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Finding the niche position — competition strategy of Taiwan's IC design industry

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Abstract

The total revenue of Taiwan's IC design industry is now the second in the world, only behind the United States. Despite the disadvantages of limited research resources and little influence over the global electronics market, it was able to build up a core competence of speed, quality, flexibility and cost through knowledge assimilation and utilization. Taiwan did not attempt to challenge the technology leadership in a confrontational manner, but focused on being a superior quick follower. The implementation of this niche strategy and the core competence of the IC design industry originates from five major factors: supportive policy, technology manpower, entrepreneurship, vertical disintegration and industrial cluster. This paper is dedicated to discussing this unique strategy and the supporting factors of Taiwan's IC design industry.

Keywords: Competition strategy; Industrial cluster; Vertical disintegration; IC design industry

1. Introduction

Since its invention in the 1950s, the semiconductor has become one of the most important industries in the 21st century. Among the sub-industries of the whole semiconductor industry, the integrated circuit (IC) design sector holds a key position by being the link between the semiconductor chip and the system. It is particularly crucial as the technology development moves toward integration of 3C (*computer, consumer, and communication*) products and SOC (*system on a chip*) design. Despite its smaller scale compared to the IC manufacturing sector, IC design is regarded as a key industry with ever-increasing importance worth serious attention.

Taiwan started its research on IC design in 1975 under governmental sponsor when the Electronic Research and Services Organization (ERSO) of the Industrial Technology Research Institute (ITRI) brought in the semiconductor technology from RCA. The first private company engaged in IC design was Syntek Design, established in 1982. Within a score of years, in 1999, 127 IC design companies had mushroomed to amass NT$74.2 billion in total revenue, second only to the United States. Besides high revenue growth (except in the years of 1990 and 1994 when the IC industry hit the bottom globally), the technology level has advanced from, when represented in the number of gates, 10K in 1988 to million-gates in 1998 (ITRI, 1991–2000). Table 1 describes the development and the status of Taiwan's IC design industry.

Taiwan's IC design industry comprises four types of designers: the independent professional designing house, the design department in an integrated IC manufacturer (IDM), the IC design center in a system vendor and the design unit of an overseas company. The products fall into the following categories: micro components, memory modules, logic modules and analog modules, with the first two categories being dominant. Microprocessors and logic products have been developed along with the prospering PC industry and consumer electronics industry. Besides the US and Japan, Taiwan is also capable of designing memory components including DRAM, SRAM, mask ROM and flash memory. The types of IC design products and applications are listed in Tables 2

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Table 1
Development indicators of Taiwan's IC design industry[a]

Year	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
Number of designing companies	18	30	50	55	56	57	59	64	65	66	72	81	115	127
Revenue (NT$100 million)	5.6	8	22	54	59	73	86	117	124	193	218	363	469	742
Growth rate (%)		42.8	175	14.5	9.3	24	30	36	6	56	13	67	29	58
Design capability (K-gates)			10	20	30	30	30	60	60	65	400	500	Million gates	
R&D/revenue (%)					9.4	9.9	10.1	9.5	10	12.2	9.5	8.8	9.4	8.9
No. of R&D personnel/total personnel (%)				28	30	32	25	51	51	49	51.8	49.5		
Average years of design experience					4	4.5	4.7	5.4	5.9	5	5.3	6.8		

[a] Source: Industrial Technology Research Institute, Taiwan.

Table 2
Product types of the Taiwan IC design industry[a]

	Memory (%)	Micro-component (%)	Logic (%)	Analog (%)
1997	28.7	41.1	24.4	5.8
1998	24.8	63.4	10.3	1.5
1999	19.7	67.4	9.4	3.5

[a] Source: Industrial Technology Research Institute, Taiwan.

and 3. The design capability has long evolved out of the far lagged early stages and moved into the current heel-treading stage with the most advanced technology of million-gates and SOC.

Technologically speaking, Taiwan lacks a deep-rooted scientific foundation in the research of semiconductor technology. It does not have research achievements in physics and electronic technologies as does the United States, nor does it have enormous capacity in material science and foundry equipment as does Japan, who has heavily invested since the 1970s. From a marketing aspect, Taiwan's role in defining product specification for any application is limited by the small scale of its domestic market and national economy. Taiwan's total demand of IC products is US$10.7 billion, only 8.2% of the global market (ITRI, 2000). In spite of these adversities, Taiwan was able to build from scratch an IC design industry that is second only to the United States in terms of total revenue. The major reason lies in the industrial strategy that seeks the advantageous position for global competition.

