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Applying Hybrid-Quantity Analysis in the Asia Semiconductor Industry

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Abstract: The semiconductor market has gradually transitioned from advanced countries to the Asian-Pacific region. Since the 1980s, Taiwan has been developing its own semiconductor industry, and after 20 years of effort, has become one of the world's major exporters of semiconductor products. Therefore, to position Taiwan in relation to other countries for competitive advantage, as defined by technology and industrial development, requires a better understanding of the developmental trends of the semiconductor technology of major competing countries in the Asian-Pacific region. This can further provide the Taiwanese government with additional strategic development proposals. We used a combination of patents, data-mining methods [multidimensional scaling (MDS) analysis, and K-means clustering] to explore competing technological and strategic-group relationships within the semiconductor industry in the Asian-Pacific region. We assessed the relative technological advantages of various organizations and proposed additional technology development strategy recommendations to the Taiwanese semiconductor industry.

Keywords: Semiconductor industry; patent-technology analysis; multidimensional scaling; k-means clustering

Introduction

Manufacturing industries have gradually transferred from advanced countries to the Asian-Pacific region. The manufacturing centers of the semiconductor industry have also transferred from Europe and the United States to Taiwan, South Korea, and China. Advanced countries have shifted their semiconductor-manufacturing bases to the Asian-Pacific region and have actively applied for patents related to manufacturing and R&D technologies. The large-scale transfer of core technologies to the Asian-Pacific region aims to make profits and save production costs, while further enhancing the R&D capabilities of the semiconductor industry.

We discuss how to effectively use systematic search methods in conjunction with multivariable models to conduct patent analysis and to further explore the following research objectives:

(a) Adopt a technology-positioning approach to analyze the strengths and weaknesses of the semiconductor industry in the Asian-Pacific region compared to the technologies of advanced countries.

(b) Assist members of the semiconductor industries in the Asian-Pacific region to face various technology barriers, and further analyze and evaluate how to strengthen the competitive advantage of the Taiwanese semiconductor industry.

Introduction to the Semiconductor Industry

Characteristics of the Semiconductor Industry in the Asian-Pacific Region

From the beginning of the twenty-first century, the growth of the semiconductor industry in the Asian-Pacific region has become the focus of considerable attention. According to an analysis by [1], in 2008, 43% of the total world production of electronic products was conducted in the Asian-Pacific region; a figure that is expected to rise to 50% by 2012. The growth of semiconductors, which form the core of electronic products, has been tremendous. According to a study conducted by the U.S. Semiconductor Industry Association (SIA), from 2004 to 2008, sales in the Asian-Pacific region were expected to experience an overall growth rate of 69%, with the amount of revenue in 2008 alone reaching USD150.4 billion. Of the various markets worldwide, the overall growth in the Asian-Pacific region is the highest.

Further analysis of this phenomenon indicates that other than Japan, which developed its semiconductor industry at an earlier period, investment by South Korea and Taiwan only commenced in the late twentieth century. The South Korean semiconductor strategy was mainly based on national government supervision, which pushed companies to expand from the top-down within a limited time period. The government provided maximum support by allocating a massive amount of funds to pay for the enormous costs involved. This development approach was similar to that of Japan and the United States, and is considered an integrated-development strategy. A company that falls under such a strategy is known as an integrated-device manufacturer [2]. In contrast, the Taiwanese government adopted a different approach, emphasizing the principle of original-equipment manufacturing (OEM). The government has also stratified the division of labor of the semiconductor industry's vertical-integration manufacturing process into five sub-industries, including design, photo-masking, manufacturing, packaging, and testing. The division of labor is based on the industry type. Each of these development strategies has its own advantages and disadvantages. South Korea’s semiconductor industry-development strategy rises and falls frequently as it follows the cyclical movement of various economic and political factors. Thus, such an overall development strategy is greatly influenced by the government and a few large enterprises. However, the overall developmental advantage of such a strategy is the synergy created, which is why the semiconductor industry in South Korea has the most competitive market prices. Using the South Korean semiconductor industry's most concentrated memory-chip development as an example, in a situation where memory-chip oversupply in the market has already caused profit contractions, strong government support and corporate economies-of-scale allow South Korean memory-chip manufacturers to maintain profitability [3, 4].

