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Finding Research Gems for Cooperation -A Pilot Study about LED Technologies to Bridge China's Universities and Taiwan's Industries

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ABSTRACT: As the political tension between Taiwan and China eases, R&D capability of Chinese research institutions have gained more attention. By statistics, the patent application from Chinese universities has surpassed public research organization during the same period of time. This study ascertains how academic achievements in China can be strategically introduced to Taiwan. The research methodology consists of a case study of cross-strait LED industries, bibliometric analysis of journal publications and patent counts from five selected universities to identify suitable partners and technologies for future cooperation. In addition, legal viewpoints are also proposed as the reference of IP management and strategic planning. Three models of cooperation are suggested to accommodate different natures of internal R&D in Taiwanese counterparts: joint R & D, a center-satellite system, and research outsourcing. The study unearths academic intelligence of LED in China, and considers what Taiwan, a close neighbor and partner of China, can do about in the fierce global competition. This pilot study offers a scientific approach in decision-making and can be further extended to many other fields of interests.

KEYWORDS: Patent analysis; LED; R&D Management; Innovation management.

I. INTRODUCTION

According to a report in 2008, China is emerging as one of the leading innovation countries based on the worldwide patent statistics and its patent portfolio became more high-tech focused, resembling the developed countries' portfolios [1]. After the economic crisis, intellectual property (IP) fillings worldwide rebound strongly in 2010. In China, IP growth rates were even more than double its GDP, with 24.3% for patent applications and 29.8% for trademark applications [2]. In the 11th and 12th five-year planning in the mainland China, patents, standards and other related intellectual properties are highly emphasized and seen as concrete performance indicators as the degree of innovation. Research institutions contribute greatly to industries through new inventions. The prominence of university patenting in China was confirmed by the national patent statistics, where university accounts for more than 13% of total patent applications from 1980 to 2010, while the public research organization approximately 7% [3]. It is also worth mentioning that most of the R&D funding in China comes from the national key science and technology programs and these projects are often entrusted to universities and research institutes [4].

Taking the development of LED technology as an example, the global players and their market shares include Japan (30%), Korea (26%), the U.S. (11%), and Europe (8%), whereas Taiwan and China take 19% and 6% respectively [5]. In addition, many countries, including the U.S., Japan, and Korea, are rushing to set their own standards [6]. It is

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foreseeable that various LED standards will compete with each other. In addition, the LED industry in China is rapidly becoming Taiwan's serious competitor. In the past, the development of China's LED industry focused on the downstream, and Taiwan might still have a dogfight with China in the downstream LED industry [7]. Currently, China is investing heavily in the upstream. Both epitaxies and sapphires are required in the upstream LED industry. In 2010, 124 billion RMBs were invested in epitaxies, corresponding to 57% of its total LED investment in that year, and 22.7 billion RMBs were invested in sapphires, roughly 10% of the total amount [8].

That being said, some analysts have warned that the expansion of the LED market in China is going too strong and fast to maintain its momentum. China has strategically promoted domestic production since 2008 with government incentives on 2" MOCVD (Metal-organic Chemical Vapor Deposition), the special machine manufacturing epitaxies. In 2011, the number of MOCVD in China increased by more than 400, nearly 60% of worldwide new installations of MOCVDs in that year [9]. Capital invested in the entire LED market was also too large to be well-managed. Some heavily-funded LED companies in China exhibit poor return on assets. On the other hand, LED is a major industrial technology which the government in Taiwan has been strongly promoted. Considering the potential market size, production bases, and supply chain on the other side of Strait, the Taiwan LED industry must work with Chinese partners, though the circumstances are harsh. As a result, the LED industry is one of the chosen industries of the Cross-Strait Bridge Building Project (hereafter the Project) planned by Taiwan's government [10]. The Project is envisaged to coordinate activities and efforts from various companies in both China and Taiwan by building a "unified" platform where different parties of interests can align their product development, form industrial standards, build cooperation in production and marketing and find investment partnership. In fact, Taiwan's LED companies have found a strategy by building joint ventures with China's local governments and companies rather than competing with them directly, leading to new LED alliances between China and Taiwan [11]. The strategy enables Taiwan's LED companies to easily connect with local retailers.

II. RELATED WORK

However, it is equally important for Taiwan's LED companies to consider how to reinforce their R&D activities. Under these circumstances, one has to ask whether how two companies or research institutions in different countries initiate the cooperation. As previously mentioned, more patent applications have been filed from Chinese universities than research institutions since decades. Traditionally, university-industry cooperation has featured a linear model of innovation describing industrial innovation as a process of basic research, applied research, and commercialization [12]. The use of science as a means to generate competitive advantages on part of the firms, the integration of scientific research and industry and the globalization of the economy are subjects analyzed in several papers [13-19]. Basic research at universities provides the building blocks for future products in the market. The cooperation between industry and university, seen as a link, can create synergies which lead to the improvement of the economic and technological potential of partners that cooperate, and consequently, to increase the level of competitiveness of universities, companies and countries [20].