Among the many attractive viewpoints in exploring the explanations of the industrial development, this study begins with the argument of domestic policy and industry structure. Some important factors like linkage between firms and contributions of foreign buyers are downplayed in this research scope, but could be further discussed. The following sections analyze the unique competition strategy adopted by Taiwan's IC design industry and uncover the origin of its core competence.

2. Competition strategy of Taiwan's IC design industry

Understanding the industrial structure and relationships is important in capturing the idea of competitive advantages (Porter, 1985). When analyzed by the whole picture of up-/downstream together with the general digital circuit design flow as shown in Fig. 1, Taiwan's IC design industry is uniquely positioned. Compared to the advantages possessed by the US and European countries in system/application specification and the advantages aggressively pursued by Japan in material technology and fabrication processes, Taiwan's competitiveness originates from the design speed, quality, cost and flexibility. These competitive factors coincide with Betz's concept for the economic evaluation criteria of technology (Betz, 1998).

A successful IC design resides not only in the circuit design flow but also in two aspects of product implementation. The first is specification for products and applications in the upstream of design flow and integration of system architecture. The second is the subsequent process of wafer fabrication and related material and equipment technology.

Product specification generally has a direct impact on the methodology, function and performance requirements for a circuit design. A leading role in specification therefore means a firm grasp of the blueprint for product implementation. To lead in product specification requires profound knowledge in terms of overall system architecture for all products on the one hand, and vast market influence on the other hand. The US and the European countries have long dominated specification in the market due to their early engagement in research and development of electronics technology, particularly information technology for the US and communication technology for European countries, with each being backed up by ample markets. Despite all its hard efforts of trying from its manufacturing and OEM background to catch up with advanced electronic technologies, Taiwan lacks experience in the field of system architecture integration. The inherent limitations of the domestic

Table 3
Application types of the Taiwan IC design industry[a]

	Information (%)	Communication (%)	Consumer (%)	Others (%)
1997	**56.7**	13.3	24.1	5.9
1998	**62.1**	12.9	24.4	0.6
1999	**69.1**	13.1	16.9	0.9

[a] Source: Industrial Technology Research Institute, Taiwan.

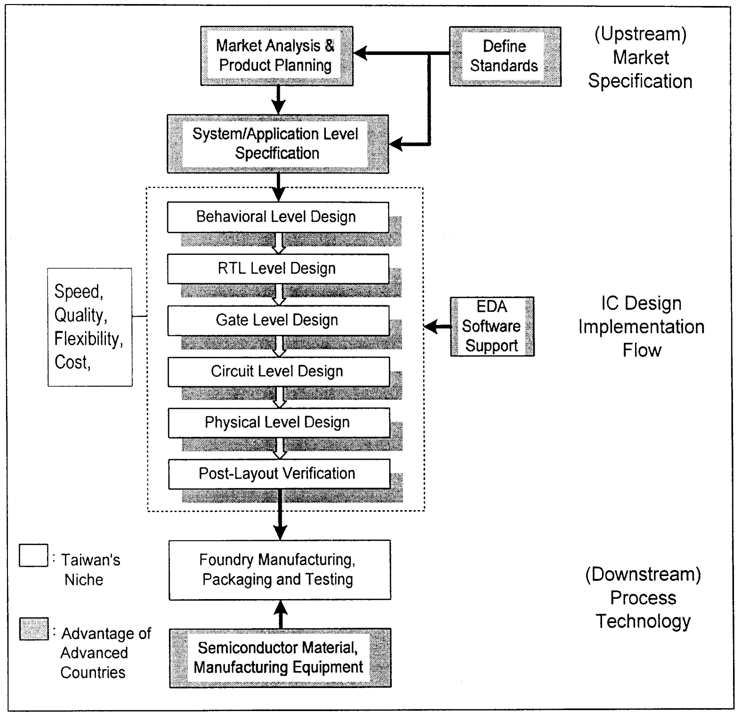

Fig. 1. Digital circuit design flow and competitive advantage analysis.

market further hinders its pursuit of the leading role in defining specification. The most Taiwan can do is to proactively partake and rapidly access those specifications.

In the field of wafer fabrication and the material and equipment supply, the US and Japan have firmly anchored their technology leadership after decades of aggressive development and fierce competition in the 1970s and 1980s. Taiwan has recently made much progress in the technology of the fabrication process by adopting the foundry strategy. Nevertheless, after relying on a technology alliance with major US and Japanese companies (Mathews, 1997), Taiwan is still at its infancy in terms of the fundamental material science and precision machinery, and has yet to fully grasp the leadership of next-generation wafer fabrication. As for the EDA (electronic design automation) tools, Taiwan also depends on import, mostly from the US (Chen and Sewell, 1996).

