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Analysis of Patent Portfolio and Knowledge Flow of the Global Semiconductor Industry

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***Abstract*--This study aims to analyze semiconductor patents in following dimensions: characterizing patent, forecasting future trends, uncovering key patent, as well as proposing patent strategies for the development of semiconductor industry. In addition, this research studies investigate of patents, in 1) national, 2) industrial and 3) organizational levels, through social network analysis, two-dimensional contour map analysis and patent characteristics analysis. In this study, semiconductor patents are retrieved, on the basis of IPC, from the United State Patent and Trademark Office (USPTO) database. Furthermore, the development trend and knowledge flow are investigated and visualized through the analysis of the numbers of patents, litigated patents, technological life cycle, patent citations and patent information, etc.**

I. INTRODUCTION

Proprietary technology is a cornerstone of business success and an important asset in semiconductor industry. The majority of technological improvements that companies believe to be patentable and important are documented in patent applications[1], and the one of features of a patent is to protect intellectual property right in the knowledge economy [2]. Therefore, patents provide protection of companies' assets and useful insights into the competitive position of the country and company. Furthermore, patents have long been considered to be up-to-date and valuable information sources in technology [3]. Analyzing the characteristics of the patents can understand lots of information and also offer an outlook into tomorrow's competitive landscape. Therefore, for understanding technological competitiveness and overall technology trends [4], this study aims to analyze the characteristics of the patents in semiconductor industry.

Besides, patent maps are used to arrange or visualize the calculated patent statistics or complex technological relationships from patent analysis in easily-understood forms [5]. A number of researches have noted that patent citations trace out technological building relationships among inventions [6,7]. Also, citation has been widely used in bibliometric study to evaluate technology development, research performance, and even map knowledge evolution, knowledge flows, technological trajectory [8-17]. Therefore, this study aims to understand the technological trajectory and knowledge diffusion by analyzing the patent citation. Also, this study converts 3-dimensional citation network to a 2-dimensional patent map which can be more easily interpreted by human eyes. The quantitative 2-dimensional map provides a quick way, which is much easier than complex equations or theories, for people to directly perceive technological change through human eyes.

On the other hand, this study firstly analyzes the characteristics of the patents in the national and industrial level, and secondly analyzes the characteristics of the patents in the organizational level. In addition, this study analyzes patent characteristics for understanding basic informations; analyzes social network diagram for understanding technology evolution and analyzes two-dimensional network diagram for understanding knowledge flow.

A. Semiconductor Technology Development

A semiconductor is a material which has electrical conductivity to a degree between that of a metal and that of an insulator. Also, semiconductors are the foundation of modern electronics, including transistors, the microprocessor, solar cells, light-emitting diodes and lots of high-tech industries. In addition, the core technology of integrated circuit and microprocessor is from semiconductor industry. Most of today's electronic products, such as computers, mobile phones or digital recorder are closely related to semiconductor.

On the other hand, the development and evolution of the semiconductor are both efficient and rapid. Intel co-founder Gordon E. Moore, who described the trend of the semiconductor industry and called Moore's law. This law is the observation that, over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years [18]. Fig. 1 illustrates the evolution of the technology over the last 40 years. We can see from that figure that, the process speed of CPU increased year by year, the advancement of semiconductor manufacturing-process technologies allowed to scale down, and the number of transistors that could be combined on the same chip increased.

The development of semiconductor technology could be talked from 1947. The bipolar transistor was invented in December 1947 at the Bell Telephone Laboratories by John Bardeen and Walter Brattain under the direction of William Shockley. In earlier, people used vacuum tube for computer arithmetic. Compared to transistor, the disadvantage of vacuum tube is too bulky, slowly and not universal. Therefore, the invention of the transistor gradually replaced vacuum tubes and significantly reduced the volume of its required. At that time the transistor technology was not mature, hence could not be commercialized production. Then Bell Labs authorized to jointly develop this technology with other manufacturers for commercialized production.

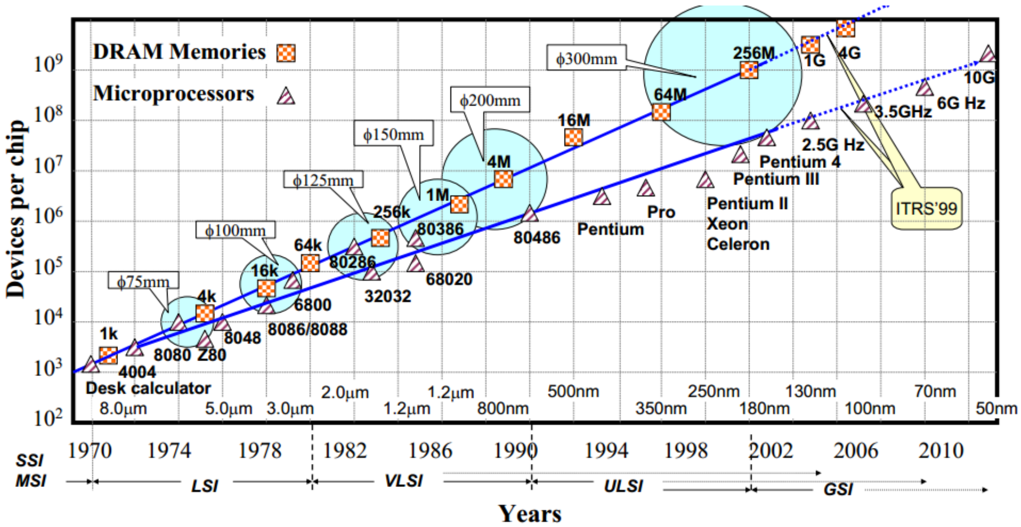

Fig. 1 Moore's Law and Technology Scaling
Source:[19]

In 1952, Texas Instruments entered in semiconductor industry, when Motorola set up solid state electronic laboratory for studying transistors in Phoenix. The first working silicon transistor was developed at Bell Labs in 1954 and while the first commercial silicon transistor was produced by Texas Instruments. After then, transistors began commercialized production. The structure of silicon transistors is planar, so the process is simple. Therefore, the cost of silicon is cheaper than germanium. Then the silicon transistors gradually replaced germanium transistors.

The scientists hoped to integrate transistors, resistors, capacitors and other components on a small volume of silicon chip, thus constitute a large and complex electric circuits, or even the entire system (such as computers, radios, television sets). Then Jack Kilby invented integrated circuit, who worked for Texas Instruments. And he created small ceramic wafers, each one containing a single miniaturized component. Components could then be integrated and wired into a bidimensional or tridimensional compact grid. In 1961, Fairchild and Texas Instruments, both successful launched first commercial integrated circuits. Therefore, they opened a new era of the semiconductor industry. After then, the semiconductor industry began to develop rapidly. In 1962, semiconductor revenue has more than one billion U.S. dollars.