The South Korean semiconductor-development strategy requires enormous capital and a completely integrated upstream/downstream system to work. This type of strategy is currently used less in Asia-Pacific countries. The semiconductor-industry development strategy of Taiwan has higher flexibility, and the requirement for an integrated upstream/downstream system is less critical. Other Asian-Pacific countries, such as Singapore, Malaysia, and China, currently favor using this type of development model. Although this type of development strategy has lower-entry barriers, its ability to develop technologies that can achieve market economies-of-scale is more problematic. Therefore, discussing and integrating the technologies of Asian-Pacific countries is worthy of further analysis and assessment.

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Technical Analysis of the Semiconductor Industry

The technical analysis method in this study is mainly derived from the analytical methods by [5-7]. We first performed a quick breakdown of the technical analysis characteristics of the semiconductor industry. Because the technical characteristics of the semiconductor industry are complex, finding an appropriate categorization method for effective technical-industry classification is the main study focus. After determining the research object by expert analysis, we adopted the International Patent Classification (IPC) method of [6], combined with the revealed patent advantage (RPA) analysis method by [5] to conduct analysis to identify appropriate technology positioning. We then used this positioning to assist manufacturers in Asian-Pacific countries in technical analysis, and to assess the objectives and strategic planning for future development of the semiconductor industry by Taiwanese manufacturers.

Numerous researchers have attempted to use patent-clustering analysis to solve different types of problems. [8] incorporated an ontology schema to extract and represent patent concepts. They proposed a clustering algorithm with non-exhaustive overlaps to overcome the deficiencies of exhaustive-clustering methods used in patent mining and technology discovery. [9] proposed a novel hierarchical-clustering approach for knowledge-document self-organization, particularly for patent analysis. These two methods improve the current keyword-based methodologies for the patent-document content management of technical content that is used for cluster analysis. The hierarchical-clustering approach automatically interprets and clusters knowledge documents more effectively than traditional keyword methods. However, these methods require powerful text-mining programming ability and an understanding of machine-learning algorithms and are too difficult for general researchers to understand.

Methodology

Methodology Process

We conducted a literature discussion and secondary-data collection to determine the analysis targets. We then proceeded to conduct a comprehensive patent search. After classifying the retrieved patent-search information according to the patentee and IPC country of origin, we totaled the number of patents in each IPC category from each country. To calculate the comparative technological advantage of each country, we classified the patent information according to IPC standards, calculated corresponding patent counts, and converted them into a relative RPA index to represent the relative strength of different countries in various technology categories. Finally, we used the quantitative-dimension reduction of the multidimensional scaling (MDS) analysis technique and K-means clustering classification to obtain the position status within the technology category. The procedure is shown in Figure 1.

Multi-Dimensional Scaling and K-means Clustering Analysis

We used MDS analysis to explore the semiconductor technology-development positioning and strategic groupings of five countries. The analysis used N number of subjects, based on P number of criteria, to assess M number of objects for using spatial positions in observed values after clustering to conduct a perceptual-positioning analysis [2, 10, 11]. The original data and spatial degree of adaptability were reflected by stress coefficients. The smaller a stress coefficient is, the better the degree of adaptability, which often reduces the dimensions to 2 or 3D space. We applied K-means analysis for the adjacent points in space, according to data-point similarity, to determine strategic grouping.

