tive index areas is formed between layers of the organic EL device having a large difference in refractive index among the respective layers. U.S. Patent Application Publication No. 2004/0217702 entitled "Light extracting designs for organic light emitting diodes" by Garner et al., similarly discloses use of microstructures to provide internal refractive index variations or internal or surface physical variations that function to perturb the propagation of internal waveguide modes within an OLED. When employed in a top-emitter embodiment, the use of an index-matched polymer adjacent the encapsulating cover is disclosed. US20050142379 A1 entitled "Electroluminescence device, planar light source and display using the same" describes an organic electroluminescence device including an organic layer comprising an emissive layer; a pair of electrodes comprising an anode and a cathode, and sandwiching the organic layer, wherein at least one of the electrodes is transparent; a transparent layer provided adjacent to a light extracting surface of the transparent electrode; and a region substantially disturbing reflection and refraction angle of light provided adjacent to a light extracting surface of the transparent layer or in an interior of the transparent layer, wherein the transparent layer has a refractive index substantially equal to or more than the refractive index of the emissive layer.

[0009] However, scattering techniques, by themselves, cause light to pass through the light-absorbing material layers multiple times where they are absorbed and converted to heat. Moreover, trapped light may propagate a considerable distance horizontally through the cover, substrate, or organic layers before being scattered out of the device, thereby reducing the sharpness of the device in pixellated applications such as displays. For example, as illustrated in FIG. **6**, a prior-art pixellated top-emitting OLED device may include a plurality of independently controlled pixels **50**, **52**, **54**, **56**, and **58** and a scattering layer **22** located between the transparent second electrode **16** and the cover **20**. A light ray **5** emitted from the light-emitting layer **14** may be scattered multiple times by scattering layer **22**, while traveling through the cover **20**, organic layer(s) **14**, and transparent second electrode **16** before it is emitted from the device. When the light ray **5** is finally emitted from the device, the light ray **5** may have traveled a considerable distance through the various device layers from the original pixel **50** location where it originated to a remote pixel **58** where it is emitted, thus reducing sharpness. Most of the lateral travel occurs in the cover **20**, because that is by far the thickest layer in the package. Also, the amount of light emitted is reduced due to absorption of light in the various layers.

[0010] Light-scattering layers used internally to an OLED device are described in U.S. Patent Application Publication No. 2005/0018431 entitled "Organic electroluminescent devices having improved light extraction" by Shiang and U.S. Pat. No. 5,955,837 entitled "System with an active layer of a medium having light-scattering properties for flat-panel display devices" by Horikx, et al. These disclosures describe and define properties of scattering layers located on a substrate in detail. EP1603367 A1 entitled "Electroluminescence Device" an electroluminescent device successively comprising a cathode, an electroluminescent layer, a transparent electrode layer, an evanescent light-scattering layer comprising a matrix composed of a low-refractive material containing light-scattering particles, and a transparent sheet/plate. EP1603367 A1 also includes an internal low-refractive layer to inhibit the propagation of light in a cover or substrate.

[0011] Co-pending, commonly assigned U.S. Ser. No. 11/065,082, filed Feb. 24, 2005, describes the use of a transparent low-index layer having a refractive index lower than the refractive index of the encapsulating cover or substrate through which light is emitted and lower than the organic layers to enhance the sharpness of an OLED device having a scattering element. US 20050194896 describes a nano-structure layer for extracting radiated light from a light-emitting device together with a gap having a refractive index lower than an average refractive index of the emissive layer and nano-structure layer. In various described embodiments, such nano-structure layer may be used in combination with color conversion material or color filter layers. Such disclosed designs still, however, do not completely optimize the use of emitted light, particularly for displays with four-color pixels including a white emitter.

[0012] Light-extracting layers as described in the above references are typically formed by creating a rough surface or coating scattering particles within a matrix of material. In the first case, it is difficult and expensive to form a rough surface on organic and electrode layers without damaging the layers, for example by employing blast treatments, corona treatments, plasma treatments, or etchants. In the second case, the scattering layer is limited in its scattering ability, thereby requiring a thicker layer than might otherwise be necessary, increasing the reflectivity and absorption of the layers and decreasing the amount of light output.

[0013] There is a need therefore for an improved organic light-emitting diode device structure that avoids the problems noted above and improves the efficiency and sharpness of the device.

SUMMARY OF THE INVENTION

[0014] In accordance with one embodiment, the invention is directed towards a top-emitting organic light-emitting diode (OLED) device, comprising:

[0015] a substrate;

[0016] an OLED comprising a reflective electrode formed on the substrate; one-or-more layers of organic light-emitting material formed over the reflective electrode; and a transparent electrode formed over the one-or-more layers of organic light-emitting material;

[0017] a light-scattering layer having a rough surface formed over and in contact with the OLED,

[0018] a cover affixed to the substrate forming a gap between the cover and the light scattering layer; and

[0019] wherein the gap is a vacuum or the gap is filled with a relatively low-refractive index gas and the light-scattering layer comprises a plurality of relatively high-refractive index light-scattering transparent particles projecting into the gap without contacting the cover and further comprising an adhesive binder in contact with at least some of the light-scattering particles to adhere the light-scattering particles to the OLED.

ADVANTAGES

[0020] The present invention has the advantage that it increases the light output from, and improves the sharpness of, an OLED device.