Both ends (the semiconductor foundation and application domain) of IC technology are beyond the range of easy catch-up for a newly developed country like Taiwan. As for the major IC design steps shown in the middle portion of Fig. 1, encompassed by the dotted frame, the key competitiveness lies in the speed to implement, the quality of the design output, flexibility in response to changes in specification and market demand, and the overall cost level. Taiwan enjoys a core competence of an inexpensive but outstanding local design capability pool, as well as a superior supporting foundry system. By leveraging these factors, Taiwan adopts the strategy of being a rapid follower to provide flexible and quick IC design that is less expensive than what can be provided by most advanced countries, with quality much better than that delivered by other developing countries. As "leveraging" is a critical concept for a resource limited country like Taiwan to compete (Mathews, 1995), and there are even more opportunities for non-leaders to succeed (Schnaars, 1994; Hamel and Prahalad, 1994), this unique strategy therefore helps to establish Taiwan as a significant foothold in the global market.

A typical representation of Taiwan's global competition strategy for its IC design product is the CD-ROM chip that has taken up over 50% of the global market share. The CD-ROM and DVD are products with dual features: consumer oriented and multimedia application. CD-ROM technology was developed in the early 1980s and had established an annual worldwide output of millions of chips by the early 1990s.

Taiwan entered this market neither at the early stage of technology development nor at the initial growth stage of the market, but at the rapid growth stage that was confirmed by the booming multimedia PC market pushed by Intel and Microsoft. It was shown in the 1990s that Taiwanese players quickly respond to market demand with flexibility that is evidenced by mushrooming of new companies into this field. An example was UMC (United Microelectronic Co.) spinning off its multimedia design department to form the Media Tek IC Design Company specialized in CD-ROM and DVD products. Under R&D support by the government-sponsored research institute (Opto-Electronics and Systems

Lab.), and based on superior design human resources, the new company was able to rapidly acquire technology (within a period of between 6 months and a year) and launched the production of the CD-ROM chip. With market-acceptable quality at a very competitive cost (compared to Japanese and Korean product lines) supported by domestic OEM companies, these CD-ROM chips quickly took up the global market share, peaking at 4–5 million chips of monthly output.

Along the product lines, Taiwan had been actively participating in an alliance in anticipation of acquiring the subsequent DVD product of which the specification was not completely defined until a few years ago, after long dominance by American title owners and Japanese system providers. The purpose was to exercise the rapid follower strategy. All Taiwanese players have fully deployed their R&D resources and are constantly testing the market response for spotting the demand growth stage in which they will be well prepared to take over the market with cost and flexibility advantages.

Despite neither being an inventor of advanced technologies nor a leader of market specification, Taiwan is still trying to establish its niche position via acute sensing of market opportunities from foreign alliances, quick entry into the market by clever leveraging of superior manpower and governmental R&D sponsorship in technology acquisition, flexible business operation sustained by entrepreneurship, and cost advantage realized by specialized vertical disintegration and industrial clusters. Fig. 2 summarizes this strategy and the supporting factors. The following section describes these factors in the development of Taiwan's IC design industry.

3. Core competence and the supporting factors of Taiwan's IC design industry

The advantages of Taiwan's IC design industry reside in speed, quality, flexibility and cost. This competitiveness originates from the following factors that foster the evolving capability of quick assimilation and the utilization of relevant technologies (Sharif, 1997; Roessner et al., 1992):

3.1. Government support for science and technology

The Taiwanese government adopted a strategy of accelerating technology development through supporting research and development based on imported technology (Chang et al., 1999b). The strategy absorbed part of the industrial risks and geared up investments (Choi, 1988) that laid the foundation for IC design technology and shaped the early IC design industry.

In the 1960s, Taiwan's IC industry was mainly in the field of packaging from foreign investment. The fundamental theories of semiconductor technology were only exercised in the laboratory of the ChiaoTung University and were taught as part of some courses. The government-sponsored ITRI-ERSO was established in 1974 and brought in a research project on semiconductor technology, which was transferred from RCA in 1975. The project was targeted at the 7 μm CMOS process technology that covered comprehensive product design and testing, relevant technologies in site operation, as well as personnel training (Chang et al., 1999a). It laid a solid overall foundation for Taiwan's semiconductor industry.

To rapidly acquire experience of successful and effective IC design, Taiwan chose the field of lower-end consumer products that gave such advantages as easy technology access, adequate capability in technology adoption and products' marketability. Products like electronic watches and melody ICs were easily commercialized to allow the whole industry to exercise the overall design flow as well as to support the downstream electronics companies and toy manufacturers in their requirements for exporting to Southeastern Asian countries. Taiwan's IC design industry was therefore able to start establishing its technology foundation through experienced know-how in design, manufacturing, marketing and commercialization.