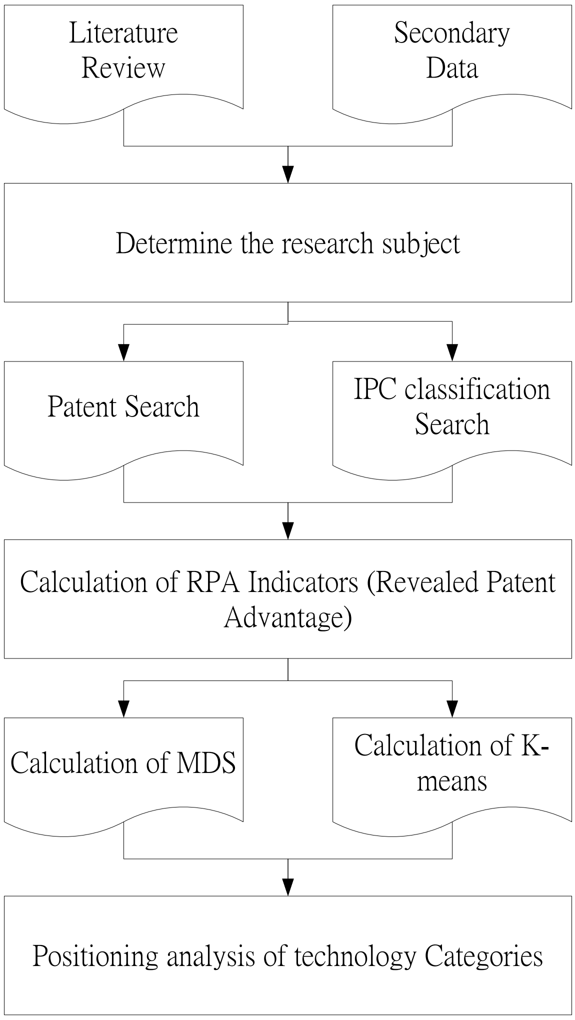


Figure 1. Research Process.

Research Results

Patent Search Results

The patent data was derived from the Worldwide Patent Statistical Database (PatSTAT), which contains 20 million items of patent information. We used USPTO-approved patent information from January 1976 to December 2009. The content includes the International Patent Classification IPC, name of patent, patent application date, patent publication date, patent approval date, patent category, patent inventor, and patent authority.

We used the eighth edition of the IPC system. Writing uppercase letters A-H in English is conventional to represent all IPC knowledge domains. "H" is the section in which semiconductor technology belongs within "Electricity." We used patent information to match to the research scope. Table 1 presents an explanation of the meaning of the various patent categories. Detail information can be shown at (http://www.wipo.int/ipc/itos4ipc/ITSupport_and_downl oad_area/20100101/definitions_viewer/en/en_20100101_definitions_viewer.htm); Table 2 shows the results after compilation.

Revealed Patent Advantage

Because R&D strategies differ among countries, strictly identifying the technological advantage by the number of patents is inappropriate. Therefore, we used the RPA proposed by Schmoch (1995) to evaluate the relative technological advantage of each country, which is defined as follows:

$$RPA_{ij} = 100 \tanh ln\left[(P_{ij} / \sum_i P_{ij}) / (\sum_j P_{ij} / \sum_i \sum_j P_{ij})\right] ,$$

where P_{ij} is the number of patents from j^{th} country in i^{th} patent category, and $\sum_i P_{ij}$ represents the total number of patents from j^{th} country. Therefore, the value of $P_{ij} / \sum_i P_{ij}$ represents the importance of the i^{th} patent category for companies in j^{th} country. The $\sum_i P_{ij}$ represents the total number of patents in the i^{th} technology category, with $\sum_i \sum_j P_{ij}$ representing the total number of patents. Therefore, $\sum_j P_{ij} / \sum_i \sum_j P_{ij}$ represents the importance of the i^{th} technology category to industry technology. Variable $\left[(P_{ij} / \sum_i P_{ij}) / (\sum_i P_{ij} / \sum_i \sum_j P_{ij})\right]$ represents the distribution use of overall industry patents to measure the relative importance of the i^{th} patent category to the j^{th} country. However, the difference in the importance level of various technology categories among countries could be large and could form maximum or minimum extreme values, affecting subsequent position analysis. Therefore, we used the ln function to manage extreme values and the tanh function to adjust the technology intensity to a value between 1 and -1. We multiplied the calculated result by 100, making the final RPA value fall between -100 to 100.

Finally, we used the RPA value to describe the technological strength of a specific country. Regarding a specific-patent category, its value is bound from -100 to +100. A positive RPA value represents a relatively high technology level. A negative RPA value represents a relatively low technology level. A difference of 15 or more between two RPA values indicates a statistically significant difference between the two technological capabilities. By combining the RPA formula with data shown in Table 2, we obtained 33 types of RPA values in the technology categories of five countries, as shown in Table 3.

Table 1. Definition of IPC Categories [12].

