Development of OLED Lighting Panel with World-class Practical Performance

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Using its proprietary device technology, Lumiotec Inc. specializes in the development, manufacture and distribution of practical lighting panels made of organic light-emitting diodes (OLED) with high luminance and a long product life. Lumiotec started manufacturing and selling fluorescent panels in January 2011, followed by the launch of the new P05 series, a line of 40-lm/W power-saving panels based on phosphorescent light emission, in the spring of 2012. Targeting use in galleries, etc., the company released the P06 series high-color rendering panels in the summer of 2012, featuring the capability to reproduce a color closer to natural light. Although OLED lighting panels are at present inferior to LED lighting in terms of efficiency, the company is planning to supply, from the spring of 2013, a 60-lm/W high-efficiency panel incorporating its light out-coupling technology currently under development. By promoting the light out-coupling technology, the company is also aiming to launch next-generation panels with an efficiency of 80 - 100 lm/W in 2014 to 2015.

1. Introduction

With the growing consciousness of energy conservation in terms of the global environment in recent years, high hopes have been placed on OLED lighting, along with LED, as next-generation lighting. It is a type of semiconductor lighting that emits light based on a principle different from that of the existing light sources. It has characteristics such as the use of a thin and lightweight diffusion light source that is gentle to the eyes, low-temperature operation free from ultraviolet rays, low power consumption, a high color rendering index and a long product life.

Toward the practical use of OLED lighting, the development of applications taking advantage of such characteristics is attracting much attention recently. In such a background, Lumiotec, which is marking its fifth anniversary this year, has added new practical products with high efficiency and a high color rendering index to its portfolio. The company is now promoting the development of new technology and setting up a mass-production system with an eye to a phase of full-scale, widespread use of OLED lighting.

This paper outlines a newly developed panel series featuring a luminous efficacy of 40 lm/W and a color temperature of 2,800 K (lamp color), and a high-color rendering (Ra 93) panel series with a color temperature of 4,700 K (natural white color). It also discusses the production line for these panels. Furthermore, the paper details the development of a next 60-lm/W high-efficiency model and next-generation panels.

2. Development of 40-lm/W High-efficiency Panel

The P05 series, which has been mass-produced since April 2012, includes lamp-color panels enabling high-luminance, high-efficiency light emission at a rated luminance of 3,000 cd/m^2 and a rated luminous efficacy of 40 lm/W. **Figures 1** to **3** illustrate a comparison of luminous performance with the existing P04 panel series. To enhance the efficiency, the fluorescent material

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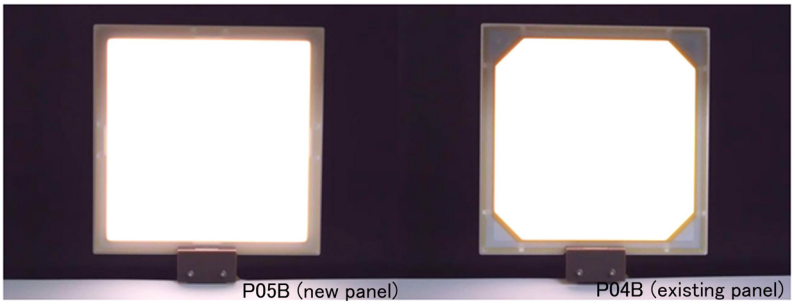
used thus far has been entirely replaced by a phosphorescent material. This significantly improved the panel properties, because theoretically a phosphorescent material can achieve an internal quantum efficiency of 100%, whereas that of the fluorescent material is approximately 25%. However, a phosphorescent material generally tends to have a shorter product life than a fluorescent material. Lumiotec addressed this problem by using its proprietary multi-photon emission (MPE) device structure in combination with the phosphorescent material. The MPE structure is a laminated-type planar LED device structure consisting of multiple light-emitting units that are connected in series via charge generation layers. As one of its advantages, the MPE device can reduce the drive current required to achieve the same luminance. This consequently reduces the load on each light-emitting unit, thereby improving the product life properties.