From the 1950s to the 1970s, US companies were the uncontested leaders in semiconductor industry: the US invented the three important innovations of semiconductor technology– the transistor, the integrated circuit and the microprocessor –and US companies made the three of them be commercialized production. And at that time, the US dominated the international market of semiconductors [20-22]. In the 1980s, the memory and microprocessor technology is developing rapidly and the number of transistors on a chip grows almost obeying Moore's Law. After 1980, Japanese companies began to enter in the semiconductor market and competed with the leader country: the US [23-24] In the 1990s, the rise of latecomer Asian countries like Taiwan and South Korea quickly grew up and also changed the scenario of the previous decade[25-28]. However, European firms didn't remain their competitiveness in the semiconductor market. Therefore, now they play a relatively peripheral role in the semiconductor industry [29-30].

B. Semiconductor Market Development and Industry Overview

TABLE 1 WORLDWIDE SEMICONDUCTOR ANNUAL GROSS OUTPUT VALUE

Year	**1976**	**1981**	**1986**	**1991**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**
US($B)	2.9	9.3	25.9	54.4	140.7	134.2	136.8	125.7	145.4	201.1	147.2
Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
US($B)	138.3	162.9	210.6	225.5	246.1	255.5	255.3	219.7	295.3	300.9	291.1

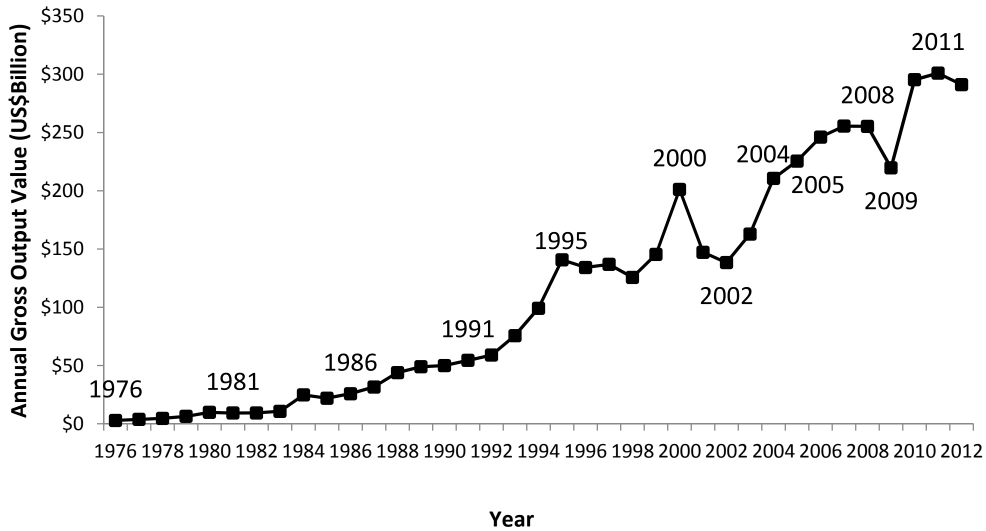

Fig. 2 Worldwide Semiconductor Annual Gross Output Value Changes
Source: [31]

The semiconductor market development is as shown in Table 1 and Fig. 2. Since 1976, the semiconductor industry has grown steadily. The semiconductor industry's annual gross output value was US$2.9 billion in 1976, and then reached US$140.7 billion in the 1990s. The global semiconductor industry is growing at an average annual rate of growth of 17%, and was reaching a peak $ 201.1 billion in 2000. After recession and cycle, semiconductor industry came to a peak $ 300.9 billion again. Now the gross output value is at least US$300 billion.

Furthermore, since 1970, semiconductor manufacturing process has improved year by year. The development of wafer size has been from 4-inch through 6-inch, 8-inch, 10 inch to today's 12-inch, and in the future will enter in the 18-inch. In addition, the development of line-width roughness(LWR) in CMOS Technology has been from 0.35μm, 0.25μm, 0.18μm, 0.13μm, to current 90nm, 65nm, 45nm, 22nm, and even 14nm in the future. Also, the miniaturization of electronic components by means of Very-large-scale integration (VLSI) technologies has improved significantly. Besides, the global semiconductor industry specialization enables the marginal cost of products continue to decline. Above many reasons are creating a powerful driving force for the rapid development of the semiconductor industry.

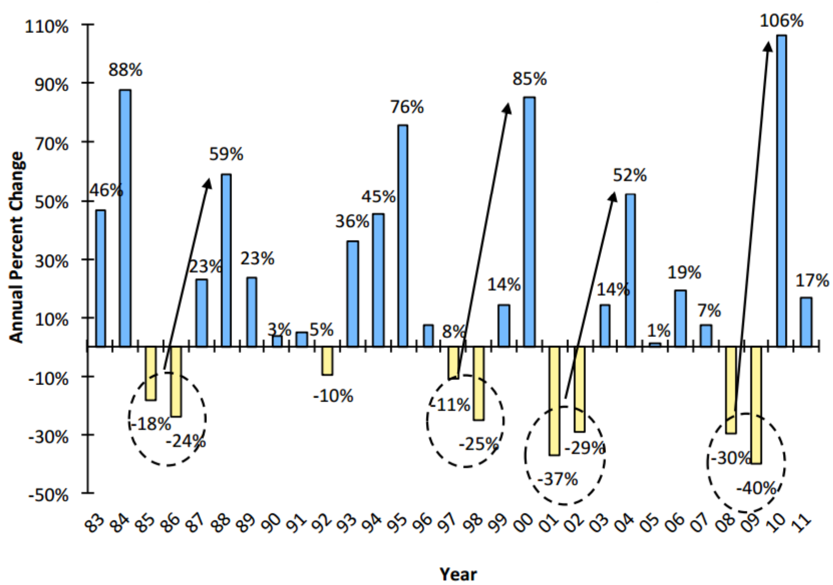

Fig. 3 1983-2011 Annual Semiconductor Capital Spending Changes
Source: [32]

Semiconductor industry is highly cyclical industry. Since 1976, the semiconductor business cycle has been about five years for a small loop cycle and about ten years for a big loop cycle, and this is also known as "silicon cycle". As shown in Fig. 3, since 1983, that has gone through four small cycles and two major cycles, as shown in below. The first small cycle was a negative growth of 18% in 1985, and then reversed to a positive growth of 59% in 1988; The second small cycle was a negative growth of 11% in 1997, and then reversed to a positive growth of 85% in 2000; The third small cycle was a negative growth of 37% in 1997, and then reversed to a positive growth of 52% in 2004; The fourth small cycle was a negative growth of 30% in 2008, and then reversed to a positive growth of 93% in 2010.

II. RESEARCH METHOD

A. Initial patent sampling

The research data are downloaded from the United State Patent and Trademark Office (USPTO) database from the year of 1976 to 2012, including a total of 4,388,043 patents; Index method is through searching the International Patent Classification system for relative patents of the Semiconductor industry. Compared with other countries in the patent database, the U.S. patent database has the advantage of extensive and highly detailed coverage information [33]. And a total number of semiconductor patents are 192,103.

B. Analyze characteristics of patents

In the course of reviewing the literature, consulting with experts in this field, important characteristics of patents are retrieved from every patent document. In the patent search process, we will gain the characteristics of patents, and select the required information fields to analyze the data, which includes the following features of the patent. Table 2 shows literatures for the 13 patent characteristics.