Additionally, technology selection can be a critical challenge in decision-making. Fuzzy Delphi method is utilized to obtain critical factors of technology or criteria for selection [21]. The analytic hierarchy process (AHP) was proposed by Saaty[22] and is widely used tool for decision makers to evaluate each technology alternatives against the set of previously identified criteria. The combination of fuzzy Delphi and AHP is employed to build a technology selection framework [23]. On the other hand, Ma applied bibliometric method on patent information for technology opportunities analysis (TOA) to support policy-makers or managers in making strategic technical decision in the dye-sensitized solar cell technology [24].

From the aspect of a Taiwanese enterprise or manager, the IPs, manpower, funding and other resources associated with certain academic institution could be valuable foundation for the business development or alliance in near future. The literature argues that the technology transfer generally occur through licensing, foreign direct investment, trade in goods and services, and movement of personnel [25, 26]. In fact, all these four channels all play roles with different degree of importance for LED companies across the Taiwan Strait during the course of competition and/or cooperation. From the government viewpoint, though the decision making is often done by high-level officers as the Elite theory

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suggests, a science-based selection methodology, e.g. bibliometric analysis, will be more beneficial and objective, so that a relatively fair evaluation can be performed. In fact, patent information and analysis has been used to facilitate various R&D stages from innovation[27], to technology transfer[28].

The objective of the study was to conduct a patent analysis of LED technologies on selected Chinese universities. Considering the time gap between the public date and filing date of a patent, we also included an analysis based on scientific publications to reflect the up-to-date research progress. Next, various research groups from aforementioned universities would be identified as the potential and prioritized partners for collaboration. Different models of cooperation were suggested by taking into account of the delicate situation between China and Taiwan. Finally, related legal viewpoints were also suggested for strategic planning and management. Our study is envisaged to help Taiwan's LED industry identify valuable research activities and teams in China and the information can be used as the knowledge reference for technology transfer or industry-academia cooperation in near future.

III. METHODOLOGY

In an attempt to bridge the LED industries in Taiwan and China, this study applied bibliometric analysis to search for the technology fields, either upstream or downstream, with the associated research teams for Taiwan to engage in R&D cooperation. It is also to note that technology licensing can only occur when one of the parties owns valuable intangible assets, known as Intellectual Property (IP)[29] Patent is one of these important assets which can be publicly accessed. Though patent data provides an effective way to learn information of a specific technology or general trend [30], it is worth noting that even the latest issued patents only disclose information two to several years ago due to the examination process. As a result, it will be necessary to include the analysis of journal publications which contain the most up-to-dated research findings.

The study targeted international journal publications, patent counts in China (SIPO) and the US (USPTO), assisted with market reports to explore the current LED-related technologies and R&D achievements obtained by five of China's leading universities: Tsinghua University (THU), Shanghai Jiao Tong University (SHJT), Harbin Institute of Technology (HIT), Zhejiang University (ZJU), and Huazhong University of Science and Technology (HZUST). This study expected to identify the extraordinary LED technologies possessed by the five leading Chinese universities and to suggest cooperation models.

3.1 Patent Search

Patent documents serve as traceable records of knowledge flows, and they are trustworthy [31]. Commercial patent analysis software was used in the study as the main analysis tool for the analysis of previous patent trends, International Patent Classification (IPC) analysis, corporate R&D intensity analysis, and review of the patents applied for by each research team, to understand the directions and technological features in the five universities' major developments.

The patent databases of China's State Intellectual Property Office (SIPO) and United States Patent and Trademark Office (USPTO) were explored. A patent database can be divided into two categories: issued patents and published patent applications. The former refers to the patent data being properly reviewed and approved, whereas the latter includes information automatically published 18 months after the filing of patent applications. It is clear that the former is more accurate for this study's purposes because the patents have gone through the review process. However, time lag often occurs because the issued patents were largely filed two or three years or more before approval. The analysis of published patent applications captures recent development trends through the number of applications, but there is a certain level of inaccuracy and uncertainty because published patent applications still await approval. Therefore, the patent analysis performed in this study targeted at issued patents and the bibliometric procedure is illustrated in Figure 1.

3.2 Journal Publication Search

The Thomson Reuters Web of Science (WOS) database served as the major source for the statistics on academic papers. As a database system that covers the fields of natural and social sciences, the WOS database possesses a collection of more than 10,000 important journals worldwide, providing over 1,100,000 bibliographies and 23,000,000 citing articles

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each year, and so science researchers rely heavily upon it. In addition, the unique citation indices of this database allow researchers to obtain more complete research reference information and follow the directions of previous studies while gaining a better understanding of the studies of their peers and opponents.

The WOS system contains three major databases: (1) Science Citation Index Expanded (SCI), (2) Social Sciences Citation Index (SSCI), and (3) Art and Humanities Citation Index (A&HCI). This study uses the first database as its main instrument. Unless otherwise specified, this study focuses on the WOS journal papers (including conference papers) published between 2006–2011 to mitigate the time lag regarding the disclosure of patents.