Items	Units	Lamp color type	
		P05B (new panel)	P04B (existing panel)
Panel dimensions	(W×L×t) mm	145×145×2.3	
Luminous flux	lm	145	99
Rated power	W	3.6	9.6
Luminous efficacy	lm/W	40	10
Luminance	cd/m^2	3000	2800
Correlated color temperature	K	2800	

Some of the materials and technology provided by: Universal Display Corporation's Universal PHOLED®

Figure 1 Table of performance comparison with existing panel

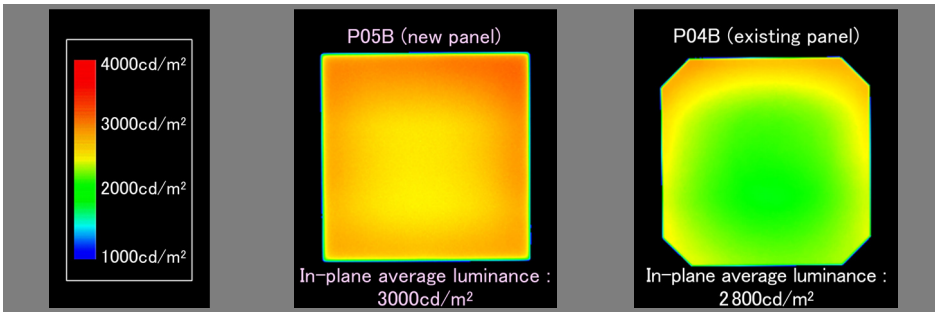


Figure2 In-plane luminance distribution of new panel (145-mm square panel driven at rated power)

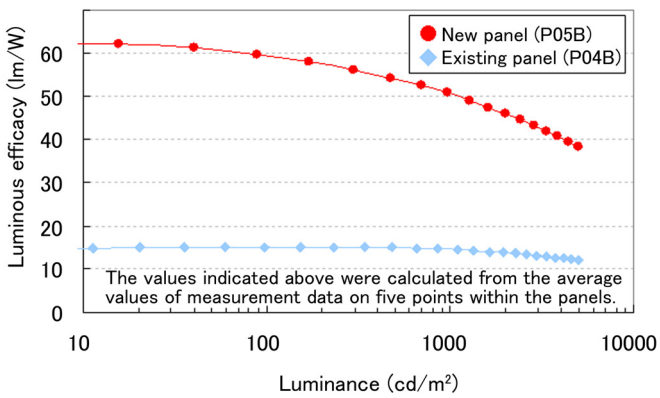
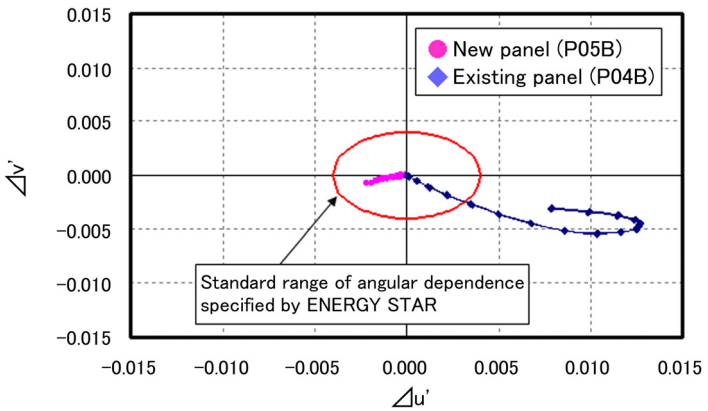


Figure3 Luminance-luminous efficacy curve of 145-mm square panel (newly developed)

In the development of technology relating to light out-coupling, the company focused on, along with the improvement of luminous efficiency, eliminating angular dependence, which has been a problem of planar LED. (Angular dependence is a phenomenon where the lighting color changes when viewed from different angles.) Lumiotec thus adopted a light out-coupling film jointly developed with Toppan Printing Co., Ltd. and thoroughly re-evaluated the optical design, including the adjustment of the film thickness of each OLED device layer. As a result, the angular dependence was dramatically improved compared with that of the P04 series. In the angle range of 0 - 80°, the new series achieved properties compliant with the standard range of angular dependence of light sources for solid-state lighting specified by Energy Star[*1] (**Figure 4**).

