bad
	knowledge about component capability for specific area	bad	good

Figure 2. Change of the architecture causes that of value chain structure



Source: Grove (1995).

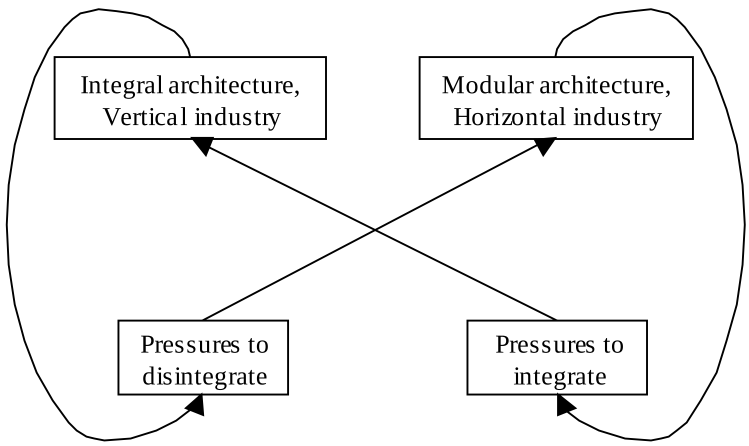
architecture. In other words, different types of knowledge are required in different types of architecture (Ulrich, 1995). When the system has an integral architecture (consists of tightly coupled subsystems: Simon, 1996) we need mutual coordination and architectural *knowledge (knowledge about the system)* in order to produce, develop or operate that system. When the system has a modular architecture (consists of nearly decoupled subsystems) we do not need knowledge of the system but we need special, detailed *component knowledge* (Henderson & Clark, 1990, Sanchez & Mahoney, 1996) (Figure 1).

Because of these relationships, value chain structure can be laid out in accordance with the product or process architecture (Figure 2). In integral architecture, a firm should have architectural knowledge, so it will choose a vertically integrated form of organization, whereas in modular architecture the firm should take a specialized form in order to focus its resources on a limited area (Sturgeon, 2002).

2.2. When the architecture changes

Next we will consider changes in the product or process architecture. As we saw in the previous

Figure 3. Continuous shift of the architecture



Source: Fine (1998), modified by the author

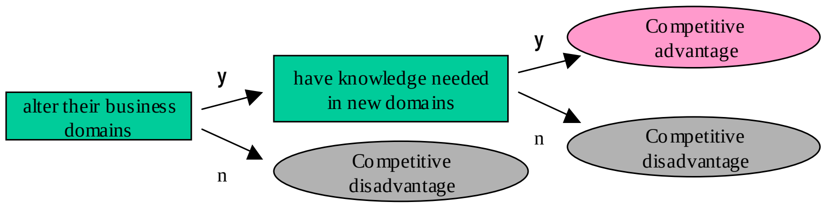
subsection, the architecture decides the value chain structure. Thus, changes in architecture cause changes in the value chain structure.

When the architecture of an industry is relatively stable, it is easy for firms to take adequate strategies and organization design. In modularity, a firm should specialize their domain where they have core competence. In integrity, a firm should integrate its business activities. However, when the architecture changes continuously, the problems faced can become difficult. In turbulently changing competitive environments, known as hypercompetitive (D'Aveni, 1994) or fast-clockspeed industries (Fine, 1998), the structure of interactions between business activities can change continuously and violently (Figure 3). Within such a turbulent architectural change, how do firms decide on their strategies and organizational designs?

In a continuously changing architecture, firms should neither focus on specific areas nor integrate vertically. Consider the situation in which product architecture gradually becomes modular in a turbulent environment. Should a firm specialize its business? Specialization gives firms a competitive advantage in modularity, but if the product architecture changes toward reintegration, specialized firms will lose their competitive advantage (Kusunoki & Chesbrough, 2001). And the possibility of re-integration is high in turbulently changing environments. If firms choose integrated business models, the story becomes opposite. They can get competitiveness if the product architecture goes integral, but they lose competitiveness when architecture keeps going modular.

From the discussion above, we can say that firms should not fix their strategies and their business domains when the product architecture is changing turbulently. Rather, they need flexible

Figure 4. When the product or process architecture changes, how do firms respond to that?



modifications of strategies and domains. To put it simply, firms should alter their business domains in accordance with the architectures with which they are confronted. That is, when architecture changes toward modular, firms should specialize, and when architecture goes integral, then firms should expand their business domains and reintegrate them.

