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Positioning and shifting of technology focus for integrated device manufacturers by patent perspectives

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ABSTRACT

The relationship between integrated device manufacturers (IDMs) and contract chip makers (foundries) in the semiconductor industry has changed over the past three decades. An increasing number of IDM companies have diversified or branched off as foundry companies, whether officially or privately. This paper explores the technology focus of IDM companies and the shifting of that focus by examining the shifts in focus of productivity, quality, and integrated measurement of selected IDM companies between 1981 and 2010 by patent perspective. The results of this research reveal that AMD, one of the more notable companies to have established a pure foundry company from an IDM company, is located in the foundry-oriented area. Additionally it shows that, although Micron and TI have not officially announced their intentions to diversify or branch off as foundry companies, the two are located in the foundry-oriented area as a means of showing their competitive positions with regard to joining the foundry business.

1. Introduction

The semiconductor industry has been one of the most important industries over the past three decades. Due to the wide use of semiconductors in telecommunications, computers, and consumer electronics, the semiconductor industry has all but become a core upstream element in every part of electronics industries. Much research regarding the semiconductor industry has been conducted. Appleyard [1] examined inter-firm information flows in the knowledge-intensive semiconductor industry. Appleyard and Kalsow [2] built a framework for the degree of similarity in organizations' technical prowess. Chang and Tsai [3] studied strategies adopted by Taiwan's semiconductor industry at different stages in its technology development, specifically focusing on the research consortium strategy and industry consortia. The knowledge-based view applied to firm boundary decisions and the implications of the performance of those decisions have also been examined [4]. In general, there are three major characters in the semiconductor value chain: Design Houses, which only design and sell devices (such as Qualcomm, Broadcom, and Nvidia); Foundries, which manufacture devices under contract with other companies and do not design them (such as TSMC, UMC, and GlobalFoundry); and IDMs, which engage in manufacturing and selling integrators as well as designing devices (such as Intel, Samsung, and IBM), as shown in Fig. 1. Generally speaking, IDMs play an integrational role—designing, manufacturing, and selling—in the semiconductor industry and Foundries provide IDM and Design Houses with manufacturing capacity. In the early stages of the development history of the semiconductor industry, IDMs dominated the entirety of the industry's development of technological capability and manufacturing capacity. Due to IDMs' integrational role in the semiconductor value chain, they can diversify or shift their character in the semiconductor value chain toward either Foundries or Design Houses. In short, IDMs may, to some extent, be competitors of Design Houses or Foundries. In fact, over the past decade, an increasing number of IDM companies

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have claimed positions in the foundry business or taken the “Fab-Lite” strategy to ease financial burdens. Compared with IDMs, Foundries and Design Houses have retained their current roles in the semiconductor value chain. There are many reasons for IDM companies to shift their technology focus, such as financial problems, manufacturing capacity, and geographical clusters. With regard to development trends in the semiconductor industry, Ernst [5] discussed the growing geographic mobility of chip design and its dispersion in Asia. He argued that, to cope with such demanding requirements, firms must have a strong incentive to concentrate on innovation in their home countries. For capacity planning, many IDM companies or Design Houses commonly suffer from foundry capacity shortages when the industry is prosperous. A method that accepts this uncertainty of demand and uses stochastic integer programming to find a tool set responsive to shifts in demand was presented by Hood et al. [6], who considered a set of possible discrete demand scenarios with associated probabilities, determined the tools to be purchased, and minimized the weighted average unmet demand under a budget constraint. The semiconductor industry is highly capital-intensive, so it would be natural to apply the strategic alliance approach to the technology development. To provide value-added directions and information to semiconductor companies that want to select partners for R&D cooperation among different characters and technology fields, character shifting is one of the most important factors to consider. Character shifting may also attract researchers to explore semiconductor technology shifts within roles. Most research into the shifting of or relationship among these roles has focused on economics [7], manufacturing capacity [8], and strategy management [9]. Regarding technology position, Debackere et al. [10] explored regional technological capabilities, linked technological position to economic growth, and found a competitive advantage in European patent data. Research into corporate technology strategy that secures competitive positions by patent analysis was also discussed in this research [11]. Patent data are a valuable source of information for technological development. Because they contain standardized data relating to new ideas and technological developments and are available to all, patents have been treated as the most important output indicators of innovative activities [12] and patent data have become the focus of many tools and techniques used to measure innovation [13–15]. Patent analysis is widely applied to the exploration of competitive advantages among companies or industries. Henderson and Cockburn [16] attempted to measure heterogeneous organizational competence using patent data in pharmaceutical research. Fleming and Sorenson [17] demonstrated that technology should be considered a complex adaptive system based on patent data. Several researchers, such as DeCarolis and Deeds [18] and Gittelman and Kogut [19], conducted empirical studies using patent and financial data from biotechnology firms. Long [20] regarded patents as a signaling mechanism by which technology firms can credibly publicize information. Daim et al. [21] explored forecasts in three emerging technology areas by integrating the use of bibliometrics and patent analysis into well-known technology forecasting tools such as scenario planning, growth curves, and analogies. The aforementioned literature measured innovation activities or explored the technology development in various industries. However, little research focuses on the detection of position and the position shifting of technology focus in a specific industry. In addition to previous applications, we applied the framework to detect messages delivered by selected IDM companies concerning the shifting of technology focus. Much research has explored companies' technology positions as a means of monitoring and understanding their technological strength. This information will usually be provided to the decision makers of a company as a means of internally managing their technology. On the other hand, company stakeholders, such as shareholders and analysts, have an increasing interest in assessing a company's technological competence because of its strong impact on a company's future competitiveness [22,23]. Position and the shifting of technology focus of specific companies or industries are important strategic information for decision makers of companies, and could be used to detect their relative technology levels in the industry. In addition to industry practitioners, industry researchers could also apply the information as a means of grasping the technology evolution in specific industries. This study aims to provide decision makers of companies with the overall position of technology focus for specific IDMs. By using the position map created from this study, decision makers can detect their relative technology levels within the industry. This study also aims to explore the shifting of technology focus for specific IDMs. The decision makers of companies or industry researchers could apply the shifting map created in this study to detect the character evolution for specific companies or industries while still in the early stages.

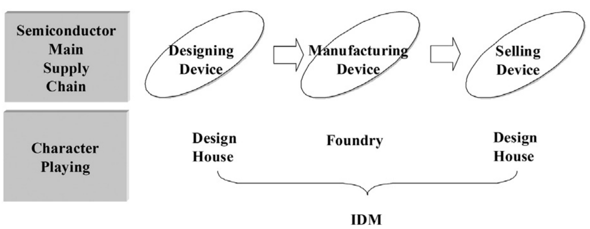

Fig. 1. Major value chain of a semiconductor industry.

The positioning and position shifting of technology focus help monitor the overall competitiveness or cooperation possibilities for decision makers of R&D or management teams in the IDMs. Moreover, decision makers could apply the information gleaned to monitor the shifting of targeted companies or industry while still in the early stage. Hence, we apply a patent analysis for the detection of positions and position shifting of technology focus for IDM companies.

The paper is organized as follows. Section 2 presents research data and methods. Section 3 describes the research results. Section 4 presents our conclusion and considerations for future research.