In addition to the P05 series, the company is also preparing for and promoting the development of the mass-production of a high-color temperature (4,000 K), high-efficiency panel slated for shipment by the end of 2012.

[*1] A program promoted by the Environmental Protection Agency (EPA) and Department of Energy (DOE) in the United States.



Angular dependence of u'v' chromaticity when the front side is taken as a reference (0 − 80°).

Figure 4 Angular dependence of panel

3. Development of High-color Rendering Panels for Galleries

Similarly to panel efficiency and product life, the color rendering index is one of the properties that indicate lighting performance. In particular, it is a critical indicator for applications in galleries and similar places, where the colors of exhibited works must be reproduced faithfully under artificial lighting. In addition, since infrared and ultraviolet rays can result in the deterioration of exhibits, high-color rendering lighting with lower emission of such rays is required.

Recently, Lumiotec developed the P06 series, a line of natural white color (4,700 K) OLED lighting panels achieving the world-class color rendering index of Ra 93[*2] that meets the requirements mentioned above. To ensure the high color rendering index, the spectral distribution of the panel in the visible wavelength range should be approximated to that of sunlight, without being biased to a certain wavelength range. This requirement was met by making the emission intensity balance uniform among the blue, green and red regions through the selection of appropriate light-emitting materials and the optical interference design. In particular, the company worked on improving the efficiency of the blue device, which has the lowest efficiency despite its effectiveness in improving the color rendering index. At the same time, the device structure was so designed that the intensities of green and red are well-balanced when combined with the light out-coupling film. As a result, the new series achieved high color reproducibility for all test color samples, including red and flesh color, which have been regarded as difficult to reproduce (**Figure 5**). The adoption of the new panels made it possible to provide a more comfortable visual environment, and Lumiotec expects demand for applications in galleries and museums, where lighting that emits little harmful light and that is approximated to sunlight is required, as well as in fresh food and clothing stores.

[*2] The symbol "Ra" indicates a general color rendering index. The index is determined by quantifying and averaging visual differences between test colors (R1 - R8) and reference illuminants when the test colors are illuminated by a light source under evaluation. The closer the index is to 100, the higher the color reproducibility.

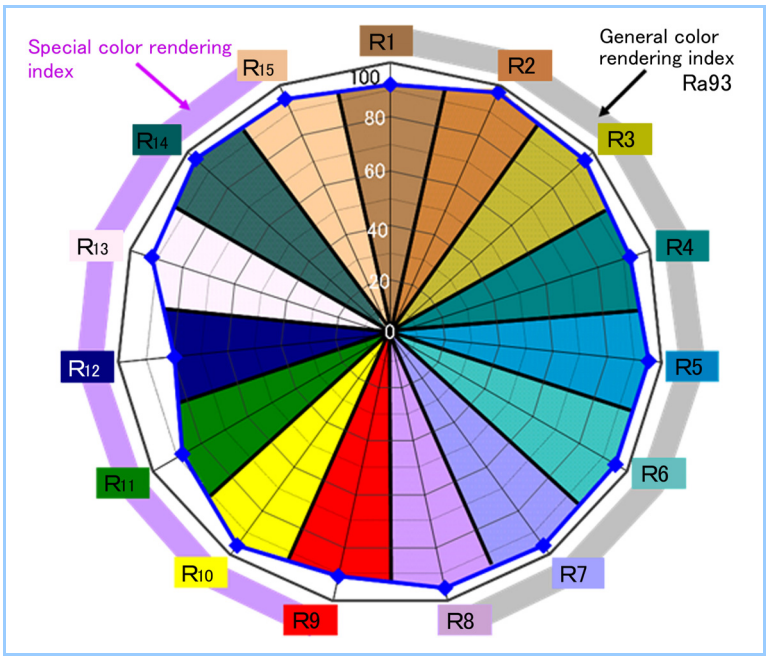


Figure 5 Color rendering index of high-color rendering panel

4. Development of Mass-production Technology

In film formation processes for organic layers and cathodes, Lumiotec uses an "in-line deposition apparatus with linear evaporation sources," which is suitable for mass-production (external view shown in **Figure 6**). As a sealing process, the company employs a highly reliable gel encapsulation process. In addition, the company developed an automatic inspection system based on image processing and constructed a production line intended for low-cost mass-production. Visual checks thus far performed by skilled examiners during lighting inspections and lighting property tests have been replaced by the use of this system.