However, alterations of domains would cost a great deal. When a firm specializes its business, it has to abandon some of its tangible and intangible assets. Firms have to abandon some plants, R&D centers and sales departments, as well as manufacturing capabilities, technological knowledge or sales know-how. On the other hand, when a firm integrates its business, it has to get new capabilities. Firms have to merge with other companies and invest in new assets. In addition, to integrate business activities firms build up architectural knowledge, in other words, coordination capabilities between old capabilities and new ones. In short, knowledge needed changes as a firm's domain changes (Demsetz, 1991), so the alteration of domain would take costs to build or abandon knowledge.

Thus, we can infer that a firm can alter their domains by keeping various kinds of knowledge. Consider the condition that product architecture goes integral and a firm has specialized form. If that firm has knowledge about the system, it can realize the reintegration and keep competitiveness in integral architecture. When architecture becomes modular and a firm has integrated form, it can respond to modularity if it has detailed knowledge about one specific area. By keeping knowledge about the system and the component, firms are thought to be able to respond to any architectural changes easily (Figure 4).

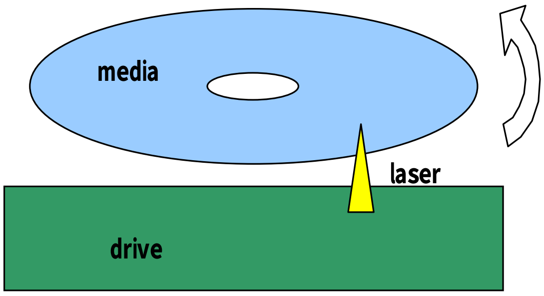
So far, we considered the problem from a theoretical perspective. From the next section, we think about it from an empirical point of view. In order to certify how a firm can keep competitiveness in a turbulently changing value chain structure, we adopted one hypercompetitive industry as a unit of the study, that is, optical storage media industry. Whether strategies mentioned above gives firms competitiveness or not will be clear from the case studies.

3. Research method

This paper is based on one detailed industry case study. The industry analyzed here is the writable optical storage media industry (here I call it OSMW: optical storage media writable industry). The data were collected from a field based study program of the optical storage industry in 2003 to 2006.[1] Initially the data were collected by interviews with the managers of the firms concerned. A total of 65 interviews were executed. For the information on financial performances, I basically used the firms' IR brochures. For national or whole-industry statistics I was supported by the IEK (the Taiwanese Government's research institute) and Techno System Research (a research company in Japan). Also, I used several secondary sources such as newspapers, catalogs and some academic papers and books to triangulate the facts.[2] We piled up those data and made up the industry level analysis.

Optical storage is a system of reading, erasing and storing data by the optical technology. It is famous as CD or DVD. This system is made up of two devices: the drive and the media. The drive reads, writes and erases the data on the media (Figure 5). The media and drive are physically separate from each other. The *business* of the optical media is also separate from that of the drive. Writable optical storage media, which we analyzed here, are optical media on which information can be written. They are known as 'CD-R' (compact disc-recordable) or 'DVD-R' (digital versatile disc-recordable).

Figure 5. System of optical storage

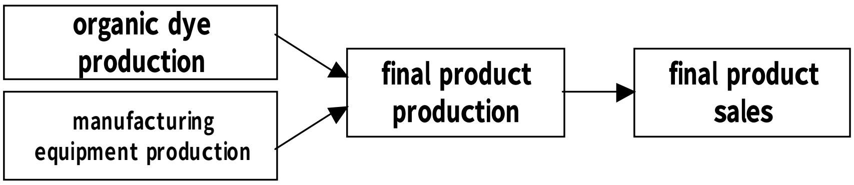


In the case study, we focused on the conditions of process architecture of OSMW industry. We analyzed the process architecture, because the production process of optical storage media is process-intensive, so the industrial structure is affected by process architecture more than product architecture. To make the analysis simple, we picked up three important processes among the whole production processes. I picked out three activities; 'final product production,' 'organic dye production,' 'manufacturing equipment production.' Organic dye is the most important material in making writable optical storage media, because the specifications and the qualities of organic dye mainly decide the lifetime of final product and the precision of data writing. The manufacturing equipment production is also important, as it affects on final product's cost and quality. Furthermore, I added the 'final product sales' into the analytical unit of the case study, because the relationships between production and sales are also the important factor for the settings of industrial structure. The flow of those activities is

[1] The research project had been undertaken by five research staffs (including me) at the University of Tokyo.

[2] I was helped by Yin (1994) and Fujimoto (2003) in designing the case study.

Figure 6. Flowchart of important activities of OSMW industry



depicted in Figure 6. We will analyze the interactions between these activities to determine the changes in the process architecture of the OSMW industry.

