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1 Executive Summary

The story of David and Goliath unfolded nearly 3,000 years ago, but it is an appropriate description of the current state of the global LED (light-emitting diode) lighting industry. Small niche companies are engaging in fierce competition for shelf space with large global corporations, each one more determined than the next to bring to market the lighting technology of the future.

LED lighting stands to benefit from a paradigm shift to household technologies that are sustainable, networked, personalized, and smart. LED lighting is also having a significant impact in diverse areas like residential and commercial lighting, street lighting, and digital communication. Another key application of LED technology is to improve the quality of displays in monitors and mobile devices. Analysts predict an industry growth rate greater than 54% in 2013, reaching $25 billion in annual global sales. In fact, LED technology is expected to play an enormous role in the surging growth of the semiconductor sector during the next several years. On the precipice of a sea change, which companies are positioned to reap the most benefits: David or Goliath?

One indicator of future success in the marketplace is the strength of the patent portfolios owned by the competing companies. This is especially true in the LED lighting industry, where aggressive patent prosecution, licensing, and litigation practices have become commonplace in recent years. There are currently more than 22,000 granted U.S. patents relating to LED technologies, most of which were filed in the last 5-10 years. Major players in the LED industry are currently involved, on an average, in almost three active litigations per company, and in numerous additional licensing agreements. By all appearances, the LED industry’s patenting practices have matured even before the technology itself has.

This report examines the current LED patent landscape and offers analysis of existing patent holdings of various companies. There are companies, such as Lumileds (now owned by Philips) and Cree that have been heavily involved in R&D activity since the early 2000s. Their patent portfolios are mid-sized but contain many seminal patents, which increases their value. Then there are global electronics suppliers, like Samsung and LG, which have massive R&D budgets but have only entered the LED lighting market in the last 5 years. Their patent portfolios are typically large but contain relatively fewer seminal patents.
2 Introduction

2.1 Technology Overview - LED Lighting

An LED light bulb is a solid state lighting solution designed to be used as a drop-in replacement for incandescent light bulbs, the type used in homes and offices throughout the world. Its main benefits are longevity and energy efficiency, both of which make it a convenient and environmentally friendly lighting choice. Additionally, its small form factor, color-tunability, and connectivity enable new applications that are beyond the capabilities of traditional light bulbs.

The technology challenge facing LED manufacturers is that the light emission produced by the LED bulbs has to meet strict requirements in terms of brightness, color, and directionality in order to appear similar to a conventional light bulb. Moreover, all of this has to be accomplished in a cost effective manner, an especially daunting task, considering incumbent incandescent technologies enjoy significant competitive advantages in cost, scale and experience. Adding to the technology challenges facing LED manufacturers is the fact that LED light bulbs are more complex than conventional bulbs. LED light bulbs must contain an assortment of high performance technologies within a small and economical package.

In terms of function, LED lighting can be categorized into multiple technology sub-domains.

1. **Light emission**: The heart of any LED light bulb is the diode, a semiconductor chip that is patterned and connected to electrodes in order to produce light when electrical current is applied. The characteristics of the emitted light depend on the materials and the processes used to manufacture the chip. The most commonly used material in LED chips for lighting applications is gallium nitride (GaN), which emits blue light. Since the early 1990s, numerous advances have been made in GaN film growth (front-end processes such as epitaxy and doping) and processing (back-end processes such as delamination and surface texturing) to boost their light emitting power and efficiency.

2. **Light management**: The light that emerges from an LED chip is typically unsuitable for many traditional lighting applications. It is often the wrong color (blue rather than white) and emits light with varying intensity in different directions. Advanced phosphor coatings, such as YAG:Ce, have been developed to encapsulate the LED chip or the bulb cover in order to convert the blue light into white light. Reflectors and diffusers are used
to control the directionality. The combined effect is to make the output of an LED chip resemble the warm, omni-directional light of an incandescent bulb despite the drastically different underlying physics.

3. **Heat management**: When turned on, an LED chip emits light and heat. Managing the heat is just as important as managing the emitted light to an LED bulb’s functionality and performance. Typically, heat is drawn away from the diode using a heat sink made of a conductive material such as aluminum. The material and design of the heat sink, the adhesive material between the LED chip and heat sink, and the air flow around the heat sink can all be engineered and optimized for improved performance and cost.

