

The patent profile of green LED light bulbs: cases in the US, Japan, Taiwan and China

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There is an increasing demand for LED (light-emitting diode) bulbs, and technological development has become extremely significant, especially pertaining to patents. In this article, relevant LED bulb patents from the database of the United States Patent and Trademark Office (USPTO) from 1976 to 2014 have been examined and analysed. The applied patent indicator tools include patent analysis, technology life-cycle analysis, R&D ability analysis and patent classification analysis. The analysis was completed at the national, company and technology levels. At the national level, the US has the best performance. At the company level, the Switch Bulb Company, Inc. has obtained the most number of patents. According to the technological field of US Patent Classification, green LED light bulb patents mainly focus on D26/2, 362/249.n and 313/46 – especially D26/2. American companies in general have maximum success in patenting green LED light bulbs, but the Hon Hai Group, Taiwan is the only company covering these three technology fields. We demonstrate the development trend and operation of green LED light bulbs from different aspects to show that the technology gap is an important reference for other relevant LED bulb companies that plan to develop new technologies and increase their competitiveness in the future.

Keywords: Green light, LED bulbs, patent indicator tools, patent profile.

RESOURCES on earth are limited and eventually will be completely depleted. Economic development and industrialization have overly exhausted fossil energy sources, resulting in climate change and global warming. Therefore, countries globally work to save energy and reduce carbon emission. LED (light-emitting diode) lighting is a green lighting product. LEDs have a cold light source, smaller size, longer lifetime, lesser impact on the environment, low DC voltage source, immediate light, better efficiency, high brightness, adjustable colour temperature, adjustable dimmer and controllable functions compared to traditional bulbs. Therefore, they save more energy and electricity than traditional bulbs¹.

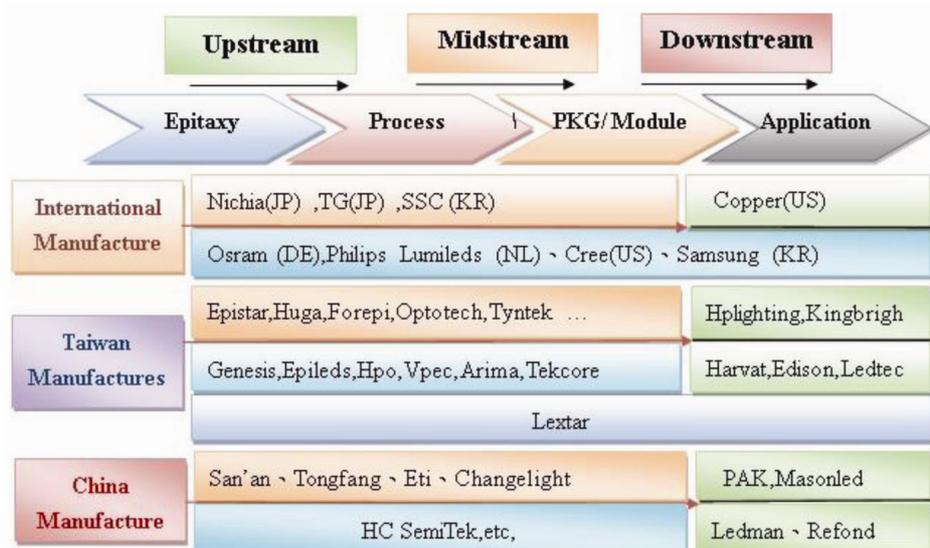
Many countries have banned traditional incandescent light via directives such as Waste Electrical and Electronic Equipment² and Restriction of Hazardous Substance³ due to energy savings, carbon reduction and environmental awareness. This action was promoted by the EU and Measures for the Control of Pollution from Electronic Information Products from China. Thus, LED lighting has gradually become the best lighting choice. The rapid development of LED technology also improves luminous efficiency⁴.

Current LED lighting products combine the internet and modern technology to develop better lighting effects than traditional light bulbs. LED users can utilize their creativity to design customized lighting. The combination of modern technology and intellectual property (IP) not only extends the lifetime of LED lighting, but also creates market value. Traditional incandescent light bulbs cover more than 50% of the market share with a yearly demand of 50 billion bulbs. However, LED bulbs with the same light port adapter can directly replace traditional incandescent light bulbs^{5,6}. Therefore, LED bulbs are a green lighting product that can take over the market demand of traditional incandescent light bulbs due to their energy savings and carbon reduction⁷. This in turn makes obtaining a higher market share, the goal for many companies in different countries. Patents can evaluate the innovative ability of the companies to analyse their technology strength⁸. Therefore, patents and technological development of LED bulbs are important factors to consider when competing with other companies in the lighting field.

Patent profiles⁹ provide information on different dimensions of IP activity by being aware of global developments¹⁰. This article analyses the development trend of the primary LED suppliers in the world: the US, Japan, Taiwan and China. We then compare the technological differences among these countries. The results will help companies understand the state-of-the-art practices in

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Source: Industrial Technology Research Institute IEK (2014/04), Hsinchu, Taiwan.

Figure 1. Introduction of LED lighting industry.

Table 1. Status of the intertwined patent network among top five LED companies in the world

LED company	Country	Patent licensees	Approved patent quantity in the US
Philips	The Netherlands	Cree, Toyoda Gosei, Osram, Seoul Semiconductor, Zumtobel, Epistar	17,907
Osram	Germany	Nichia Philips, Toyoda Gosei, Cree, Samsung, LG, Sharp	3,099
Toyota Gosei	Japan	Philips, Osram, Toyoda Gosei, Nichia, Seoul Semiconductor, Formosa Epitaxy	7,562
Cree	USA	Philips, Osram, Toyoda Gosei, Nichia, Seoul Semiconductor, Formosa Epitaxy	1,662
Nichia	Japan	Cree, Toyoda Gosei, Sharp, Seoul Semiconductor, Luminus Devices	901

*Source: USPTO AN/IN LED keyword search updated statistics until 1 July 2015.

