New, all-phosphorescent organic light-emitting diodes

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Novel quality-control and lifetime-estimation measures enable the production of phosphorescent organic light-emitting diodes for general lighting applications.

No longer used solely for display purposes, organic light-emitting diodes (OLEDs) feature unique characteristics that also make them popular for general lighting purposes. Thin and lightweight, OLEDs are energy-efficient, mercury-free, and capable of producing a broad, warm spectrum that is well-tolerated by human eyes. Many OLED products have been released to the market,\textsuperscript{1–3} including our own, made using original materials and with novel layer design technologies,\textsuperscript{4} which we released for consignment production to Philips Technologie GmbH\textsuperscript{5} in 2011. The panel’s performance, at 45lm/W, was the most efficient OLED lighting product marketed at the time, featuring such desirable characteristics as a warm white color emanating from a black body, uniform brightness, and a small angular dependence of color. We named our advanced, all-phosphorescent OLED the Symfos OLED (see Figure 1 and Table 1).

We determined it was critical to develop a method of estimating the lifetime of OLED products to evaluate quality during mass production. In the past, it was customary to estimate lifetime by calculating the acceleration factor $n$ to the power of luminance ratio. However, the initial decay element, which is not influenced under standard conditions, increased enough under accelerated conditions to influence total decay. As a result, the acceleration factor $n$ fluctuated. To address this, we developed an accelerated test-estimation method based on the statistical analysis of lifetime behavior. This enabled a sampling method that swiftly calculated the half-decay time of luminance.\textsuperscript{6}

During mass production we were able to assume, from the numbers that the lifetime data yielded, a luminous decay curve that is comprised of two elements: degradation in the early stage (initial decay) and degradation through the evaluation stage (normal decay). The measured total decay, and both the separated initial decay and the normal decay (acceleration condition: 4000cd/m$^2$), are shown in Figure 2. Both the initial decay and normal decay curves are essentially linear on a semi-log plot. Hence, the total decay is comprised of two semi-log curves. We also found that only the normal decay, obtained by subtracting initial decay from total decay, had a stable degree of acceleration, but we could not ignore the variations. We found that we could calculate a more reliable acceleration factor $n$ by comparing the mean time to failure derived from Weibull statistics.

\begin{table}[h]
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\begin{tabular}{|l|c|}
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Characteristic & Performance \\
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Luminous efficacy & 45lm/W \\
Thickness & 1.9mm \\
Area & $\sim$ 55cm$^2$ \\
Luminance & 1000cd/m$^2$ \\
Current / Voltage & 71.5mA / 3.6V \\
Color coordinate & $(x, y)=(0.45, 0.41)$ \\
Color temperature & 2800K \\
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\textit{Figure 1.} The world’s first all-phosphorescent organic light-emitting diode (OLED) lighting product kit, Symfos OLED-010K.

\textit{Table 1.} OLED panel product performance.

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The acceleration factor $n$, from accelerated conditions (4000cd/m$^2$) to standard conditions (1000cd/m$^2$), was 1.5–1.6. We found that an accurate lifetime expectation under standard conditions can be estimated in three steps from only 300 hours of testing under both standard and accelerated conditions: separating the total accelerated lifetime decay curve from both the initial decay and the normal decay curves (see Figure 2); using $n$ to convert the normal decay curve under accelerated conditions to the normal decay curve under standard conditions; and, finally, obtaining the standard total decay curve by sliding the standard normal decay curve down for the luminance drop at 300h.

We confirmed that the estimate corresponded closely to actual measured results. Given our success in developing the first all-phosphorescent OLED using our novel lifetime-estimation method, we believe the process can be used to develop improved OLED products in the future. For example, we are designing an OLED device that will confer three times the lifetime that the Symfos OLED offers.

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