2. Data and methods

2.1. Selecting IDM companies

Because the semiconductor industry is a cross-field industry, we searched related patents of other technology fields and queried the patent data. Because business diversification has become increasingly popular in the industry, we also defined the role of the semiconductor industry for each company, IDM or foundry, according to professional industrial institutes, such as IC Insights or Gartner [24,25]. If a company was classified as an IDM by a professional industrial institute, we defined it as an IDM, even if it was also a part-time foundry company. For example, Samsung has diversified its business from IDM to foundry, but we classified it as an IDM based on our reference to IC insights. We queried the overall IDM companies to explore their technology focuses over the past three decades (1981–2010) from the United States Patent and Trademark Office (USPTO) database. The USPTO is an agency within the United States Department of Commerce that issues patents to inventors and businesses for their inventions and provides trademark registration for product and intellectual property identification purposes.

Since there is a high concentration ratio of patent count in the semiconductor industry, we selected the major IDM companies that accounted for 66% of the total patent count; 33 other IDM companies accounted for the remaining 34% in the total USPTO patent count, as shown in Table 1. Since the other 34% of the total patent count was distributed across another 33 IDM companies, we selected the main 11 companies as the focus for this study.

2.2. Data source

We classified the patents involving the semiconductor field according to how they were sorted by the National Bureau of Economic Research (NBER) [26]. NBER identifies 12 technology fields in the semiconductor industry. The NBER has specific definitions for category, subcategory, and US patent classes, as shown in Table 2. We selected eight major technology fields (subcategories), which accounted for nearly 80% of the total number of semiconductor patents, including electronics communication, computer software and hardware, digital information storage, semiconductor making or forming, semiconductor manufacturing, semiconductor package, active solid-state devices, and chemistry, as shown in Table 2. A total of 75 US patent classes are distributed among these eight major technology fields. For example, electronics communication is composed of US patent classes 178 (telegraphy) and 333 (wave transmission lines and networks), as shown in Table 2. All 75 patent classes are used in this paper. To focus on the business view of the assignees of patents, we excluded non-profit organizations such as universities and research centers, as well as related front-end and back-end suppliers such as tool vendors and testing or assembly houses. In short, we only focused on corporate assignees. Then, we targeted the patents in the semiconductor industry, including IDMs and Foundries, from the major technology fields; these accounted for a total of 109,773 patent counts granted by the USPTO, as shown in Table 1. Since most Design Houses (such as Qualcomm, Broadcom, and Nvidia) possessed patents mainly for electronics communication, computer software and hardware, and digital information storage, we classified these patents of technology fields as "wafer-design application patents." Because most foundry companies possessed patents mainly for semiconductor making or forming, semiconductor manufacturing, semiconductor packaging, active solid-state devices, and chemistry, we classified these patents as "wafer-process patents" to reflect their industry properties, as is shown in Table 2. To provide a base for comparison, we also explored the technology focus positions for overall foundry companies and the shifting of that focus as it averagely aligned with relative research methods.

There are several basic patent data applied in this research to detect the positions of targeted IDM companies. All patent data were retrieved from USPTO records created from 1981 to 2010. The total number of patents in wafer-design application and wafer-process portray the amount of technology production. The number of wafer-design application patents and wafer-process patents was evaluated for the different technology fields of each selected IDM company. Their shares were used to measure the preferences or specialties for the selected IDM companies and the overall IDM and foundry industries. Their total citation counts were used to measure the overall citation impact of relative patents. Their average patent citations were defined as the ratio of total citation count and total patent counts on wafer-design application technology and wafer-process technology, respectively.

Table 1
Selected IDM companies (1981–2010).

Company	Abbreviation	Number of total patents	Share (%)
International Business Machines Corporation	IBM	15,410	15%
Hitachi, Ltd.	Hitachi	6819	7%
Micron Technology, Inc.	Micron	6550	6%
Toshiba Corporation	Toshiba	5844	6%
NEC Electronics Corporation	NEC	5818	6%
Samsung Electronics Co., Ltd.	Samsung	5604	5%
Intel Corporation	Intel	5244	5%
Fujitsu Limited	Fujitsu	5106	5%
Mitsubishi Corporation	Mitsubishi	4571	4%
Advanced Micro Devices, Inc.	AMD	4031	4%
Texas Instruments Inc.	TI	3761	4%
Selected 11 IDM companies		68,758	66%
Other IDM companies (33 companies)		35,919	34%
Total IDM companies		104,677	100%
Foundry industry		5096	
Total – IDM and foundry		109,773	

Sorted by share of selected 11 IDM companies.

2.3. Two-dimensional methods for position detection

It was our aim to explore positioning and shifting for the selected IDM companies from the perspective of technology focus. The productivity of technology focus means the performance of resources invested in specific technologies for each company or industry. The quality of technology focus means the recognition of the performance of resources invested in specific technologies for each company or industry. We designed combination charts with productivity (PTd) and quality (QTd) of technology focuses on wafer-design application patents as the X-axis and Y-axis to simultaneously express the productivity and quality of technology focus for the selected IDM companies. Similarly, we designed combination charts with productivity (PTp) and quality (QTp) of technology focuses on wafer-process patents as the X-axis and Y-axis. The two indices used to explore

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Table 2
Major technology fields for the semiconductor industry.

Classifications	Major technology fields (subcategory name)	US patent classes (main)
Wafer-design application	Electronics communication	Total 12 patent classes: 178 (Telegraphy), 333 (wave transmission lines and networks), 340, etc.
	Computer software and hardwareTotal	Total 17 patent classes: 341 (coded data generation or conversion), 380, 382, etc.
	Semiconductor devices—digital information storage	Total 4 patent classes: 360 (dynamic magnetic information storage or retrieval), 365, etc.
Wafer-process	Semiconductor making or forming	Total 1 patent class: 505 (superconductor technology: apparatus, material, process)
	Semiconductor devices—semiconductor manufacturing	Total 1 patent class: 438 (semiconductor device manufacturing: process)
	Semiconductor package	Total 1 patent class: 53 (package making)
	Semiconductor devices—active solid-state devices	Total 1 patent class: 257 (active solid-state devices, e.g., transistors, solid-state diodes)
	Chemistry	Total 38 patent class: 23 (chemistry: physical processes), 34, etc.

the position of each IDM company's technology focus are as follows:

(1) Productivity:
The productivity of technology focuses on wafer-design application for company *i* (PTd)

$$\mathrm{PT_d} = \frac{S_{d(i)} - S_{d(Min)}}{S_{d(Max)} - S_{d(Min)}} \tag{1}$$

where $S_{d(i)}$ denotes the share of wafer-design application patents for company i and $S_{d(Min)}$ and $S_{d(Max)}$ denote the minimum and maximum shares, respectively, of wafer-design application patents among selected companies.
The productivity of technology focuses on wafer-process for company *i* (PTp)

$$\mathrm{PT_p} = \frac{S_{p(i)} - S_{p(Min)}}{S_{p(Max)} - S_{p(Min)}} \tag{2}$$

where $S_{p(i)}$ denotes the share of wafer-process patents for company *i* and $S_{p(Min)}$ and $S_{p(Max)}$ denote the minimum and maximum shares, respectively, of wafer-process patents among selected companies.