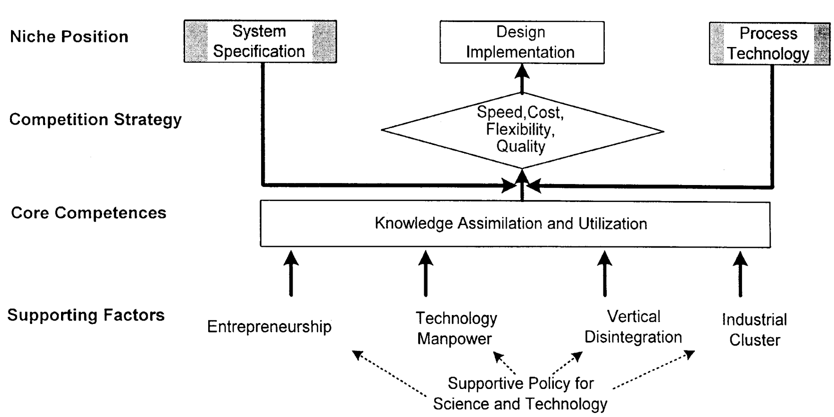

Fig. 2. Competition strategy of Taiwan's IC design industry.

However, despite its preliminary CMOS and bipolar IC design capability, ITRI was still engaged in product design of lower-level functionality (of only hundreds of transistors) at the 1979 year end. A lack of computer-aided design (CAD) tools further worsened the situation in terms of global competition. Because most of the design process was completed by traditional circuit board testing, the time lag for product design to be prototyped usually took 1.5–2 years. To alleviate the problem, more governmental funds were poured into enhancing design capability and developing CAD tools during 1979–83. Meanwhile, based on the experience obtained in designing the electronic watches, ITRI introduced computer simulation software and developed the logic simulation software and the photomask design automation software to speed up the design and to expand the development of more IC products. Besides consumer electronics ICs, the design of 16K-bit memories was completed at the end of 1981 and 32K/64K-bit memories were introduced in 1982. Research into higher-level processor ICs such as CPU, RAM and firmware was started in 1979 and 4-bit microprocessors were ready in 2 years and 8-bit microprocessors by 1982 (ITRI, 1991).

Technology importing was an effective way to boost the level of industrial technology. In order for domestic industry to keep up with advanced sub-micron technology, the Taiwanese government sponsored a R&D program aimed at introducing and developing sub-micron technology (Hou and Gee, 1993). The program was led by the *Sub-micron Task Alliance* formed by ITRI and industrial players. Besides governmental sponsorship of the special program, the industrial players contributed comparable funds and human capital. The research was targeted toward developing a 0.7 μm, 8-in. wafer fabrication process technology for DRAM products, and toward the design, pilot run and product testing of 16M DRAM. The NT$7 billion project was divided into six sub-projects, with the *Memory IC circuit development sub-project* targeted at the design and debugging of DRAM and SRAM. This sub-project was implemented by the Etron Technology Co., formed by overseas Chinese experts, to gear into the design work, personnel training and technology transfer. Etron was one of the few technology teams capable of designing DRAM worldwide at that time. This approach, obviously of great value to the establishment of Taiwan's sub-micron technology and memory IC design knowledge, speeded up the advanced technology to ensure Taiwan's global competitiveness as a close follower.

Regarding design flow technology, ERSO developed Taiwan's first set of testable IC design software and standards to assist the industry in their development of highly sophisticated IC components and to dramatically compress the time required for quality testing. Four types of EDA software and six sets of reliability testing systems were also developed in 1992. At the same time, a mixed-mode flow set was developed to facilitate the design of analog products by applying the P&R (placing and routing) tools and other domestically developed software for analog layout automation in 1996.

Certainly, the foreign providers made a great contribution to the technology introduction. Through the strategy of technology transfer by the government-sponsored research institute (ITRI), integrated learning of design technology and overall product implementation helped to accumulate experience and knacks that later proved to be beneficial to the industry. The major type of IC design products at the early stage is logical device; the percentage of memory device grew in the latter. Analog products also grew significantly, although remaining the smallest share. When analyzed by product application, dominance of consumer electronics in the early stage was replaced by information IC (69.1%) and communication IC (13.1%) recently (ITRI, 2000). The trend was from lower-level products such as electronic watches advancing to higher-level products such as chipsets. Besides expanding product types, the progressive technology advancement helped to maintain Taiwan's competitive advantage in speed and quality.