LED patents^{11,12}. The results may also be an important reference for future strategy planning and development¹³.

Current status of LED lighting industry

The LED lighting industry can be divided into components, modules and applications (Figure 1). Components include epitaxy, chip process and packaging¹⁴. Epitaxy refers to the growth of a single-crystal film on top of a crystalline substrate on the basis of MOCVD (metal-organic chemical vapour deposition). Blue InGaN packaging is processed to make white LEDs. Epi-wafers form LED chips after going through film deposition, photo, etching and chip tests. LED chips are processed to become LED components after a series of packaging steps: polishing, cutting, die-bonding, wire-bonding, dispensing and testing¹⁵. These components are assembled with cooling, electronic control and optical devices to complete the LED light module or lighting application¹⁶.

Five companies currently control LED technology¹⁷. Table 1 shows that the development of LED technology has formed an intertwined patent network among these

five companies, which allows them to retain their market competitiveness¹⁸. On a country level, Taiwan and Japan both participated in the initial development of LEDs. On the other hand, China has the second largest market for LED lighting and shows a rapid growth in the LED market. The three primary LED applications are backlight, lighting and headlight. According to a report from Industrial Economic and Knowledge, Industrial Technology Research Institute¹⁹, the market size of LED will reach 72.6 billion in 2019. It indicates a growth doubling within the next two years¹⁹. Therefore, lighting applications are the main growth sector. Philips has also announced the licensing of more than 1000 patents to the global players in the market. This further confirms the importance of patents in dominating the global market.

Research methods

Patent profile

Patent profiles allow companies to understand information such as patent type, technological development and

technological operation from different dimensions via charts. Patent data provide broad coverage, high reliability and allow for a differentiated perspective of technological analysis. The analysis of patent data can offer great visibility on the leading patents, patent filers, subject-matter clusters and technology trends in an area of technology²⁰. Therefore, it is easier to understand technological change and development trends to judge and predict more accurately regarding patent technologies in the future²¹.

Quantitative analysis method

Patent data and indicators are collected and analysed on the basis of quantitative analysis to yield a conclusion^{22,23}. Patent quantities are used as the basis to collect information. This article analyses a number of items, including the year of announcement, technology life-cycle analysis²⁴, countries, patentees, inventors and patent classification to understand the status of technological development. Patent analysis can not only illustrate the patent quantity owned by various countries or companies, but also identify the most active and developing technologies.

Analysis of LED bulb patents

This article uses 'LED Bulb', 'LED Light Bulb', 'Light Bulb' and 'LED Lamp bulb' as its keywords to search for relevant information in the database of the United States

Patent and Trademark Office (USPTO). The results demonstrate that the total number of patents approved by USPTO is 735. After eliminating the irrelevant ones, there are 362 patents for further analysis. These were issued between 1 January 1976 and 31 December 2014. This article analyses five primary items: patent quantity, country, company, inventor and US Patent Classification (UPC or USPC) on the basis of the date of announcement.

Results and discussion

Analysis of patent quantity

Analysis of annual patent quantity provides an insight on patent quantity in the field of industrial technology and development factors, such as involved company quantities and patentees via the change of annual patentees, inventors and patent quantities. The technology life cycle in Figure 2 reveals that the development of LED bulbs started from 1980. However, the technological development was slow before 2005. After 2006, the technology applied in the LED industry showed significant improvement and sharp increase in LED lighting sources, LED bulb lifetime and light extraction efficiency.

Meanwhile, an increasing number of countries have announced bans against traditional incandescent light, and many countries have started to take part in the development of the LED industry. This has led to a significant breakthrough in LED technological development in a