IPC Categories	Meaning
H	Electricity
H01	Basic electrical components
H01L	Semiconductor Equipment
H01L21	For the manufacture or processing of semiconductor devices or components or solid methods or equipment
H01L23	Semiconductor devices or other solid components
H01L25	Most single semiconductor devices or other solid components of the assembly
H01L27	A common substrate formed in or on the number of semiconductors or other solid components of the device
H01L29	Semiconductor devices specially adapted for rectifying, amplifying, oscillating, or switching and having at least one potential-jump barrier or surface barrier; Capacitors or resistors with at least one potential-jump barrier or surface barrier (e.g., PN-junction depletion layer or carrier concentration layer)

Table 2. Countries Involved in the Semiconductor-Technology Category and Approved Patents.

	Taiwan	Japan	South Korea	China	Singapore	Subtotal
H01L21/0	6,213	25,499	4,921	52	667	37,352
H01L21/1	11	117	12	0	3	143
H01L21/2	2,110	9,828	1,804	15	245	14,002
H01L21/3	6,252	18,917	4,747	53	749	30,718
H01L21/4	2,769	6,757	1,872	37	371	11,806
H01L21/5	352	2,310	194	4	82	2,942
H01L21/6	1,326	8,780	771	15	94	10,986
H01L21/7	7,102	16,011	4,554	35	735	28,437
H01L21/8	4,256	8,689	3,041	42	221	16,249
H01L21/9	21	139	10	0	1	171
H01L23/0	386	2,567	233	7	61	3,254
H01L23/1	261	2,813	175	1	25	3,275
H01L23/2	439	3,233	275	7	65	4,019
H01L23/3	1,246	4,427	384	53	122	6,232
H01L23/4	2,655	15,455	1,556	48	248	19,962
H01L23/5	1,897	10,376	1,039	16	240	13,568
H01L23/6	390	1,042	109	3	34	1,578
H01L25/0	149	1,214	74	4	10	1,451
H01L25/1	47	781	61	1	3	893
H01L27/0	1,023	7,919	735	23	94	9,794
H01L27/1	2,016	12,948	2,139	24	75	17,202
H01L27/2	44	660	98	0	1	803
H01L27/3	34	497	82	0	0	613
H01L29/0	798	7,837	1,096	18	78	9,827
H01L29/1	208	2,139	257	6	9	2,619
H01L29/2	149	1,125	102	0	25	1,401
H01L29/3	15	452	20	1	1	489
H01L29/4	1,618	7,699	1,415	15	184	10,931
H01L29/5	73	594	58	0	20	745
H01L29/6	866	6,944	934	10	71	8,825
H01L29/7	1,937	13,353	2,102	31	147	17,570
H01L29/8	126	1,858	104	10	6	2,104
H01L29/9	334	2,023	377	5	19	2,758
Subtotal	47,123	205,003	35,351	536	4,706	292,719

Table 3. RPA Value of Technology Categories.