3.2. Entrepreneurship nourished in the Science Park

The Hsinchu Science Park, established in 1979 under consensus of the government and private sectors for developing high-tech industries, aroused much interest of public and private businesses and bank syndicates in technology ventures by providing favorable policy support such as subsidized land development, tax incentives and administrative assistance. At that time, research institutes were the main holders of IC technologies and spun-off companies seemed the most efficient way to diffuse technology into industry. In 1979, ITRI's design experience of over a dozen products such as telephone keypad ICs, calculator ICs and melody ICs was transferred to UMC, ventured by the Executive Yuan's Development Fund and Philips Company. UMC was the first IC company in the Hsinchu Science Park and it was able to break even in one year thanks to its strategy of penetrating the market with low-end consumer ICs.

UMC was established as the IDM model instead of a specialized IC design company. Taiwan's first private-sector chipless chip company was Syntek Design Co. formed in 1982 in Hsinchu Science Park under the support of ITRI's technology team and private-sector venture capital. Its semi-ASIC and other relevant technologies were transferred from the ERSO. In 1983, Holtek IC Company was also transferred the CMOS LOVAG technology by the ITRI (Liu, 1993). With the benefit of space and administrative support from the Science Park and technological backing by the research institutes, the private sector quickly revealed flourishing entrepreneurship. Eighteen IC designing companies had been in operation in 1986 and the great demand for EDA software tools attracted an American EDA company, Cadence, to set up its branch office in Hsinchu Science Park in the same year.

Being a brain-intensive industry with fierce competition and rapid growth, IC design sees the critical impact of the intellectual property (IP) related legal environment on the market discipline of fair competition and on the willingness of investment. Taiwan drew up its *Chip Protection Law* in 1989 and the Executive Yuan passed the *IC Layout Protection Law* in 1994. During the same period, many patent infringement cases were filed and the industry players learned to adopt patent strategies and acquired practical experience in handling IP issues. The companies started constructing a patent application system to encourage internal entrepreneurship. Under such a favorable competition environment, more design technology and capability had been accumulated that further enhanced competitiveness under the pressure of urgent market response.

The keen market sense and flexible organizational response that are inherent with Taiwan's small and medium enterprises (Lee and Pecht, 1997) allows IC designers to quickly grasp key technologies when they are confronted with ever changing market demand, diverse application trends and new technology specifications. With the addition of strong entrepreneur ambition, progressively comprehensive IP legislatures, governmental support in a R&D environment, and flourishing private venture capital business resulting from financial liberation during the latter part of the 1980s, technologies thus could be efficiently assimilated, diffused and implemented on industrial innovations. Technology teams equipped with innovation and R&D capabilities were able to quickly acquire financial and administrative support. Market opportunities therefore could be seized.

In the early 1990s, many overseas Taiwanese experts came back with years of valuable design experience and an acute sense about the overseas market which had been closely scrutinized. The new teams pushed the diversification of product lines. Etron (established in 1991) pushed the design of Taiwan's memory products and Via Tech (established in 1992) opened up a new wave of chipset design. These were examples established by homebound overseas Taiwanese experts, who brought back advanced technologies and communication channels with the Silicon Valley in the US. They integrated with local engineers raised in ITRI, ChiaoTung University and TsingHua University to form a web of knowledge assimilation and technology diffusion.

3.3. Establishment of vertical industrial disintegration

In 1987, the Taiwan Semiconductor Manufacturing Company (TSMC) was founded as the first professional wafer foundry ever established in the world. The foundry business is tightly linked with the IC design industry: the professional design industry creates a market demand for a wafer foundry, whose existence makes it possible for designers to drop the capital-guzzling manufacturing facility which in turn spurs a bigger design industry. Combined with the existing packaging industry and subsequently emerging photomask companies and silicon wafer companies, Taiwan's whole semiconductor industry forms a unique system of vertical disintegration, represented in Fig. 3.

Taiwan's local foundries could support over 90% of the production capacity that IC designers require and almost 100% of packaging and testing work can be completed locally. This gives the industry a definite advantage in terms of cost and delivery speed. As the industry grows and is in pursuit of economy of scale in its production capacity, the relationships between foundries and designers starts to change. IDMs begin to release their production capacity. For attracting the client designers, IDMs also begin to spin off their designing departments to avoid legal disputes on IP issues. On the other hand, in seeking a good link with foundries to ensure sufficient capacity and in response to foundries' requests for their expansion, the designers have started joint ventures in new foundry investment. An example is UMC that spun off its designing department according to the product lines into Media Tek (CD-ROM control chip), Novatek (consumer IC control chip), and professional design companies such as ITE, AMIC and Davicom. UMC together with designers also jointly established some Fabs, such as UICC, USC and USIC, that were merged to form a bigger professional foundry later in 1999.

