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 and reducing manufacturing costs.

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 light-emitting element, and a cathode. The organic element disposed between the anode and the cathode commonly includes an organic hole-transporting layer (HTL), an emissive layer (EML) and an organic electron-transporting layer (ETL). Holes and electrons recombine and emit light in the EML 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. **5**, a top-emitting OLED suggested by the prior-art has a transparent substrate **10**, a reflective first electrode **12**, one or more layers **14** of organic material, one of which is light-emitting, a transparent second electrode **16**, a gap **19** and an encapsulating cover **20**. The encapsulating cover **20** may be coated directly over the second transparent 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. Such filler may be selected to match the refractive index of the cover to reduce interlayer reflections at the interface thereof. Light emitted from one of the organic material layers **14** can be emitted directly out of the device, through the cover **20**, as illustrated with light ray **1**. If gap **19** is filled with a material of index greater than unity, light may also be emitted and internally guided in the cover **20** 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 and transparent electrode **16**, as illustrated with light ray **3**. Light ray **4** emitted toward the reflective first electrode **12** are reflected by the reflective first electrode **12** toward the cover **20** and then follow one of the light ray paths **1**, **2**, or **3**.

[0007] A variety of techniques have been proposed to improve the out-coupling of light from thin-film light emitting devices. One such technique is the use of scattering layers to scatter waveguided light of the layers in which they are trapped. For example, Chou (International Publication Number WO 02/37580 A1) and Liu et al. (U.S. Patent Application Publication No. 2001/0026124 A1) taught the use of a volume or surface scattering layer to improve light extraction. The scattering layer is applied next to the organic layers or on the outside surface of the glass substrate and has optical index that matches these layers. Light emitted from the OLED device at higher than critical angle that would have otherwise been trapped can penetrate into the scattering layer and be scattered out of the device. The efficiency of the OLED device is thereby improved but still has deficiencies as explained below.

[0008] U.S. Pat. No. 6,787,796 entitled "Organic electroluminescent display device and method of manufacturing the same" by Do et al. issued 20040907 describes an organic electroluminescent (EL) display device and a method of manufacturing the same. The organic EL device includes a substrate layer, a first electrode layer formed on the substrate layer, an organic layer formed on the first electrode layer, and a second electrode layer formed on the organic layer, wherein a light loss preventing layer having different refrac-