(2) Quality:
The quality of technology focuses on wafer-design application for company *i* (QTd)

$$\mathrm{QT_d} = \frac{AC_{d(i)} - AC_{d(Min)}}{AC_{d(Max)} - AC_{d(Min)}} \tag{3}$$

where $AC_{d(i)}$ denotes the average patent citation of wafer-design application patents for company *i* and $AC_{d(Min)}$ and $AC_{d(Max)}$ denote the minimum and maximum average patent citations of wafer-design application patents among selected companies, respectively.
The quality of technology focus on wafer-process for company *i* (QTp)

$$\mathrm{QT_p} = \frac{AC_{p(i)} - AC_{p(Min)}}{AC_{p(Max)} - AC_{p(Min)}} \tag{4}$$

where $AC_{p(i)}$ denotes the average patent citation of wafer-process patents for company *i* and $AC_{p(Min)}$ and $AC_{p(Max)}$ denote the minimum and maximum average patent citations of wafer-process patents among selected companies, respectively.

2.4. Integrated measurement for wafer-design application and wafer-process technologies

We designed an integrated index, the length from the origin (a reference point corresponding to the two index scores) of wafer-design application patents (Ld) and wafer-process patents (Lp) to obtain an integrated measurement of wafer-design application technologies, the productivity and quality of technology focuses on wafer-design application (PTd/QTd) and wafer-process (PTp/QTp) for the selected IDM companies. The value of Ld or Lp will be between 0 (both PTd and QTd or PTp and QTp are equal to 0) and 1.4 (both PTd and PTd or QTp and QTp are equal to 1).

In summary, the equations are as follows:

Integrated measurement of wafer-design application technologies (Ld)

$$\mathrm{L_{d(i)}} = \left[PT_{d(i)}{}^2 + QT_{d(i)}{}^2 \right]^{\frac{1}{2}} \tag{5}$$

where *PTd*(*i*) and *QTd*(*i*) denote the productivity and quality of technology focuses on wafer-design application for company *i*, respectively.
Integrated measurement of wafer-process technologies (Lp)

$$\mathrm{L_{p(i)}} = \left[PT_{p(i)}{}^2 + QT_{p(i)}{}^2 \right]^{\frac{1}{2}} \tag{6}$$

where PTp(*i*) and QTp(*i*) denote the productivity and quality of technology focuses on wafer-process for company *i*, respectively.

3. Results

3.1. Technology focus of IDMs and Foundries

From these results, it is clear that during the targeted period (1981–2010) the technology focus of IDMs was in wafer-design application technologies (share of wafer-design application patents = 77%). However, the technology focus of Foundries was on wafer-process technologies (share of wafer-process patents = 74%). These results are shown in Fig. 2. We identified the development trend of wafer-process patents and design application patents for major IDM companies based on these results. Thus, the technology focuses of IDMs and Foundries were wafer-design application and wafer-process, respectively. With regard to the technology focus development trend, the share of wafer-design application technologies for IDM and foundry companies has increased during the past three decades, as shown in Fig. 2.

Of the selected IDM companies, IBM dominated the number of total patents and Hitachi ranked second among the total, as shown in Table 3. Most of the technology focuses of the selected IDM companies were share of wafer-process patents, as the IDM industry shows, but some companies, such as AMD (share of wafer-process patents = 46%), Micron (share of wafer-process patents = 44%), and TI (share of wafer-process patents = 32%), put relatively more resources into the development of wafer-process patents than other IDM companies (IDM industry share of wafer-process patents = 23%), as is shown in Table 3. Micron (total citation counts of wafer-process patents = 5105), IBM (total citation counts of wafer-process patents = 4494), and AMD (total citation counts of wafer-process patents = 4039) showed higher total citation counts for wafer-process patents, as shown in Table 3. As to the indices of average patent citation, AMD, TI, and Mitsubishi are the top three companies in average patent citation of wafer-design application. AMD, TI and Intel, meanwhile, are the top three companies in average patent citation of wafer-process, as shown in Table 3.

3.2. Trend of technology focus for IDMs

3.2.1. The productivity and quality of technology focuses on wafer-design application (PTd and QTd)

The two indices, productivity and quality of technology focuses on wafer-design application (PTd and QTd), are shown in Table 4. We divided the selected IDM companies into two groups, one of companies for which PTd and QTd are above the IDM average (PTd = 0.75 and QTd = 0.39, 1981–2010), and the other of companies for which PTd and QTd are below IDM average, as shown in Table 4. The PTd of the top three companies above the PTd of IDM average (Intel, Fujitsu, and IBM) is shown in Table 4. This result implies that these IDM companies have significantly higher PTd in comparison to

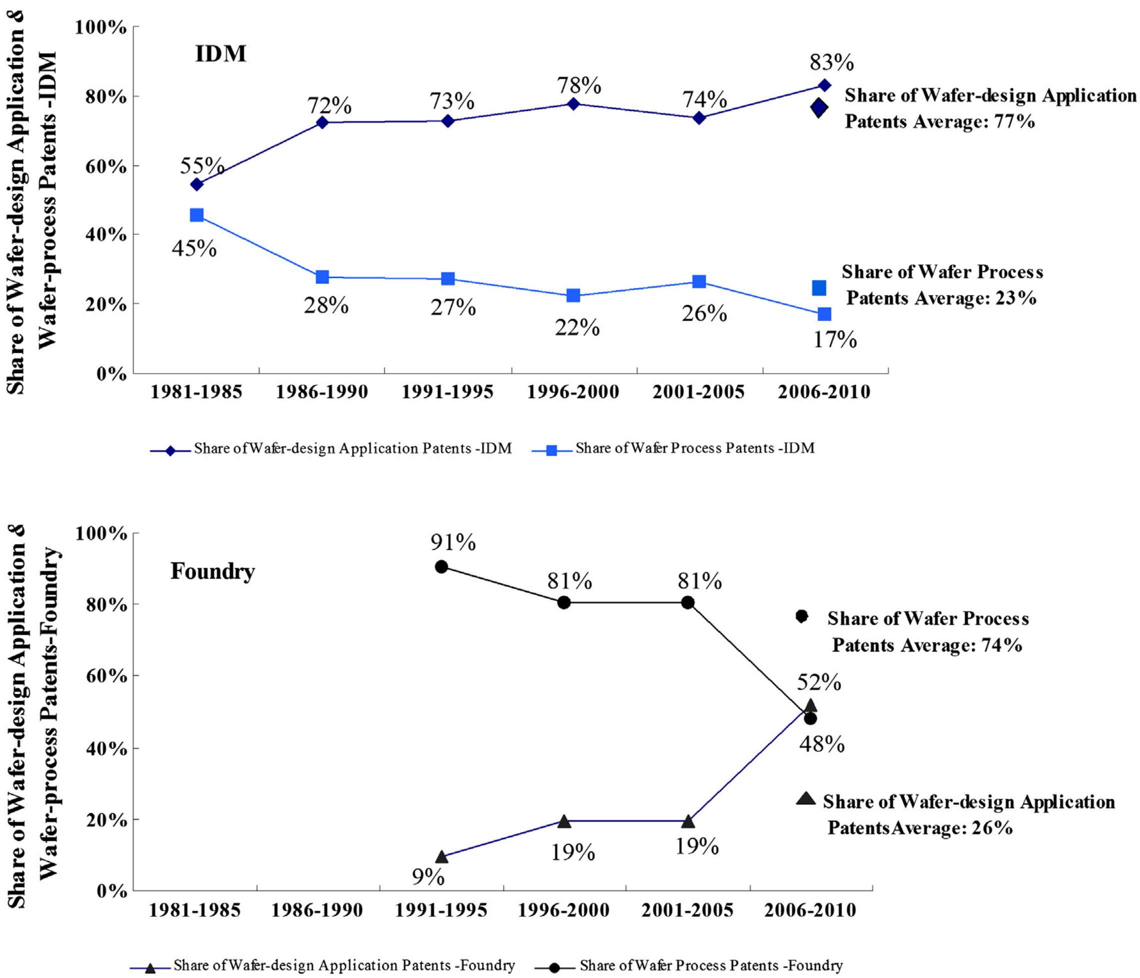

Fig. 2. Development trend for IDMs and Foundries by shares of wafer-process patents and wafer-design application patents, 1981–2010.