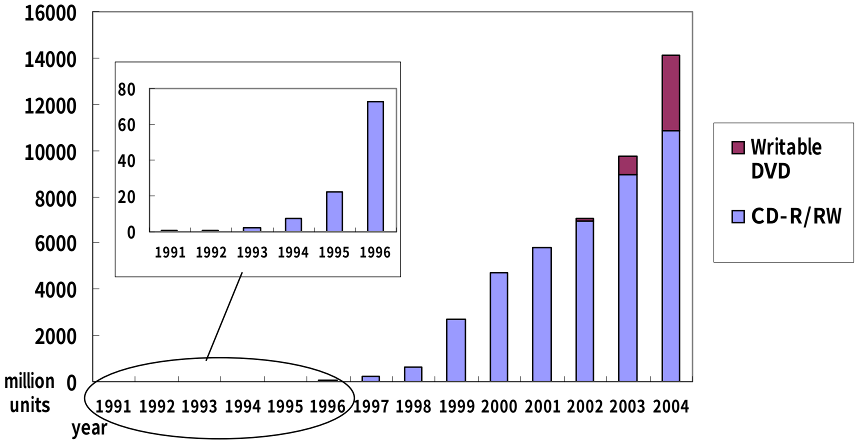
4. Case studies: Writable optical storage media industry

The writable optical storage media (OSMW) industry started in 1989, when the first CD-R was produced. After that, the industry developed step by step, and in 2004, the OSMW industry yielded sales of about 4.5 billion dollars and produced 14 billion units of products (Figure 7).

4.1. The first stage of OSMW industry

The OSMW industry started in 1989 when Sony and Taiyo Yuden developed and produced the CD-R. At that time Sony mainly commercialized the CD-R *drive* and Taiyo Yuden did the CD-R *media*. Taiyo Yuden's concept of CD-R media business was that 'everyone can make his own original CD at a relatively low price,' so the target of the CD-R was the consumer market. But that plan did not go well. Sony did not sell CD-R drives actively to consumers because Sony was into music content business too (its target market being also consumers) and felt worried about the negative effect of the CD-R, onto

Figure 7. Trend in writable optical storage media sales



Sources: Techno System Research (1991-2000), author (2001-2004) which people can copy music, on its music business. So the CD-R standard did not spread into the consumer market in the early 1990s. In other words, the early CD-R business had no customers. Firms had to find customers other than consumers.

Therefore, the early entrants into the OSMW industry looked for demand through their own efforts. For example, Taiyo Yuden sold their media to corporate and government customers such as NASA who needed fast, high-volume, stable data storage technology. Kodak sold CD-Rs as storage media for digital photographs (photo-CDs).[3] To increase production volume, firms had to find usage and customers for CD-Rs, so the process architecture between sales and final product production seemed to be integral in this sense.

Not only the customers, but also the production technology, were different in each firm. Every entrant adopted a different material (organic dyes) and different production technologies (manufacturing equipment), which were developed through each firm's own efforts. Manufacturing equipment and materials (especially organic dyes) were functionally interactive, so firms had to develop and adjust them to improve the final product quality. In order to differentiate in quality and adjust to the customers' several needs, firms made CD-R media with original technology that used original organic dyes and original equipment.

To meet the architecture described above, the entry firms, Taiyo Yuden, TDK, Mitsubishi Kagaku, Mitsui Kagaku and Kodak selected a vertically integrated form. No firm specialized in any one activity. Every firm used original dyes and manufacturing equipment, made high quality products, and sold them to corporate customers. This vertical structure stayed in place until 1996.