4. **Electronics**: The diode requires DC electrical current supply, but the electricity from a wall socket is AC. Therefore, compact, cheap, and accurate AC-DC converters are needed within an LED bulb package. Moreover, many emerging LED products have functionality beyond that of a traditional light bulb, including color-tunability, dimmability, and even networking capabilities. Both power management hardware (e.g. rectifiers, regulators, pulse width modulation (PWM) circuitry for dimming and buck converters) and software running on embedded microprocessors are responsible for optimal and versatile operation of LED lights.
3 Analysis of LED Patent Landscape

3.1 LED Landscape & Classification

The LED landscape has been categorized along two dimensions as shown in Figure 1:
1. Technology domains as listed in previous section
2. Applications of LED lighting

![LED Landscape & Classification Diagram](image)

3.2 Patent Categories & Distribution

The breadth and complexity of technologies and applications of LED, and the innovation needed to bring them all together, have resulted in aggressive patenting activity over the years. Based on analysis, around 22,662 U.S. patents have been granted in the LED domain – 17,869 patents related to LED technology and 4,793 patents related to applications of LED. Table 1 shows the distribution of patents across categories.

<table>
<thead>
<tr>
<th>Level 1 Categories</th>
<th>Level 2 Categories</th>
<th>Number of U.S. Patents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology domains</td>
<td></td>
<td>17,869</td>
</tr>
<tr>
<td>Light Emissions (8,932 patents)</td>
<td>Materials</td>
<td>5,153</td>
</tr>
<tr>
<td></td>
<td>Front-end Processing</td>
<td>2,158</td>
</tr>
<tr>
<td></td>
<td>Back-end Processing</td>
<td>1,621</td>
</tr>
<tr>
<td>Electronics (3,878 patents)</td>
<td>Power Supply</td>
<td>2,097</td>
</tr>
<tr>
<td></td>
<td>Software</td>
<td>1,781</td>
</tr>
<tr>
<td>Light Management</td>
<td>Directionality</td>
<td>2,522</td>
</tr>
</tbody>
</table>
### Table 1: Level 1 & Level 2 Categories with Number of Granted U.S. Patents

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of Patents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phosphors</td>
<td>1,304</td>
</tr>
<tr>
<td>Heat Management (1,233 patents)</td>
<td></td>
</tr>
<tr>
<td>Air Flow</td>
<td>863</td>
</tr>
<tr>
<td>Heat Sinks</td>
<td>370</td>
</tr>
<tr>
<td>Applications</td>
<td>4,793</td>
</tr>
<tr>
<td>Displays (3,472 patents)</td>
<td></td>
</tr>
<tr>
<td>Backlit</td>
<td>2,174</td>
</tr>
<tr>
<td>Active Matrix</td>
<td>1,298</td>
</tr>
<tr>
<td>Lighting (940 patents)</td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>806</td>
</tr>
<tr>
<td>Commercial/ Industrial</td>
<td>134</td>
</tr>
<tr>
<td>Others (381 patents)</td>
<td></td>
</tr>
<tr>
<td>Indicators</td>
<td>238</td>
</tr>
<tr>
<td>Healthcare</td>
<td>75</td>
</tr>
<tr>
<td>Communication</td>
<td>68</td>
</tr>
</tbody>
</table>

- Significant patent investments have been made in areas related to LED efficiency, production cost and other key engineering metrics.
- The light emissions category has 8,932 patents, indicating that much of the innovation in the last decade is related to materials and processing of LED chips.
- Displays dominate the application of LEDs with 3,472 patents, driven by investments among global electronics manufacturers like Samsung, LG and Panasonic in LED display technology that preceded their push into LED lighting market.

### 3.3 Top Patent Holders in the LED Landscape

The top companies in the LED landscape with respect to their U.S. portfolio size are:
Table 2 shows the distribution of U.S. patents for the top companies across categories:

<table>
<thead>
<tr>
<th>Company</th>
<th>Light Emissions</th>
<th>Light Management</th>
<th>Heat Management</th>
<th>Electronics</th>
<th>Lighting</th>
<th>Display</th>
<th>Others</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>665</td>
<td>129</td>
<td>18</td>
<td>80</td>
<td>3</td>
<td>469</td>
<td>5</td>
<td>1369</td>
</tr>
<tr>
<td>LG</td>
<td>455</td>
<td>68</td>
<td>25</td>
<td>23</td>
<td>4</td>
<td>162</td>
<td>-</td>
<td>737</td>
</tr>
<tr>
<td>Philips</td>
<td>212</td>
<td>166</td>
<td>24</td>
<td>115</td>
<td>33</td>
<td>48</td>
<td>1</td>
<td>599</td>
</tr>
<tr>
<td>GE</td>
<td>127</td>
<td>116</td>
<td>17</td>
<td>40</td>
<td>13</td>
<td>14</td>
<td>1</td>
<td>328</td>
</tr>
<tr>
<td>Osram</td>
<td>120</td>
<td>111</td>
<td>31</td>
<td>31</td>
<td>19</td>
<td>8</td>
<td>1</td>
<td>321</td>
</tr>
<tr>
<td>Panasonic</td>
<td>160</td>
<td>50</td>
<td>10</td>
<td>21</td>
<td>15</td>
<td>34</td>
<td>-</td>
<td>290</td>
</tr>
<tr>
<td>Kodak</td>
<td>177</td>
<td>23</td>
<td>3</td>
<td>10</td>
<td>3</td>
<td>69</td>
<td>-</td>
<td>285</td>
</tr>
<tr>
<td>Cree</td>
<td>120</td>
<td>81</td>
<td>21</td>
<td>8</td>
<td>22</td>
<td>12</td>
<td>-</td>
<td>264</td>
</tr>
<tr>
<td>Seiko</td>
<td>195</td>
<td>16</td>
<td>6</td>
<td>5</td>
<td>-</td>
<td>40</td>
<td>-</td>
<td>262</td>
</tr>
<tr>
<td>Sony</td>
<td>150</td>
<td>18</td>
<td>3</td>
<td>23</td>
<td>1</td>
<td>65</td>
<td>1</td>
<td>261</td>
</tr>
<tr>
<td>Sharp</td>
<td>141</td>
<td>35</td>
<td>5</td>
<td>10</td>
<td>4</td>
<td>63</td>
<td>-</td>
<td>258</td>
</tr>
<tr>
<td>AU Optronics</td>
<td>108</td>
<td>26</td>
<td>2</td>
<td>16</td>
<td>0</td>
<td>97</td>
<td>0</td>
<td>249</td>
</tr>
<tr>
<td>Hitachi</td>
<td>101</td>
<td>24</td>
<td>9</td>
<td>7</td>
<td>0</td>
<td>83</td>
<td>0</td>
<td>224</td>
</tr>
<tr>
<td>Hon Hai</td>
<td>61</td>
<td>42</td>
<td>38</td>
<td>27</td>
<td>11</td>
<td>13</td>
<td>17</td>
<td>209</td>
</tr>
<tr>
<td>Semicon Energy</td>
<td>155</td>
<td>6</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>32</td>
<td>0</td>
<td>203</td>
</tr>
</tbody>
</table>

**Table 2: Patent Distribution of Top Companies across Level 1 Categories**

Philips, Cree, Samsung and LG have established an advantage over their competitors through patenting in the early growth stages of the LED lighting industry. Samsung and LG have done so through the scale of their R&D operations and their interest in developing LED display technology. Philips and Cree have been early movers in the industry and have established R&D programs.

While all of the LED manufacturers have large patent portfolios in the light emission sub-domain, the coverage of their patent portfolios vary. Samsung has the highest number of patents in the display sub-domain, followed by LG. This is quite obvious given their interest in smart phones and high-end TVs which are powered by high-performance LED display technology.

Figure 3 below displays the technology evolution tree for the Level 1 categories, with each circle representing the number of U.S. patents filed in the corresponding year in each category.
3.4 Analysis of Seminal Patents

The entire LED patent landscape was analyzed and ranked using iRunway’s portfolio analysis solution, COMPASS\textsuperscript{SM}. A list of seminal LED patents was generated based on a combination of manual research and a proprietary algorithm for strength calculation. The seminal patent set constituted the top 5% of ranked patents. The strength of the patents was determined based on multiple parameters such as infringement detection, number of independent and dependent claims, technology activity rate, backward and forward references, age of the patent, etc.