The publication search helps researchers to keep abreast of the latest worldwide developments and trends in (academic) R&D through the analysis of academic literature. However, problems such as missing or incomplete data might occur during the publication search, when identifying authors and their belonging groups or laboratories. We provide explanations for the following four aspects to improve the quality of data interpretation: (1) data sources for publication search, (2) identification of authors of the papers searched, (3) queries, and (4) a solution.

1. Data sources for publication search:

The search procedure consists of four major steps: (1) entering keywords in the topic field and the English name of a university in the address field to perform a search; (2) correcting the name of the institute according to the results obtained in the preceding step, and correlate the results; (3) sorting the search results on the basis of the number of citations, and start from the top ten papers, and extend the scope if necessary; (4) output the data in the topic field and confirm the results manually to prevent from low accuracy caused by abbreviated keyword searches in the system.

2. Identification:

Investigate authors listed in the author field. Special attention was given to the first author and the corresponding author. One the representative author is confirmed, it is also necessary to identify the belonging research group or laboratory under one of the five targeted universities.

3. Queries:

The questions usually occurred including whether the name shown in the author field is only a Romanized abbreviation, whether the authors are not full-time research scholars but graduate students or visiting scholars, and whether the original authors have resigned.

4. Solution:

The identity of representative authors could be assisted by referring to different online databases or official university websites. In the event the author's identity could not be verified, only the name of the institute or department was entered.

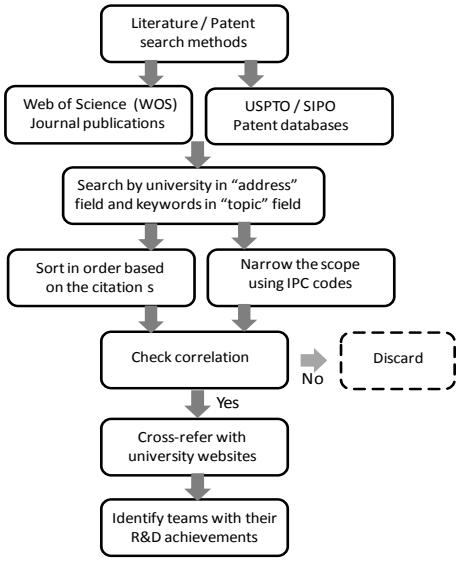

Fig. 1Bibliometric methodologies for the patent and literature research

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IV. BIBLIOMETRIC ANALYSIS RESULTS

4.1 Overview of Selected Universities

As an overview, the numbers of journal publications in WOS, issued Chinese patents in SIPO and US patents in USPTO from five selected universities were investigated. Overall, Zhejiang University ranks high in both the number of issued patents and the total number of academic papers published. Tsinghua University holds the second highest number of total issued patents. Shanghai Jiao Tong University has the second largest number of journal publications and ranks third in the issued patents. Harbin Institute of Technology and Huazhong University of Science and Technology, in comparison with the other universities, have fewer patents and research papers. Huazhong University of Science and Technology has a higher proportion of utility model patents, but Harbin Institute of Technology produced the fewest research papers among the five universities. The research findings suggest that these differences seem directly related to the size and policies of the universities as well as the resources invested. Table 1 provides a summary of the universities' overall performance.

Table 1 General distribution of patents and research papers of the five universities

R&D Outcomes / University	Number of WOS Papers(2006-2011)	Number of Patents at SIPO			Number of Patents in USPTO
		Invention	Utility Model	Design	
Zhejiang University	29,224	10,172	3,000	353	6
Shanghai Jiao Tong University	24,226	7,787	619	18	2
Harbin Institute of Technology	12,438	4,321	462	7	1
Tsinghua University	19,387	9,365	1,556	16	424
Huazhong University of Science & Tech.	13,516	2,174	n/a	18	6

4.2 Chinese Patents

This research targeted issued patents whose assignees belong to these five selected universities. The results were sorted by time to observe the trends over the past decade. This study further identified the development trends at each university, as exhibited in Figure 2, on the basis of patent counts. Here, we can observe the patent application performance of each university in recent years and the differences among them. In terms of invention patents, Shanghai Jiao Tong University and Huazhong University of Science and Technology exhibit a decline in the number of invention patents over the past few years, but the other three universities display overall growth trends, particularly Zhejiang University, which tops the other four universities, as shown in Figure 2(a). Figure 2(b) reveals that in utility model patents, all the universities seem to maintain a certain number of applications each year except for Zhejiang University, which demonstrates substantial growth. The same situation occurs in the applications for design patents. As illustrated in Figure 2(c), the four universities other than Zhejiang University seem to pay no particular attention to design patents. In general, we can see that Zhejiang University demonstrates the most remarkable performance; in addition to outstanding performance in invention patents, this university has devoted efforts to utility model patents and design patents. In fact, many fields of technology require integration of invention patents that embody advanced concepts of R&D with the utility model patents or design patents necessary for market applications and product development.

