Analysis on Technological Trend of Solar Cell using Patent Database

Min-ho Suh, Young Il Kwon, Il-Hyung Lee

Korea Institute of Science and Technology Information
66, Hoegei-ro, Dongdaemun-gu
Seoul 130-741, Korea
mhsuh@kisti.re.kr, ylkwn@kisti.re.kr, ihlee@kisti.re.kr

Abstract

Though the market demand of solar cell was depressed due to the global economic crisis, the continuous interests of leading country in the regenerable energy are vitalizing the solar cell market. Despite the rapid increase in demand for non-silicon solar cells, which represent the next generation of solar cell technology, silicon solar cells still dominate the market. It goes without saying that non-silicon type thin-film solar cells are the next generation solar cells and will increase their market share in the solar cell market. Silicon solar cells are helping to expand the solar cell market by enhancing efficiency and cost competitiveness, while non-silicon thin-film solar cells are rising in demand following the widening of its applications. In this study, we studied patents of silicon and non-silicon type solar cells in order to analyze research trends regarding solar cells, along with the characteristics and level of patents by country and main research institute. We would like this study to help the work of researchers and R&D planners, and to suggest various forms of competitive intelligence information that can be provided through patent analysis.

Keywords: Solar Cell, Silicon, Non-silicon Thin-film, CIGS, Dye-sensitized, Organic Polymer, Patent

1. Introduction

Under today’s rapidly changing business environment, corporations try to maintain their competitiveness by monitoring and corresponding to the latest technological trends. By monitoring the latest technological trends, they prepare themselves for crisis and strengthen their capacity for innovation. Therefore, companies are closely monitoring their competitors and the latest technology in order to keep abreast of technological trends and obtain more business opportunities[1-2]. Patents are regarded as the among the most important parts of technological development, and thus they have been widely used to evaluate technologies and to plan technological development[3-4]. Patent analysis has been used competitively to evaluate competitors and patent infringement status[5-6].

The conventional method for figuring out trends in scientific research and technology was the peer review, in which researchers seek the opinion of a relatively small number of experts[7]. However, since a qualitative approach such as peer review has number of methodological limits. As a result, a quantitative method for figuring out technological trends – called scientometrics – has also been considered. Patent analysis can be considered a result of the scientometric approach. In patent analysis, there is a qualitative approach where one closely analyzes the claims and technological content of each patent of the technology in question; on the other hand, there is a quantitative approach in which the analysis is made based on a quantitative data of the trend through time series analysis on the number of patent of the related technology[8-10]. This study is mainly the result obtained from applying the latter, quantitative approach.

This study provides various analyzing frames that help corporations, researchers and R&D planners to make decisions based on quantitative analysis, specifically by using patent analysis to understand the trends of the related technology. In particular, analyzing various portfolios using citation information from US patents suggests at a variety of recommended presentation methods for competitive intelligence information. Patent analysis are presented as example of analysis results on solar cell technology, and the trend by sub-technology was analyzed under 2 main solar cell types: silicon and non-silicon solar cell. Chapter 2 describes the scope of patents subject to analysis, Chapter 3 describes the trends of each technological category, Chapter 4 describes the portfolio analysis result, and Chapter 5 concludes.
2. Patent subject to analyze

Patents analyzed in this study were registered in Korea, USA, Japan and Europe. WIPS(www.wipsglobal.com) was used as database, and the search period for registered patent application dates was between 2001 and 2010.

<table>
<thead>
<tr>
<th>Country, DB</th>
<th>Search scope of patent</th>
<th>Field search range</th>
<th>Search period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea, Japan, USA, Europe, WIPS</td>
<td>Registered patent</td>
<td>Title, Summary, General claim</td>
<td>2001.01.01 ~2010.12.31</td>
</tr>
</tbody>
</table>

Upon searching all patents regarding solar cells by defining and elaborating upon the search formula in Korean and English from the above patent database, a total of 1,816 patents were obtained as follows. A detailed quantitative analysis was then carried out.

<table>
<thead>
<tr>
<th>Country</th>
<th>Korea</th>
<th>Japan</th>
<th>USA</th>
<th>Europe</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>244</td>
<td>367</td>
<td>278</td>
<td>38</td>
<td>927</td>
</tr>
<tr>
<td>Non-silicon</td>
<td>327</td>
<td>323</td>
<td>181</td>
<td>58</td>
<td>889</td>
</tr>
<tr>
<td>total</td>
<td>571</td>
<td>690</td>
<td>459</td>
<td>96</td>
<td>1,816</td>
</tr>
</tbody>
</table>

3. Trend by technology

Solar cells can be classified into two types which are the silicon type and the non-silicon type. The silicon type solar cells include silicon wafer and silicon thin-film solar cells. The non-silicon type solar cells include CIGS, dye-sensitized, organic polymer solar cells. The trend analysis by technology was carried out for silicon type and non-silicon type, respectively. In each subsection, trend by sub-technology was illustrated.