	Taiwan	Japan	Korea	China	Singapore
H01L21/0	3.269765	-2.55532	8.67928	-26.7402	10.46387#
H01L21/1	-62.8237	15.4276	-34.8778	0	26.00318#
H01L21/2	-6.59644	0.222377	6.460257	-49.0008	8.447576#
H01L21/3	23.02984	-12.7895	24.16733	-5.94079	39.3986#
H01L21/4	35.95163	-19.9143	26.57506	49.1009	58.51205*#
H01L21/5	-28.8346	11.38506	-54.0669	-28.9221	50.07069#
H01L21/6	-28.0296	13.12811#	-49.5106	-28.5346	-55.8539
H01L21/7	41.2929	-21.4827	27.49412	-37.7606	44.20686#
H01L21/8	45.16334*#	-26.3425	41.20197*	33.16822	-16.5707
H01L21/9	-26.4266	14.79059#	-62.0115	0	-76.6295
H01L23/0	-29.6202	11.84822	-47.9793	15.97246#	15.24115
H01L23/1	-60.6332	20.13336#	-67.2559	-94.5891	-63.205
H01L23/2	-36.9494	13.76858#	-51.3985	-5.00023	0.597362
H01L23/3	21.33639	1.421238	-58.69	91.13905*#	19.44359
H01L23/4	-18.8647	9.99557	-41.184	26.59026#	-25.222
H01L23/5	-14.0062	8.774364	-42.6466	-41.3683	9.52547#
H01L23/6	40.42219#	-5.876	-50.6997	3.751539	28.473
H01L25/0	-42.1578	17.60043	-69.7316	38.77255#	-68.9524
H01L25/1	-80.6868	21.85921#	-51.5232	-45.5606	-91.6323
H01L27/0	-40.7474	14.27028	-44.2848	24.37933#	-47.4495
H01L27/1	-30.7207	7.197947#	2.91909	-26.5385	-86.2984
H01L27/2	-79.235	15.87203#	1.04988	0	-98.8071
H01L27/3	-78.778	14.53763#	10.1886	0	0
H01L29/0	-59.4326	12.9185#	-7.94125	0.0317	-60.804
H01L29/1	-60.8514	15.25346	-20.4654	22.03708#	-91.2614
H01L29/2	-39.2324	13.59385#	-46.6887	0	10.39324
H01L29/3	-92.9928	27.05973*#	-79.4214	11.00245	-96.8155
H01L29/4	-8.37633	0.567609	6.93019#	-28.0729	4.592019
H01L29/5	-45.9339	12.89615	-41.2861	0	47.2064#
H01L29/6	-45.8181	11.5954#	-13.122	-44.6183	-59.9451
H01L29/7	-36.1492	8.155513#	-0.94169	-3.71097	-57.3781
H01L29/8	-75.6877	22.7782	-71.3029	74.15092#	-93.8992
H01L29/9	-27.722	4.623129	12.32409#	-0.99886	-68.9734

Note: * Strongest performing country within the category: # Strongest performing specific-technical category of a country.

MDS Analysis of Semiconductor-Technology Positioning for Each Country

We first divided the approved patents from the five countries in the semiconductor-technology category into 33 technology categories according to the IPC. However, the highly complex nature of the data hindered clear expression of the positioning of these countries; therefore, we reduced the dimension based on the streamlining principle. This allowed us to fully disclose the technology positioning of each country. Therefore, we used the least squares method of SPSS to perform MDS analysis. The resulting MDS analysis was used as the main analytical tool to use smaller dimensions to explain the relative distance in technological capabilities among countries. The more dimensions used during analysis, the more accurate the information expression of the object under analysis. Analysts must choose between dimension reduction and explanatory power. We only used two dimensions to express the semiconductor-technology positioning of each country, as shown in Figure 2; this explains approximately 78% of the data variance. The horizontal and vertical axes indicate the two dimensions using this method.

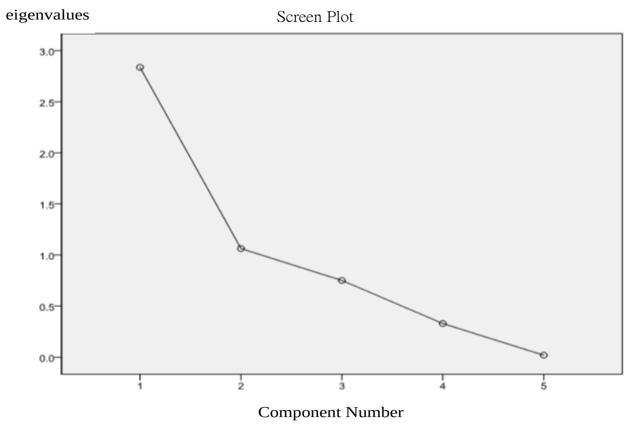


Figure 2. Screen Plot of Dimensions.

Technology Positioning

We conducted MDS analysis on the RPA indicators of the 33 technology categories in these five countries to estimate the technological-positioning score of each country in 2D space, as shown in Table 4. The patterns of these 33 types of technology categories in technology-positioning space are shown in Table 5. From the obtained score pattern, we drew a perceptual similarity map for the semiconductor-technology development of each country and the layout position of the semiconductor-technology field for the five countries of Taiwan, Japan, South Korea, China, and Singapore, as shown in Figure 3. The technological-positioning diagram adopts the relative capability of each country in various technology categories to analyze the technology-capability similarities of countries and technology categories. Therefore, by projecting each country score on the positioning map as the length of the technology-categorization vector, we derived the original index value representing the relative capability of each country in various technology categories.