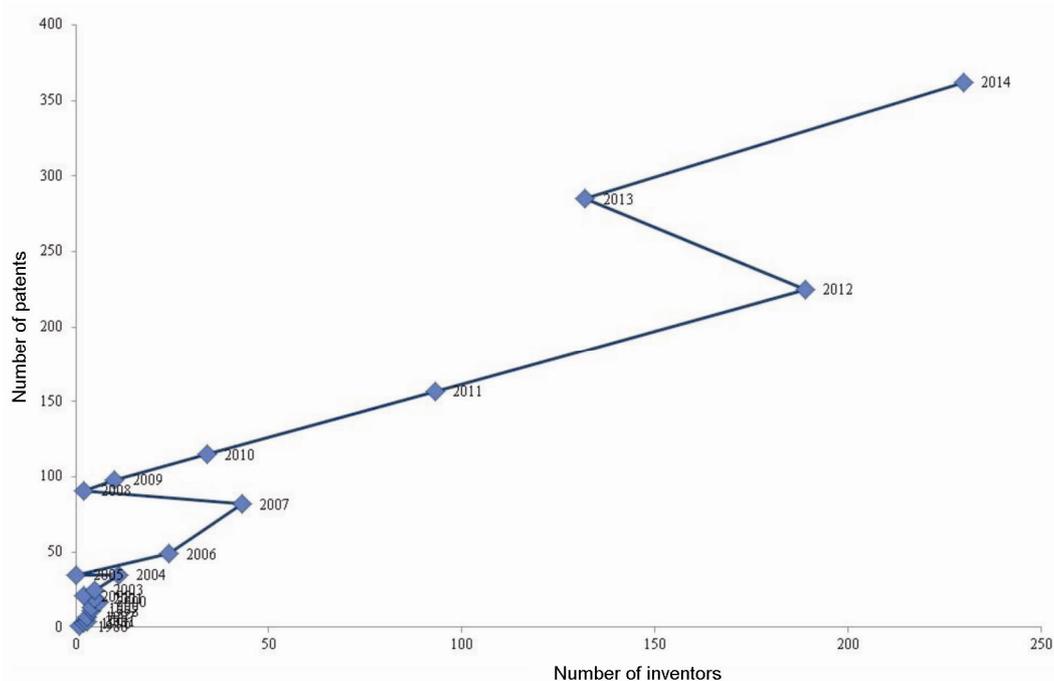


Figure 2. LED bulbs technology life cycle.

GENERAL ARTICLES

Table 2. Annual LED bulb patents in each country

Year Country	1980	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Quantity
US	1	2	0	0	2	1	0	0	1	4	8	0	11	13	4	4	2	14	32	30	45	174
CA	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	2	2	1	7
JP	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	11	4	5	22
TW	0	0	0	1	2	0	2	2	1	0	1	0	2	3	3	2	5	6	17	13	14	74
SG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	2	2	6
CN	0	0	0	2	0	1	2	0	0	0	0	0	1	1	1	0	3	19	3	7	7	47
NL	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0	2	0	2	1	3	23
KR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	1	1	0	6
IL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
DE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1
NZ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1

US, America; CA, Canada; JP, Japan; SG, Singapore; CN, China; NL, Netherlands; KR, Korea; IL, Israel; DE, Germany; NZ, New Zealand.

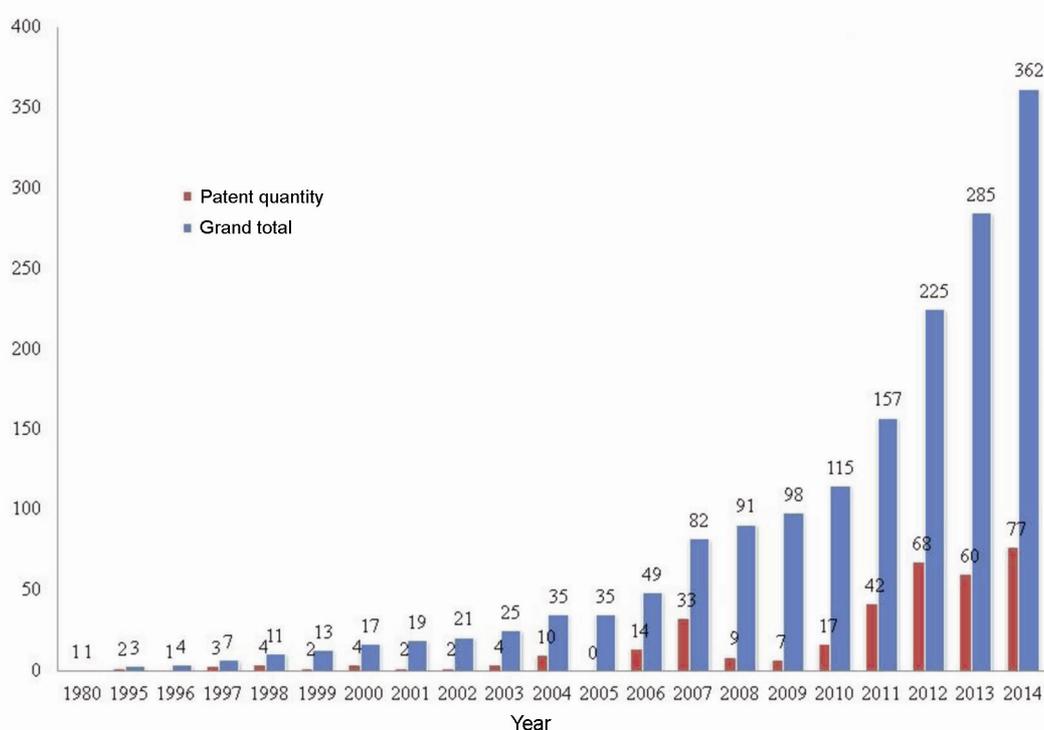


Figure 3. Annual number of LED bulb patents.

short period of time. The increase in the number of patents in 2012 slowed down because each country announced electrical product safety and lighting standards regarding its LED lighting products. After 2013, the expansion of lighting applications and the rise of perceived value in the lighting market lowered the relevant costs and resulted in a dramatic increase in the number of patents and patent inventors. Figure 2 demonstrates that LED bulb technology is in the growth stage.

Table 2 and Figure 3 clearly show the annual development of LED bulb patent technology in each country. According to the statistics of LED bulb patent quantity, the five leading countries for producing LED bulb patents are

the US (174), Japan (22), Taiwan (74), China (47) and the Netherlands (23). Of these 340 patents, the percentage of patents used in this study is 93.9 and they are mostly from the US.

Country analysis

Country analysis evaluates countries that develop green lighting products for LED bulb technology. This article specifically looks at the US, Japan, Taiwan and China. Table 3 shows the statistics of LED bulb patent quantity in these four countries; the US leads in technological development. Figure 4 shows the percentage of LED bulb

patent quantity each country holds around the world: US (48), Taiwan (21), China (13) and Japan (6).