Hence, the balanced performance of Zhejiang University pertaining to patents might indicate that the university is capable of conducting integrated development in related fields of technology. It seems that Zhejiang University's capability may be attributed to the institutionalized mechanism of its R&D administration. The university has established systems and standards in intellectual property management, reward systems, institution establishment, enforcement rules, and so on. Thus, the university regulations must have contributed to some degree to its balanced development.

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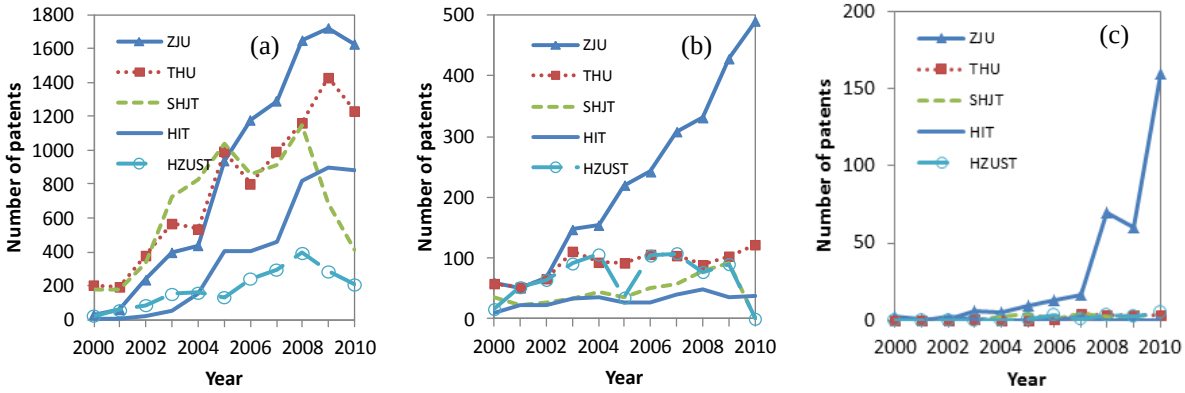

Fig. 2. Number of issues SIPO patents from five selected universities over the last decade - (a) invention; (b) utility models; (c) design patents

4.3 U.S. Patents

Using the assignee's name, city and country, it is possible to obtain the patents from five selected universities. Table 2 shows the related patent indices of the five universities. The data of these universities are highlighted in gray, and their affiliated companies, if available, that filed the patents together with the universities as one of the patent holders are included in the discussion.

As accessed in July 2012, Zhejiang University and Huazhong University of Science and Technology both have 6 U.S. patents. Shanghai Jiao Tong University has 2 patents and Harbin Institute of Technology has one. It is worth noting that none of these patents is related to the LED technology.

On the other hand, Tsinghua University is leading with a total of 464 U.S. patents, of which 298 were applied with Hon Hai Precision Industry (Foxconn Technology Group) in Taiwan, 77 with Nuctech in Beijing, 10 with Capitalbio Corp. in Beijing, 5 with Samsung Electronics in Korea, and 1 with Aviva Bioscience Corp. in the U.S. Among these, there are a least 9 patents that are identified and related to the LED or organic LED technologies. Professor Yong Qiu and Professor Liduo Wang, from the Department of Chemistry, are the chief co-inventors of 6 U.S. patents about organic LED and their research interest is focused on organic semiconductors, the fundamental theories of organic electronics, organic light emitting materials and devices. Dr. Shou-shan Fan, an Academician of Chinese Academy of Science, is the major inventor of patents in which carbon nanotubes and nanotechnology are applied. All LED-related U.S. patents with Tsinghua University as the assignee are listed in Table 3.

More than 80 percent of their issued U.S. patents have industrial corporations as the co-assignees. This indicates that Tsinghua University has a very different policy and management of their intellectual properties (IP) at campus. The cooperation with industrial partners or licensing of university R&D results not only bring lab research much closer to practical applications, but also more possible financial incomes and research funding. Apparently, the versatile IP strategies of Tsinghua University deserve further study.

Table 2 Comparison of U.S. patents held by the five universities (grey rows) and co-applicants (white rows)

Patentassignee	No. of patents	No. of citations	No. of self-citations	No. of inventors	Average patent age
Tsinghua University	464	62	64	444	2
Zhejiang University	6	0	0	13	2
Shanghai Jiao Tong University	2	0	0	13	1

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Huazhong University of Science & Tech.	6[1]	0	0	8	4
Harbin Institute of Technology	1	0	0	8	1
Hon Hai Precision Industry Co.	167	48	48	88	1
Nuctech Company Limited	55	14	14	131	1
Capitalbio Corp.	8	0	0	35	2
Samsung Electronics Co., Ltd.	4	0	0	23	1
Aviva Biosciences Corporation	1	0	0	12	0