Table 4. Semiconductor-Technology Positioning of each Country.

	Horizontal Axis	Vertical Axis
Taiwan	0.951	0.1216
Japan	-1.5749	-0.5156
South Korea	0.5907	1.1122
China	-1.3644	0.2224
Singapore	1.3976	-0.9406

Analysis of the Main Technology Categories

We further used the K-means clustering method to group various technology categories according to their strengths using the main technology focus in the semiconductor industry of each country as the clustering criteria. A cluster of four groups reaches a convergence condition where its within-group difference is minimal and its between-group difference is maximal. We also judged it to be a cluster possessing similar resources and implementing similar strategies according to definitions proposed by [13, 14]. Through interviews with experts and literature review, we effectively defined the 33 technology categories into four groups, which are defined as follows:

Group 1: Semiconductor-component assembly process group. The fourth-order IPC of this group is focused on H01L21 and H01L23, where H01L21 is defined as the patents for semiconductor-manufacturing processes and H01L23 is defined as the patents for semiconductor-component parts. Such a grouping can be used to determine the strengths and weaknesses of the semiconductor-component assembly process. This group is more suitable for determining the capabilities of the semiconductor-manufacturing process.

Group II: Semiconductor-assembly technology group. This group contains H01L21 semiconductor-manufacturing process patents, H01L25 semiconductor-component patents, and H01L29 semiconductor-material patents. The combined characteristics from these three patent groups are more appropriately assigned to the semiconductor-assembly technology group.

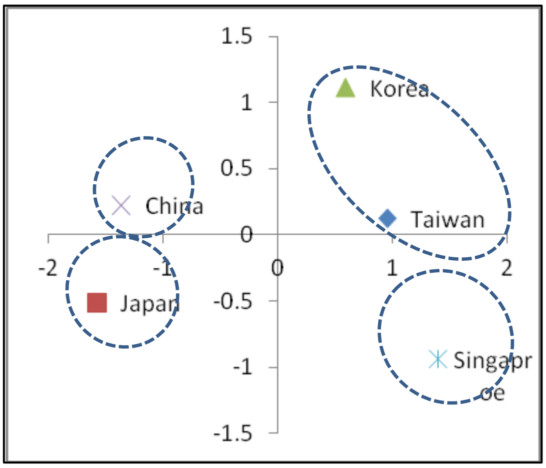
Table 5. Technology Positioning within Technology Categories.

	Horizontal Axis	Vertical Axis
H01L210	1.3829	-0.7278
H01L211	0.1604	-0.5825
H01L212	0.825	-1.1028
H01L213	2.6961	-0.0607
H01L214	2.7106	1.0407
H01L215	0.7386	-0.6127
H01L216	-1.2713	-0.3891
H01L217	2.3972	-0.4035
H01L218	1.6894	1.9113
H01L219	-1.0907	0.3551
H01L230	0.1388	0.2407
H01L231	-0.9339	-1.0554
H01L232	-0.3861	-0.6364
H01L233	0.8013	1.0283
H01L234	-0.3261	0.6787
H01L235	0.085	-1.466
H01L236	1.3852	0.2297
H01L250	-0.9061	0.7105
H01L251	-1.3018	-0.4503
H01L270	-1.0888	0.6036
H01L271	-0.8466	0.3647
H01L272	-1.1106	0.4899
H01L273	0.0183	-0.1346
H01L290	-1.2561	0.2314
H01L291	-0.9162	0.613
H01L292	-0.2309	-0.7778
H01L293	-1.4547	0.097
H01L294	0.777	-1.0438
H01L295	0.729	-0.4047
H01L296	-1.207	-0.6939
H01L297	-1.0051	0.4067
H01L298	-0.6307	0.7606
H01L299	-0.5724	0.7801