Table 3 illustrates the patent distribution for top seminal patent holders, their share of seminal patents and their share of all U.S. LED patents:

<table>
<thead>
<tr>
<th>Company Name</th>
<th>Count of Seminal Patents</th>
<th>Share of Seminal Patents</th>
<th>Count of All LED Patents</th>
<th>Share of All LED Patents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samsung</td>
<td>69</td>
<td>3.97%</td>
<td>1369</td>
<td>6.04%</td>
</tr>
<tr>
<td>LG</td>
<td>58</td>
<td>3.34%</td>
<td>737</td>
<td>3.25%</td>
</tr>
<tr>
<td>Philips</td>
<td>120</td>
<td>6.90%</td>
<td>599</td>
<td>2.64%</td>
</tr>
</tbody>
</table>
## Table 3: Top Seminal Patent Holders
(Source: iRunway analysis based on patent data from USPTO)

<table>
<thead>
<tr>
<th>Company</th>
<th>Patents</th>
<th>Seminal</th>
<th>Portfolio</th>
</tr>
</thead>
<tbody>
<tr>
<td>GE</td>
<td>26</td>
<td>1.50%</td>
<td>328</td>
</tr>
<tr>
<td>Osram</td>
<td>28</td>
<td>1.61%</td>
<td>321</td>
</tr>
<tr>
<td>Panasonic</td>
<td>18</td>
<td>1.04%</td>
<td>290</td>
</tr>
<tr>
<td>Kodak</td>
<td>10</td>
<td>0.58%</td>
<td>285</td>
</tr>
<tr>
<td>Cree</td>
<td>40</td>
<td>2.30%</td>
<td>264</td>
</tr>
<tr>
<td>Seiko</td>
<td>12</td>
<td>0.69%</td>
<td>262</td>
</tr>
<tr>
<td>Sony</td>
<td>17</td>
<td>0.98%</td>
<td>261</td>
</tr>
<tr>
<td>Sharp</td>
<td>9</td>
<td>0.52%</td>
<td>258</td>
</tr>
<tr>
<td>AU Optronics</td>
<td>4</td>
<td>0.23%</td>
<td>249</td>
</tr>
<tr>
<td>Hitachi</td>
<td>9</td>
<td>0.52%</td>
<td>224</td>
</tr>
<tr>
<td>Hon Hai</td>
<td>16</td>
<td>0.92%</td>
<td>209</td>
</tr>
<tr>
<td>Semicon Energy</td>
<td>5</td>
<td>0.29%</td>
<td>203</td>
</tr>
</tbody>
</table>

Samsung, LG and Philips have a substantial number of patents in the LED domain. The top 15 companies hold around 25% of the seminal patents in this technology area. Philips has the highest percentage of seminal patents in the LED technology domain, despite having less than half the number of patents that are held by Samsung.

In order to better understand the strength and quality of the portfolios that companies hold, iRunway analyzed the ratio of the number of seminal patents to their respective U.S. portfolio sizes. Figure 4 shows this metric for the top seminal patent holders:
Analysis of this metric revealed certain interesting insights. There are companies in the landscape that hold key patents in the LED domain and have the highest percentage of seminal patents in their portfolios.

- Philips holds a stronger portfolio compared to other large players in the industry.
- Cree does not have an expansive LED patent portfolio like other top players, but has a relatively higher number of seminal patents.

Table 4 shows the distribution of seminal U.S. patents for top companies across categories:

<table>
<thead>
<tr>
<th>Company</th>
<th>Seminal Patent Distribution across Level 1 Categories</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light Emissions</td>
<td>Light Management</td>
</tr>
<tr>
<td>Samsung</td>
<td>40</td>
<td>4</td>
</tr>
<tr>
<td>LG</td>
<td>39</td>
<td>5</td>
</tr>
<tr>
<td>Philips</td>
<td>18</td>
<td>32</td>
</tr>
<tr>
<td>GE</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>Osram</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Panasonic</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Kodak</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Cree</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Seiko</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Sony</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Sharp</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>AU Optronics</td>
<td>3</td>
<td>-</td>
</tr>
<tr>
<td>Hitachi</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Hon Hai</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Semicon Energy</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>185</strong></td>
<td><strong>78</strong></td>
</tr>
</tbody>
</table>

Table 4: Distribution of Seminal Patents across Categories
(Source: iRunway analysis based on patent data from USPTO)
3.5 Patent Filing and Grant Trends

Figure 5 shows the LED patent filing trends of the top 5 companies from 1995-2012:

- Patenting activity in the LED domain picked up dramatically in the early-to-mid 2000s.
- Samsung and LG led the charge, filing in excess of 100 patents annually by the late 2000s.
- Philips has filed a significant number of patents annually since the early 2000s and maintained an average rate of over 25 per year. Its early patenting lead has translated into ownership of the industry’s most valuable patent portfolio, containing twice the number of seminal patents as its nearest competitor.