[a]including 3 patents from the former Huazhong Institute of Technology

Table 3 LED/OLED related U.S. patents by Tsinghua University

Patent	Title	Inventors (Tsinghua Uni.)	Technology
6806491	Organic light-emitting devices	Yong Qiu, YudiGao, Peng Wei, Deqiang Zhang, Liduo Wang	OLED
7232616	Organic electroluminescent materials and devices made from such materials	Yong Qiu, Juan Qiao	OLED
7317280	Organic light-emitting devices and their encapsulation method and application of this method	Yong Qiu, LianDuan, Yang Li, Liduo Wang	OLED
7501755	Electron injection layer material for organic electroluminescence device	YongQiu, YudiGao, Deqiang Zhang, Wang Liduo	OLED
7609241	Double-faced light emitting diode display	Pi-Jin Chen, Peng Liu, Li Qian, Yang Wei, Lei-Mei Sheng, You-Hua Lei, Liang Liu, Shou-Shan Fan	LED
7786471	Organic electroluminescence device	Yong Qiu, YudiGao, Deqiang Zhang, Liduo Wang	OLED
7812361	Light emitting diode	Zhen-FengXu, Guo-Fan Jin	LED
7923924	Organic electroluminescent display/source with anode and cathode leads	Yong Qiu, Shenfu Zhang, Guohui Zhang, Kongwu Wu, YudiGao	OLED
8021902	Method for fabricating light emitting diode	Qun-Qing Li, Kai-Li Jiang, Shou-Shan Fan	LED

4.4. Journal publications

In order to avoid the study becoming another kind of academic assessment among universities or individual researchers, herein we prefer to portrait some selected research themes or teams, based on the WOS publications and their citation counts between the periods from 2006 to 2011.

Keywords like “LED” or “light emitting diode” are given in the “topic” field separately and the search was supported by adding the location city of a selected university. The results are then summed up by the Boolean operator. Publications from the search results are summarized in Table 4. In general, Zhejiang University has achieved the greatest number of publications from 2006 to 2011, whereas Harbin Institute of Technology has accumulated 760 publications in the same period. Figure 3(a) illustrates the annual counts of published items. As shown, Zhejiang University has continuously produced the greatest amount of publications in recent years. Tsinghua University increased its publication abruptly in 2008 and keeps improving the record since then. Shanghai Jiao Tong University and Huazhong University of Science and Technology have similar trends by constant growth of publications. The

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publication number from Harbin Institute of Technology seems slowed down in the last few years; however, one can have a different perspective when the citations are of concern. Figure 3(b) shows the accumulated citation counts in each year. It is to note that citation only occurs after the publication of a certain paper. The effect of citation might reach the maximum after having been published for some years and it decreases with time after then. As a result, it is important to take this into accounts in interpretation. For example, Tsinghua University surpassed Shanghai Jiao Tong university by the number published items in 2008, but the citation of publications from Tsinghua university did not catch up with Shanghai Jiao Tong University until 2011. In addition, Zhejiang University also shows the highest citation counts in recent years. Compared with the publication number, the citations of publications from Harbin institute of technology are still increasing and it is expected that the number might decrease slightly.

Table 4 Publications related to LED from five selected universities between 2006- 2011 in WOS database

No.	Keyword in the "Topic"	ZJU	THU	SHJT	HIT	HZUST
#1	LED	1881	1299	1400	745	963
#2	Light Emitting Diode	192	98	64	20	111
#3	#1 or #2	2039	1381	1447	760	1023

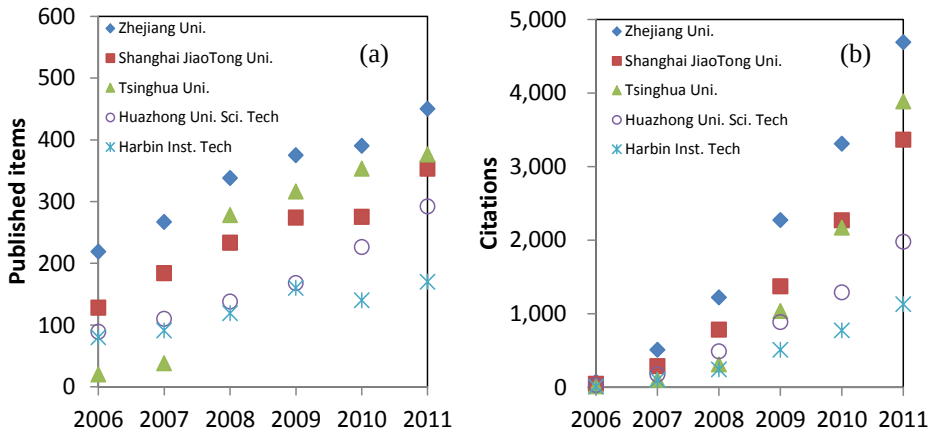

Fig. 3. (a) Annual published items from selected 5 universities; (b) citations of published items by year