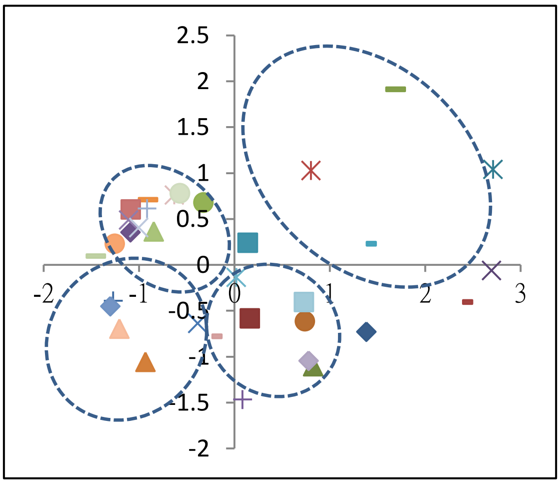
Group III: Semiconductor-materials design group. This group contains the four major IPC categories of H01L21, H01L23, H01L25, and H01L29, but only a small amount of IPC. According to IPC analysis, this group leans more toward the design process, and therefore, is defined as the semiconductor-material design group.

Group IV: The component assembly-process technology group includes partial H01L21, H01L23, H01L27, and H01L29 categories. This group is more suitable for use in determining overall integrated manufacturing, and therefore, is considered a packaging-test group.

We also grouped countries, such as Taiwan, Japan, South Korea, China, and Singapore, into four major categories. The first category is the component assembly-process technology of Taiwan and South Korea; the second category is the packaging technology of China; the third category is the material-design technology of Japan; the fourth category is the component assembly-process technology of Singapore. We aggregate the results of MDS and cluster analysis in Figure 3.



(a) Technological positioning distribution cluster



(b) Semiconductor technology

Figure 3. Distribution for Semiconductor Technology-Positioning of each Country.

Table 6. Countries with Strong-Technology Positions and Expert Opinions.

Country	Strong technology position (IPC code)	Expert opinions
Japan	H01L29/3 (most significant technology), H01L21/6, H01L21/9, H01L23/1, H01L23/2, H01L25/1, H01L27/1, H01L27/2, H01L27/3, H01L29/0, H01L29/2,H01L29/6, H01L29/7(superior technology).	Japan leads Asia in the semiconductor industry; however, it lost production ability following the 2011 Tohoku Earthquake. (http://www.teema.org.tw/english/index.aspx)
Taiwan	H01L21/8 (most significant technology), H01L23/6(superior technology).	Taiwan excels in IC design, foundry, and packaging and testing, LED, and other related industries. Foundry and IC packaging and testing continue to rank first worldwide, IC design ranks second worldwide. Semiconductor equipment and materials, and the amount of investment in Taiwan ranked second worldwide in 2012.(Department of Investment Services, Ministry of Economic Affairs, 2008) [15] (http://www.elecsound.cn/news/571.html)
South Korea	H01L21/8,H01L29/4, H01L29/9 (superior technology), No more significant technology (Korea generally seems very strong in many areas, however, in this study this country just shows superior in many areas, with no significant technology).	Semiconductor exports in South Korea posted a record high last month. Their semiconductor market-share worldwide has also exceeded 50%. According to the Ministry of Knowledge Economy on September 7, 2010, semiconductor exports in August set a record high of USD 4.740 billion, 64.9% higher than the same period last year. (http://www.investkorea.org/)
China	H01L23/3 (most significant technology), H01L23/4, H01L25/0, H01L27/0, H01L29/1, H01L29/8.	Since the late 1980s, the Chinese government has attempted to build an indigenous semiconductor industry by providing financial incentives, developing talent and technology, and crafting alliances with global players. Although the country has assumed a central role in manufacturing numerous computing and consumer-electronics products, its role in the semiconductor sector has remained surprisingly limited. In the industry value chain, China has a strong share in assembly-and-test and back-end-manufacturing segments. Aside from these two (admittedly considerable) areas, the country is largely missing from semiconductor-league tables. (http://www.mckinsey.com/client_service/semiconductors/latest_thinking/the_challenge_of_china)

Singapore	H01L21/4 (most significant technology), H01L21/0, H01L21/1, H01L21/2, H01L21/3, H01L21/5, H01L21/7, H01L23/5, H01L29/5.	Singapore's eminence in the electronics industry is evident in the quantity and scope of facilities currently located in the country. Singapore is home to over 14 semiconductor wafer-fabrication plants (including two 300 mm fabrication plants), 20 assembly and test operations, and 40 IC design centers. However, numerous disk-drive manufacturers have moved to lower-cost countries, leading to less assembly and testing activity in Singapore. Specialization in Microelectronics, report by Prof. Hua Chun Zeng