Figure 6 shows the LED patent grant trend of the top 5 companies from 1997-2013:
4 LED Display Technology in Mobile Devices

Among 3,472 patents related to display, Samsung has the highest share with 469 patents followed by LG with 162 patents. Mobile devices are smaller than general display devices and the attributes required for the mobile displays are a bit different. The display has to be thin, lightweight, outdoor readable, should have less power consumption, and have high quality screen visibility.

There are two types of technologies in displays: active-matrix display and passive-matrix display. Over the past few years, the use of passive-matrix displays such as MSTN and CSTN (Monochrome and Color Super-Twisted Nematic) LCDs have declined sharply due to their limited color range display capacity. On the other hand, the use of active-matrix display technologies such as TFT LCD, IPS LCD and Organic Active-Matrix Light Emitting Diode (AMOLED) in mobile displays has significantly increased. Display technology has evolved from LCDs into LEDs which have superior performance characteristics.

4.1 Display Technology in Mobile Devices

TFT LCD Display
Thin Film Transistor Liquid Crystal Display (TFT LCD) uses Thin-Film Transistor (TFT) technology to enhance image quality. It offers better image quality and higher resolutions compared to earlier generation LCD displays. The drawbacks of TFT-LCD include narrow viewing angles, poor visibility in sunlight and it consumes more power. This technology is cheaper and is used in budget phones and low-end smart phones.

IPS-LCD Display
IPS (In-Plane Switching) LCD offers better display quality than normal TFT LCD display. It provides wider viewing angles and consumes less power, which in turn improves battery life. This technology is costlier than normal TFT LCD. LG is the leading manufacturer of this IPS-LCD display, which is adopted in LG Optimus smart phones. Apple uses a high resolution version of IPS-LCD in its iPhone 4 and 5, which is called “Retina Display” because of its excellent picture quality1.

S-LCD Display
Super LCD (S-LCD) displays differ from regular LCDs. In S-LCD, there is no air gap between the outer glass and the display element, and that makes the overall display unit thinner. It

reduces the glare outdoors and makes interactions seem more natural. S-LCD screens also have improved power consumption. This display was used in HTC smart phones, and is actually manufactured by S-LCD Corporation (a joint venture between Sony and Samsung) which was acquired by Samsung².

**OLED Display**

OLED (Organic Light Emitting Diode) display technology is often considered much better than LCD display technology because of its excellent color reproduction, faster response times, wider viewing angles, higher brightness and extremely lightweight designs.

**Advantages over LCDs:**

- Display screens using OLED technology consist of electro-luminescent pixel elements which emit light directly and give OLEDs a higher contrast ratio than LCD and lower power consumption.
- Unlike LCDs, OLEDs do not have backlight which makes it thinner and lighter with better light efficiency.
- OLEDs do not use polarized light, which results in lower energy consumption.
- Transition time of OLEDs can be less than 1ms, offering a refresh rate of up to 1000 Hz.
- OLED screens can display bright images that are viewable from almost any angle.

**Challenges in OLED Technology³:**

- OLEDs have advantages over LCDs, but there are higher manufacturing costs. Though production of OLED is theoretically cheaper than LCD, fabrication of the OLED substrate is costlier than TFT-LCD. The complete process steps are expensive and time consuming.
- OLEDs have a shorter lifespan due to use of organic materials. Manufacturers are aiming to increase the lifespan of OLED displays by improving light out-coupling, thus achieving the same brightness at a lower drive current.
- OLEDs consume around 40% of the power of an LCD while displaying an image in black background, but it uses more than three times the power to display an image with a white background, such as a document or web site. OLED is not ideal for eReader applications because it consumes more power than LCD when displaying white content such as ebooks.

Due to these challenges, the current use of OLEDs (more so AMOLEDs) in mobile devices is confined only to the high end smart phones.

4.2 Samsung & LG

Samsung is the clear leader in OLED technology. It produced its first AMOLED display phone in 2009 and it is investing a lot in OLED display - $4.8 billion in 2011, $6 billion in 2012 and $4 billion in 2013\(^4\). It has sold more than 160 million OLED displays that are used in the Galaxy S series products\(^5\). Samsung developed super AMOLED technology in 2010 that offers significantly better performance than AMOLED displays and many of their smart phones including the Galaxy S4 and the Note III are produced with Super AMOLED display\(^6\). In October 2013, Samsung announced that it has developed the Flexible OLED display that will be adopted in the Galaxy round smart phone\(^7\).