TABLE 2 LITERATURES FOR THE 13 PATENT CHARACTERISTICS

No.	Characteristics	Literatures
1	First Assignee Type	[34]
2	No. of Assignee	[35,36]
3	No. of Assignee Country	[37]
4	No. of Inventor	[35,36]
5	No. of Inventor Country	[37]
6	No. of Patent Reference	[8,38-44]
7	No. of Patent Citation Received	[8,42,44-50]
8	No. of IPC	[38,39,48,51,52]
9	No. of UPC	[52]
10	No. of Claim	[35,42,44,47,50,53]
11	No. of Non-Patent Reference	[8,41,43,48,50,54-56]
12	No. of Foreign Reference	[8,41,48]
13	Litigation	[50,57]

C. Patent citation network

This study uses Netdraw as a research tool; draws a line of patent citation networks and relationships, and calculates each node of the network centrality. Netdraw can draw social networks graphics, and this method has been widely used in various fields, such as Sociology[58], Information Science[9], Communication Science[59] and other fields.

Hanneman &Riddle considered that social network analysis is the individual's network of relationships, which is composed of actors, link and relation [60]. And this behavior can be individuals, organizations or countries. "Relationship" in the network means network tie. Furthermore, the "link direction" provides the researchers to determine actors' direction of information flow [61]. In addition, the social network analyzes nodes, links, and transforms relationship into the distance, direction and density. And use clear and understandable graphics or matrix analysis results to present.[9] Data collection and analysis through social network could explain the overall structure of social relations, and thus resolve the issues [62].

In social network theory,"Centrality" is a key network property to estimate how easy an actor retrieves or controls resources from the network. Freeman proposed three ways of measuring network centrality, Degree Centrality, Betweenness Centrality, and Closeness Centrality. The higher centrality indicates more associations with actors in a network. Brass and Burkhardt pointed out the higher centrality of a person in a social network, the more power possesses from the viewpoint of organizational behavior [63]. This research also uses the three ways of measurement for obtaining centrality of patented technology in order to understand the importance, influence, diffusivity and convergence of a patented technology.

Degree Centrality

Network nodes (actor) which directly linked to a specific node are in the neighborhood of that specific node. The number of neighbors is defined as nodal degree, or degree of connection. Granovetter suggested nodal degree is proportional to probability of obtaining resource. Nodal degree represents to what degree a node (actor) participates the network, this is a basic concept for measuring centrality.

In Degree Centrality: the number of time that patent i is cited by other patents. The higher In Degree Centrality, the more times that patent i is cited, meaning the higher momentum of knowledge diffusion from patent i to other patents.

Betweenness Centrality

The concept of betweenness is a measure of how often an actor is located on the shortest path (geodesic) between other actors in the network. Those actors located on the shortest path between other actors are playing roles of intermediary that help any two actors without direct contact reach each other indirectly. Actors with higher Betweenness Centrality are those located at the core of the network.

Closeness Centrality

The Closeness Centrality of an actor is defined by the inverse of the average length of the shortest paths to/from all the other actors in the network. Higher Closeness Centrality indicates higher influence on other actors. In a directed network, Closeness Centrality can be divided into InClosenesss Centrality and OutCloseness Centrality.

D. Two-dimensional map of patents

In this study, a patent citation map is obtained by calculating relative positions and density of network actors in a two-dimension map on the basis of network constructed previously. This study use algorithm proposed by Van Eck and Waltman's in 2007 [64].

1) Actor position: the positions of network actors in the map are based on visualization of similarities. If there are totally n actors, a two-dimensional map where the actor 1–n are positioned in a way that the distance between any pair of actor i and j reflects their association strengths a_{ij} as accurately as possible, i.e. distance between i and j is proportional to a_{ij} , Van Eck and Waltman's algorithm is used to minimize a weighted sum of the squared Euclidean distance between all pairs of actors, the objective function to be minimized is given as below:

$$E(x_1,\dots,x_n) = \sum_{i<j} a_{ij} \left\| x_i - x_j \right\|^2$$

Where the vector $x_i = (x_{i1}, x_{i2})$ denotes the location of actor i in a two-dimensional space and ||•|| denotes the Euclidean norm.

2) Actor density: actor density at a specific location in a map has to be calculated. The actor density is calculated by first placing a kernel function at each actor location and taking a weighted average of the kernel function. The actor density at location $x = (x_1, x_2)$ is given by

$$D(x) = \frac{1}{h^2 \sum_{i=1}^{n} c_{ii}} \sum_{i=1}^{n} c_{ii} K\left(\frac{x_1 - x_{i1}}{h}, \frac{x_2 - x_{i2}}{h}\right)$$

Where K denotes a kernel function and h denotes a smoothing parameter. C_{ii} denotes the number of occurrence of actor I and $x= (x_1, x_2)$ denotes the location of actor i in the map. The kernel function K is a non-increasing Gaussian kernel function given by

$$K(t_1, t_2) = \frac{1}{2\pi} \exp\left(-\frac{t_1^2 + t_2^2}{2}\right)$$

III. RESULTS AND DISCUSSION

A. National and Industrial level

Patent characteristics

As it has been widely accepted that more patents the country has create more value and more completive. Fig. 4 observes the relation between development and the number of patents. The US and Japan is the leader countries, both have large number of patents. The comparison between Taiwan and Korea shows that both countries have been growing gradually since 1990s'. Taiwan has a lot more patents than Korea between 1999 and 2005, and the number of Taiwanese patent came to peak at 1451 in 2001. However, Korea overtook Taiwan between 2006 and 2012, and he number of