4.2. The way to modularity

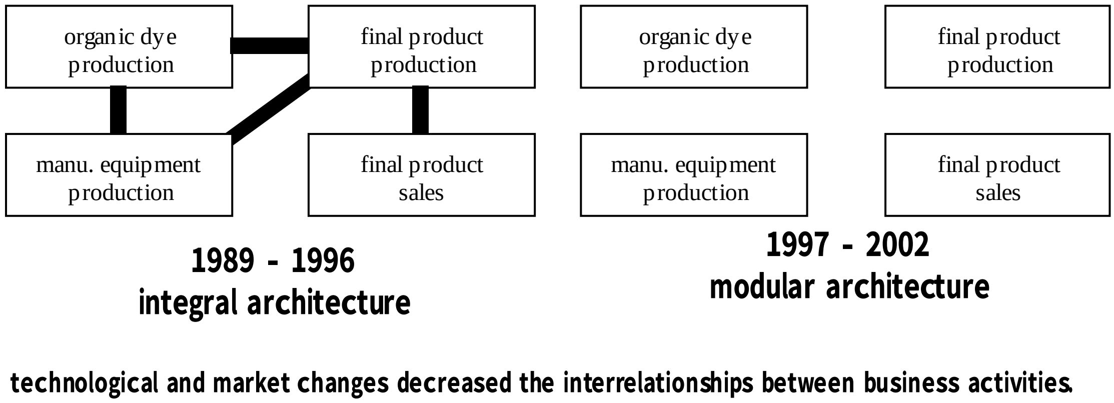
In the late 1990s the process architecture of OSMW industry went modular. On the production side, some technological innovations led to modularity. Gradually, functional interrelations between materials and equipment came to be clarified, and development activities for both materials and equipment could be done independently. Ciba Specialty Chemicals developed the organic dyes, by which firms could produce good CD-R media using any equipment. Similarly, some equipment companies produced the manufacturing equipments, called in-line equipments, which yielded good quality CD-Rs stably in any environment and with any material. By using these dyes and equipments, 'everyone can produce CD-R, if he can get the materials and equipments. No knowledge of equipments and materials is required.'[4]

The market for CD-R media also changed in the late 1990s. From 1997, CD-R drives for personal computers were developed and spread rapidly, as personal computers were being sold all over the

[3] For the early phase of the OSMW industry see Nakajima (1998).

[4] Comment by the process engineer of a Japanese OSMW firm.

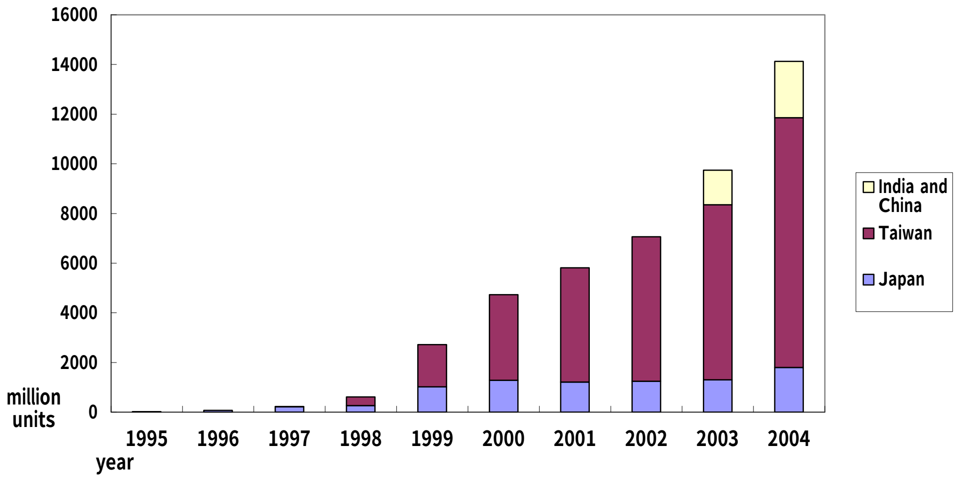
Figure 8. Business architecture went modular in the late 1990s



world. As a result, consumers started to use the CD-R at last. The market changed rapidly from corporate to consumers. In the early 1990s corporate customers bought good quality CD-R media, but in the late 1990s the consumers bought low price CD-Rs with famous brand names on it; they were not so concerned about quality. In addition to such qualitative changes, quantitative change also heavily affected sales activities of the firms. In the past, firms had sold millions of CD-R media, but now they sold from several hundred million to a billion CD-R media. Sales activities needed large administrative functions, marketing professionals and a great distribution network. These capabilities were specialties for sales, so sales activity became functionally independent from production activity. Figure 8 summarizes changes of the architecture. Technological and market changes led to modularity of business activities. All the interactions between activities were no longer needed.

