High-Contrast Top-Emitting OLEDs for OLED Displays

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Top-emitting organic light-emitting devices (OLEDs) have been subjects of intensive interest recently due to their technical merits for active-matrix OLED displays (AMOLEDs) [1-2]. Top-emitting OLEDs in general contain a reflective bottom contact for light out-coupling, which consequently induces rather strong reflection and degrades the display contrast. Polarizer or filter films may be laminated to reduce reflection and enhance the contrast. However, their use reduces the power efficiency by over 50% and also adds extra complexity and cost. In this paper, we report a top-emitting OLED structure that implements both low ambient light reflection within the OLED structure and reasonable emission efficiency.

Along with a control bottom-emitting device, the top-emitting OLED investigated is shown in Fig. 1, which uses a reflective metal as the bottom anode and a semitransparent thin metal as the top cathode. Cr with high work function and moderate reflectivity (~50-60%) is used as the bottom anode to achieve hole injection and broad-band low-reflection characteristics. The organic structure consists of m-MTDATA, α-NPD, and Alq as the hole-injection layer, the hole-transport layer, and the electron-transport and emitting layer. The cathode is composed of multiple functional layers to achieve both effective electron injection and desired optical properties. Ultrathin layers of LiF (0.5 nm) and Al (1 nm) are deposited in sequence as the electron-injecting contact [3]. A thin layer (20 nm) of Ag, which has relatively low optical absorption and the highest conductivity among all metals, then overlays the LiF/Al contact for reducing sheet resistance. The cathode is further capped with alternating high-/low-index dielectric layers as the antireflection (AR) coating to enhance the optical transmission of the thin metal cathode and suppress the reflection from the whole device. Thicknesses of the organic layers and the dielectric layers are optimized for emission colors, efficiency, and ambient light reflection of devices.

Fig. 2 shows the measured and calculated reflectance spectra of different OLEDs: top-emitting OLEDs with and without the AR coating, and the bottom-emitting OLED. The reflectance of the bottom-emitting device is high (70-80%) over the visible range, while that of the top-emitting OLED with AR remains low over the same range (with a reflectance minimum of ~2%, an average reflectance of 12%, and a sun/eye-integrated reflectance of 8%). Without the AR coating, the top-emitting device also exhibits reduced reflection in a limited spectral range (near resonance wavelength), but adding an appropriate AR coating dramatically suppresses the reflectance over a wide bandwidth. Photos in Fig. 3 show the appearance of a low-reflection top-emitting OLED and a bottom-emitting OLED under strong illumination, clearly indicating the dark background of the present top-emitting OLEDs.

Fig. 4 shows the EL spectra at viewing angles of 0°, 30°, and 60° off the surface normal for the low-reflection top-emitting device, in comparison with photoluminescence of Alq. The stronger microcavity effect in top-emitting OLEDs usually would lead to large variation of colors with viewing angles [4]. Nevertheless, layer thicknesses in the present device structure could be optimized to nearly eliminate such color shift (Fig. 4), indicating that the device indeed can be engineered to obtain low reflection without trading off other viewing characteristics. Fig. 5 shows the current-voltage characteristics of the low-reflection top-emitting device. The low turn-on voltage indicates the effectiveness of both the bottom Cr anode and the top cathode for carrier injection. Fig. 6 compares the brightness-current characteristics for the bottom-emitting device and the low-reflection top-emitting device. The top-emitting device exhibits an efficiency of 2.8 cd/A, which is about 57% of that of the bottom-emitting device (4.7 cd/A). Such efficiency performance is superior to that using polarizers or filters, apart from other advantages.

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In summary, we have shown that ambient light reflection from a top-emitting device can be effectively suppressed by using a moderate bottom reflector and top antireflection coating, meanwhile retaining acceptable EL efficiency and other viewing characteristics for display applications.

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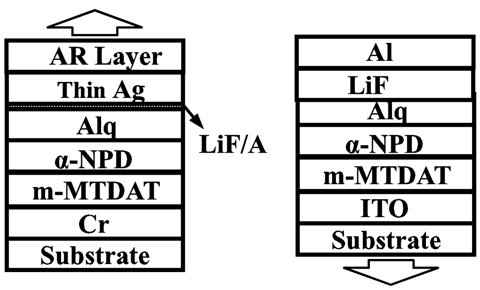

Fig. 1. Device structures of the top-emitting and bottom-emitting OLEDs.

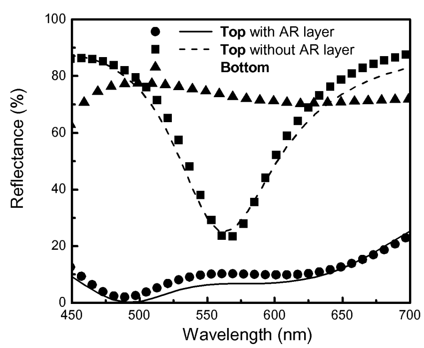

Fig. 2. Calculated (lines) and measured (symbols) reflectance spectra of various OLEDs.

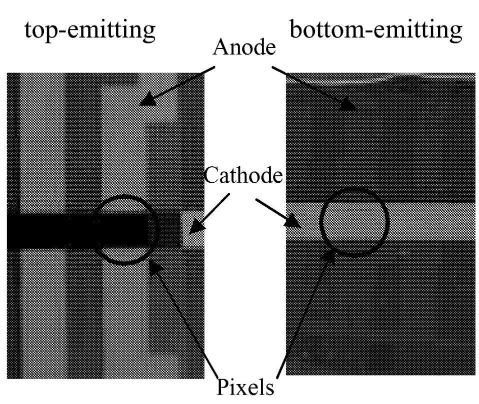

Fig. 3. Photos of low-reflection top-emitting and bottom-emitting OLEDs.

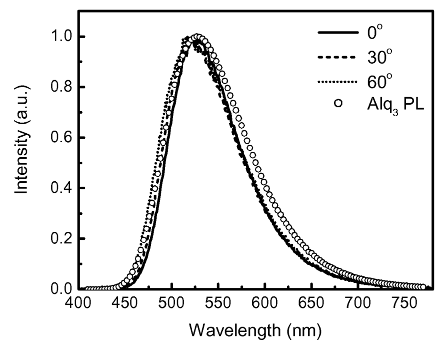

Fig. 4. EL spectra of the low-reflection top-emitting OLED at 0°, 30°, 60°, along with PL of Alq.

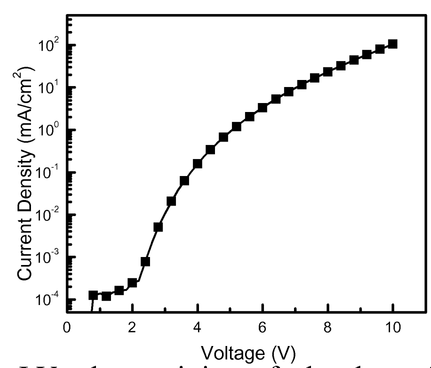

Fig. 5. I-V characteristics of the low-reflection top-emitting OLED.

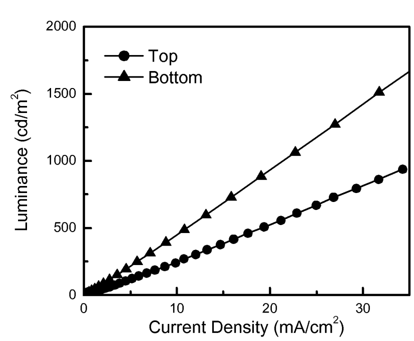

Fig. 6. L-I characteristics of low-reflection top-emitting and bottom-emitting OLEDs.