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Table 3
Summary of patent scorecards for the selected IDM companies, IDM industry, and foundry industry, 1981–2010.

Industry/company	Number of total patents	Number of wafer-design application patents (%)	Number of wafer-process patents(%)	Total citation counts of wafer-design application patents	Total citation counts of wafer-process patents	Average patent citation of wafer-design application patents	Average patent citation of wafer-process patents
IBM	15,410	12,938 (84%)	2472 (16%)	21,715	4494	1.68	1.82
Hitachi	6819	5596 (82%)	1223 (18%)	9587	2127	1.71	1.74
Micron	6550	3636 (56%)	2914 (44%)	6099	5105	1.68	1.75
Toshiba	5844	4701 (80%)	1143 (20%)	8678	2232	1.85	1.95
NEC	5818	4657 (80%)	1161 (20%)	7994	2263	1.72	1.95
Samsung	5604	3950 (70%)	1654 (30%)	6280	2899	1.59	1.75
Intel	5244	4519 (86%)	725 (14%)	8232	1439	1.82	1.98
Fujitsu	5106	4376 (86%)	730 (14%)	7324	1278	1.67	1.75
Mitsubishi	4571	3310 (72%)	1261 (28%)	6346	1919	1.92	1.52
AMD	4031	2191 (54%)	1840 (46%)	4532	4039	2.07	2.20
TI	3761	2574 (68%)	1187 (32%)	4978	2502	1.93	2.11
Selected 11 IDM companies	68,758	52,448 (76%)	16,310 (24%)	91,765	30,297	1.75	1.86
IDM industry	104,677	80,195 (77%)	24,482 (23%)	137,192	44,336	1.71	1.81
Foundry industry	5096	1348 (26%)	3748 (74%)	3897	8549	2.89	2.28
Total — IDM and foundry	109,773	81,543 (74%)	28,230 (26%)	141,089	52,885	1.73	1.87

In a descending order according to the total number of patents (1981–2010) for IDM companies.

other IDM companies. That is, Intel, Fujitsu, and IBM put greater focus on the development of wafer-design application technologies over past three decades than other companies. Meanwhile, AMD, Micron, and TI are the three bottom companies below the PTd of IDM average. These selected IDM companies put fewer resources into the development of wafer-design application technologies. In addition to PTd, the index QTd is an objective index revealing the quality of patent performance. Regarding QTd, Micron, AMD, and Intel are the top three companies with higher QTd than the IDM average, 0.39, as shown in Table 4. This finding implies that the QTd of these companies is better than that of the other IDM companies with regard to wafer-design application patents. NEC, Fujitsu, and Samsung are the three bottom companies below QTd of IDM average, as shown in Table 4.

The PTd and QTd for major IDM companies and all IDM companies were also tested by Z-test with a 95% confidence interval. This determined whether the ratios between major IDM companies and all IDM companies were statistically different.

The two-dimensional method was applied to detect the position and development trends for wafer-design application technology. The position of the selected IDM companies in wafer-design application technologies is classified by IDM's PTd (0.75) and QTd (0.40), as shown in Fig. 3. Intel, IBM, and Toshiba performed significantly well in both PTd and QTd. These three companies retained competences in wafer-design application technologies. On the other end, Samsung performed relatively poorly in both PTd and QTd. It is clear that Samsung put fewer resources into wafer-design application technologies. Meanwhile, Micron, AMD, and TI are three companies located in the upper-left area (foundry-oriented area), as shown in Fig. 3.

To distinguish between them more easily, we divided the selected IDMs into three groups to explore their development trends in PTd and QTd. The three groups are above (Intel), closed (NEC), and below (AMD) PTd of IDM average, respectively, as shown in Fig. 4. Generally speaking, the development trend of technology focus on wafer-design application technologies for IDM has moved to the upper-right area, meaning high PTd and QTd. This implies that most IDM companies put more resources into wafer-design application technologies that had high quality. However, compared to the prosperous development trend of PTd, the QTd has been in recession since 2000. For the selected IDM companies for which PTd was above IDM average, Intel has the most significant performance in both PTd and QTd, as shown in Fig. 4. For the selected IDM companies for which PTd is below IDM average, AMD has a relatively stronger performance in QTd, as shown in Fig. 4.

3.2.2. The productivity and quality of technology focus on wafer process technology (PTp/QTp)

After assessing PTd and QTd, we evaluated another technology focus – wafer-process technologies – by PTp and QTp for the selected IDM companies. These two indices are shown in Table 5. We divided the selected IDM companies into two groups: one of companies for which PTp and QTp were

Table 4
Summary of the productivity (PTd) and quality (QTd) of technology focuses on wafer-design application of IDM and IDM companies, 1981–2010.

Company/industry (PTd, QTd)	1981–2010	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2010
Intel	(.90, .60)	(.54, .06)	(.52, .24)	(.73, .63)	(.97, .00)	(.86, .62)	(.93, .37)
Fujitsu	(.89, .29)	(.38, .05)	(.75, .29)	(.76, .33)	(.91, .34)	(.92, .34)	(.99, .15)
IBM	(.86, .44)	(.44, .07)	(.77, .31)	(.84, .35)	(.89, .67)	(.85, .45)	(.93, .30)
TI	(.62, .43)	(.52, .05)	(.52, .41)	(.44, .47)	(.66, .61)	(.63, .46)	(.74, .25)
Micron	(.41, .82)			(.00, .45)	(.39, .83)	(.38, .85)	(.54, .78)
AMD	(.39, .66)	(.33, .00)	(.37, .17)	(.57, .55)	(.52, .81)	(.30, .67)	(.51, .46)
IDM average	(.75, .39)	(.40, .04)	(.68, .27)	(.69, .33)	(.76, .54)	(.70, .43)	(.85, .28)
Foundry average	(.19, .52)			(.00, .22)	(.12, .59)	(.12, .55)	(.52, .47)