Figure 6 External view of in-line deposition apparatus with linear evaporation sources

The in-line deposition apparatus with linear evaporation sources was installed in the Yonezawa Plant in August 2009, and has been in full operation for production and development for more than three years. Since dye doping should be performed in the film formation of organic light-emitting layers, the apparatus has adopted an evaporation source arrangement that allows co-evaporation. However, in the production of high-efficiency panels using phosphorescent material, the arrangement of evaporation sources was improved from the existing double-source co-evaporation (with one host and one dopant) to triple-source co-evaporation (with one host and

two dopants) so that the features of phosphorescent material can be fully leveraged (**Figure 7**). The system, which is the first in the world for an in-line apparatus using linear evaporation sources, has been applied to mass-production and has succeeded in achieving a stable product quality.

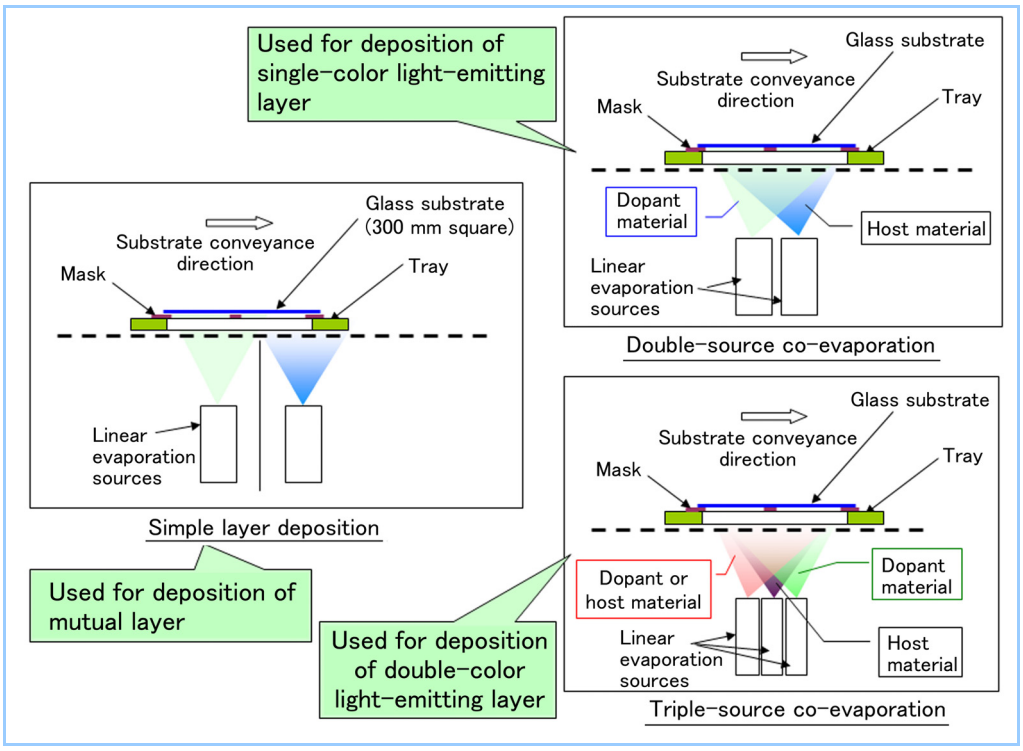


Figure 7 Deposition process using linear evaporation sources

5. Development of Next 60-lm/W high-efficiency Panel

For a general OLED lighting panel, the percentage of energy that can be out-coupled from the total light energy obtained by OLED light emission is estimated to be approximately 25% at most. Thus, to provide a high-efficiency panel of 60 lm/W or higher, the enhancement of light out-coupling efficiency is one of the most important tasks, in addition to improving the luminous performance of the devices.