In the following content, characteristic research outcomes, representative scholars and their associated laboratories were identified from the search results as elucidatory examples.The LED research teams at Zhejiang University are primarily headed by Professor Zhizhen Ye and Professor Benzhong Tang. The application ZnO to replace existing ITO (Indium tin oxide) as the new electrode material in LED has attracted commercial attentions. ZnO is a cheap, stable and non-toxic compound and it is capable to make the device having an optical spectrum ranging from ultraviolet to visible light. The efficiency of LED can be enhanced significantly. Ye and his teams have been working on the controllable growth and optical properties ZnO and its fabrication on silicon substrate for years. [32-34] Ye is also the major inventor of more than 130 Chinese patents in related technology field. Tang is interested in the electroluminescence of molecules and polymers with special attention to the aggregation-induced emission phenomenon. The research advances relate closely to the organic LED (OLED) applications. [35-37]

Professor Wenzhong Shen is the primary investigator of the LED research teams at Shanghai Jiao Tong University. Shen is interested in the synthesis of ZnO and various inorganic materials. [38-41]

Despite Harbin Institute of Technology's few LED-related articles and patents, its accomplishments are noteworthy. By the SAPMAC method (sapphire growth technique with micro-pulling and shoulder-expanding at the cooled center), Harbin Institute of Technology successfully manufactured large-size sapphire crystal, freeing China from importing

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sapphire substrates, which is the raw substrate material for the various types of LEDs. In 2006, Harbin Institute of Technology mastered the techniques in manufacturing large sapphire single crystal (240 × 210mm and 27.5 kg). [42] After the United States and Russia, China has become the third country to develop this technology successfully. Harbin Institute of Technology holds two LED patents in China, both related to the SAPMAC method, which is an upstream technology in the LED industry. The center of composite materials and the school of material engineering are two major sources driving the development of related crystal growth technology. [43, 44]

Tsinghua University LED research differs from the others with more focusing on organic LED. Comparable with U.S. patent search results shown in Table 3, Professor Yong Qiu and Professor Liduo Wang also have prominent journal publications in this field. [45][46, 47]. He is also an inventor of 39 Chinese patents. On the other hands, Dr. Shou-shan Fan and his teams published more than 70 journal publications from 2006 to 2011. Among the results, the applications of carbon nanotubes are extended to flexible acoustic devices, biological sensing microarrays or characterization tools or energy storage materials, in addition to LEDs. [48-51]

At Huazhong University of Science and Technology, Professor Sheng Liu and Xiaobing Luo are specialized in the packaging of LED, and associated issues such as color distribution, lens design and thermal analysis. In addition, Prof. Luo is also an inventor of 7 Chinese patents in relevant fields [52-55]. Professor Dexiu Huang has studied the luminescent properties and synthesis of various red-emitting phosphor based on alkaline earth sulfides for white LEDs [56], [57, 58]. Prof. Huang holds 20 Chinese patents.

V. CONSIDERATIONS FOR TAIWAN-CHINA COOPERATION

In practice, one has to consider how to realize the outcome from the cooperation or transfer related technologies. The export of patented technologies from China is currently subject to a classification of three categories: prohibited, restricted, or free. There are various administrative regulations governing the export of technologies, including "Regulations on Technology Import and Export Administration of the People's Republic of China", "Administration of Technology Prohibited or Restricted from Export Procedures", "Directories of Technology Prohibited or Restricted from Export Procedures". Under such circumstances, it could be difficult to export technologies overseas, and there have been only few successful examples for Taiwanese companies so far. Overall speaking, the following principles should be considered when introducing research outcomes or IPs from China's universities or research institutions can be described as:

- Those target technology or object clearly stated or protected by the patent or patent applications should be prioritized.
- Technology classified as "free" to export or "restricted" with authorized admission can be then considered.
- Those technologies or patents complementary to Taiwan's deficiency should be prioritized.
- Collaborative products marketable to other countries or China should be prioritized.
- Those technologies or patents advancing Taiwan's technology level should be considered.
- Those technologies or patents closely related to cross-strait standards or China's domestic market should be prioritized.

As mentioned at the outset of this paper, strategic alliances with China would make Taiwan's LED companies more competitive, and better LED patents are indispensable for taking Taiwan's LED industry to a higher level. Taiwan's LED companies frequently engage in patent litigation. From February to April 2012, two Taiwanese LED companies entered six lawsuits, either as a plaintiff or a defendant, with two Japanese LED companies and others in the U.S. and Germany [9]. Quality LED patents can aid our companies to fend off competitors, and this is exactly why the Bridge-Building Project was created.

Quality patents can also mitigate the impact of worldwide free trade agreements (FTAs) on Taiwan. Taiwan has, as of 2012, been a member of the WTO for a decade, but the importance of the WTO is being eroded by over 300 FTAs, the growth of which was triggered by the breakdown of Doha negotiations. In 2011, the U.S.–Korea negotiation was