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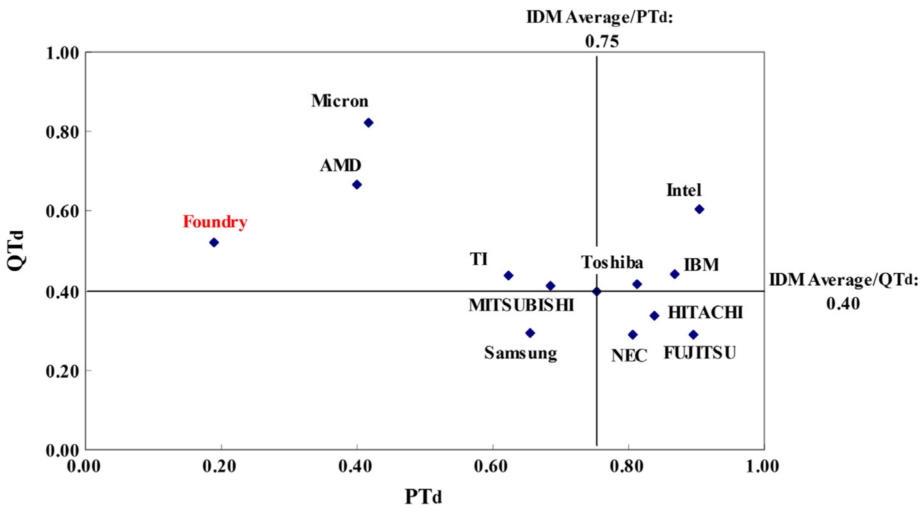

Fig. 3. Position of the productivity (PTd) and quality (QTd) of technology focuses on wafer-design application for IDM companies and foundry, 1981–2010.

above IDM average (0.24/0.44, 1981–2010) and one of companies for which PTp and PTp were below IDM. Regarding PTp, AMD, Micron and TI are the top three companies above the PTp of IDM, as shown in Table 5. This implies that these companies perform differently from other IDM companies in PTp. That is, AMD, Micron and TI put greater focus on the development of wafer-process technologies over the past three decades than did other companies. Intel, FUJISTU, and IBM are the bottom three companies in PTp. These companies put fewer resources into the development of wafer-process technologies. On the

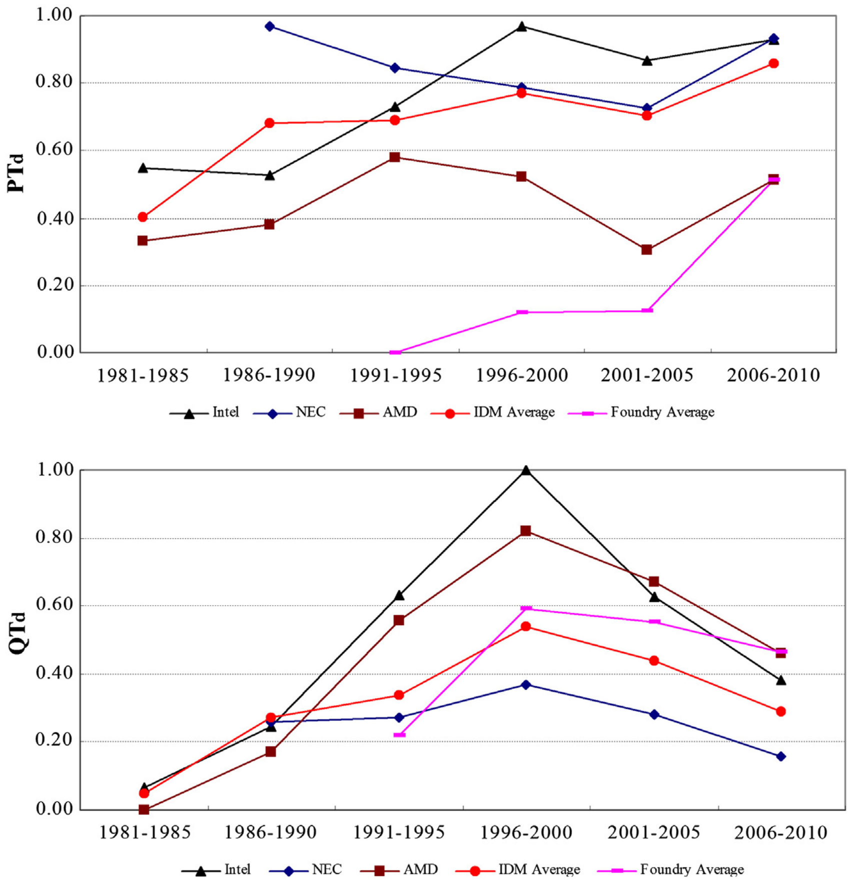

Fig. 4. Development trend of the productivity (PTd) and quality (QTd) of technology focuses on wafer-design application for IDM companies, IDM average, and foundry average during 1981–2010.

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Table 5
Summary for the productivity (PTp) and quality (QTp) of technology focuses on wafer-process of IDM and IDM companies, 1981–2010.

Company/industry (PTp, QTp)	1981–2010	1981–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2010
AMD	(.60, .58)	(.66, .00)	(.62, .48)	(.42, .42)	(.47, .67)	(.69, .61)	(.48, .32)
Micron	(.58, .79)			(1.00, .54)	(.60, .70)	(.61, .75)	(.45, 1.00)
TI	(.37, .51)	(.47, .21)	(.47, .32)	(.55, .36)	(.33, .68)	(.36, .71)	(.25, .33)
IBM	(.13, .43)	(.55, .24)	(.22, .35)	(.15, .34)	(.10, .47)	(.14, .55)	(.06, .32)
Fujitsu	(.10, .29)	(.61, .12)	(.24, .27)	(.23, .30)	(.08, .33)	(.07, .35)	(.00, .18)
Intel	(.09, .54)	(.45, .27)	(.47, .38)	(.26, .41)	(.02, .73)	(.13, .69)	(.06, .34)
IDM average	(.24, .44)	(.59, .19)	(.31, .29)	(.30, .34)	(.23, .50)	(.29, .53)	(.14, .37)
Foundry average	(.81, .65)			(1.00, .40)	(.88, .77)	(.88, .66)	(.48, .34)

other hand, Micron, AMD, and Intel are top three companies in QTp, which implies that the quality of these companies in terms of wafer-process technologies is clearly recognizable, as is shown in Table 5.

In terms of the positioning of the selected IDM companies using the two-dimensional method (IDM average PTp = 0.25 and QTp = 0.45), Micron, AMD, and TI are located in the upper-right area (foundry-oriented area), as shown in Fig. 5. These companies have significant performance in both PTp and QTp. Companies including Fujitsu, Hitachi, and IBM have worse performances in both PTp and QTp.

To clarify them more easily clarify, we divided the selected IDM companies into three groups to explore the development trend of PTp and QTp of the selected IDM companies. The three groups are above (AMD), closed (NEC), and below (Intel) PTp of IDM, respectively, as shown in Fig. 6. Most IDM companies have moved toward the upper-right area, which means that these companies have high QTp but low PTp, as shown in Fig. 6. The development trend is different from that of PTd and QTd. That is, the productivity of technology focuses on wafer-process technology is low but their quality is recognizable, except for that of some companies such as AMD. The development trend of AMD is different from most IDM companies. ADM invested more resources into the development of wafer-process technologies than most of the other selected IDM companies, as shown in Fig. 6. AMD maintained nearly the same productivity trend in terms of technology focus on wafer-process patents as did the other selected IDM companies during 1981–1990; however, its pattern shifted after 1991. In short, AMD put more resources into the development of wafer-process technologies after 1991. In addition to AMD, Intel also has high recognition in terms of QTp, as shown in Fig. 6.