Table 4 shows that each country possesses different technology strengths. For Taiwan that is H01L218, for Japan it is H01L293, for South Korea it is H01L218, for China it is H01L233, and for Singapore it is H01L214. Taiwan and South Korea are technically competing with each other. In addition to H01L218, Taiwan also possesses a technological advantage in H01L236; South Korea is stronger in H01L294 and H01L299. Japan and Singapore have a significant cluster in semiconductor-technology patents. Japan is more concentrated in H01L27, whereas Singapore is more concentrated in the H01L210-H01L215 classes. The technology categories in China that are more prominent have not been mentioned. For example, H01L233, H01L298, or H01L270 are categories that significantly avoid high-patent concentrations.

We conducted further analysis of the strategic implications of the country-based groups. Although Taiwan and South Korea have followed different development strategies, both are included in the same quadrant and the same group cluster, with key development areas toward manufacturing and component design. Examining overall development indicated that Taiwan in Group 1 tended toward Group 4, and South Korea in Group 1 tended toward Group 2. This indirectly shows that Taiwan and South Korea have recently shown different strategies in semiconductor development, with Taiwan moving more toward overall integrated manufacturing and South Korea moving more toward semiconductor-component manufacturing processes. A comparison of the development trends in Taiwan with those of South Korea shows that the Taiwanese semiconductor industry has recently gained certain advantages in assembly testing and manufacture-processing capability. However, it has certain disadvantages in components, including memory chips. South Korean memory manufacturers have excellent market-control ability.

Singapore is closing the gap with Taiwan and South Korea, and shows advantages in integrated manufacturing (packaging and testing) and manufacture processing. However, Singapore has emphasized semiconductor-manufacture processing and packaging, whereas China is emphasizing semiconductor component manufacturing. The two countries have adopted different development strategies for their semiconductor industries. Although certain scholars believe that Taiwan heavily influences the semiconductor industries in both countries, China prefers semiconductor related component manufacturing (e.g., memory chips), whereas Singapore prefers OEM because of the advantage of its geographical location.

Because of the early development of the Japanese semiconductor industry, its application of materials technology and manufacturing is demonstrated by an excellent record in patent publication. The patents produced by Japan are comparable to the patents from the other four Asian countries in manufacturing and components. Compared to other countries, Japan tends toward raw-material technology development in upstream-manufacturing supply chains. Earlier patent development results in higher patent numbers.

Numerous semiconductor experts in semiconductor-strategy research have confirmed the accuracy of our experimental research. Following Research Digitimes (http://www.digitimes.com.tw/tw/rpt/rpt_4.asp?CnlID=3), these researchers believe that Taiwan and South Korea are similar, and Singapore is closing the gap among them. China leads in semiconductor-component manufacturing and Japan is the Asian winner in the semiconductor industry. The reviewer comments are shown in Table 6.

Conclusion

The semiconductor industries in these five Asian countries all have their own specialties. Other than Japan (which developed early and favors material design), the semiconductor patents in the other countries are all concentrated in production and manufacturing. The recently acquired industry upgrade by Taiwan and South Korea is tantamount to a warning message. Improving semiconductor-industry development from production technology toward material-design technology is a critical issue for the other four Asian countries in this study.

Because of its recent integration advantage, South Korea has gradually transitioned to component production from its original manufacturing process. Unlike the unique focus on development in China, South Korea has pursued comprehensive development. Relative to Taiwan, which emphasizes the manufacturing process and integrated testing, South Korea has gradually moved from downstream toward midstream manufacturing. How to improve Taiwanese industrial competitiveness, and how to unleash the advantage of being second in the number of semiconductor patents are worthy questions for semiconductor-industry researchers and government agencies to consider. We suggest that Taiwan take advantage of the opportunity to integrate components from mainland China, while consolidating semiconductor-industry research on both sides of the Taiwan Strait. Further market integration will unleash synergic power, leading to improvements in the Taiwanese semiconductor industry by moving toward upstream-material design.

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