LG is the largest supplier of IPS LCD displays\(^8\). All the latest LG smart phones contain IPS display and it supplies Retina Display to Apple iPhones and iPads. LG also focused on developing flexible OLED technology, and invested $1.9 billion in R&D related to OLED in 2012\(^4\) and around $656.7 million in 2013\(^9\) to make flexible OLED displays for its new G flex smart phone. In 2013, both companies settled litigations on patents involving LCD and OLED technologies\(^10\).

4.3 Future Growth

According to 2013 statistics, the revenue share of AMOLEDs is 37%, followed by IPS-LCDs (36.1%) and TFT-LCD (26.5%). The increase in AMOLED revenue is primarily driven by growth in the size and resolution of mobile displays\(^11\). Extensive research is going on to develop OLEDs with a longer lifespan and better color balance techniques. With the development of cost effective production methods of OLED displays, the use of OLEDs in mobile devices will greatly increase.

\(^7\) http://www.theverge.com/2013/10/31/5050084/lgsamsung-curved-smartphone-design-flexible-oled-future
\(^8\) http://www.tftcentral.co.uk/articles/content/ips_technologies.htm
\(^9\) http://www.zdnet.com/lg-display-to-invest-657-million-inoled-industry-7000011436/
\(^11\) http://www.pcb007.com/pages/zone.cgi?a=94268
5 Other Applications of LED Technology

Apart from its well-known applications in display and lighting (commercial and residential), LED technology has a wide array of applications in the fields of health care and communications, to name two. Within healthcare, LED technology is being explored for clean and green lighting solutions in hospitals. The healthcare industry demands 24-hour electricity usage that forms the foundation for its soaring carbon footprint, and LED technology is just the ticket to tackle its high energy consumption. Patented LED lighting technology has been designed to prevent gathering of dust, bacteria and dead insects around warm light fittings\(^\text{12}\). LEDs are ideal for CT and ultrasounds owing to their dimmable feature. LED lights are MRI safe, require lower maintenance and prevent hospital bred infections from spreading, thus impacting overall wellness and productivity\(^\text{13}\).

Not only is LED technology being exploited for its lighting features in health care, it is also being researched extensively in the fields of dentistry, pain management and behavioral disorders. LED is a type of dental curing light that uses blue light-producing LEDs to cure dental material such as composite resins\(^\text{14}\). LED-curing lights generate much less heat and do not require a fan to cool, thus enabling more lightweight and durable designs\(^\text{15}\). LED technology is also being investigated for its effect on Alzheimer’s disease, jet lag, insomnia, sleep pattern disturbances and other behavioral problems and disorders. LEDs are being analyzed for their pain reduction capabilities with cancer patients undergoing chemotherapy. Pilot studies indicate noteworthy relief from the side effects of chemotherapy and radiation treatments, thereby significantly improving patients’ quality of life\(^\text{16}\).

LEDs have formed the new buzzword in the field of communications, as well. LiFi is the latest technique in the field of optical wireless communications that focuses on establishing communication links via LED lighting networks. Network providers are hoping to turn to LiFi for respite against the bandwidth crunch caused due to towering data usage. LiFi is aimed to serve as a complementary technology to Wi-Fi, Bluetooth and WiMax thanks to the high

\(^{12}\) [http://www.mhalighting.co.uk/applications/healthcare/](http://www.mhalighting.co.uk/applications/healthcare/)


\(^{14}\) [http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSu7zK1fsIxtU482elY_xev7ge17ZeVTSvTSesSSSSSS--&fn=curing_light_supplement.pdf](http://multimedia.3m.com/mws/mediawebserver?mwsId=SSSSSu7zK1fsIxtU482elY_xev7ge17ZeVTSvTSesSSSSSS--&fn=curing_light_supplement.pdf)


level of speed, connectivity and security it offers\textsuperscript{17}. The LiFi market is predicted to have a compounded annual growth rate of 82\% from 2013 to 2018 and is estimated to be worth over $6 billion per year by 2018\textsuperscript{18}.

