Development of High-Performance Green Phosphorescent Emitting Materials for Organic Light-Emitting Diodes

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Abstract

SAIT's unique technologies for developing highly efficient and robust green Pt and Ir complexes for next-generation OLED displays are presented. Our approach focuses on two key innovation points: maximizing efficiency and device lifetime by enhancing horizontal emitting dipole orientations and emission spectral shapes, and improving molecular stability through the development of new emitting chromophores. We also address the challenge of long turn-on times by reducing the permanent dipole moments of the complexes, thereby improving display quality at low luminance levels. The resulting OLED devices exhibit excellent performance, with higher efficiencies and longer lifetimes compared to devices using conventional dopants. These developments hold great promise for the future of OLED technology, enabling the creation of even more advanced and high-performing displays.

Author Keywords

Green, Phosphorescence; Dopant; OLED, Platinum complex, Ir complex

1. Introduction

Samsung has been successful in dominating the market share for the active matrix organic light-emitting device (AM-OLED) display business due to the successful mass production of AM-OLED panels over the past few decades. Additionally, the market has consistently demanded higher performance displays, necessitating better organic materials and device structures.

Light-emitting materials, particularly phosphorescent dopants, are of great importance in improving the performance of OLED displays. Among the Red, Green, and Blue (RGB) emitting materials, the green emitting material plays a crucial role in determining the high luminous efficiency, high peak luminance, long device lifetime, and color purity of OLED displays. In particular, with the increasing demand for high display quality in mobile, IT, and TV applications, the development of high-efficiency and stable green phosphorescent dopants is crucial to meet these requirements. However, the green color is the most sensitive to the human eye due to its higher luminosity function at 555 nm, [1] making it more challenging to develop high-efficiency dopants with better display quality at low luminance regions.

In this paper, we present SAIT's unique technologies for developing highly efficient and robust green Pt and Ir complexes for next-generation OLED displays. Our approach focuses on two key innovation points. Firstly, we aim to maximize efficiency and device lifetime by focusing on enhancing the horizontal emitting dipole orientations and the emission spectral shape of the complexes. Additionally, new emitting chromophores are developed to enhance molecular stability, thereby improving device lifetime. Secondly, we employ a strategy to overcome the long turn-on time issue to meet display quality requirements at low luminance conditions. This is achieved by reducing the permanent dipole moments of the Pt and Ir complexes through molecular design.

2. Results and Discussions

2.1. High efficiency and long lifetime green emitters

Horizontal Dipole Orientation: Controlling the emitting dipole orientation of phosphorescent complexes is crucial for improving out-coupling efficiency in OLEDs. [2] To this end, we have developed a disc-shaped Pt complex featuring a quadruple coordinated metal center and bulky peripheral units of non-chromophore, which are introduced to prevent aggregation of the complexes. In addition, we have developed rod-shaped Ir complexes (Ir core 1 and core 2) to enhance horizontal emitting dipole orientation. A higher horizontal dipole orientation can increase the light out-coupling efficiency and improve the device's external quantum efficiency (EQE), as shown in Figure 1(a). The Pt and Ir core 2 complexes exhibit higher horizontal emitting dipole orientations and device's EQEs than those of the Ir core 1 complex. (The target dopants are highlighted in the dashed circle in Figure 1(a)).

Spectral Shape: The spectral shape of phosphorescent complexes is another critical factor in enhancing OLED device efficiency. This is particularly important in top-emitting AM-OLED panels, which exhibit a strong micro-cavity effect. [3] We had developed Pt complexes with high charge transfer characteristics to improve their radiative decay rates. However, it is challenging to reduce the full width at half maximum (FWHM) of the photoluminescence of the Pt complexes due to their inherent charge transfer characteristics. Therefore, we have developed Ir complexes with high rigidity to achieve narrower FWHM of photoluminescence. By optimizing the molecular spectral shape through our molecular design approach, we aim to enhance the efficiency of the OLED devices. The measured FWHMs of PL spectra of the Pt, Ir core 1, and Ir core 2 complexes with horizontal emitting dipole orientations are shown in Figure 1(b), respectively. The Ir core 2 exhibits much narrower FWHMs of PL spectra and higher horizontal emitting dipole orientation than those of the Pt and Ir core 1 complexes. (The target dopants are highlighted in the dashed circle in Figure 2(a)).