In this sophisticated vertical disintegration system, the upstream and downstream players are each dedicated to specialized technologies in their own domain, with adequate responsive speed and without unwanted investment burdens. With such sophisticated links in business operation, more knowledge exchange and technology assimilation occurs. This trend further extends to the relationships with overseas players through mutual investment, licensing and alliances.

Besides growing together with foundries, packaging and testing industries, Taiwan's IC designers enjoy the booming of the local information technology industries. There are many top world PC manufacturers, network hardware manufacturers and experienced consumer electronics manufacturers in Taiwan. IC designers have close relationships with these downstream customers and could gain immediate access to relevant professional information on the requirements for system configuration, production and application. These relationships are also advantageous for partially lowering the cost of transportation, sales and administration. All these factors contribute to the competitiveness of designers in

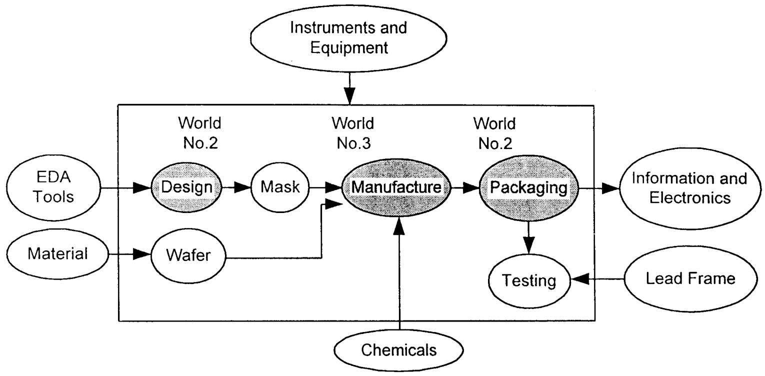

Fig. 3. Vertical disintegration of Taiwan's semiconductor industry.

Table 4
1999 top 10 design houses in Taiwan[a]

Rank	Company	Revenue (million NT$)	Major product type
1	VIA	11,245	Chipset
2	SIS	10,840	Chipset
3	Media Tek	5600	Consumer
4	Sunplus	4171	Consumer
5	Acer Lab.	4006	Chipset
6	Holtek	3600	Memory
7	ICSI	3530	Memory
8	Realtek	3196	Network
9	Novatek	2692	Consumer
10	Elan	2556	Consumer

[a] Source: Industrial Technology Research Institute, Taiwan.

response to customers' needs. With massive support from Taiwan's IT industry, the top three PC chipset providers (Via Tech, SIS and Acer Lab.) have over 50% of the global market share, which is quite impressive even though each could hardly compete individually with a world giant like Intel. Table 4 lists the top 10 design houses and shows their major products falling into IT-related categories such as the above-mentioned PC-chipset, memory, network, and consumer electronics. Table 5 shows that local customers account for over 60% of their total revenue (ITRI, 2000).

3.4. Industrial clusters formed from Hsinchu Science Park and ITRI, ChiaoTung University, TsingHua University

As most Taiwanese semiconductor companies are located around Hsinchu Science Park (see Table 6), it is not only quick for upstream and downstream players to exchange technological information between each other, but it is also easy for horizontal players to share knowledge both competitively and cooperatively. Hsinchu Science Park is adjacent to research institutes such as ITRI, ChiaoTung University and TsingHua University, thus the industry was able to obtain more expandability and great vision during the knowledge exchange. The

Table 6
Geographical distribution of semiconductor firms in Taiwan[a]

	IC design	IC manufacturing	IC package
North Taiwan	34	1	7
Hsinchu	**65**	**20**	**21**
South Taiwan	1	0	14
Total	100	21	42

[a] Note: the number of IC design houses does not include foreign-investment firms. Source: Industrial Technology Research Institute, Taiwan.

Table 5
Market areas for Taiwan's IC design industry[a]

	Taiwan (%)	Hong Kong/China (%)	North America (%)	Japan (%)	Europe (%)	Korea (%)	Southeast Asia (%)	Others (%)
1996	**63.9**	17.2	12.0	0.9	1.8	–	1.3	2.9
1997	**51.9**	29.5	10.6	0.9	1.4	–	4.8	0.9
1998	**57.1**	17.6	14.9	0.8	–	1.5	5.2	3.3
1999	**62.3**	21.7	7.7	3.0	–	2.5	1.8	0.9

[a] Source: Industrial Technology Research Institute, Taiwan.

universities in this area not only supply plenty of technology manpower (to be described in detail in the next section), but also serve as bridges for the firms to acquire advanced fundamental knowledge from abroad. The Electronics Engineering Institute and Semiconductor Lab. (which later grew into the National Device Lab.) of ChiaoTung University played important roles in the early introduction of semiconductor theory and knowledge.