**A. Silicon Solar Cell**

*(1) Annual patent trend by technology*

Silicon solar cells are categorized by material as silicon wafer and silicon thin-film. There are 638 registered patents of silicon wafer since 2000, which is more than double that of silicon thin-film. Fewer silicon wafer patents were registered in the early 2000’s, but the number of patents has gradually risen since 2004, and its trend is similar to the general trend. For the case of silicon thin-film, a constant number of patents were registered per year (~20 cases/year) until the mid 2000s, and the number has increasingly risen since 2007.

![Figure 1. Annual patent trend by technology category: silicon solar cell](image)
(2) Patent trend of each technology category by country and nationality

In the case of silicon wafer, Japan registered 272 patents amounting to 43% of total patents, followed by Korea with 182 (28%), USA with 160 (25%), and Europe with 24 (4%). In the case of silicon thin-film, USA registered 118 patents amounting to 41% of total patents, followed by Japan with 95 (33%), Korea with 62 (21%), and Europe with 14 (5%).

Figure 2. Patent trend of each technology category by country : silicon solar cell

(3) Patent trend of each technology category by assignee

Sharp, Kyocera, and Shin Etsu Handotai are leading patent technology in silicon wafer solar cell in Japan while LG Electronics and Samsung SDI are leading in Korea, showing similar trends as general silicon solar cell. In the case of silicon thin-film, Sharp, Kaneka, Fuji Electric, and Canon are leading patent technology in Japan, and Korea Institute of Science and Technology Information and LG Electronics are leading in Korea, showing a different trend from the general trend.

Figure 3. Major assignees of each technology category : silicon solar cell
B. Non-silicon solar cell

(1) Annual patent trend by technology

Non-silicon solar cell is divided into CIGS solar cell, dye-sensitized solar cell and organic solar cell depending on material. Among non-silicon solar cells registered after the year of 2000, number of patent registration of dye sensitized is 476, which is over 2 times of other non-silicon solar cells. Patent registration of CIGS solar cell decreased after having increased in the beginning of 2000, then the number is slowly increasing again since 2006. Patent registration of dye sensitized solar cell is rapidly increasing after 2004, and patent registration of organic solar cell is increasing since 2007.

Figure 4. Annual patent trend by technology category : non-silicon solar cell

(2) Patent trend of each technology category by country and nationality

As for patent trend by technology by country, in the case of CIGS solar cell, USA accounts for 35% of patent registration by registering 72 patents, followed by Japan with 63 patents(31%), Korea with 53 patents(26%), and Europe with 17 patents(8%). In the case of dye-sensitized solar cell, Japan accounts for 46% of patent registration by registering 220 patents, followed by Korea with 173 patents(36%), USA with 66 patents(14%) and Europe with 17 patents(4%). In the case of organic solar cell, Korea accounts for 49% of patent registration by registering 101 patents, followed by USA with 43 patents(21%), Japan with 40 patents(19%), and Europe with 24 patents(11%).

Figure 5. Patent trend of each technology category by country : non-silicon solar cell
(3) Patent trend of each technology category by assignee

As for major patent holders, in the case of CIGS solar cell, Sharp in Japan is holding the most with 16 patents, followed by Honda Motor, Showa Shell Sekyu in Japan and Insolartech in Korea, the leaders of patent technology. In the case of dye sensitized solar cell, Sharp in Japan is holding the most with 38 patents and ETRI, Samsung SDI in Korea and Fujikura in Japan are leading the patent technology following Sharp. In the case of organic solar cell, LG Chemical in Korea is holding the most, with 32 patents, and Merch Patnet, Novaled in Germany, Dainippon Printing in Japan are leading patent technology following LG.

![Figure 6. Major assignees of each technology category: non-silicon solar cell](image)

4. Portfolio analysis

A. Silicon solar cell

(1) Technological impact and market power

When it comes to a patent’s technological impact (CPP) and market power as determined by market penetration and qualitative level (PFS), UK, Germany, and USA had relatively high technological impact and market power while the Netherlands had high market power. As technological impact and market power were analyzed based on patents registered in USA, Korea and Japan were discovered to have relatively low technological impact and market power.