The US holds the largest number of LED patents, which can be attributed to the fact that it has pioneered LED products since 1962. According to the patent statistics shown in Figure 5, the US obtained its first patent in 1980, before any other country obtained any LED patents. Japan developed its LED products with commercial value in 1993 and obtained its first US patent in 1996, becoming the second country with a US patent as well as one of the leading countries in the LED industry. Taiwan has the second most number of patents in the world and has continued to produce a certain amount of patents every year since 2006 in the field of LED bulb technological development. In the past ten years, China has shown a significant increase in LED development and patent quantity, and is soon expected to become one of the leading countries.

Company analysis

In this study we analyse the basic patent information of each company and demonstrate the competitiveness indicators of each, such as 'analysis of patent quantity' and 'analysis of the company's R&D ability', and further analyse the technological uniqueness of each company. According to the percentage of patent quantity of each company majority of the companies are American. This study takes the top 14 leading companies with the greatest patent quantities from the US, Japan, Taiwan and China overall for analysis.

Table 3. LED bulb patent quantities in each country

Patent country	Patent quantity
America	174
Japan	22
Taiwan	74
China	47

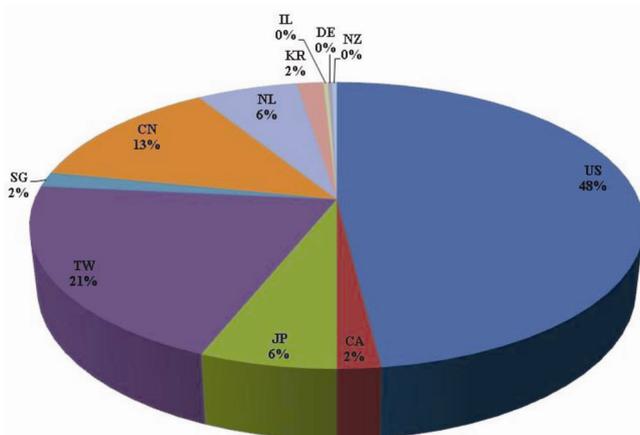


Figure 4. LED bulb patent percentage in each country.

Table 4 provides an analysis of R&D ability of each company. The results reveal that Switch Bulb Company, Inc., USA, has the most patents (29) in LED bulbs, which have been cited 38 times. On the other hand, Huizhou Light Engine Ltd, China, and three other companies (11th to 14th leading companies) have owned four patents for less than a year. This shows that their technological development is not as sophisticated as others and thus have fewer patents that are only cited 21 times. The patent quantity analysis in this study demonstrates that each company still has much room for improvement.

The average age of patents reveals that companies have better technological advantages when they have older patents. The Hon Hai Group, Taiwan ranks second in the world for its patent quantity, and has the highest patent age. Therefore, it can be inferred that this company has invested more in the technological field than the other companies. Patents in the Hon Hai Group have been cited 103 times, and the company has been involved in the technological field continuously since 2009. Recently, the Hon Hai Group cooperated with another leading Japanese company in response to lighting policies announced by each country and future strategies of the company.

S.K.G.C.O. Ltd is the first Japanese company to obtain US patents (in 1996). However, it had no patents in the following decade (Figure 6). In 2012, it obtained 10 patents. Since the average age of patents in this company is lower than others, it is possible that this Japanese company has a unique technology.

Table 5 presents companies with the top 10 cited influential patents of LED bulbs (citation counts ranked as top 10% among all the patents)^{25,26}. Color Kinetics Incorporated, an American company with 402 citation counts, is ranked first. There are six American companies whose patents are cited by other companies, making USA the leading country in the world. Taiwan, with 237 citation counts, ranks second and is followed by China with 192 citation counts.

Inventor analysis

Inventor analysis emphasizes organizing information regarding inventors in the technology field to learn more about important inventors and their companies. Moreover, this analysis is an important recruitment reference to learn about inventors with potential. This study analyses inventors receiving LED bulb patents from USPTO in the US, Japan, Taiwan and China. Table 5 clearly shows that FS Maxik from Lighting Science Group Corporation has the most patents. The top five inventors with the greatest number of patents mostly come from the top five companies with the greatest patent quantities. Among the top five inventors, four are from the US, and two of them work for the Switch Bulb Company, Inc. The second most prolific inventor comes from Japan. Among the top

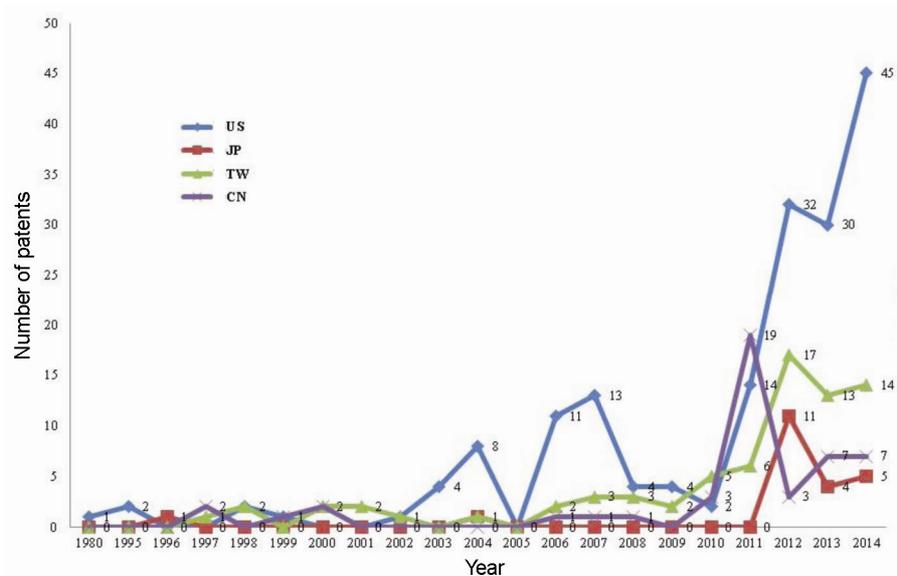


Figure 5. Patent quantity by country.