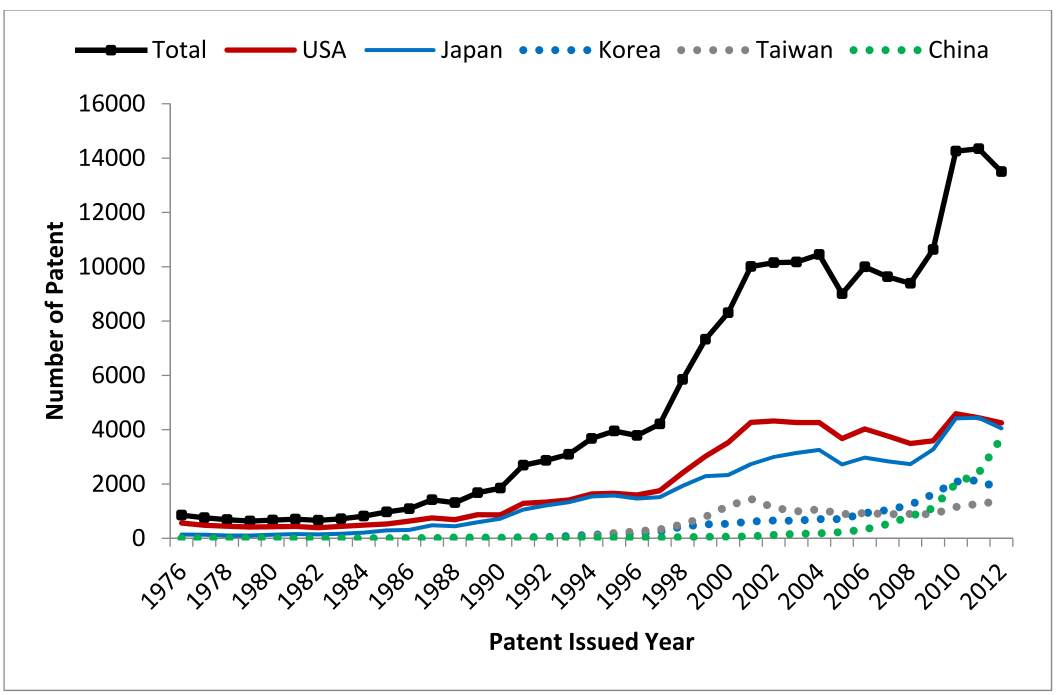

Fig. 4 Annual No. of Semiconductor Patents Changes from 1976 to 2012

Korea patents came to peak in 2011. In this year, Korea had 2142 patents and Taiwan has only 1276 patents. It is worth noting that China develop their semiconductor industry actively. In Fig. 4, the number of Chinese patents has been increasing rapidly in recent three years and actually overtook Korea in 2011. Above mention is the different situation of different countries.

The number of patents can be used to understand industrial and economic developments [65-69]. As shown in Fig. 4, this study obtains the number of annual total patents. The number of patents had increased between 1980 and 1995. In the 1980s, the technology Improvement made personal computers flourishes, i.e. the memory and microprocessor, and therefore leaded the information age. Besides, in 1989, the process speed of CPU was only 8MHZ, and now it has still enhanced the effectiveness. Between 1995 and 2001, the numbers of patents have increased faster than 1980s'. It is possible that the popularity of personal computers increases and the semiconductor technology improves: as sizes shrink, costs per chip decrease, processing speed increases and power consumption is reduced [29]. Above of all, this study observes that the technology development influences the number of patents and pushes the high growth of the number of patents.

This study provides evidence that technology development influences the number of patents. Between 1997 and 2001, table 3 shows that the LWR in CMOS technology improved once every two years. Simultaneously, the number of patents increased. However, between 2001 and 2005, the minimum LWR in CMOS technology took almost 5 years to transfer from 0.13μm to 0.09μm. The technology bottlenecks cause the number of patents growing slowly even decreasing. Between 2007 and 2013, the LWR in CMOS Technology improved significantly, and therefore the number of patents increased rapidly in 2009. It has been widely accepted, if a new technology encounter bottlenecks, other peripheral development of devices and manufacture were also affected. Above of all, it is part of reason why the number of patents declined in 2005 and increased rapidly in 2009.

Furthermore, worldwide market influences the number of patents. Every patent, whether or not it is granted, and whether or not it has commercial value, is a result of R&D activity and thus includes technological insight that can offer inspirations or hints to subsequent developments in technology [3,70]. Therefore, if the funding is not enough to support the R&D activity, the number of patents decline. In addition, if the corporations don't invest on R&D, they lose competitiveness in the industry or influence the revenues. In Fig. 5, the worldwide semiconductor annual gross output value change is consistent with the annual number of semiconductor patents change. The relation between the gross output value and the number of patents is possible reciprocal causation. In 2005, the business cycle of semiconductor industry was through, and the growth rate at that time came to negative. In August 2007, the global financial crisis happened, and it caused great recession. Lots of industries were influenced by recession, including semiconductor industry. After recession and cycle, semiconductor industry came to a peak $ 300.9 billion again. The demand of smart phones and tablet computers increased, and therefore pushed the semiconductor industry to grow up in 2011. Although an overall trend of patent number increase over time can be obtained, a temporary decline is observed in a specific period of time, i.e. 1996, 2005, 2007-2008, 2012. The overall patent growth trend indicates that the semiconductor industry is still developing.

TABLE 3 SEMICONDUCTOR MANUFACTURING PROCESS TECHNOLOGY EVOLUTION

Year	1982	1986	1990	1992	1995	1997	1999
Wafer Sizes(Inch)	4	6	8	8	8	8	8
LWR (μm)	2	1.2	0.8	0.5	0.35	0.25	0.18
Year	2001	2002	2005	2007	2008	2011	2013
Wafer Sizes(Inch)	8	12	12	12	12	12	12
LWR (μm)	0.13	0.13	0.09	0.065	0.04	0.028	0.028

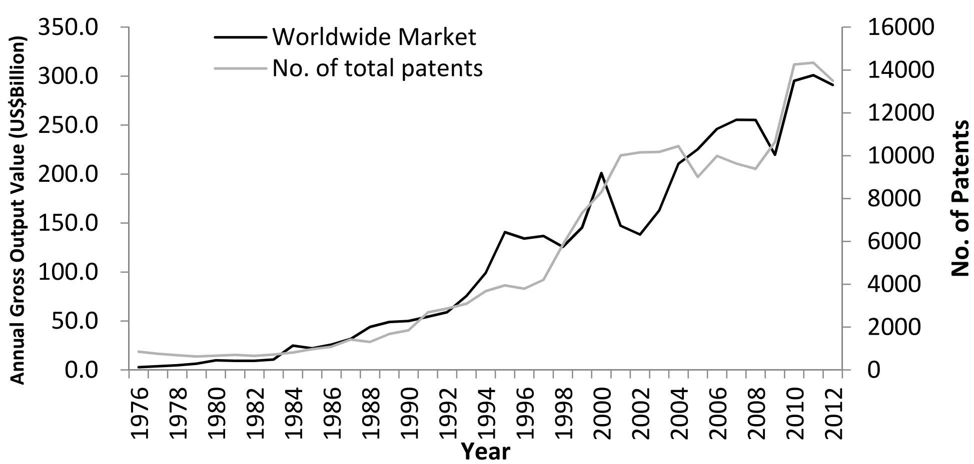

Fig. 5 Annual No. of Semiconductor Patents Change V.S Worldwide Semiconductor Annual Gross Output Value Changes from 1976-2012

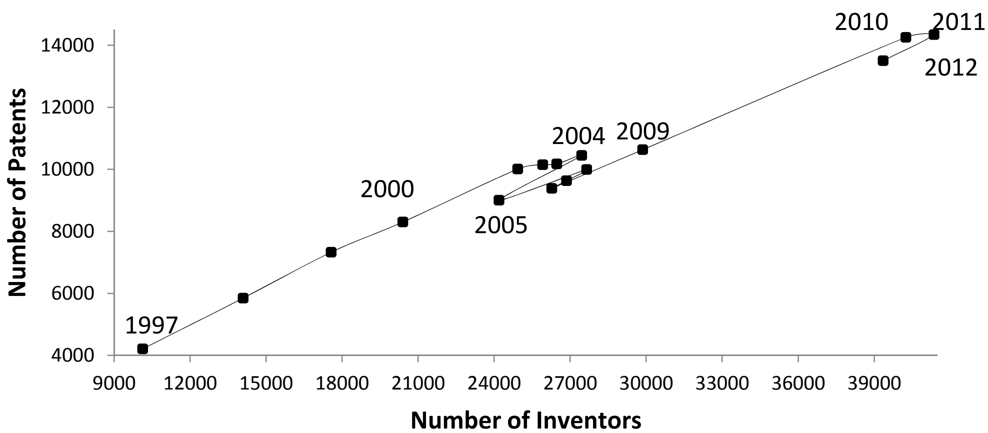

Fig. 6 Semiconductor Technological Life Cycle from 1995-2012

Fig. 6 displays the semiconductor technological life cycle from 1995-2012, and this figure sets years between 1995 and 2012. The main reason is that the number of patents is changing special between 1995 and 2012 as shown in Fig. 4. Besides, this study observes the growth of the semiconductor industrial technology is cyclical, and the total cycles are three times. The first cycle is period of 2004 to 2006, the second cycle is period of 2006 to 2009, the third cycle is period of 2011 to 2013. In addition, the bottleneck lies in the breakthroughs of semiconductor process technology, which is LWR in CMOS Technology.