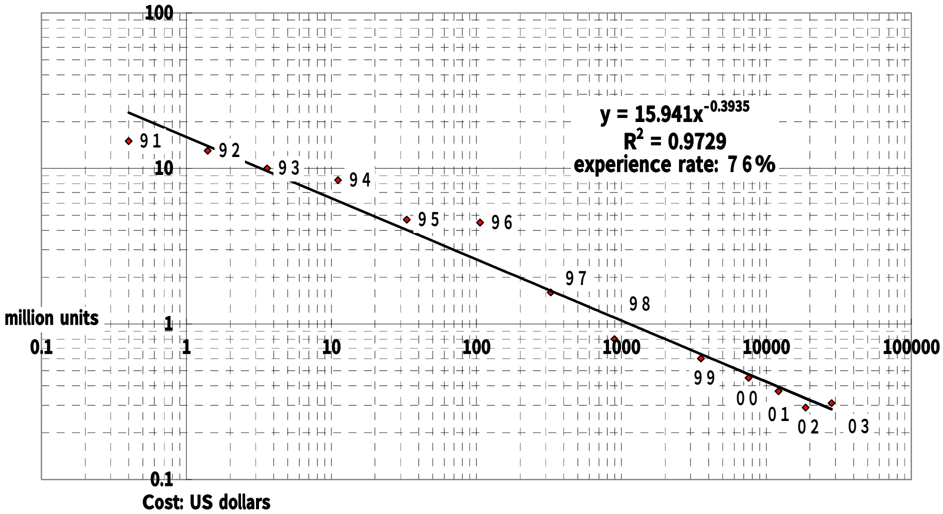
In this modularity phase, specialized firms achieved competitive advantages over vertical ones. At first, let's look at CD-R production business. As we saw before, everyone can produce CD-R media if he can buy dyes and in-line equipments from the market. So firms cannot get competitive advantage by possessing their own organic dye division or manufacturing equipment division. In addition, consumers as customers did not want differentiated CD-Rs but cheap ones, so production activity did not need integration between materials and equipments. Firms needed to focus their resources on CD-R manufacturing activity. Taiwanese CMC and Ritek took this strategy and got a total share of more than 70% in total production of CD-R. They entered the OSMW industry around 1996 by focusing on CD-R production. They exploited the Taiwanese stock exchange market and obtained a large amount of capital, and they invested it only in building CD-R manufacturing capacities larger than those of the existing firms. These huge investments on production capacities gave them economies of scale.

Figure 9. Trend of writable optical storage media production by nationality



Source: Techno System Research

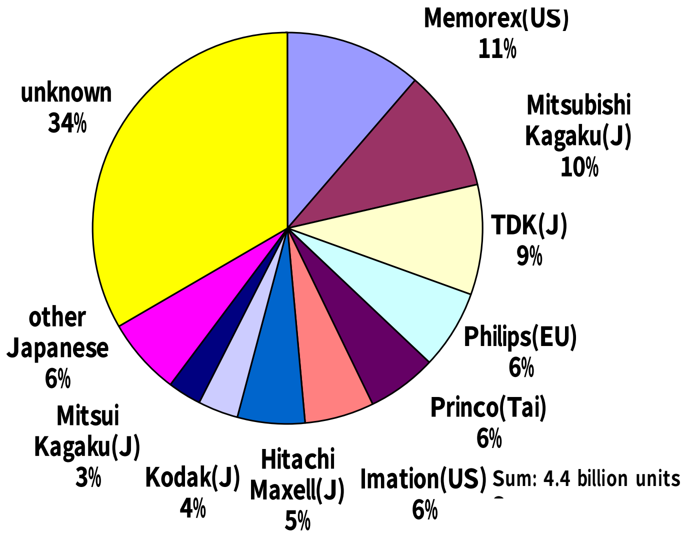
Figure 10. Experience curve of CD-R media



Source: Techno System Research

CMC and Ritek bought materials and equipments from other firms and started operation. They focused their resources on the efforts to make final production more efficiently. As a result, in the price-concerned consumer market, Taiwanese CMC and Ritek had competitiveness over Japanese. In 1998—only 3 years after their entry—CMC and Ritek caught up with the Japanese firms in production volume. Figure 9 shows the overwhelming presence of Taiwanese firms. And

Figure 11. CD-R media sales share in 2000



Source: Techno System Research

Figure 10 shows the impact of Taiwanese firms on CD-R production business. Experience curve insists that in 1997 cost suddenly lowered than expected.[5] Taiwanese firms might have caused this drastic change.

In organic dyes, Ciba Specialty Chemicals obtained a monopolistic share by selling highly equipment-independent dyes. In manufacturing equipment production, firms who had developed in-line equipments early received many orders and enjoyed high profitability. Before Ciba Specialty and process equipments makers produced those materials and equipments, firms could not make CD-R media without dyes and equipments adjusted to each other. And Japanese and American existing firms did not have sold those integrated dyes and equipments. So Ciba Specialty's dye and process firms' in-line equipments enabled Taiwanese firms to enter the OSMW industry and changed the competitive environments, by altering process architecture.

In the CD-R sales business, where marketing skills, brand names and distribution networks were effective in competition, Memorex, Imation, Philips, Mitsubishi Kagaku and TDK got competitive advantage. All of them were multidivisionals, and they exploited sales capabilities such as brand royalty, which had been built in other divisions' business.