Molecular Stability: To improve the lifetime of the devices,

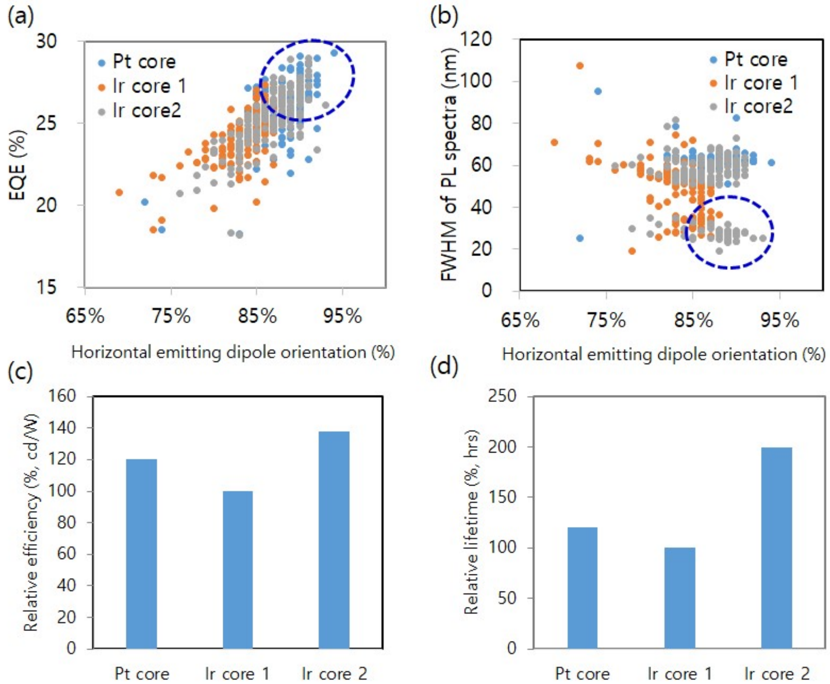

Fig. 1. Various performances of developed green phosphorescent dopants (a) EQE comparison of the OLEDs based on the Pt, Ir core 1, and Ir core 2 complexes according to the horizontal emitting dipole orientation. (b) FWHM comparison of the Pt, Ir core 1, and Ir core 2 complexes with the horizontal emitting dipole orientation. (c) Relative efficiency (cd/W, cd/A divided by operating voltage at a required luminance) of OLEDs with the Pt, Ir core 1, and Ir core 2. (d) Relative lifetime (LT) of OLEDs with the Pt, Ir core 1, and Ir core 2.

we have developed new emitting chromophores that enhance the molecular stability of the complexes. This can lead to longer-lasting displays.

Finally, high-performance top-emitting green OLEDs using the Pt, Ir core 1, and Ir core 2 complexes with an optimized device structure were fabricated and the relative efficiencies and lifetimes are shown in Figure 3 (c) and (d), respectively. The efficiencies of Pt and Ir core 2 at a required luminance are about 20% and 38% higher and device lifetime (LT) at the room temperature is 20% and 100% longer than those of an optimized device using the Ir core 1.

2.2. Fast turn-on time with pulsed current operation

Permanent Dipole Moments: To address the challenge of long turn-on times of green OLEDs, which affect display quality

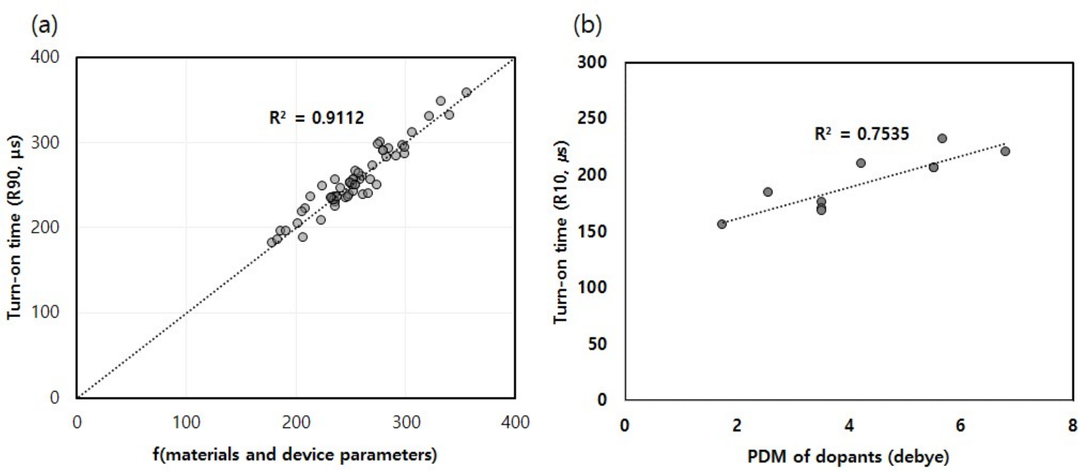

Fig. 2. Turn-on time (R90, R10) for various devices with Pt, Ir core 1, and Ir core2 (a) Turn-on time (R90) of OLEDs with various hosts and dopants according to a proposed function using material and device parameters. (b) Turn-on time (R10) of OLEDs with different dopants and a same host according to the PDM of dopants.

at low luminance, we have implemented molecular design strategies to reduce the permanent dipole moments (PDMs) of the Pt and Ir complexes. This can help to improve the turn-on speed and response of the OLED displays under low-luminance conditions.

The transient electroluminescence (EL) measurements were obtained by applying current pulses to devices composed of various dopants and host materials corresponding to 1 mA/cm^2. The turn-on times of R10 and R90 are defined as the time taken to reach 10% and 90% of maximum luminance, respectively, from the time the current pulse is applied. The turn-on times (R90) of the OLED devices with various Pt and Ir complexes, along with the best fitting curves (dashed line) using a proposed function incorporating materials and device parameters, are shown in Figure 2(a). The correlation factor (R^2) is 0.9112, indicating a strong correlation between the proposed function and the experimental data. One of important parameters in this proposed function is the permanent dipole moment (PDM) of the dopants. The turn-on times (R10) of OLEDs with different dopants and a same host, arranged according to the PDM of the dopants, are shown in Figure 2(b). Lower PDMs of dopants contribute to improved turn-on speed and response of OLED displays under low-luminance conditions.

3. CONCLUSION

In conclusion, we have developed highly efficient and robust green phosphorescent dopants, including disc-shaped Pt complexes and rod-shaped Ir complexes, to meet the increasing demand for high-quality OLED displays in various applications. Our unique molecular design strategies have focused on maximizing efficiency and device lifetime by enhancing horizontal emitting dipole orientations and emission spectral shapes, as well as improving molecular stability through the development of new emitting chromophores. Furthermore, we have addressed the challenge of long turn-on times by reducing the permanent dipole moments of the complexes, thereby improving display quality at low luminance levels. The resulting OLED devices exhibit excellent performance, with higher efficiencies and longer lifetimes compared to devices using conventional dopants. These developments hold great promise for the future of OLED technology, enabling the creation of even more advanced and high-performing displays.

References

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