Patent is an official document to legally protect invention, so legal value is essential for a patent [42,47,71-73]. Global comparison on total patents and litigated patents, shown in Fig. 7, shows that the US has the largest number of both total patents and litigated patents. As the portion of litigated patents can be correlated to patent value [42,49], the percentages of litigated patents are calculated and compared.. In Fig.7, the top three countries with the highest percentages of litigated patents are 1) USA, 2) Germany and 3) United Kingdom, all are above the global average. It indicates USA, Germany and United Kingdom have more valued patents.

There are 192,103 utility semiconductor patents and 547 litigated semiconductor patents issued by USPTO. Fig. 7 shows the top 10 countries with the largest volumes of total patents. The position of the countries on the X-axis follows the number of total semiconductor patents owned by each country, where the US is positioned on the left end and ranked as No. 1 and United Kingdom (GB) is on the right end and ranked as No. 10 in terms of number of patents. The US has the large number of litigated patents and Singapore (SG) doesn't have and litigated patents. For the top 10 first assignee countries, the percentages of litigated patents in the top 10 assignee countries is from 0% (Singapore), 0.13% (Japan, JP), 0.14% (Korea, KR), 0.17% (France, FR), 0.18% (Netherlands, NL), 0.19% (Italy, IT), 0.20% (Taiwan, TW), 0.43% (the US), 0.46% (Germany, DE) to 0.50% (United Kingdom, GB). It is worth mentioning, USA (0.43%), Germany (0.46%) and United Kingdom (0.50%) are above the global average (0.28%).

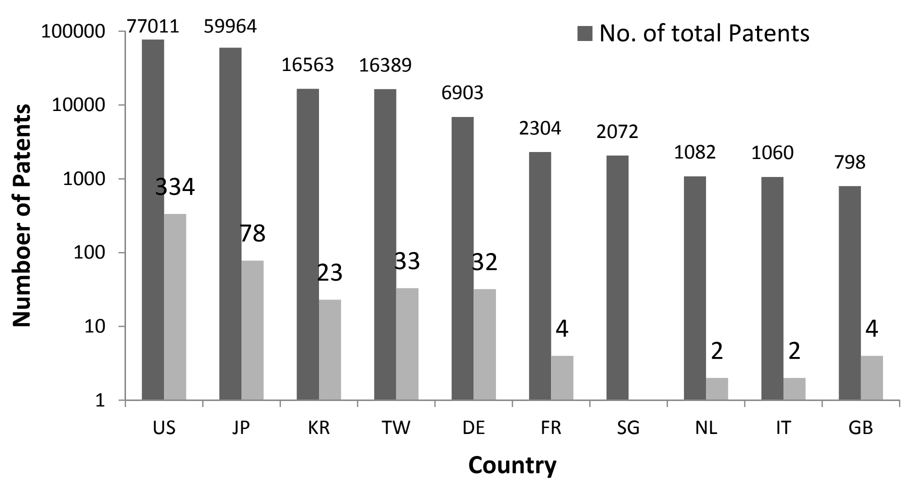

Fig. 7 Number of total and litigated Patents in Top 10 First Assignee Countries (Top 10 countries with highest numbers of patents)

Social network diagram

Social network analysis on patent citation is demonstrated in this study to explore how patented technology development from different countries can be evolved from a patent citation network, which visually represents the essential structure of technology evolution. The evolution mechanism represented by network property is a function of time in the overall technology development. Therefore, by calculating patents' network properties at different time points, a dynamic and quantitative understanding of technology evolution can be obtained [11].

Fig. 8 illustrates Patent citation network of semiconductor for different countries from 1976 to 2012, the sizes of node are based on the number of degrees and the color of node is in terms of the number of degrees, purple means above 47; red means between 30 and 47; green means between 20 and 30; yellow means below 20. In Fig. 8, where the US, Japan, Taiwan and Korea could be seen as the semiconductor patented technology leader of countries, and, of course, the US have the large number of patents, about 77,000 (Fig. 7). For all the obtained 192,103 network patents, countries with the most patents are US (77,011 patents), Japan (59,964 patents), Korea (16,563 patents), and Taiwan (16389 patents). This reveals that semiconductor dominant technologies are mainly located in the US, Japan, Korea, and Taiwan, but in fact the US is more dominant than other countries. As shown in Fig. 8, this study observes that many countries learn the semiconductor technology from the above mentioned 4 countries. Actually, lots of countries are involved in semiconductor technology, and a total number of countries are 64.

Fig. 9 illustrates patent citation network of semiconductor for different countries from 1976 to 1995, the sizes of node are based on the number of degrees and the color of node is in terms of the number of degrees, red means above 13; green means between 9 and 13; yellow means below 9. Compares Fig. 8 with Fig. 9, Fig. 9 observes that the initial techniques were developed by advanced countries such as the US, Japan, Germany, United Kingdom and France. A total number of countries which were involved in semiconductor technology were 31. Surprisingly, Taiwan and Korea were not the leading countries in the early age. However, as shown in Fig. 8, they have been both the leading countries. It means that Taiwan and South Korea grew up quickly and also changed the scenario of the previous decade [25-28]. In addition, a total number of countries which were involved in semiconductor technology grew from 31 to 64 between 1976 and 2012. It indicates that more countries invest on semiconductor technology and the semiconductor technology is important, extensive and valued all over the world.