3.2.3. Detection of technology focus shifting

3.2.3.1. Integrated results of wafer-design application patents (Ld) and wafer-process patents (Lp). From the integrated measurement point of view for wafer-design application patents (Ld) and wafer-process patents (Lp), the position and development trends of the selected IDM companies are shown in Figs. 7 and 8, respectively. Micron and Intel performed significantly in both Ld and Lp, as shown in Fig. 7. Specifically, Micron and Intel invested almost an equal amount of resources into the development of wafer-design application technologies and wafer-process technologies; meanwhile, the quality of these two technologies is also recognizable. AMD and TI, located in the lower-right area (foundry-oriented area), have high Lp but low Ld, as shown in Fig. 7. AMD and TI invested more resources and obtained higher recognition for wafer-process technologies than for wafer-design application technologies. The position of these companies is in the foundry-oriented area, implying that AMD and TI are in more competitive positions to join foundry businesses. Some companies, such as Fujitsu and Toshiba, are positioned in the upper-left area, which means that they have high Ld but low Lp, as shown in Fig. 7. This implies that these companies are positioned the same as most IDM companies.

Regarding the development trends of the integrated view by Ld and Lp, we also divided the selected IDM companies into three groups. The three groups are above (Micron), closed (Samsung), and below (Fujitsu) Lp of IDM average (0.51, during 1981–2010, as shown in Fig. 7), respectively, as shown Fig. 8. In general, the development trends of most IDM companies vary during different periods of the past three decades. Most IDM companies possessed high Ld but low Lp in the early stage lasting between 1981 and 1985. In the middle stage, they possessed high Ld and Lp. During the late stage, they possessed high Lp but low Ld, due to their being foundry average-oriented. This implies that IDM technology focuses and quality have shifted from wafer-design application technologies to wafer-process technologies over the past three decades. Of the selected IDM companies, Micron and Samsung have moved from high Ld/low Lp toward high Lp/high Ld, as shown Fig. 8, indicating that these two have put more resources into the development of wafer-process technologies consisting of high quality, thus keeping high positions in Ld. AMD has shifted from low Lp and Ld toward high Lp but low Ld, implying that it has gradually put more resources into the development of wafer-process technologies. Of the companies with lower Lp, Fujitsu shifted from high Lp/low Ld to high Ld/low Lp, as shown Fig. 8. Fujitsu should put more resources into the development of wafer-design application technologies.

3.2.3.2. Summary of the productivity and quality of technology focuses (PTd/PTp, QTd/QTp), and the integrated measurements of wafer-design application and wafer-process patents (Ld/Lp). From the point of view of Ld and Lp, it is clear that the technology focuses of IDMs and Foundries are on wafer-design application technologies and wafer-process technologies, respectively. Micron, AMD, TI, and Intel have higher Lp than most IDM companies (IDM average Lp = 0.51), as is shown in Table 6. That is, these companies, with their competitive advantages, are well-positioned to join the foundry business (Foundry Average Lp = 1.04) should they so desire. More and more, IDM companies have officially claimed to join the foundry business, such as AMD, Samsung, Intel and

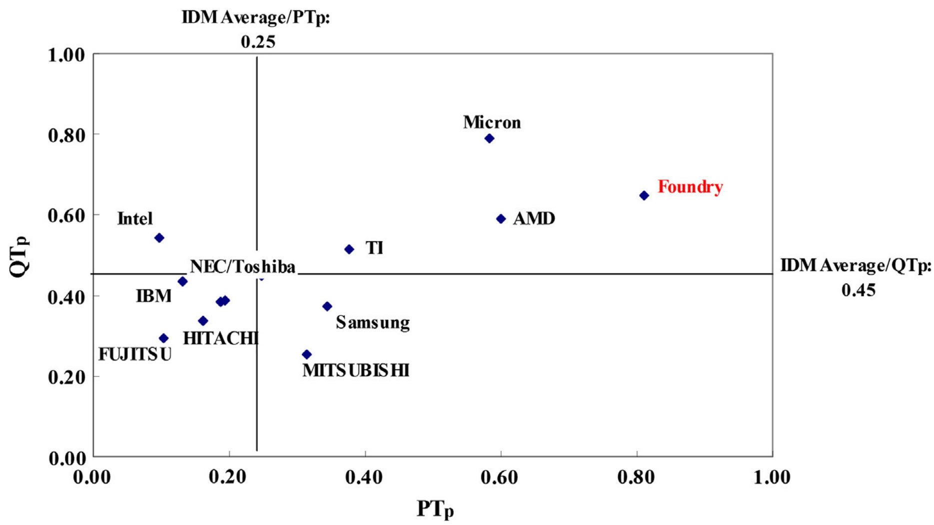

Fig. 5. Position of PTp and QTp of IDM companies and foundry during 1981–2010.

IBM. We verified these companies' Lp, and found that AMD has the most significant performance in this regard. Thus, AMD holds a better position in comparison to the other companies should it plan to join the foundry business. Micron is a role model from the point of view of Ld/Lp, showing significant performance in both wafer-design application and wafer-process technologies. Technologically speaking, Micron can play an important role in both IDM and foundry.

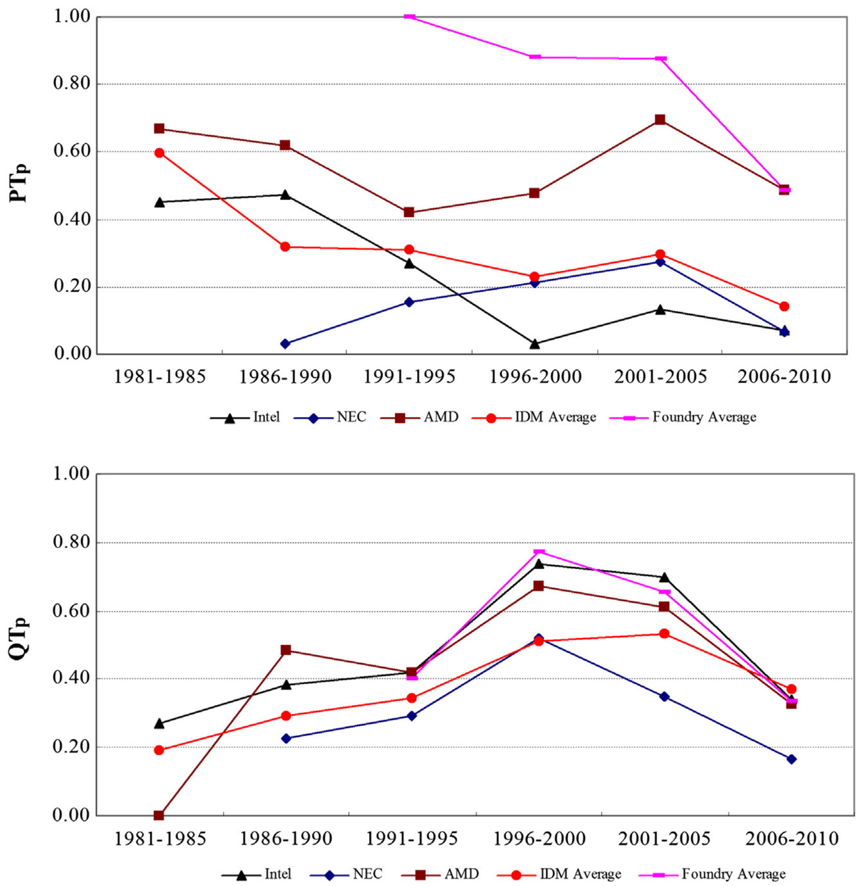

Fig. 6. Development trends of PTp and QTp for IDM companies, IDM average, and foundry average during 1981–2010.