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complete. Thereafter, Korean patent-applied-for LED products could, without tariff, enter the U.S., which is the world's second largest LED market. Taiwan, in contrast, is somewhat behind schedule in FTA. Reinforced with quality patents, it is possible for Taiwan's LED companies to make up the disadvantages caused by the lack of FTAs.
According to the 2010 global LED industry review report by the Industrial Economics & Knowledge Center (IEK) Taiwan, the market share of high-brightness LED continued to increase, and rapid growth of downstream applications was observed among end users under the guidance of government policies and the growing demand for backlight modules and lighting. However, Taiwan, whose downstream packaging technologies and applications are relatively mature, faces more disadvantages in the development of epiwafer technology that requires the highest costs in the upstream LED industry [59]. It is thus expected that the midstream production technologies possessed by the team of Zhejiang University and Harbin Institute of Technology's epiwafer production technology, such as sapphire crystal manufacturing technology, may help integrate and consolidate the technologies in the upstream and midstream sectors of the LED industry in Taiwan [60, 61]. Following the observations, the recommended teams with technologies worth introducing are the State Key Laboratory of Silicon Materials research team led by Professor Ye at Zhejiang University and Harbin Institute of Technology, which adopts the sapphire growth technique with the SAPMAC method.

VI. DISCUSSION-SUGGESTED COOPERATION MODELS

The technology lifecycle theory [62] was used as the analytical basis for the feasibility of cross-strait cooperation. As illustrated in Figure 4, cooperation is possible when a given technology is not mature either in Taiwan or China, or both.Referring to the patent and publication results, it is possible to propose three cooperation models to generalize the cooperation between Taiwan and China, depending on degree of maturity or development of each relevant LED technologies, as depicted in Figure 4: (1) Joint R&D; (2) Center-Satellite System; and (3) Outsourcing and Subcontracting.

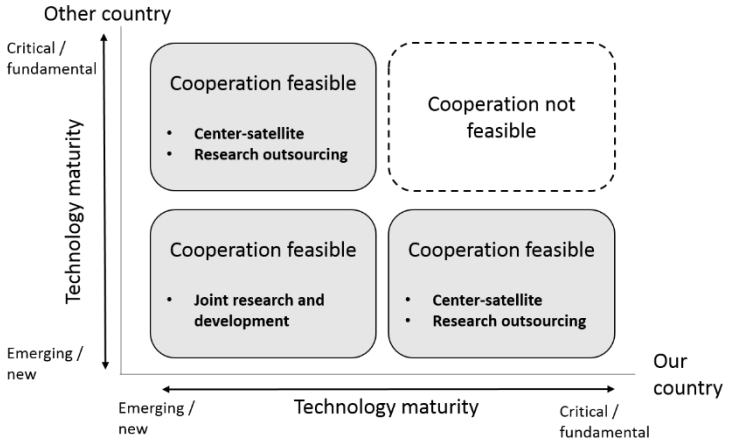

Fig. 4. Cross-strait energy technology cooperation models

6.1 Joint Research and Development

Through joint R&D, two or more manufacturers could engage in R&D activities by collectively providing funds, manpower, or technologies. Technology selection is quite a challenging decision-making issue that the manager of a technology company is faced with [23]. The joint R&D model may be adopted for technological development in basic sciences or forward-looking technologies to overcome the requirement for huge monetary investment and uncertainty during the period of R&D and reduce risks in the R&D cycle. In a study about the joint R&D activities in the Chinese wind turbine manufacturing industry, the authors have found that joint R&D has improved Chinese companies' technical capacity, human resources and financial growth, though other factors such as different preference and unequal technical capacities in two sides of the collaboration would limit the synergetic effects in innovation [63].

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Taiwan's LED industry could learn from the cooperation between Foxconn and Tsinghua University. Foxconn is a multinational electronic manufacturing enterprise headquartered in Taiwan. Foxconn has invested in and established the Tsinghua-Foxconn Nanotechnology Research Center. This study revealed that their joint R&D produced valuable results in the manufacturing and application of carbon nanotubes. Further, a considerable number of patents were obtained in Taiwan and abroad, thereby helping transforming Foxconn from a manufacturing-oriented group into a technology-oriented group [64]. Tsinghua University and Foxconn are expected to play significant roles in future applications of carbon nanotubes in display devices, medical science, and medication.

Referring to the ideas like "free licensing" or "equity based alliance", the relationship between parties involved in the cooperation is more emphasized in actual profits from future products. Therefore, the distribution of profits/results will include the evaluation of related technology or patent. The value of the invested-in technology/patent relies on bilateral negotiations and agreement terms to state each party's contribution clearly.

6.2 Center-Satellite Factory System

In such a system, the center factory, with its excellent production and management techniques, directs its satellite factories to ensure that the parts and semi-finished products they manufacture meet the center factory's quality standards. Thus, although the center factory dominates the satellite factories, both benefit. The system enables inventory reduction in the center factory and satellite factories by regulating suppliers' delivery time and costs, thereby minimizing overall production costs, and increasing competitive advantage. The relationship between the center factory and the satellite ones is more discretionary, yet complementary and interdependent [65].

Academia-industry cooperation in Taiwan produces mutual benefits similar to those of a Center-Satellite Factory System. It increases the competitiveness of small and medium enterprises (SMEs) in Taiwan through the R&D capacity of academic institutes, and the application of the universities' patents provides revenue and enhances their status. The cooperation may not be limited to particular areas or simple technology transfer between academia and industry, but focuses more on the development of applied technologies in the medium term.