There are some alliances formed by the firms and institutions to foster technological interaction and industrial evolving dynamics (Weiss and Mathews, 1994). As an example, the "Common Design Center" was formed in March 1985 by ITRI for co-developing technology with industrial players (Saghafi and Davidson, 1989). Its establishment was based on the demand to speed up IC design technology transfer, to compress commercialization development time, and to facilitate circuit design by mature software. The purpose is to train the industrial players in using computer tools to develop ASIC technologies and to accelerate relevant knowledge diffusion. Through providing design software, publishing design manuals, holding training courses, and issuing ASIC newsletters, the center promotes the industrial players' capabilities in developing their own IC products. Low-end consumer-oriented ICs have dropped from 52% of the total Taiwan designers' sales in 1984 to 30% in 1986, while both communication ICs and information ICs saw significant growth. The new data also show an upgrading trend in Table 3 (ITRI, 2000).

For Taiwan's IC design industry, a successful IT industry provides abundant downstream market capacity while the vertical disintegration system protects its upstream production edge. In terms of chip production, it enjoys the advantage of easy access to a foundry's capacity, delivery time and cost. It also provides adequate foundry process technology for meeting diversified design requirements. The horizontal players' competition and cooperation further promote innovation, flexibility and swiftness in knowledge utilization.

3.5. Diligent and inexpensive technology human resources

Human resources is the most crucial competing factor for the IP-oriented IC design industry. Taiwan has been able to form a pool of high-quality technology manpower due to educational policy, social value systems, public training systems, and the return of overseas experts (Arensman et al., 1991). The unique profit sharing system popular in the industry also spurs IC design engineers to maintain their high performance while minimizing manpower loss. This accelerates the extension of experience and know-how that ensures a competitive edge in the capability of knowledge assimilation and utilization (Argote, 1999).

Taiwan has constantly strengthened its educational and training systems in response to ever-growing industrial demand for advanced-level technology talents. In July 1983, the National Science Commission (NSC) teamed up with the Ministry of Education, ITRI, and nine universities to implement the *Multi-Project Chip* (MPC) program. In this program, ITRI supplies each university with a basic logic circuit component database and EDA tools, besides training the participating schools' faculty and students in the application of EDA and IC design technology. The output of each school is then sent to ITRI for photomask construction and wafer fabrication. This program integrates academic theory with application resources from the industry and research institutes to provide a training channel that covers both theory and practical know-how. Between 150 and 200 IC design personnel go into the industry through this program, which contributes to the manpower pool with the potential of boosting the transfer and assimilation of new technology.

In response to the manpower demand that comes along with the industrial growth and development of new-generation sub-micron IC technology, in 1993 the NSC built the "Chip Implementation Center (CIC)" subsequent to the MPC program. The CIC is assumed to support the demand for EDA tool usage and to serve the academic field and industry with prototyping and testing IC designs. It is of great value to the construction of the automatic design environment and to the development of personnel with practical design experience. About 700 faculty members of over 70 universities/colleges have used the CIC design software environment since its establishment. The MPC method has been employed to assist the academic field to accomplish over 1700 pieces of prototyping (not including the 300 pieces from the industry and research institutes). Over 2000 personnel have been trained in practical experience (CIC, 2000).

The industrial players have also been heavily engaged in manpower development. The whole IC design industry maintains R&D expenditure at a high level of 9~12% (much higher than that of foundries) of total revenue. The percentage of total R&D personnel has risen from one-third in the early stages to over a half in recent years. The average design experience has also increased from 4 years to about 7 years. A major consumer electronics IC player, Sunplus, adopted the strategy of hiring experienced design engineers with solid theoretical training to give up the "copy and duplicate" manner of technology following and to raise its competitive hurdle.

The general salary level for design engineers in Taiwan is low compared to other advanced countries. Keeping the manpower cost down is a big plus to Taiwan design players' competence. Generally speaking, Taiwan's cost advantage over the US comes from lower overheads and its advantage over Japan comes from lower production costs of OEM.

The unique profit sharing system in Taiwan's IC industry is different from stock options popular in Western countries. The flexible calculation formula of stock sharing takes into account the employees' performance, experience and position. It gives more incentives to high-quality but inexpensive engineering manpower, boosting their morale and encouraging their ambition for different missions. Taiwanese designers possess characteristics such as: flexibility in response to customers' requirements for consumer products, patience, which is required for the integration of multiple peripheral components in chipset products, and diligence, which is required in learning new specifications and technologies for high-end products. Together these characteristics form the capability of knowledge assimilation and utilization in adapting to a changing market.