First of all, for the improvement of device performance, which is the basis for out-coupling efficiency enhancement, the light-emitting dopants and the host were re-evaluated, and the voltage loss was reduced by improving the injection properties and transportability of holes and electrons. In the device optical system, the transmittance and reflectance were improved, and the optical interference design was re-evaluated to enhance the base efficiency.

Meanwhile, for the enhancement of light out-coupling efficiency over the entire panel, it is necessary to establish a technique for intensively out-coupling thin-film guided mode light (light trapped in ITO[*3] and organic thin films) and light absorbed in a metal electrode (cathode), in addition to a method for out-coupling substrate mode light (light trapped in a glass substrate) through the use of existing light out-coupling film. The types of light loss inside a device can be roughly classified into two: absorption by the cathode and guided loss into the thin film. A relatively large amount of light is absorbed by the resonance phenomenon due to interaction between electrons and light on the cathode surface. To tackle this problem, the company is now working on a method to suppress the resonance by means of light scattering (to obtain light with various phases), etc. On the other hand, the loss of thin-film guided light is mainly due to light reflection caused by the difference in refractive index between the ITO film and the glass substrate adjacent to it. Thus, the loss can be reduced by appropriately adjusting the direction of light so as to increase the light component at an angle free from reflection (critical angle). **Figure 8** is a cross-sectional conceptual view illustrating the effects of the new light out-coupling structure used in the panels.

[*3] ITO is an abbreviation for indium tin oxide, i.e., tin-doped indium oxide, which makes up a transparent conductive film.

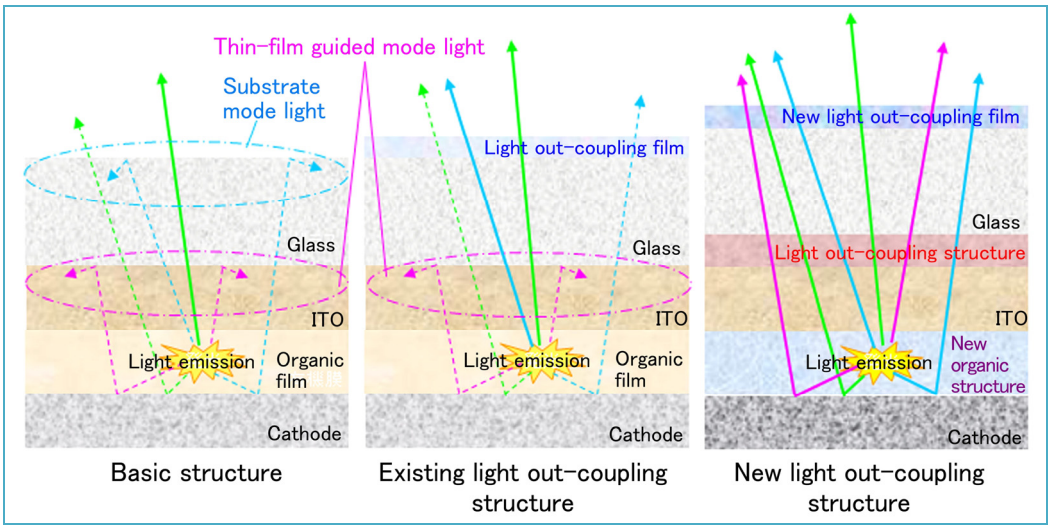


Figure 8 Cross-sectional view comparing effects of existing and new light out-coupling structures (conceptual view)

6. Development of Next-generation Panels

There is strong demand for power-saving features in next-generation lighting because power consumption by lighting accounts for approximately 20% of global electricity consumption. In theory, OLED lighting can achieve total efficiency and a product life equivalent or superior to LED. To attain such features, it is necessary to develop a technique to maximize the luminous efficiency of white light, as well as a technique to out-couple the light to the greatest extent possible. In terms of balance between the constituent colors of white light, the former technique requires a phosphorescent material that emits deep blue light. At present, however, the product life when using such materials has not reached a practical level. Thus, as a panel manufacturer, Lumiotec is primarily focused on the latter issue, that is, the development of a light out-coupling technique.