The firms who had vertically integrated structures could not keep competitiveness without changing strategies. Mitsui Kagaku and Kodak tried to keep their vertical structures, but they were beaten by specialized firms in each area and withdrew from the OSMW industry. Taiyo Yuden focused on CD-R production and TDK specialized in CD-R sales,

[5] For the reason behind the bending of the experience curve, see Abell and Hammond (1979) or Shintaku (1994).

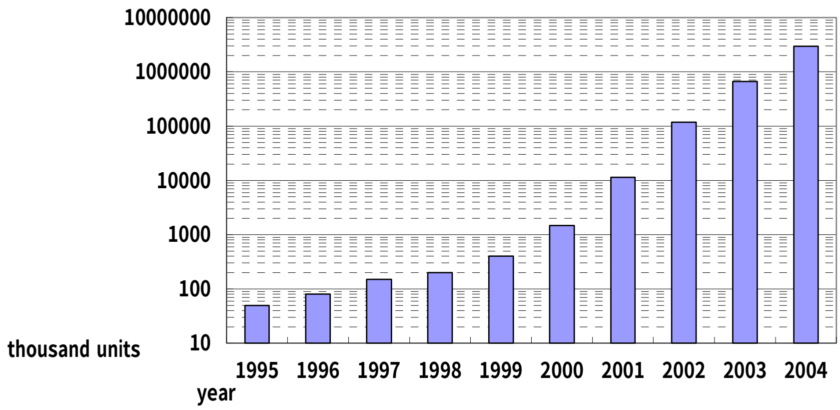
abandoning other activities. Mitsubishi Kagaku also focused their business on CD-R sales, but they maintained some CD-R production capacities and the R&D function for organic dyes and production processes. Mitsubishi Kagaku was concerned that otherwise it will lose media production knowledge though to maintain knowledge it would have required some expenditure. Mitsubishi Kagaku continued a little commercial production by selling its CD-R to niche markets, where qualitative differentiation could be desirable.

4.3. The writable DVD media: Back to integrity

In 1996, a new standard of optical storage, the Digital Versatile Disk (DVD), was determined. Although the DVD standard had only ROM (read only memory) at first, development programs for writable DVD media had continued in the late 1990s and writable DVD media standards were set around 1999.[6] The Writable DVD has 4.7 GB storage capacity whereas the CD-R has 700 MB, and writable DVD media spread gradually after 2001, replacing CD-R media.

The advent of writable DVD media made the process architecture of the OSMW industry go integral again. While everyone could make CD-R in 2000 if they can get materials and equipments, people had to have detailed knowledge of organic dyes and manufacturing equipments and integrate them in order to produce writable DVD media. The shape of the DVD media is the same as that of CD-R, but the storage capacity of the DVD is about seven times bigger than that of the CD-R. To realize that

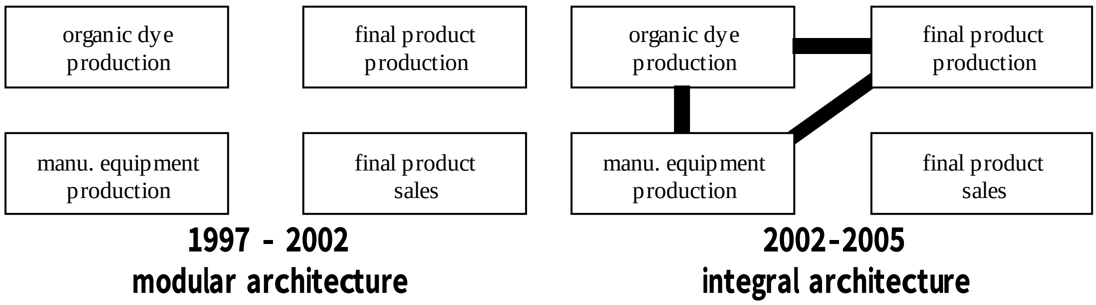
Figure 12. Writable DVD media production



Sources: Techno System Research (1995-1999), author (2000-2004).

[6] Writable DVD media had various standards, such as DVD-R, DVD+R or DVDRAM. All of them were determined in 1996-2000.

Figure 13. Reintegration of business architecture



huge capacity, firms have to realize strict specifications by integrating material technology and process technology. For example, the quality of the writing layer on DVD media, where the data are recorded, is determined by the interaction between injection machine performance and the organic dye's specifications. In addition to realize strict specifications, the users had wanted DVD media to be better quality than CD-R media. In 2002 a DVD recorder for TV diffused into the market as one of digital home appliances but people came to dislike the writing errors of DVD media that occurred when they recorded TV programs, as VCR had rarely failed to record. So DVD media manufacturers tried to improve the product quality by adjusting the materials and equipments to respond to customer needs.