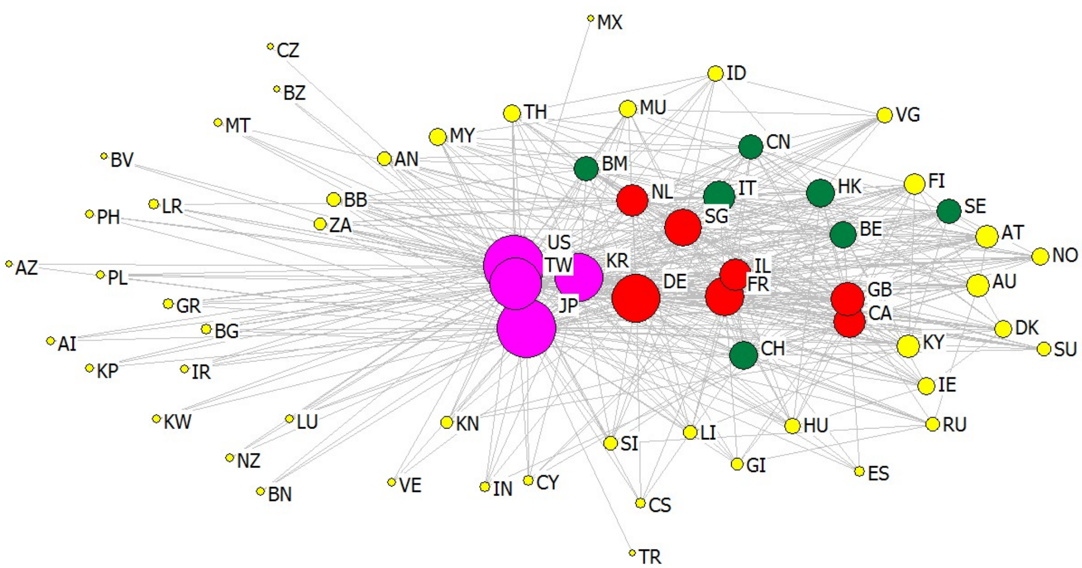

Fig. 8 Patent citation network of semiconductor for different countries from 1976 to 2012
(Use WIPO-standard two-letter codes to represent country names)

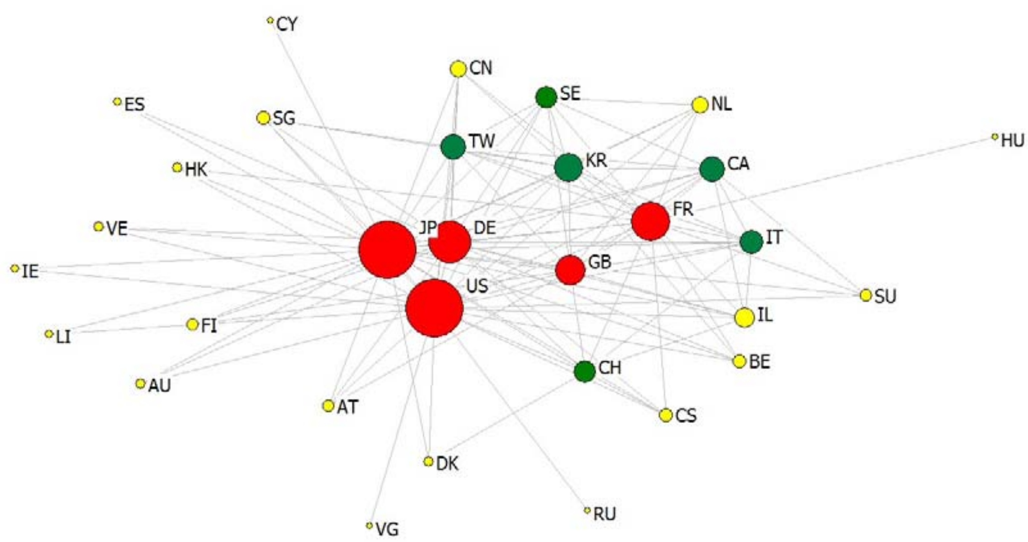

Fig. 9 Patent citation network of semiconductor for different countries from 1976 to 1995
(Use WIPO-standard two-letter codes to represent country names)

Two-dimensional network diagram

The patent citation map with country as actor from 1976 to 1995 is shown in Fig. 10 (Color gradient from blue to red indicates low to high actor density) where only one domains reflecting pattern of global techniques. It means that the global semiconductor techniques are dominated by the two countries with top 2 highest number of patents— the US and Japan. Where the US and Japan can be seen as the technology leader of countries. The US easily becomes the leading country of patented technologies due to its advantage of Sci-Tech resources and, of course, the large number of patents in many aspects. Furthermore, the position between Germany and Japan is close. It means that Germany and Japan exchange knowledge and collaborate more frequently. The result matches the previous research proposed: the US and Japan dominate the semiconductor in the early. [22-24]

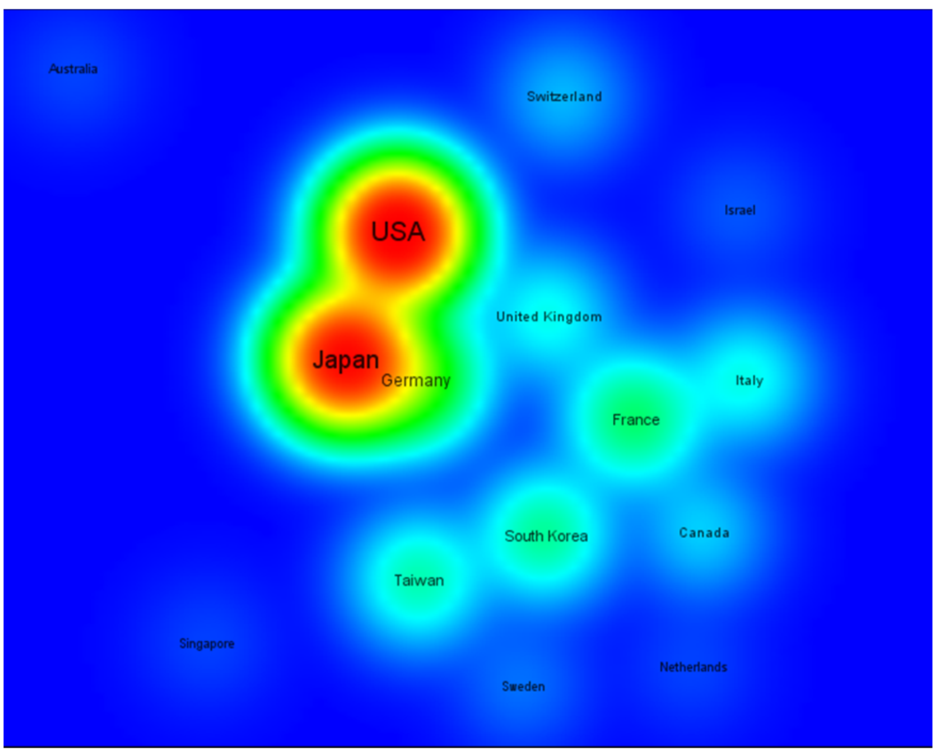

Fig. 10 2-dimensional patent citation map with country as patent as actor from1976-1995