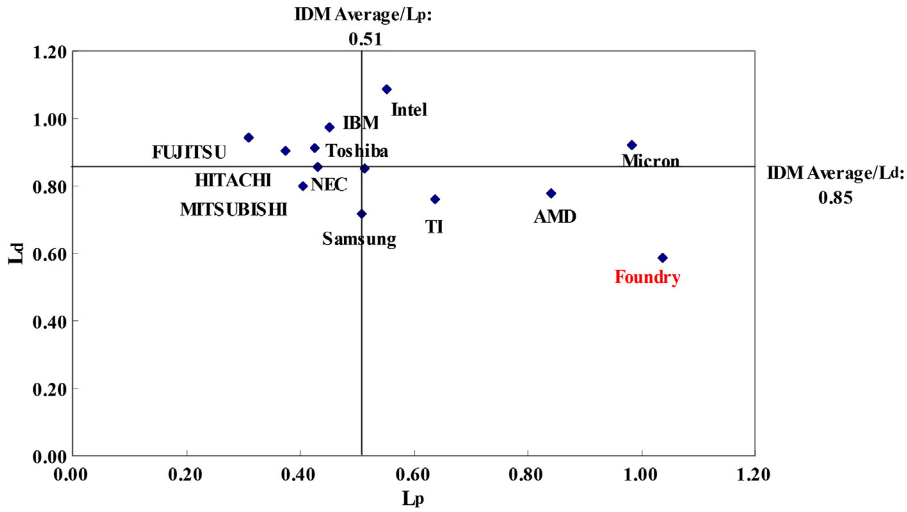

Fig. 7. Position of integrated results of wafer-design application patents (Ld) and wafer-process patents (Lp) of IDM companies and foundry during 1981–2010.

From the ANOVA test result, the PTd/PTp, QTd/QTd, and Ld/Lp of the targeted IDM companies are significantly different. The data has also been subjected to post-hoc (Scheffe) testing, with the results showing significant differences.

4. Discussion and conclusion

Traditionally, IDMs needed foundry manufacturing capacities in high demand seasons. However, this situation has shifted

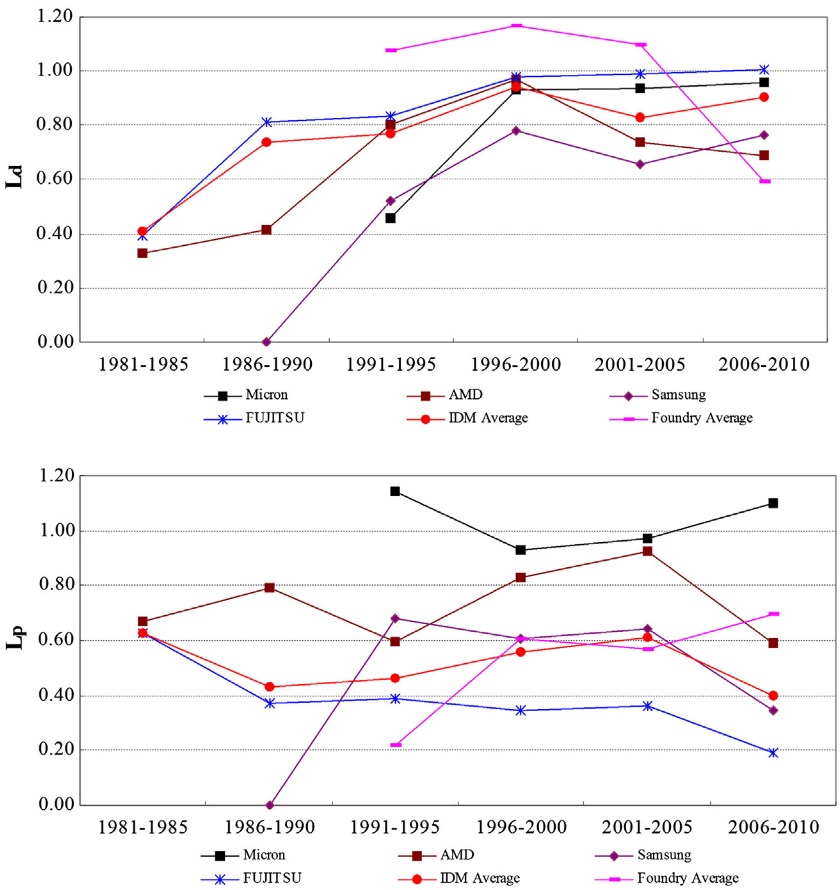

Fig. 8. Development trends for integrated result of wafer-design application (Ld) and wafer-process patents (Lp) for IDM companies, IDM average, and foundry average during 1981–2010.

over time. Recently, most IDM companies have faced a tough challenge in regard to Design Houses and Foundries in terms of finances, role in the supply chain, and even technologies. They have struggled with the shifting of the overall semiconductor industry. To take advantage of foundries' increasing potential profitability, more and more IDM companies are diversifying or even taking the branch-off route from traditional IDMs to Foundries. There are many core competences in a successful foundry company. As stated by representatives of the Taiwan Semiconductor Manufacturing Company (TSMC), the world's largest dedicated independent semiconductor foundry, the company's core competences are advanced technology, excellent manufacturing, and customer partnerships. On the other hand, more and more IDM companies have adopted the "Fab-Lite" strategy, coping with dynamic demand uncertainly by retaining a small IC wafer manufacturing capacity and releasing major orders to foundry companies rather than building fabrication plants. This strategy effectively eases the financial burden on the IDMs. This study focuses on the technology elements and applies a patent analysis. Certain IDM companies' greater focus on wafer-process technologies rather than wafer-design application technologies implies that they might be planning to diversify their technology character from IDM to foundry. For example, in 2008 AMD spun off its wafer manufacturing business unit and cooperated with the Advanced Technology Investment from Abu Dhabi to establish the independent chip foundry company, GlobalFoundry. As a supply chain strategy, this is a classic example of competition in the semiconductor industry, in which AMD's industry category shifted from IDM to foundry, and its role shifted from customer and partner (cooperation) to competitor (competition).

This study detected the position and position shifting of technology focus for the selected IDM companies from a patent perspective. For individuals who make the technology development and character decisions in companies, this study could provide a comprehensive picture for detecting relative competitiveness between their company and competitors (or the industry average) in the semiconductor industry. For industry researchers, this study could be applied to other industries to detect the overall picture of the corporate business decisions of targeted companies in the early (development) stage through patent analyses. There is a strong link between IDM companies, such as AMD, which officially announced entering the foundry business, and the shift of technology focus. For other IDM companies that have not officially announced their intention to migrate or branch off as foundry companies, such as Micron and TI, shifting positions in technology focus hints that their strategy has changed. Thus, as Micron and TI have put more resources into the technology development required for the foundry business, we can expect that these IDM companies may adopt that strategy.