The light out-coupling technique mentioned in the previous section has already been implemented at the prototype level, but it needs to be improved to the mass-production level in terms of cost, yield and reliability by the end of this fiscal year. For this purpose, the company is currently accumulating expertise on the development of production equipment and the development/adoption of manufacturing technology and new materials.

The company is planning to set up a full-scale mass-production line, which is to be the pinnacle of such techniques, within a few years so as to be prepared for the phase of full-scale, widespread use of next-generation lighting. **Figure 9** depicts the company's latest achievements and a roadmap toward next-generation lighting.

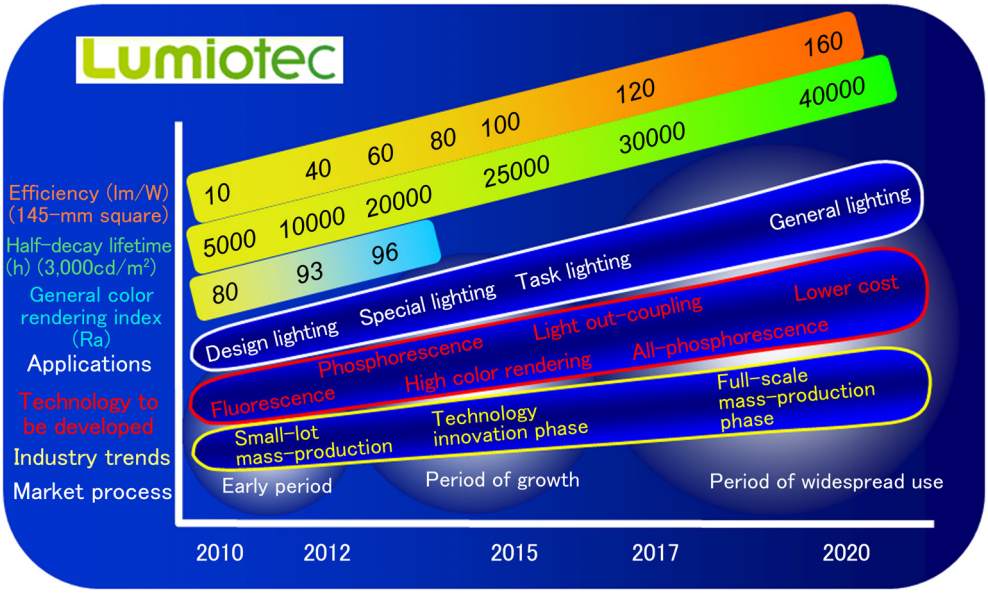


Figure 9 Roadmap of OLED lighting

7. Conclusions

Aiming at the widespread use of OLED lighting, Lumiotec has been focused on the development, manufacture and distribution of panels with practical performance, ahead of all other manufacturers around the world. In 2012, the company succeeded in commercializing the P05 and P06 lighting panel series, which are among the largest in the industry (maximum emission area: 203 cm^2). The P05 series is a line of high-efficiency (40 lm/W), high-luminance (3,000 cd/m^2) models that utilize the company's proprietary MPE structure and phosphorescent device technology. The P06 series takes full advantage of the features of OLED and achieves one of the highest color rendering indexes in the world (Ra = 93). At the same time, the company has established a production process and manufacturing technology that enable small-lot mass-production of these panels, and is making continuous efforts to further improve the yield and reliability. Furthermore, the company is vigorously promoting the development of next-generation panels and plans to release a 60-lm/W panel incorporating a new light out-coupling technology in the spring of 2013. As medium- to long-term goals, the company intends to develop a high-efficiency MPE device using a long-life deep blue phosphorescent material and implement a full-scale mass-production system adapted to general lighting, as well as thin, lightweight lighting devices requiring high reliability. By attaining such goals, the company hopes to make a contribution to energy saving in society.

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3. Hori, K. et al., Development and Mass-Production of an OLED Lighting Panel - Most-Promising Next-Generation Lighting -, Mitsubishi Heavy Industries Technical Review Vol. 49 No. 1 (2012)