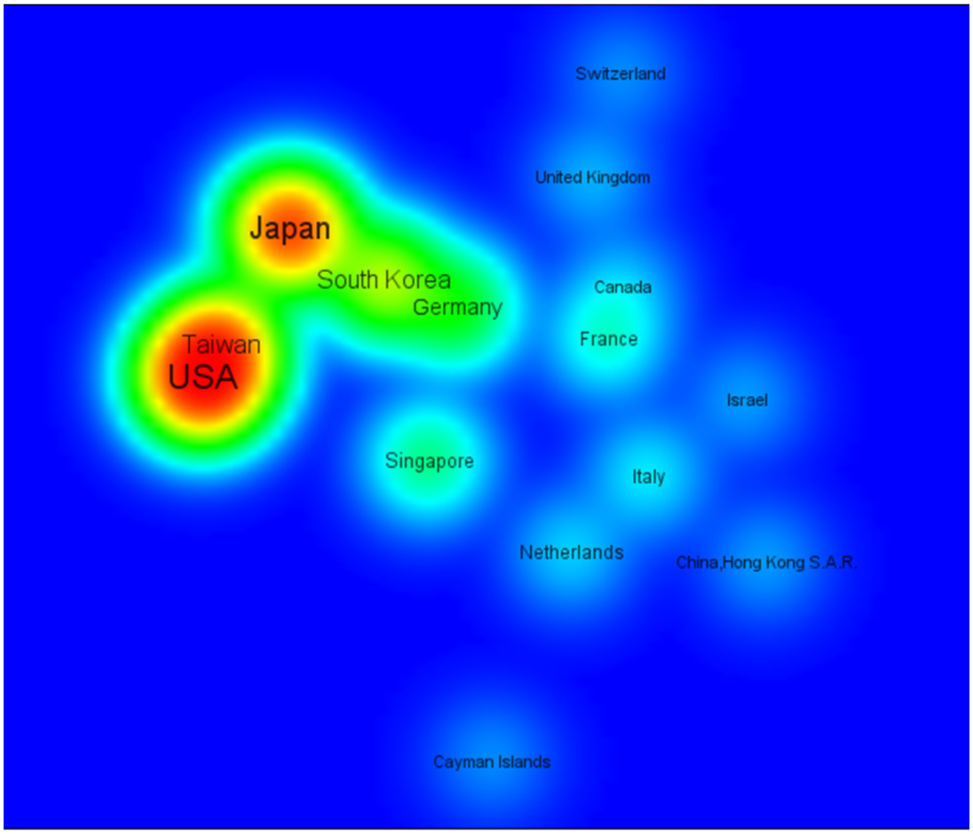

Fig. 11 2-dimensional patent citation map with country as patent as actor from 1996-2012

The patent citation map with country as actor from 1996 to 2012 is shown in Fig. 11, where two separate domains reflecting distribution pattern of global semiconductor techniques. The two domains dominated by the two countries with highest number of patents— the US and Japan, where the US can be seen as the technology leader of countries of Taiwan. On the other hand, Japan can be regarded as technology leader of Korea and Germany. Surprisingly, compared the years between 1976 and 1995, Taiwan and Korea becomes the dominant countries in semiconductor industry and be close to the dominant domain. And Europe is still in the same domain. This indicates Taiwan and Korea improved and invested their semiconductor techniques. No wonder that both countries Taiwan and Korea are playing the important role in high-tech industries all over the worlds. Also, this indicates the semiconductor technology of Europe is not as competitive as before. Furthermore, Singapore becomes more mature in semiconductor techniques and the growth of techniques increases rapidly. The result matches the previous research proposed: the rise of latecomer Asian countries quickly grew up and also changed the scenario of the previous decade. [25-28]

B. Organizational level

Patent characteristics

The top three corporations with the highest percentages of litigated patents are 1) Semiconductor Energy Laboratory Co., Ltd. and 2) Advanced Micro Devices, both are above the global average. It indicates both have more valued patents in organizational level. There are 192,103 utility semiconductor patents and 547 litigated semiconductor patents issued by USPTO. Fig. 12 shows the top 10 companies with the largest volumes of total patents. The position of the companies on the y-axis follows the number of total semiconductor patents owned by each company where the Micron Technology, Inc. is positioned on the top and ranked as No. 1 and Intel Corporation is on the bottom and ranked as No. 10 in terms of number of patents. The Semiconductor Energy Laboratory Co., Ltd. has the large number of litigated patents and Samsung Electronics Co., Ltd. has only one litigated patent. For the top 10 first assignee companies, the percentages of litigated patents in the top 10 assignee companies is from 0.02% (Samsung Electronics Co., Ltd.), 0.06% (Intel Corporation), 0.07% (Kabushiki Kaisha Toshiba), 0.09% (Mitsubishi Denki Kabushiki Kaisha), 0.10% (Micron Technology, Inc.), 0.12% (International Business Machines Corporation), 0.13% (Texas Instruments Incorporated), 0.16% (NEC Corporation), 0.33% (Advanced Micro Devices, Inc.) to 0.45% (Semiconductor Energy Laboratory Co., Ltd.).

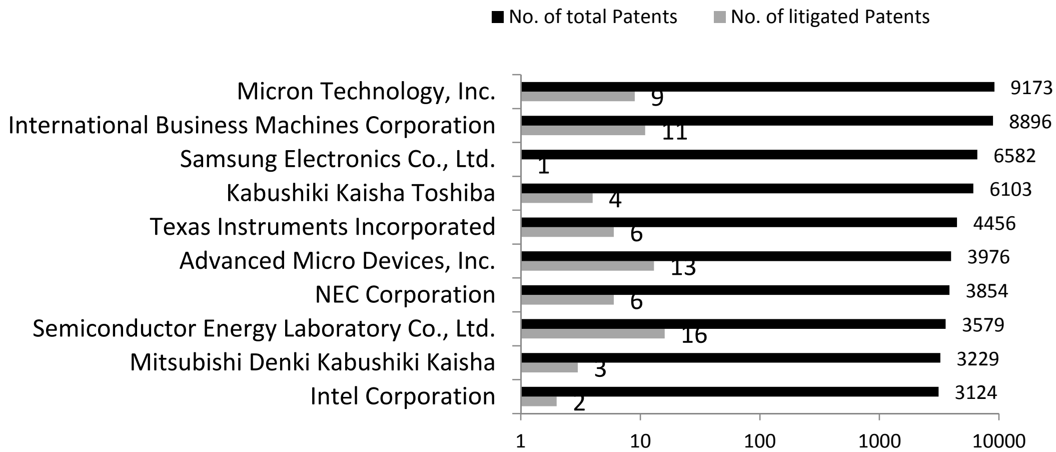

Fig. 12 Number of total and Litigated Patents in Top 10 First Assignee Companies (Top 10 Companies with highest numbers of patents)

Two-dimensional network diagram

The patent citation map with corporation as actor from 1976 to 2012 is shown in Fig. 13 where patents uniformly occupy different spots of the map and form a big continent, 4 domains reflecting pattern of global techniques. The leader corporations are almost US corporations, including Micron Technology, International Business Machine, Advanced Micro Device, Motorola, Texas Instruments and Intel Corporation; only few leader are not US corporations, such as Samsung Electronics, Fujitsu Limited and Kabushiki Kaisha Toshiba. It means that US corporations are powerful and influence in global semiconductor industry. Furthermore, this study observes there are lots of Japanese corporations, such as NEC Corporation, Canon Kabushiki Kaisha, Sony Corporation, etc. It indicates the Japanese corporations are more competitive in semiconductor technologies than the other countries except for the US. And the position between the US corporations and Japanese corporations is very close. It means that both of them learn knowledge from each other to sustain their competitiveness.