(2) Analysis on relations between backward citation and forward citation

When the technical impact of a research entity was studied by evaluating the number of patents cited backward and forward, it was found out that USA and UK had more forward citations and thus had stronger technological impact. They also had more backward citations, suggesting that their technologies were at a relatively more mature stage. Japan, Germany and Australia have more backward citations and possessed more mature technologies despite having less forward citations. It was found that Korea’s technological impact was low, as it had a low number of backward and forward citations, even if the subject of this study was only the patents registered in USA.
(3) Technological competitiveness analysis between countries

The technological competitiveness of a country was studied using patent share, which shows the quantitative index of a patent, and forward citation share, which shows the qualitative index of a patent. Japan (patent share 46%, forward citation share 52%) and USA (patent share 33%, forward citation share 34%) demonstrated both quantitatively and qualitatively higher shares than Korea (patent share 2%, forward citation share 1%).
B. Non-silicon solar cell

(1) Technological impact and market power

When a degree of influence of a patent (CPP) and quality of a patent through market power of a patent of each research author (PFS) are reviewed, it was shown that USA had relatively higher technical influence and market power whereas Germany and Japan had higher technical influence. Since technical influence and market power are based on the patents registered in USA, Korea and Taiwan are shown to have relatively lower technical level and market power than their competitor countries.
(2) Analysis on relations between backward citation and forward citation

When the technical influence of a particular research author was reviewed by evaluating the number of patent cited backward and forward of a particular research author in a certain country, USA and Germany were found out to have relatively mature stage of technology, as they have higher technical influence having both higher backward citations and forward citations. Japan secured a number of technologies in mature stage having higher forward citation, in spite of lower backward citation, whereas Korea is found out to have relatively low technical influence, having lower number of forward and backward citations.

Figure 11. Analysis on relation between backward-forward citation of each technology : non-silicon solar cell (Subject of analysis: Patent registered in USA)

(3) Technological competitiveness analysis between countries

When technical competitiveness of a country was reviewed using patent application share which shows quantitative index of a patent and backward citation share which shows qualitative index of a patent, Japan (patent application share 37%, backward citation share 42%) and USA (patent application share 34%, backward citation share 36%) are showing quantitatively and qualitatively higher shares then Korea (patent application share 9%, backward citation share 3%).

Figure 12. Technological competitiveness between countries : non-silicon solar cell (Subject of analysis: Patent registered in USA)
5. Conclusions

This study presented the quantitative analysis results of solar cell patents registered in USA, Japan, Europe, and Korea. The patent search period was between 2001 and 2010. The increase of patent registrations of silicon wafer type from 2005 and that of silicon thin-film type from 2007 can be explained by the rapid increase in demand for solar cells from the mid-2000s and the recent steep increase in demand for thin-film solar cell demand, which was reflected in the patent trend. The findings that Japan and Korea are leading in silicon wafer type technology and that the USA is leading silicon thin-film technology are attributed to the good performance of Sharp in Japan, which enjoyed monopolistic market activity until 2007, and First Solar in USA, which led the thin-film solar cell market in 2010. On the other hand, as for non-silicon solar cell, patent registration count of CIGS solar cell, dye-sensitized solar cell and organic solar cell is showing increasing tendency from 2006, 2004 and 2007, respectively. This is the same time when expectation on thin film solar cell grew from 2007 when patent registration count of silicon thin film solar cell began to increase. Even though it is a quantitative analysis, the result that Korea took 3rd place in CIGS solar cell, 2nd in dye-sensitized solar cell, and 1st in organic solar cell in country ranking shows that Korea's effort on patent registration is increasing in areas closer to future thin film solar cell. While larger corporations and government institutions are prominent in non-silicon solar cell area as ETRI, Samsung SDI, and LG Chemicals are leading in dye-sensitized solar cell, organic solar cell, and organic solar cell, respectively, it is remarkable to see what InsolarTech has achieved in compound solar cell area. The various portfolio analysis results using patent citation information are somewhat advantageous to USA, since the result is based only on patent data from USA. Despite such a limitation, the significance of this study is in its presentation of various portfolio analysis types. As a quantitative patent analysis such as this helps macro-level technological planning and R&D direction, if accompanied by micro-scale qualitative analysis of high citation patents, then technological trend analysis using patent database will help businesses develop more practical and specific strategies and greater technological breakthroughs.

6. Acknowledgement

This work was supported by the National Research Foundation of Korea Grant funded by the Korean Government (MEST) (NRF-C1AAA002-2011-0002336).

7. References