4. Concluding remarks

IC design is the driving force for the future development of the semiconductor industry. Being a brain-intensive industry, it has a smaller economic scale and requires less investment than the IC manufacturing industries. Working more closely with the IC users than the foundry, it thus requires the capability of responding to market trends.

Taiwan's IC design industry began in 1973 when it first introduced the semiconductor technology, and it hit the growth stage in 1990. Its flourishing has benefited from some critical developments: policy-oriented projects for introducing RCAs and sub-micron technology to build up basic knowledge; Common Design Center architecture for setting up a knowledge sharing mechanism between the industrial sector and research units; a MPC program and establishment of CIC for manpower training; foundry establishment that combines the existing design, packaging and testing industries into a vertical disintegration system, together with flourishing IT industries that give a better edge in terms of production cost and market flexibility; and Hsinchu Science Park's support and attraction for semiconductor ventures that help to form an effective cooperation network.

All these findings show that a technology follower, before being able to fully catch up with technology leaders in fundamental scientific research, can still establish its core competence through appropriate industrial development strategies, enabling it to find out its global niche position. Taiwan did not attempt to develop its own advanced technology from fundamental research. Instead, it levers its limited resources to focusing on becoming a superior rapid follower by assimilating leaders' technologies. In the hope of standing on top of the giant's shoulder to maintain the advantage of speed, quality, cost and flexibility in the application of existing technology, Taiwan has found its own competing position and a growing space for its industry.

It should be noted that there are other factors contributing to the growth of Taiwan's IC design industry. For example, foreign capital and imported technologies are the critical two, significant especially from the viewpoint of the development stage. In the early days, government policy had great influence on the industry. Then the importance of firms' linkage to foreign business gradually appeared. Many American and Japanese companies played the role of both product buyers and technology providers. Later on, the business alliances enabled Taiwan's IC design firms to become deeply established in the global market and thus they enjoyed good growth.

However, it is not beyond the realms of possibility that Taiwan's strategies will still work in the future. It is a great challenge for Taiwan to maintain the advantages of being a quick follower. Taiwan's IC design players have to assure lower costs than those of advanced countries and at the same time they must design faster than the latecomers of Southeast Asia. The success of this hard task relies on timely upgrading of their design capabilities and relevant technologies. There are deficiencies in Taiwan's supporting factors for the design industry to meet these future challenges. The government's supportive policy is somewhat short-term oriented. The human resources do not seem adequate for continued growth. Uncovering the ambitious investment energy of the entrepreneurs, there is a lack of technological innovation and market creativeness. In the industrial disintegration system, weakness exists at the system manufacturers of communication and non-PC information products.

Explicitly speaking, Taiwan needs to strengthen its design-related technology, especially in the analog field and the wireless communication systems. For supporting the industrial growth and technological upgrading, more skilled designers are required. Designers possessing practical know-how are critical to the core competence of speed and quality, meanwhile engineers with abundant system-level knowledge are urgently needed to foster development in the sub-industries like networks, communications, and multimedia systems, which relates to the industrial structure supporting competitiveness of cost and flexibility. The government's resources have to be reallocated using more foresighted policies on R&D sponsorship and expanding training systems.

Entering the 21st century, the global semiconductor industry will open up the third industrial revolution under the driving force of 3C application and SOC technology. The last 5 years have seen the impact of the budding SOC technology. Besides the existing four types of IC design players, new business models are evolving out of the old professional designers: silicon IP providers, design foundries, design service providers and system design integrators. Taiwan formed a 3C integration planning team from the NSC and NIIA (National Information Infrastructure Enterprise Promotion

Association) in May 1997. All governmental, industrial and academic segments have coordinated trying to promote the establishment of R&D teams to form business units for implementing 3C integration programs. The actions include: promoting global cooperation, encouraging large-scale SOC R&D projects, building SIP design technology, creating mechanisms for integrating system firms, designers and manufacturers, constructing the infrastructure for SOC design, and building common SIP component bases and design standards information management (NIIA, 1999). These show the attempt to maintain core competence to ensure effectiveness of the close-follower strategy through R&D in next-generation design technologies, development of human resources, establishment of ventured businesses and industrial infrastructure construction. Taiwan's IC designers still have to try very hard to prove their capability in maintaining their edge of the competition strategy to hold onto their niche position.

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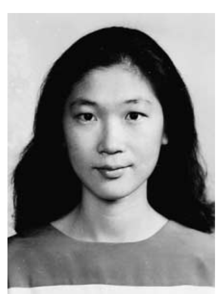

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