Also, this study compares with Table.4 (Semiconductor sales leaders ranking for year 2012), the US leader corporations are all in the top 20 semiconductor sales in 2012, except for IBM. The foundry activities of IBM are excluded from this table, but actually IBM was still in the top 20 before 2005. It has been widely accepted that the number of patents can be used to understand competitiveness and innovation. However, this study observes only the one domain which leaded by IBM doesn't include any corporations in top 20 sales, even though IBM is top 2 in term of patents number. It indicates IBM Corporation needs to be further explored. It is possible that IBM patent is not value to increase revenue, the competiveness is less in this domain, the R&D management is not appropriate, etc. Furthermore, the top 2 semiconductor sales leaders, Intel Corporation, and Samsung Electronics, are both in same domain. It shows that both of them sustain their competitiveness by learning each other and both of their patents play an important role in technique to dominate the market.

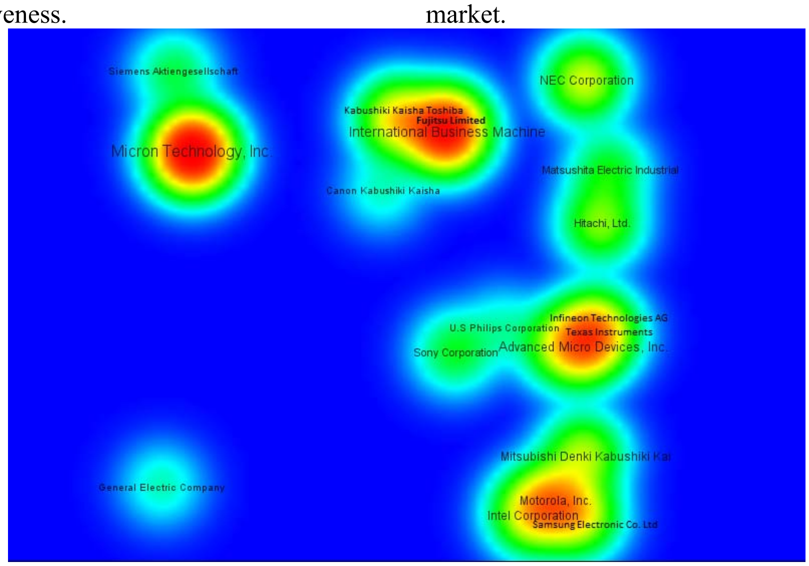

Fig. 13 2-dimensional patent citation map with corporation as patent as actor from 1976-2012

TABLE 4 SEMICONDUCTOR SALES LEADERS RANKING FOR YEAR 2012 (FOUNDRIES EXCLUDED)

Source: IHS iSuppli Semiconductor preliminary rankings for 2012

Rank	Company	Country of origin	Revenue(million $ USD)	Market share
1	Intel Corporation	USA	47 543	0.157
2	Samsung Electronics	South Korea	30 474	0.101
3	Qualcomm	USA	12 976	0.043
4	Texas Instruments	USA	12 008	0.04
5	Toshiba Semiconductor	Japan	10 996	0.036
6	Renesas Electronics	Japan	9 430	0.031
7	SK Hynix	South Korea	8 462	0.028
8	STMicroelectronics	France Italy	8 453	0.028
9	Broadcom	USA	7 840	0.026
10	Micron Technology	USA	6 955	0.023
11	Sony	Japan	6 025	0.02
12	AMD	USA	5 300	0.017
13	Infineon Technologies	Germany	4 826	0.016
14	NXP	Netherlands	4 096	0.014
15	NVIDIA	USA	3 923	0.013
16	Freescale Semiconductor	USA	3 775	0.012
17	MediaTek	Taiwan	3 472	0.011
18	Elpida Memory	Japan	3 414	0.011
19	Rohm Semiconductor	Japan	3 170	0.01
20	Marvell Technology	USA	3 113	0.01

IV. CONCLUSION

This study downloads a total of 192,103 semiconductor patents from USPTO and 547 of them are litigated patents. As shown in this study, different countries have different annual numbers of patents, Fig. 4. Although an overall trend of patent number increase over time can be obtained, a temporary decline is observed in a specific period of time, i.e. 1996, 2005, 2007-2008, 2012. As it has been widely accepted that patents can be used to understand industrial and economic developments, the overall patent growth trend indicates that the semiconductor industry is still developing. The comparison between Taiwan and Korea shows that both countries have been growing gradually since 1990s'; Taiwan has a lot more patents than Korea between 1999 and 2005; However, Korea overtook Taiwan between 2006 and 2012; China overtook Korea between 2011 and 2012.

The comparison between patent numbers and technological development explains how technology bottleneck influences patent number. As shown in Fig. 5, patent number and gross output value are correlated to each other. Also, a semiconductor technology life-cycle similar to those in other industry can be observed in Fig. 6. Global comparison on total patents and litigated patents, shown in Fig. 7, shows that the US has the largest number of both total patents and litigated patents. As the portion of litigated patents can be correlated to patent value [42][49], the percentages of litigated patents are calculated and compared. The top three countries with the highest percentages of litigated patents are 1) USA (0.43%), 2) Germany (0.46%) and 3) United Kingdom (0.50%), all are above the global average (0.28%). Fig. 12 shows that the Semiconductor Energy Laboratory Co., Ltd. has the large number of litigated patents and Samsung Electronics Co., Ltd. has only one litigated patent. The top three countries with the highest percentages of litigated patents are, 1) Semiconductor Energy Laboratory Co., Ltd. (0. 45%) and 2) Advanced Micro Devices, Inc. (0.33%) are both above the global average (0.28%)

Furthermore, in Figs. 8, 9, social network analysis on patent citation explores how patented technology development from different countries. Compared Fig. 8 with Fig. 9, obtains a dynamic and quantitative understanding of technology evolution by calculating patents' network properties at different time points. The 2-dimensional patent citation maps with country or corporation as actor are shown in Figs. 10, 11 and 13. This allows a straightforward view of the whole development of selected industry, and provides a quick idea of how the global technology has been developed, or a so-called knowledge map for positioning every patented technique in the patent citation map. Compared Fig. 10 with Fig. 11, the development of technology from different time and the position changes from the latecomer Asian countries can be observed. However, in Fig. 13, this study only demonstrates the construction of patent citation map with corporation by the use of overall patents without considering time horizon. The comparison between Fig. 13 and Table 4 explains the relation between the technology and sales revenue.

In Summary, this study provides a way of evaluating patents and understanding technology development in the 1) national, 2) industrial and 3) organizational level by a systematic pattern, which facilitates more efficient technology management. Also, this study focuses more on analyzing the characteristics of the patents and building social network diagram and 2-dimensional map. The development trend and the knowledge flow are investigated and visualized through the analysis of the basic patent statistics, technological life cycle, patent citations and patent information, etc. In addition, this study approach contributes to obtain an overview of the semiconductor industry. And the more important thing is this paper provides a quantitative way of evaluating patent, and possibly proposes patent strategies for patent portfolio. e.g. R&D resource allocation, research performance evaluation, patent valuation, 2-dimensinol patent map visualization, etc.

However, there are some limitations in this study. First, the selected patents are all issued by USPTO and this study doesn't analyze the patents from other patent database. Secondly, by the index method is through searching the International Patent Classification system; the selected patents not include IC related patents, but actually lots of semiconductor corporations participate in IC design.

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