Based on these findings, we suggest that patents not only express company technology capability, but also imply business strategies. Industry practitioners could apply this analytical model to detect positions and position shifts in technology focus. From an integration point of view (Ld/Lp), both AMD and TI are located in the foundry-oriented area (lower-right area, high Lp but low Ld, as shown in Fig. 7). In early 2009, AMD was one of the most typical examples of a company taking practical steps toward establishing a pure foundry company, as it did with GlobalFoundry [27]. Therefore, from a patent perspective, AMD may have significantly shifted its technology character. Other IDM companies, such as Micron, have also shown significant performance in those criteria without officially announcing their intent to enter the foundry business, which perhaps indicates their intention to make the decision to change. Our result interprets the messages that certain IDM companies have sent by shifting their technology focus from wafer-design application technologies (IDM oriented) to wafer-process technologies (foundry oriented). Whether these selected IDM companies have announced a technology character shift, their technological readiness is stronger than that of other IDM companies if they plan to migrate to the foundry business. If companies can analyze other's patents based on this working framework, their decision makers will have business intelligence through which they will be better equipped to cope with changes in the strategies of their competitors, and even their partners, at the earliest stage. The actual strategic actions of these companies reflect on the map of positioning for integrated results, as shown in Fig. 7. For example, AMD was a typical IDM company before 2008 and acted traditionally as a foundry's customer or partner, particularly in the high-demand season. When AMD spun off its manufacturing function (fab) as an independent corporation, it became a competitor to other foundry companies, such as TSMC. Foundry companies with advance business intelligence of current IDM customer and partner patent trends could reduce the impact of strategy changes by adapting their own technologies, human resources, financial aid, and other factors in preparation. In addition to AMD, Samsung and Intel are other companies that openly took action to join the foundry business. The position of technology focus for these companies kept them well positioned in both wafer-process and wafer-design application technologies. Samsung openly announced its plans to join the foundry business in 2004 and aggressively grasped the orders of Apple Inc. over the past two years [28]. The announcement from Samsung in 2004 reflects the rising trend of the integrated measurement of wafer-process technologies (Lp) after 1990, as shown in Fig. 8. In contrast to Samsung, Intel delayed announcing its plan to join the foundry business until 2010 and focused more on specific or advanced technologies of the foundry business [29]. The actions of Intel display how the

Table 6
Summary of PTd/QTd, PTp/QTp and Ld/Lp of IDM companies, IDM average, and foundry average during 1981–2010.

Company/industry	PTd	QTd	Ld	PTp	QTp	Lp
Micron	0.42	0.82**	0.92	0.58	0.79**	0.98
AMD	0.40	0.67**	0.78	0.60	0.59**	0.84
TI	0.62	0.44	0.76	0.38	0.51	0.64
Intel	0.90	0.61**	1.09	0.10	0.54	0.55
Samsung	0.66	0.29**	0.72	0.34	0.37	0.51
IBM	0.87	0.44	0.97	0.13	0.43	0.45
NEC	0.81	0.29**	0.86	0.19	0.39	0.43
Toshiba	0.81	0.42	0.91	0.19	0.38	0.43
Mitsubishi	0.69	0.41	0.80	0.31	0.25**	0.40
Hitachi	0.84	0.34	0.90	0.16	0.34	0.37
Fujitsu	0.90	0.29	0.94	0.10	0.29**	0.31
IDM average	0.75	0.40	0.85	0.25	0.45	0.51
Foundry average	0.19	0.52	0.55	0.81	0.65	1.04

Note:
1. The data are sorted by Lp.
2. ** Significant at 1% level.

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company has prepared well in terms of both the integrated measurement of wafer-design application and wafer-process technologies (Ld and Lp), as shown in Fig. 7 (locating in the upper-right area). Some companies, such as Fujitsu and Mitsubishi, retained their positions, as did most IDMs. These companies still played their traditional roles. The actions of Fujitsu and Mitsubishi aligned with the results shown in Fig. 7, demonstrated that it performed well only in the integrated measurement of wafer-design application technologies and not in wafer-process technologies. We attempted to implement a working model from the patent perspective that is applicable to other industries with regard to shifting of technology character. This study's results also provide a strategic map of competitive analysis for industry practitioners in mutual positions in patent perspectives.

There are some limitations of using patent data in research. For example, not all technologies or inventions are patented because of strategic concerns or under patentability criteria of the USPTO. Besides, the patent data were queried only from USPTO excluding other areas such as European, Japan, and China. It may affect the research completeness for specific fields. The following are the reasons that the authors selected the USPTO as the patent database. Approximately half of the inventions of U.S. patents are foreign-owned, and each country's invention patents in the U.S. are roughly proportional to their country's Gross Domestic Product (GDP) [30]. Taking geographical factors into consideration, the USPTO patents provide detailed address information of assignees and inventors that are essential to analyze geopolitically-related collaboration. For other patent data sources, some have small foreign-owned patent shares, such as the State Intellectual Property Office of P.R.C. (SIPO), which has only 8% issued foreign-owned patents in 2011 [31]. Some sources lack detailed address information for assignees and inventors in patent text content. Thus, the USPTO is the most appropriate source to analyze relative researches. In addition to the selection of the patent database, there are some limitations for the patent statistics in the research. For example, the appearance of an absolute decline in inventive activity was largely a statistical mirage, caused by a bureaucratic rather than an economic or technological cycle [32]. Meanwhile, patent rights increasingly become bargaining chips in the patent portfolio races [33]. In addition to the above limitations for using patent data as analysis tool, the link between patent quality and value in cumulative innovation is also weak [34]. That is, more and more strategic thinking is used for the patent information especially in complex technologies. It will somehow impact the effectiveness for the research result by patent perspectives.

There exist a number of other avenues for further research into this subject. For example, IDM companies and the competitive relationship between each selected IDM and its related foundries can be studied from patent perspectives via technology forecasts. The relationships between specific technologies for each role would also be a topic for future research. Besides, future research may apply more advanced patent indicators or models to analyze the evolution of specific industries or companies. Chang [35] used patent information to establish an effective model for the technological position of business methods. The Revealed Patent Advantage (RPA) proposed by Schmoch in 1995 [36] was used due to the differences in R&D strategies and company scale of firms. Meanwhile, two indicators applied to measure the inflow and outflow degree of fusion of a specific patent class belongs to cross-disciplinary technology [37]. The main trends in U. S. patenting over the last 30 years, including a variety of original measures constructed with citation data, such as backward and forward citation lags, indices of “originality” and “generality”, and self-citations were presented [38]. Three semantic similarity measurements were applied to discover un-commercialized research fronts by comparing scientific papers and patents: Jaccard coefficient, cosine similarity of term frequency-inverse document frequency vector, and cosine similarity of log-term, frequency-inverse document frequency vector [39]. Finally, both self-citations and external citations can be classified within or beyond industry citations, leading altogether to four different kinds of citations: (1) self citations within the industry, (2) self citations beyond the industry, (3) external citations within the industry, and (4) external citations beyond the industry. Novel patent analysis methods were applied to analyze technological convergence and provide tools for anticipating the early stages of convergence [40].

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