On the other hand, the relationships between production and sales did not change drastically. Though users want quality more than low cost, basically the target market—the consumer—did not change. Sales companies did not have to alter methods of sales and distributions. They did not need mutual interactions with production and they focused on sales activities only, that is, marketing, branding or building distribution systems.

In this integration phase, Mitsubishi Kagaku became a leading company in the OSMW industry. Mitsubishi Kagaku had integrated all its activities vertically in early 1990s, but it specialized in sales when the industry went modular. And then, Mitsubishi Kagaku succeeded in the technical integration of writable DVD in 2002. The profit rate of Mitsubishi Kagaku had not been announced, but about a half of our interviewees answered that Mitsubishi Kagaku is the best performer in the OSMW industry. Now Mitsubishi Kagaku had about a 20% share in final product sales, which is the largest in the world. And it had monopolistic share in organic dyes, but it did not have DVD production capacity. How did Mitsubishi Kagaku succeed in the DVD business?

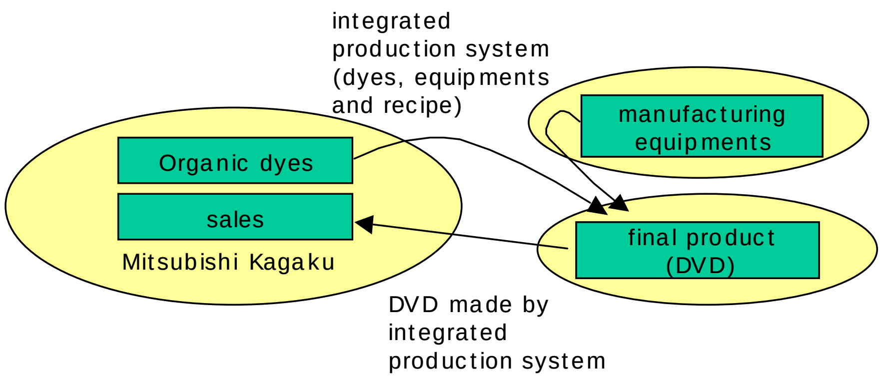
Mitsubishi Kagaku did not internalize business activities into its domain, and kept specialization in limited areas. But, Mitsubishi Kagaku succeeded in integration of the process architecture. To realize integration, Mitsubishi Kagaku was in charge of the system integration activity and exploited external knowledge in the area where integration was not needed. Mitsubishi Kagaku developed the production system of DVD, which consisted of organic dyes and process equipments adjusted to each other. Mitsubishi Kagaku itself did organic dye production, and then, about the detailed design of process equipment, Mitsubishi Kagaku was helped by the other firms who specialized in equipment business. Mitsubishi Kagaku was also helped by Taiwanese media producers, especially CMC, in final writable DVD production. And Mitsubishi Kagaku bought writable DVD media from Taiwanese suppliers and did final product sales.

Mitsubishi Kagaku could realize the integration of the architecture because it had knowledge of the whole system of production of writable DVDs. It was called as the 'recipe' of writable DVD media. Mitsubishi Kagaku kept the 'recipe' by keeping possessing some CD-R production capacities and the R&D function for organic dyes and production processes still in the modularity phase. Mitsubishi Kagaku outlaid some costs to keep these capabilities, but after 2000 those capabilities remained gave Mitsubishi Kagaku the chance to leap forward.

Mitsubishi Kagaku's 'recipe' was an aggregate of know-how for making good quality writable DVD media. By using that recipe, Mitsubishi Kagaku and an equipment maker jointly developed the dyes and the equipment. Mitsubishi Kagaku (and the equipment producers) obtained a large share in dye business (or equipments business). In addition, Mitsubishi Kagaku sold the dyes, the equipment and the recipe as an integrated production system only to some exclusive producers. They could produce better DVD media by that integrated system than by using dyes and equipment bought separately from markets. Mitsubishi Kagaku bought better quality DVD media produced from those exclusive producers and sold them. In this way Mitsubishi Kagaku succeeded in the DVD business.