Despite its potential, no similar situations have been observed in current Taiwan–China cooperation. Thus, the door is open for an alternative, a strategic alliance among universities and research institutions, such as the Taiwan's Industrial Technology Research Institute, Institute for the Information Industry, or the Automotive Research & Testing Center, working with China's higher education research institutes could be foreseeable in order to achieve lasting and extensive cooperation.

In a center-satellite factory system, the development of relevant industries may have advanced to a certain degree, and the technological development is no longer in the basic R&D phase. Therefore, the main purpose of a center-satellite factory system is the pursuit of synergy. In terms of the cooperation with academic institutions, more emphasis could be placed on technology standards, quality standards, and a common accreditation system for products. Trough patent licensing or acquisition, parties of interests could establish commonly shared standards or enhance the competitiveness of the whole industry.

6.3 Research Outsourcing

The participating parties could hire a research institute(s), with or without involving the parties' own researchers, to develop new technologies and retain the priority right of technology transfer. Research outsourcing seeks to yield maximum results with minimal effort. Such outsourcing comes with well-defined research targets and expected results. Although research outsourcing seems relatively simple compared with the aforementioned models of cooperation, risk management for ownership of the outcome and the intellectual properties, distribution of benefits, and dispute resolution should not be ignored under such circumstances and be implemented by written contracts.

6.4 Where Are We Now?

Through the Cross-Strait Bridge Building Project, LED industry business talks between Taiwan and China have taken placed several times. The short-term goal is to work out a feasible model of cooperation. It is hoped to expand the

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global market share together in the long term. In 2009, the Taiwan Optoelectronic Semiconductor Industry Association and the China Solid State Lighting Alliance signed a memorandum of understanding (MOU) with five key points [66]:

(a) Jointly establishing an accredited LED lighting testing and inspection institution in order to enhance the global competiveness for companies in China and Taiwan;
(b) Drafting cross-strait semiconductor lighting patent strategies including a joint early alerting mechanism, collective patent portfolios, cross-licensing, and common priority mechanisms;
(c) With the global market as the target, complementing each other with the respective technological advantages, collaborating to develop high-power semiconductor lighting materials and new processing technologies, planning for the cooperation in the demonstration and deployment projects of LED lighting, accelerating the adoption of new technologies, and gradually developing semiconductor lighting-related intellectual property rights for the Chinese communities;
(d) Promoting industrial investment and discussing cross-strait cooperation in establishing a world-class semiconductor lighting business;
(e) Establishing a working group and forming a mechanism for regular exchange.

In the past years, the Bridge Meeting has taken placed annually and several MOUs have been signed. For example, following the path of the 2009 MOU, the MOUs in 2012 took a step further. Selected Chinese cities started to open to Taiwan's LED companies to take parts in the LED street lighting demonstration and deployment projects. A draft for the classifications and standards of LED interface specifications has been jointly proposed by corresponding industrial associations in China and Taiwan. Furthermore, some Taiwanese companies, especially those in the electronics industry, play a significant role in the global economy, but their brand names are still overshadowed by internationally renowned companies such as Google, HP, Apple, and Samsung [67]. It is also envisaged to form a joint brand by cross-strait collaboration. The MOUs have provided Taiwanese companies with the best opportunity to date to enter certain domestic LED markets in China. The five key points agreed in the latest MOU echo with proposed models of cooperation. Taiwan's technology hubs such as the Industrial Technology Research Institute and Institute for Information Industry may take the lead by working with selected research institutions in China on LED standard-setting, forming common LED patent strategies to reinforce mutual LED patent portfolios, and building an early alert mechanism for potential LED patent conflicts.

VII. CONCLUSION

How to select a suitable partner for transferring or licensing required technologies becomes more difficult, especially when the cooperation involves industries and academic institutions from different places and cultures. The work proposes a methodology to extract useful technological intelligence for strategic planning, decision making or policy formulation. Bibliometric patent and journal publication analyses on five chosen universities were conducted in order to identify potential cooperative partners and select appropriate LED technology to bridge China's academic institutes and Taiwanese industries. Characteristic research outcomes, representative scholars and their associated laboratories were identified from the search results as elucidatory examples.

The goal is to achieve a win-win for cross-strait LED industries by establishing a cooperative link between industries and academia. Nevertheless, even in cooperation, one should not ignore legal risks, especially when it is under two different legal frameworks.Reciprocity, equality, ownership, distribution of benefits, dispute resolution, and other factors could seriously affect bilateral relationship and should be handled prudently in legal documents.

Though the case drawn on Taiwan and China is relatively special to many other countries, it is clear that many principles can be generalized, duplicated, modified or referred by many other countries or organizations.It is believed that the proposed method and pilot study offer a scientific perspective for decision-making and can be extended to many other fields of interests.We believe that the proposed method offers a way to assess potential candidates objectively. In addition, three different cooperative models are also suggested to accommodate different organization cultures and IP management.

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