Table 4. Analysis of the R&D ability of each company

Country	Company (country)	Patent quantity	Activity year	Inventor	Average age in years
US	Switch Bulb Company, Inc. (US)	29	4	108	1.7
TW	Hon Hai Group (TW)	20	6	53	3.3
US	Lighting Science Group Corporation (US)	15	5	23	2.7
JP	S.K.G.C.O. Ltd (JP)	11	3	33	1.1
US	Forever Bulb, LLC (US)	10	4	22	2.7
US	Fusion Optix, Inc. (US)	8	3	29	2.5
US	Rambus Delaware LLC (US)	7	2	23	1.3
US	Osram Sylvania Inc. (US)	6	3	11	2.3
US	GE Lighting Solutions LLC (US)	5	4	19	1.8
US	Lodhie; Pervaiz (US)	5	3	5	1.8
US	The Procter & Gamble Company (US)	4	3	20	2.0
US	iLumisys, Inc. (US)	4	3	9	2.3
US	Lights of America, Inc. (US)	4	2	4	1.5
CN	Huizhou Light Engine Ltd. (CN)	4	1	8	2.0

Table 5. Top 10 companies with the most citation counts of their patents

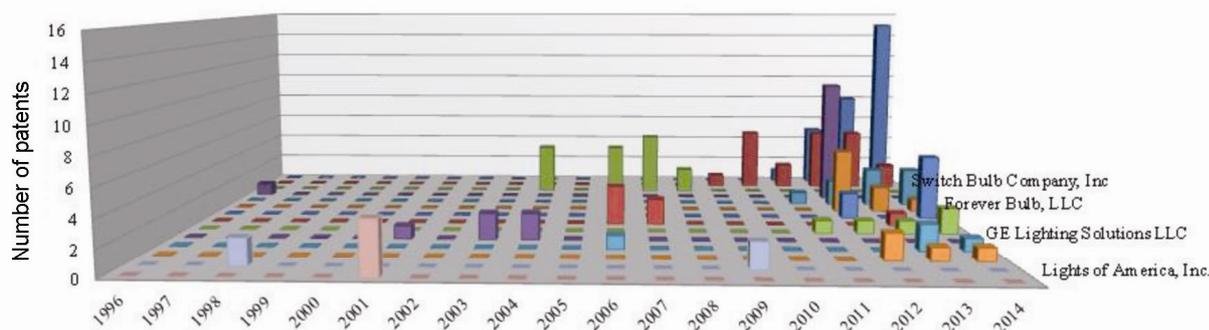
Company/unit	Country	Citation count
Color Kinetics Incorporated	USA	402
Lee; Hsin-Chih Chung	TW	237
Mule Lighting, Inc	CN	192
Lighting Science Group Corporation	US	153
The Procter and Gamble Company	US	150
Koninklijke Philips N.V.	NL	138
Lodhie; Pervaiz	US	135
Lighting Science Group Corporation	US	125
ATEX Co. Ltd.	JP	119
Lighting Science Group Corporation	US	119

21 patent inventors, 5 are Taiwanese with their patent quantities ranked seventh and eighth in the world. Three out of these five inventors work for the Hon Hai Group,

which is also among the top five companies (Figure 7). Table 6 shows that there are three Chinese inventors with three patents each, revealing the skills and R&D abilities of each inventor.

USPC analysis

Most countries use the International Patent Classification to organize the content of their patent technology when it comes to patent classification. This study applies the USPC to analyse patent classification based on the function of the patent. The American patent literature has listed USPC and its corresponding IPC since 1969. The USPC is divided into two sections: class and subclass. These are shown with numbers and separated with a slash. The table of contents for each classification has annotations. Figure 8 and Table 7 show that LED bulb



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Switch Bulb Company, Inc	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	8	15
Hon Hi Group	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	2	5	2
Lighting Science Group Corporation	0	0	0	0	0	0	0	0	4	0	4	5	2	0	0	0	0	0	0
S.K.G.C.O. Ltd,	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0
Forever Bulb, LLC	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	2	3	3
Fusion Optix, Inc.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	1
Rambus Delaware LLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	5
Osram Sylvania Inc.	0	0	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0	1	0
GE Lighting Solutions LLC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	2
Lodhie; Pervaiz	0	0	0	0	0	1	0	2	2	0	0	0	0	0	0	0	0	0	0
The Procter & Gamble Company	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	1
iLumisys, Inc.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1
Lights of America, Inc.	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Huizhou Light Engine Ltd.	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 6. Annual patent quantity/number of patentees of each company.