Besides the hi-tech applications of LED technology, it plays a pivotal role in enhancing the shopping experience. LED solutions are being implemented to fashion tailor-made effects for the perfect retail milieu: from vividly theatrical to attractive and appealing looks to stimulate customers’ interest in desired products and services. LEDs are known to increase efficiency by providing the right lighting based on the time of day and adapted to work requirements in an office environment\textsuperscript{19}.

The use of LEDs as indicator lights is one of the oldest known applications of LED technology. We encounter these types of indicator lights when using the caps lock key on our computer keyboards; checking time on our digital watches; doing math on a calculator; playing our favorite music on the stereo; and checking the fuel tank level on our automobiles; among the multitude ways in which we interact with LED technology in our day-to-day lives\textsuperscript{20}.

\begin{footnotesize}
\textsuperscript{19} http://www.lighting.philips.co.in/lightcommunity/trends/led/led_lighting_possibilities.wpd
\textsuperscript{20} http://www.patentinsightpro.com/techreports/0410/Gridlogics%20Technology%20Insight%20Report-LEDs%20in%20Lighting.pdf
\end{footnotesize}
6 Key Players in the LED Patent Landscape

6.1 Samsung

- Samsung started offering LED lighting products in late 2011, but their patent filings in this domain date back to the early-to-mid 2000s.
- Samsung has the largest LED portfolio with 1,369 granted U.S. patents.
- Samsung has the highest number of patents related to displays (469 patents). In spite of their focus on displays, the underlying technology used by LED displays and LED light bulbs is similar.
- Samsung also has over 600 U.S. patents in the light emission sub-domain and ranks second on the list in terms of number of seminal patents.

Figure 7: Technology Evolution Tree of Samsung’s LED U.S. Patent Filings
(Source: iRunway analysis based on patent data from USPTO)
6.2 LG

- LG has 737 U.S. LED patents and is ranked 2\textsuperscript{nd} in terms of portfolio size, but has a coverage similar to Samsung.
- LG has focused its patenting efforts predominantly in light emission and display sub-domains. It has 455 patents in light emission and 162 patents related to displays.
- LG has the second highest number of U.S. patents in displays next to Samsung.

Figure 8: Technology Evolution Tree of LG’s LED U.S. Patent Filings
(Source: iRunway analysis based on patent data from USPTO)
6.3 Philips

- Philips has 599 U.S. patents and is ranked 3rd in the list in terms of portfolio size.
- Philips has the strongest portfolio in the LED landscape – 120 seminal patents (6.9% share of all seminal patents) and the highest concentration of seminal patents (20.03% of its patents are seminal).
- Unlike some other companies, Philips has good patent coverage across various sub-domains – light emission, light management, electronics, lighting and displays.
- Lumileds (now owned by Philips) is one of the early players in the LED market. It has continued to be a leading innovator, often being the first to market LED products that integrate cutting edge technology.
6.4 GE

- GE is one of the global leaders in incandescent lighting, and with the changing market it has focused its R&D and patenting efforts heavily on LED technology.
- GE first invented the visible spectrum LED in 1962, which is considered a significant breakthrough in commercial LEDs. In spite of its early research efforts in LEDs, GE has fewer patents compared to Samsung and Philips.
- GE has 328 U.S. patents in the LED landscape and a majority of its portfolio consists of patents in the light emission category (127 patents), followed by light management (116 patents).
- GE Lighting Solutions, a subsidiary of GE, focuses on the LED business. Recent acquisitions of Lightech Ltd. and Albeo Technologies are viewed as a step forward in strengthening its LED product portfolio.
- GE is involved in lawsuits in the areas of light emission, electronics and lighting.

![Figure 10: Technology Evolution Tree of GE’s LED U.S. Patent Filings (Source: iRunway analysis based on patent data from USPTO)](image-url)
6.5 Cree

- Cree is one of the earliest entrants into the LED market, with products and patents dating back to the late 1980s.
- Cree holds a significant number of seminal patents in the U.S. LED landscape (40) and has the second highest concentration of seminal patents (15.15% of its patents are seminal). Given the strength of the patents, we believe the technology used in their products may continue to lead the industry in the near future.
- LED lighting is the core business for Cree and it generates higher income from LED-related activities. It has mature technology and patent licensing programs, which bring in revenue even when LED sales are low.

