OLED DEVICE HAVING IMPROVED LIGHT OUTPUT

FIELD OF THE INVENTION

[0001] The present invention relates to organic light-emitting diode (OLED) devices, and more particularly, to OLED device structures for improving light output.

BACKGROUND OF THE INVENTION

[0002] Organic light-emitting diodes (OLEDs) are a promising technology for flat-panel displays and area illumination lamps. The technology relies upon thin-film layers of materials coated upon a substrate. However, as is well known, much of the light output from the light-emissive layer in the OLED is absorbed within the device. Because light is emitted in all directions from the internal layers of the OLED, some of the light is emitted directly from the device, and some is emitted into the device and is either reflected back out or is absorbed, and some of the light is emitted laterally and trapped and absorbed by the various layers comprising the device. In general, up to 80% of the light may be lost in this manner.

[0003] OLED devices generally can have two formats known as small molecule devices such as disclosed in U.S. Pat. No. 4,476,292 and polymer OLED devices such as disclosed in U.S. Pat. No. 5,247,190. Either type of OLED device may include, in sequence, an anode, an organic EL element, and a cathode. The organic EL element disposed between the anode and the cathode commonly includes an organic hole-transporting layer (HTL), an emissive layer (EL) and an organic electron-transporting layer (ETL). Holes and electrons recombine and emit light in the EL layer. Tang et al. (Appl. Phys. Lett., 51, 913 (1987), Journal of Applied Physics, 65, 3610 (1989), and U.S. Pat. No. 4,769,292) demonstrated highly efficient OLEDs using such a layer structure. Since then, numerous OLEDs with alternative layer structures, including polymeric materials, have been disclosed and device performance has been improved.

[0004] Light is generated in an OLED device when electrons and holes that are injected from the cathode and anode, respectively, flow through the electron transport layer and the hole transport layer and recombine in the emissive layer. Many factors determine the efficiency of this light generating process. For example, the selection of anode and cathode materials can determine how efficiently the electrons and holes are injected into the device; the selection of ETL and HTL can determine how efficiently the electrons and holes are transported in the device, and the selection of EL can determine how efficiently the electrons and holes be recombined and result in the emission of light, etc. It has been found, however, that one of the key factors that limits the efficiency of OLED devices is the inefficiency in extracting the photons generated by the electron-hole recombination out of the OLED devices. Due to the high optical indices of the organic materials used, most of the photons generated by the recombination process are actually trapped in the devices due to total internal reflection. These trapped photons never leave the OLED devices and make no contribution to the light output from these devices.

[0005] A typical OLED device uses a glass substrate, a transparent conducting anode such as indium-tin oxide (ITO), a stack of organic layers, and a reflective cathode layer. Light generated from the device is emitted through the glass substrate. This is commonly referred to as a bottom-emitting device. Alternatively, a device can include a substrate, a reflective anode, a stack of organic layers, and a top transparent cathode layer. Light generated from the device is emitted through the top transparent electrode. This is commonly referred to as a top-emitting device. In these typical devices, the index of the ITO layer, the organic layers, and the glass is about 2.0, 1.7, and 1.5 respectively. It has been estimated that nearly 60% of the generated light is trapped by internal reflection in the ITO/organic EL element, 20% is trapped in the glass substrate, and only about 20% of the generated light is actually emitted from the device and performs useful functions.

[0006] Referring to **FIG. 13**, a prior-art bottom-emitting OLED has a transparent substrate **10**, a transparent first electrode **12**, one or more layers **14** of organic material, one of which is light-emitting, a reflective second electrode **16**, a gap **19** and an encapsulating cover **20**. The encapsulating cover **20** may be opaque and may be coated directly over the second electrode **16** so that no gap **19** exists. When a gap **19** does exist, it may be filled with polymer or desiccants to add rigidity and reduce water vapor permeation into the device. Light emitted from one of the organic material layers **14** can be emitted directly out of the device, through the substrate **10**, as illustrated with light ray **1**. Light may also be emitted and internally guided in the substrate **10** and organic layers **14**, as illustrated with light ray **2**. Alternatively, light may be emitted and internally guided in the layers **14** of organic material, as illustrated with light ray **3**. Light rays **4** emitted toward the reflective second electrode **16** are reflected by the reflective second electrode **16** toward the substrate **10** and then follow one of the light ray paths **1**, **2**, or **3**.

[0007] Referring to **FIG. 14**, a top-emitting OLED device as proposed in the prior art is illustrated having a substrate **10** (either reflective, transparent, or opaque), a reflective first electrode **16**, one or more layers **14** of organic material, one of which is light-emitting, a transparent second electrode **12**, a gap **19** and an encapsulating cover **20**. The encapsulating cover **20** is transparent and may be coated directly over the transparent electrode **12** so that no gap **19** exists. It has been proposed to fill the gap with polymeric or desiccating material. Such polymers and desiccants typically will have indices of refraction greater than or equal to that of the substrate **10** or encapsulating cover **20**, and it is generally proposed to employ materials having indices of refraction matched to that of the encapsulating cover to reduce inter-layer reflections. Light emitted from one of the organic material layers **14** can be emitted directly out of the device, through the encapsulating cover **20**, as illustrated with light ray. **1**. Light may also be emitted and internally guided in the encapsulating cover **20** and organic layers **14**, as illustrated with light ray **2**. Additionally, light may be emitted and internally guided in the layers **14** of organic material, as illustrated with light ray **3**. Light rays **4** emitted toward the reflective first electrode **12** are reflected by the reflective first electrode **12** toward the substrate **10** and follow one of the light ray paths **1**, **2**, or **3**. In some prior-art embodiments, the first electrode **12** may be opaque and/or light absorbing.

[0008] A variety of techniques have been proposed to improve the out-coupling of light from thin-film light emitting devices. For example, diffraction gratings have been proposed to control the attributes of light emission from thin