Table 6. Analysis of inventors and patents

Inventor	Company	Patent quantity	Country
Maxik; Fredric S.	Lighting Science Group Corporation	11	USA
Sakamoto; Mitsuhide (Aichi, JP), Yagi; Toshiaki	S.K.G.C.O. Ltd	10	JP
Carroll; David W.	Forever Bulb, LLC	9	US
Lenk; Ronald J	Switch Bulb Company, Inc.	8	US
Webb; Andrew.	Switch Bulb Company, Inc.	7	US
Rochat; Alex.	Switch Bulb Company, Inc.	6	US
Parker; Jeffery R.	Rambus Delaware LLC	6	US
Vakil; Usman.	Lighting Science Group Corporation	4	US
Wheelock; Glenn.	Switch Bulb Company, Inc.	4	US
Lodhie; Pervaiz	Lodhie; Pervaiz	4	US
Sherman; Matthew	Fusion Optix, Inc.	4	US
Wang; Zhong-Qing	Hon Hai Group.	4	TW
Lai; Chih-Ming	Hon Hai Group.	4	TW
McGuire; Kenneth Stephen.	The Procter and Gamble Company	3	US
Johnston; Raymond P.	3M Innovative Propetrise Company	3	US
Lin; Kang-Tien	Lin; Kang-Tien	3	TW
Lo; Kang-Hua	Lee; Hsin-Chih Chung	3	TW
Lin; Chih-Yung	Hon Hai Group	3	TW
Zhang; Zhou-Kui	Mule Lighting, Inc.	3	CN
Wey; James	Homelite Limited (Jiangsu)	3	CN
Shi; Jie	—	3	CN

technology mainly clusters on the technology field of D26, 313, 315, and 362 in USPC classifications. Moreover, there is a significant change regarding the patent quantity since 2010, particularly in the increase in patent quantity of D26.

Table 8 and Figure 9 demonstrate that LED bulb patent technology mainly clusters on the technology fields of D26/2, 313/46 and 362/249.n, particularly in D26/2. The US has the most number of patents, making it a leading country in the technology field, followed by Taiwan with

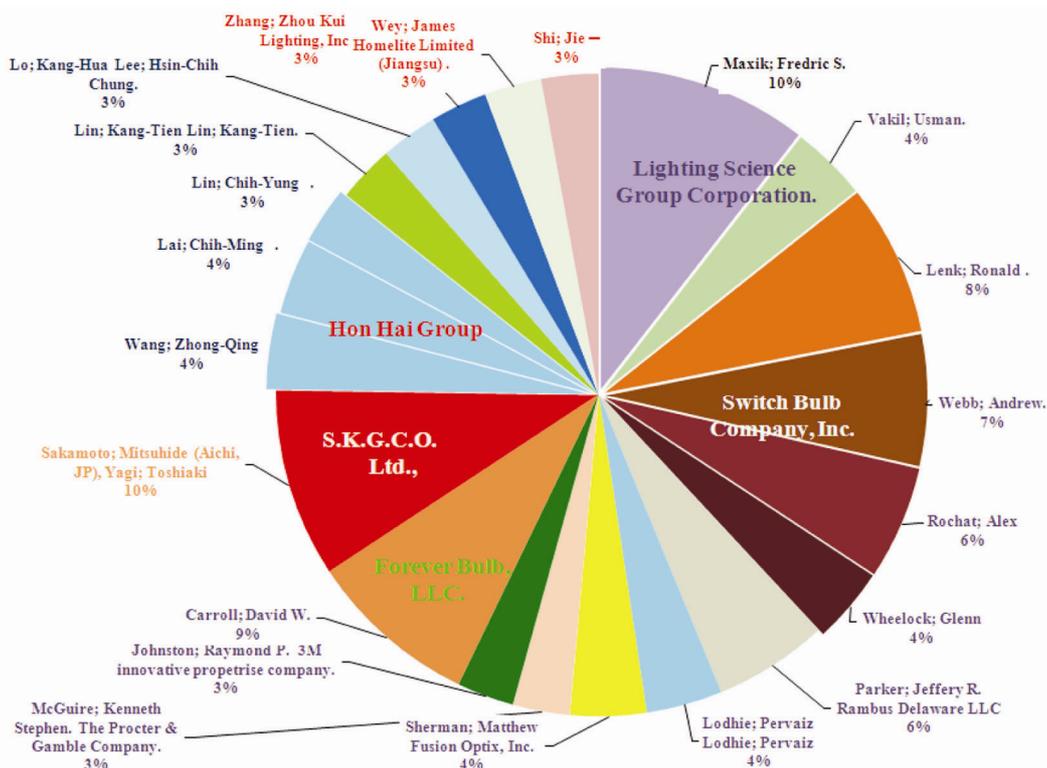


Figure 7. Distribution of the primary inventors.

Table 7. Comparison of United States patent classification in the first section

Class	Number and title	Class definition
D26	Lighting	This class provides for design patents claiming ornamental designs for (1) light source, (2) candle holder and (3) light fixture.
313	Electric lamp and discharge devices	
315	Electric lamp and discharge devices: systems	
362	Illumination	

Note: Design patents are classified by what is claimed and shown in full lines only. Broken, hatched or stippled lines, which may be included in design patent drawings, are considered as environment only. Subclass 2 indent level is one type electric light bulb³⁴.

37 patents, China with 30 patents and Japan with 10 patents. Taiwan is slightly ahead of other countries in the technology field of 313/46, while China and Japan show no significant performance regarding these three technology fields.

In the second section, patent quantity was analysed between companies. Figure 10 clearly demonstrates that the Hon Hai Group has a leading status regarding D26/2. Moreover, in the second section, the Hon Hai Group is the only company with skills in these three technology fields. Japan and China only have patents in D26/2. Rambus Delaware LLC and Lodhie/Pervaiz from the US perform well in two technology fields in the second section.