Figure 11: Technology Evolution Tree of Cree’s LED U.S. Patent Filings
(Source: iRunway analysis based on patent data from USPTO)
Within the semiconductor industry, the LED domain has been in an active litigation mode. Over the past few years, LED patents have become the subject of numerous lawsuits in the U.S. We analyzed the litigations of top companies in this landscape and the patents asserted since 2011. Table 5 provides a summary of parties involved in these litigations.

<table>
<thead>
<tr>
<th>Company</th>
<th>As plaintiff against</th>
<th>As defendant against</th>
</tr>
</thead>
</table>
| Samsung | • Osram             | • LED Tech Development  
                      • Boston University  
                      • Osram               |
| LG      | • Osram             | • Osram             
                      • Bluestone Innovations |
| Cree    | • Cooper Lighting   | • Cooper Lighting   
                      • SemiLEDs            
                      |                     | • National Cheng Kung University  
                      |                     | • SemiLEDs            
                      |                     | • Schubert            |
| Philips | • Aurora Lighting   | • National Cheng Kung University  
                      • Nexxus Lighting    
                      • Lux Electronic Products  
                      |                     | • Schubert            
                      |                     | • Relume Corp.        
                      |                     | • Bayco Products      
                      |                     | • Takion Co.          
                      |                     | • Lektron             |
| GE      | --                  | • Relume Corp.       
                      |                     | • Light Transformation Technology  
                      |                     | • Lektron             |
| Osram   | • Samsung           | • Cathode Lighting Systems  
                      • LG                  
                      |                     | • Samsung             
                      |                     | • LG                  
                      |                     | • Kadence Designs     
                      |                     | • Schubert            
                      |                     | • CAO Group           
                      |                     | • Lexington Luminance  
                      |                     | • Jam Strait           |

Table 5: Summary of LED Litigations involving Top Companies

- Philips and Osram have been involved in the highest number of litigations (both as plaintiff and defendant).
All LED market players have filed a large number of patents in the light emission category, a result of intense research in this field. Light emission is also the predominant area of litigation activity involving these companies.

Universities and research institutions have also filed lawsuits against manufacturing companies such as Samsung and Philips for infringement of LED technology developed in their optoelectronics research labs. This trend could grow with increasing number patents being filed by academic institutions.

The other technology area with frequent lawsuits is heat management. Among the various applications categories, lighting plays an important role in litigation. Cree, GE, Philips and Osram have been involved in lawsuits that include patents on lighting.

Patent licensing has also picked up in recent years. Numerous licensing and cross-licensing agreements are now in place among the key patent holders in the LED industry. Many LED-related technologies have applications outside of the LED industry, presenting further opportunities to monetize LED patent portfolios. For example, patents related to semiconductor materials and power electronics owned by Cree are offered for licensing through its website.

Here are a few specific examples of litigations and licensing deals in the last few years:

- Osram entered into multiple cross licensing agreements with Nichia, Philips, Toyoda Gosei, Cree, Samsung, Sharp, and LG. All these agreements comprise patents in the field of opto-electronic semiconductor components, and lighting products including these components.\(^{21}\)
- In 2009, Nichia and Seoul Semiconductor settled all their litigations across multiple countries and entered into a cross-licensing agreement covering LED and laser diode technologies.\(^{22}\)
- In 2010, Philips and Lemnis Lighting signed a license agreement giving Lemnis access to Philips’ vast portfolio of patents related LED-based luminaires and retrofit bulbs. At the same time, Philips obtained access to the LED-bulb architecture and control patents of Lemnis.\(^{23}\)

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• In November 2009, Nichia Corporation filed a lawsuit alleging that certain white LED-application products marketed by Jiawei contained patent infringing white LEDs. This case was settled in 2010, with Jiawei agreeing to pay an undisclosed amount to Nichia.\(^{24}\)

• In 2009, Light Transformation Technologies (a subsidiary of Acacia Research) filed two cases against 17 defendants, alleging infringement of its patent entitled “Highly Efficient Luminaire Having Optical Transformer Providing Precalculated Angular Intensity Distribution and Method Therefore”. In 2010, LTT settled its lawsuit and entered into a license agreement with Philips and Dialight Corp.\(^{25,26}\)

• In 2012, Bluestone Innovations LLC filed a patent lawsuit against Best Buy and LG, alleging infringement of a patent covering technology improving the brightness of LED. It also filed lawsuits against multiple companies in 2010 alleging infringement of LED patents.\(^{27}\)


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