After Mitsubishi Kagaku's leap forward, some firms followed Mitsubishi's ways and tried to integrate architecture. Among them TDK succeeded in integration of the process architecture. TDK also kept knowledge for integrated production system, so TDK could follow Mitsubishi's way. Taiyo Yuden was the third successful company. Taiyo Yuden chose final product manufacturing business in the late 1990s. Then Taiyo Yuden did not compete directly with Taiwanese makers. Taiyo Yuden focused their business on differentiated niche where the customers needed above normal product quality, so it kept integrated production way. So Taiyo Yuden could respond to the change of the architecture when the writable DVD media emerged. Taiyo Yuden would realize integration in DVD business easier than Mitsubishi Kagaku because only it had to do was to continue the same way of business as it did in CD-R business. But Taiyo Yuden did not have sales functions, so they could not earn more than Mitsubishi Kagaku. To think from the opposite side, Mitsubishi Kagaku's success was attributed to the

Figure 14. Business model of Mitsubishi Kagaku



creation of effective business model that Mitsubishi Kagaku could exploit whole value chain by possessing the upper end (organic dyes) and the lower end (sales to final customers).

Specialized firms that did not participate in Mitsubishi's or TDK's group lost competitiveness. Ciba Specialty Chemicals continued organic dye development by itself in the DVD business, but their dyes did not satisfy the customer's quality needs. Firms who developed only equipment also lost market position. In DVD final production, CMC or Indian company MBI (Moser Baer India), who placed importance on cooperation with other companies, improved their performance. They introduced Mitsubishi's or TDK's integrated system and got orders from them, so they could produce better DVD media and achieved a relatively stable competitive environment. However, firms that did not cooperate with others were placed in a position of fierce competition. They could not make good quality DVD media, so they had no way to sell them at lower price.

In the DVD sales business, although Mitsubishi improved its share and the sales specialists showed a decrease in profits, a general survey of the situation did not change drastically. Memorex and Imation still kept their profit by specializing in sales, because performance in this area was decided by sales capability, regardless of the strength of these companies' other capabilities.

5. Discussion and conclusion

In the previous section, we observed the OSMW industry from a process architecture perspective. And we confirmed that the changes in process architecture drove changes in the value chain structure. In the early 1990s process architecture was integral and firms had vertical integrated forms. Next, in the late 1990s, process architecture went modular and specialized firms got competitive advantage over vertically integrated ones. However, after 2001, in the DVD business, firms had to integrate their business activities to produce good quality DVDs, and Mitsubishi Kagaku realized the integration of the process architecture by collaborating with other specialized firms.

This case study gives us hints as to how to compete in a changing architecture. First, firms have to alter their strategies and business domains in accordance with the process architecture with which they are confronted. That is, in a modularity situation firms have to specialize, and in integrity firms have to coordinate some activities. Second, and even more importantly, firms have to retain their component and system knowledge. This might be the very condition that makes firms easy to alter their domains. If firms keep both component and system knowledge, they can do business both in specialized activities and in integrated activities so they can change business domains. Firms have to keep system knowledge even if firms did not need it in modularity. Because they may use system knowledge in the future integrity phase. Firms should also keep component knowledge in integrity to respond to future modularity. Thus we conclude that firms should alter their domain as the product or process architecture changes, but they should keep their system and component knowledge.

Keeping knowledge would decrease the difficulty in changing business domain. However, some costs still remain. Mitsubishi Kagaku kept system knowledge during the modular architecture phase by retaining a small production capacity for the final product and also its R&D function for dyes and equipments. These slack resources do not meet their cost. The question of how to lower the cost of slack resources is not solved from the case study of the OSMW industry. It is to be solved in the future. Now, what we can say is that firms should have such resources so that they can keep their knowledge in a turbulently changing architecture, even if it comes at a cost, because firms cannot respond to architectural change without it.

Finally the contributions of this paper will be discussed. This paper's novelty exists in its dynamic view of competition. Past research has suggested strategies in modularity (Baldwin & Clark, 2000, Sturgeon, 2002) and those in integrity (Takeishi, 2003). But there has been little research on how to compete when the architecture changes. Kusunoki and Chesbrough (2001) and Fine (1998) dealt with the dynamics of architecture, but they did not reach a solution to it. This paper has tried to find out how to compete in the change of the architecture. I consider this the main contribution of this study.

Some researchers have already reached the conclusion that knowledge should be kept widely regardless of the domain of a firm's business (Brusoni & Prencipe, 2001; Takeishi, 2003). Those researches insisted that knowledge wideness is important from static analysis. This paper extends the discussion from static to dynamic. That is, here we insist that to keep knowledge leads to competitiveness in a dynamic changing environment. In such turbulent environments, firms have to achieve strategic flexibility in order to respond to the changes (D'Aveni, 1994). From this study, we can say that keeping knowledge would be one of the bases of strategic flexibility.

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