The development of LED bulb technology continues to grow. Therefore, companies have to obtain sufficient resources and accurate strategies to remain competitive among various competitors. The US is the leading coun-

try for its patent quantities and patent inventors and owns 174 of the 362 patents. Taiwan is second with 74 patents and shows great potential in this field. At the company level, Switch Bulb Company, owns 29 patents and ranks first in the world. The second ranked company is Hon Hai Group, with 20 patents.

As for the number of patent citations, the US ranks first in the world, followed by Taiwan. The company with the most patents from the patent inventors is the Lighting Science Group Corporation with 11 patents in total. From the comparison table of USPC patent quantity in the second section, the primary technology clusters on D26/2, 362/249.n and 313/46, particularly in D26/2. The US is also the leading country in the field of technology followed by Taiwan. Hon Hai Group is the only company that owns patent technology in three fields. It also has a leading role in the field of D26/2.

Table 8. Comparison of USPC patent classification in the second section

Class	Number and title
D26/2	Electric light bulb
362/249.n	A, Light sources, per se; B, Light modifiers; C, Light source supports or housings; D, Signalling and communication; E, Combinations of devices provided for I other classes and illuminating means; F, Special application
313/46	Having heat conducting path

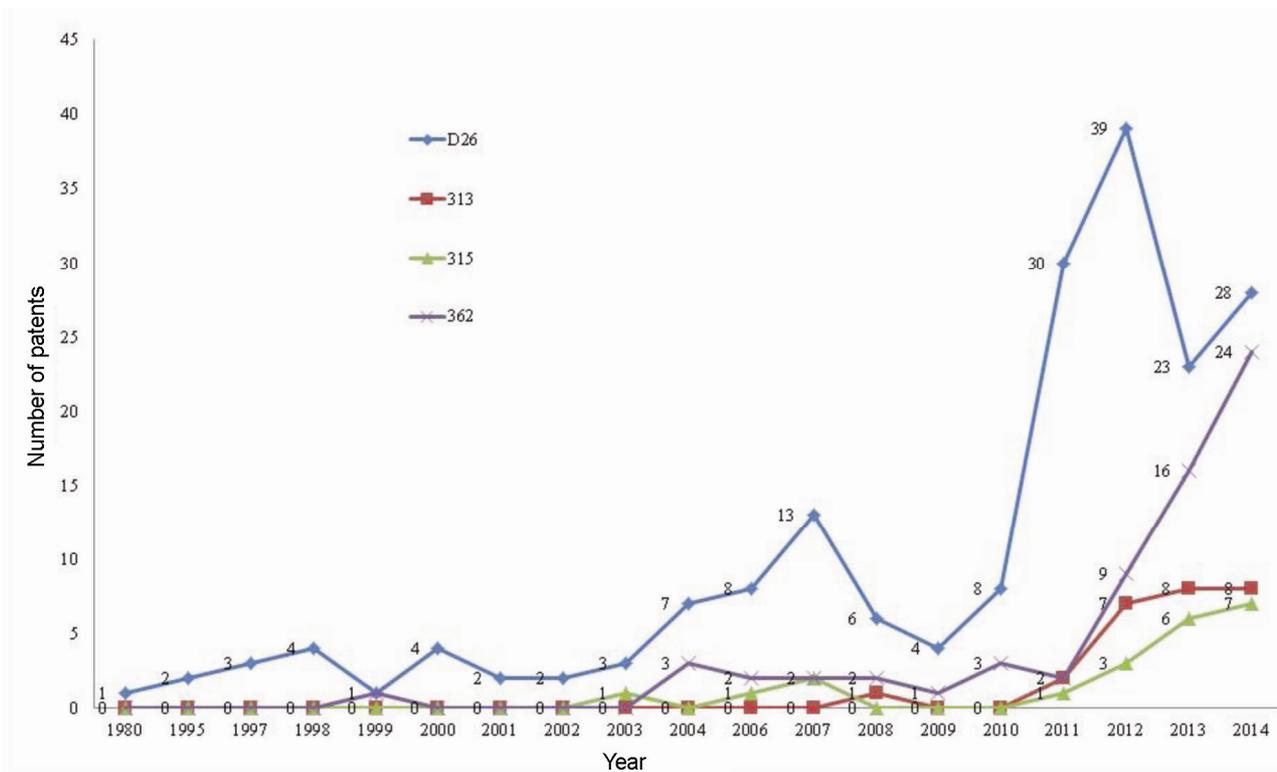


Figure 8. Analysis of USPC classification in the first section.

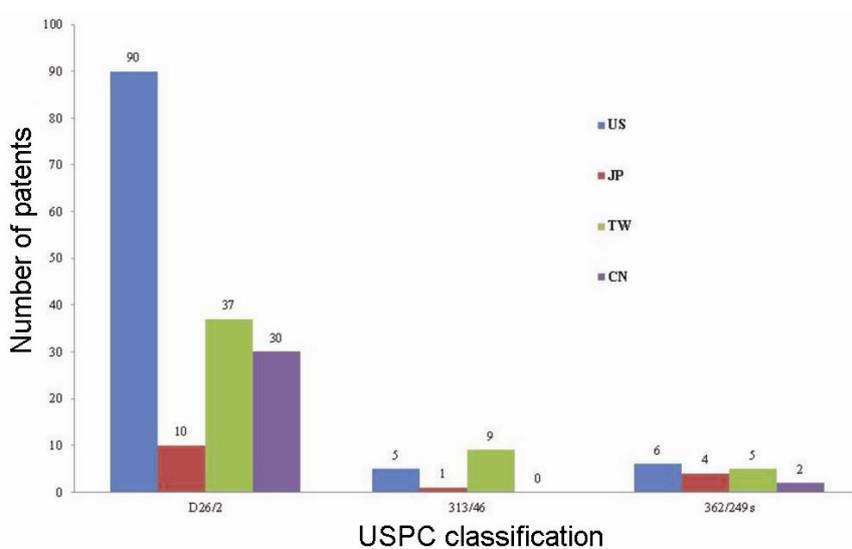


Figure 9. Analysis of USPC classification in the second section.

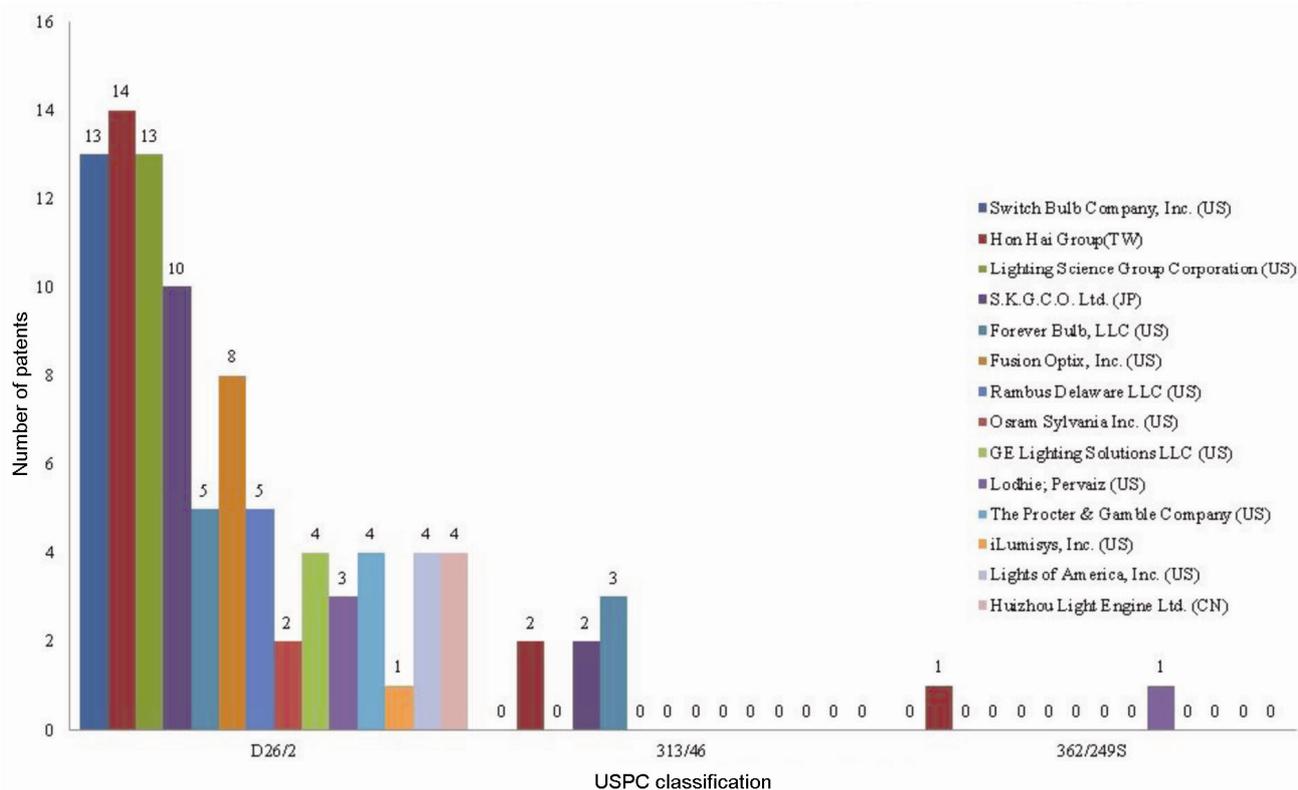


Figure 10. Analysis of patent quantity in USPC in the second section.

These findings demonstrate that there is no overlapping problem among companies that hold LED bulb patent technology and key technology of the elements. The analyses also show that the US is the leading country at the national, company and technology levels. Even though companies in Taiwan still have room for improvement in the future, it is helpful to understand the trend of LED bulb development from different aspects via the results of patent profile. The findings can provide a reference for other relevant LED bulb companies that plan to develop new technologies and increase their competitiveness.

Conclusion and future research

This article deals with patent analysis of LED bulbs patents. The patent profile was used to explore the technological development status of LED bulbs at the national, company and technology levels. Information from the database of USPTO was used to analyse American patents from the US, Japan, Taiwan and China. Primary analytical items included patent quantity, country, company, inventor and USPC. The results show that the US ranks first in terms of patent numbers and is the leading country in the field of LED bulb technology, followed by Japan, Taiwan and China. The results will help managers identify key patents, map their own patent deployment, and

gain insights into the best ways to navigate within such technologies.

Despite the proven effectiveness of the patent analysis on the development trend of LED bulbs, there are limitations associated with this study. First, patent-based indicators of innovation exclude non-codified and unpatented inventions. Using patent-based indicators underestimates innovation. Secondly, some companies tend to hide technology that they are developing. They may forego the patent process and keep their inventions a trade secret. Third, the particular role of patenting the complex process of invention and innovation and its role in the strategies of companies may vary. There are also differences in patenting behaviour across sectors, patent institutions, markets and type of inventor firms. Finally, empirical analysis benchmarking of patent profiles with other performance variables should also be carried out. All of these issues will be the topics of our future studies.

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