HIGHLY TRANSPARENT NON-METALLIC CATHODES

FIELD OF INVENTION

[0001] The present invention is directed to non-metallic cathodes that may be used in optoelectronic devices, particularly, highly transparent non-metallic cathodes.

BACKGROUND OF THE INVENTION

[0002] Optoelectronic devices include those which convert electrical energy into optical energy, or vice versa, as well as those that detect optical signals through electronic processes. Such devices include photodetectors, phototransistors, solar cells, light emitting diodes and lasers. Such devices typically include a pair of electrodes with at least one charge-carrying layer between the electrodes. Dependent on the function of the device, the charge-carrying layer or layers may be comprised of a material or materials that are electroluminescent when a voltage is applied across the device or the layer or layers may form a heterojunction capable of generating a photovoltaic effect when exposed to optical radiation.

[0003] In particular, organic light emitting devices (OLEDs) are comprised of several organic layers in which one of the layers is comprised of an organic material that can be made to electroluminesce by applying a voltage across the device, C. W. Tang et al., *Appl. Phys. Lett* 51, 913 (1987). Certain OLEDs have been shown to have sufficient brightness, range of color and operating lifetimes for use as a practical alternative technology to LCD-based full color flat-panel displays (S. R. Forrest, P. E. Burrows and M. E. Thompson, Laser Focus World, February 1995). Since many of the thin organic films used in such devices are transparent in the visible spectral region, they allow for the realization of a completely new type of display pixel in which red (R), green (G), and blue (B) emitting OLEDs are placed in a vertically stacked geometry to provide a simple fabrication process, a small R-G-B pixel size, and a large fill factor.

[0004] A transparent OLED (TOLED), V. Bulovic, G. Gu, P. E Burrows, M. E. Thompson, and S. R. Forrest, *Nature* 380, 29 (1996), which represents a significant step toward realizing high resolution, independently addressable stacked R-G-B pixels, was reported in U.S. Pat. No. 5,703,436, Forrest et al I. This TOLED had greater than 71% transparency when turned off and emitted light from both top and bottom device surfaces with high efficiency (approaching 1% quantum efficiency) when the device was turned on. The TOLED used transparent indium tin oxide (ITO) as the hole-injecting electrode and a Mg—Ag-ITO electrode layer for electron-injection. A device was disclosed in which the ITO side of the Mg—Ag-ITO electrode layer was used as a hole-injecting contact for a second, different color-emitting OLED stacked on top of the TOLED. Each layer in the stacked OLED (SOLED) was independently addressable and emitted its own characteristic color. This colored emission could be transmitted through the adjacently stacked transparent, independently addressable, organic layer, the transparent contacts and the glass substrate, thus allowing the device to emit any color that could be produced by varying the relative output of the red and blue color-emitting layers. U.S. Pat. No. 5,707,745, Forrest et al II, disclosed an integrated SOLED for which both intensity and color could be independently varied and controlled with external power supplies in a color tunable display device. Forrest et al II, thus, illustrates a principle for achieving integrated, full color pixels that provide high image resolution, which is made possible by the compact pixel size. Furthermore, relatively low cost fabrication techniques, as compared with prior art methods, may be utilized for making such devices.

[0005] Such devices whose structure is based upon the use of layers of organic optoelectronic materials generally rely on a common mechanism leading to optical emission. Typically, this mechanism is based upon the radiative recombination of injected electrons and holes. Specifically, OLEDs are comprised of at least two thin organic layers separating the anode and cathode of the device. The material of one of these layers is specifically chosen based on the material's ability to assist in injecting and transporting holes, a "hole transporting layer" (HTL), and the material of the other layer is specifically selected according to its ability to assist in injecting and transporting electrons, an "electron transporting layer" (ETL). With such a construction, the device can be viewed as a diode with a forward bias when the potential applied to the anode is more positive than the potential applied to the cathode. Under these bias conditions, the anode injects holes (positive charge carriers) into the hole transporting layer, while the cathode injects electrons into the electron transporting layer. The portion of the luminescent medium adjacent to the anode thus forms a hole injecting and transporting zone while the portion of the luminescent medium adjacent to the cathode forms an electron injecting and transporting zone. The injected holes and electrons each migrate toward the oppositely charged electrode. When, for example, an electron and hole localize on the same molecule, a Frenkel exciton is formed. Recombination of this short-lived state may be visualized as an electron dropping from its conduction potential to a valence band, with relaxation occurring, under certain conditions, preferentially via a photoemissive mechanism. Under this view of the mechanism of operation of typical thin-layer organic devices, the electroluminescent layer comprises a luminescence zone receiving mobile charge carriers (electrons and holes) from each electrode.

[0006] The materials that function as the electron transporting layer or as the hole transporting layer of the OLED are frequently the same materials that are incorporated into the OLED to produce the electroluminescent emission. Such devices in which the electron transporting layer or the hole transporting layer functions as the emissive layer are referred to as having a single heterostructure. Alternatively, the electroluminescent material may be present in a separate emissive layer between the hole transporting layer and the electron transporting layer in what is referred to as a double heterostructure.

[0007] The material that is used as the cathode layer of an OLED has until now been comprised of a metal which has a low work function, for example, Mg:Ag. Such metallic cathode layers provide an electrically conductive path for current flow as well as a means of injecting electrons into the adjacent electron transporting layer. However, such metallic layers are also highly reflective and absorptive in the visible region of the spectrum.

[0008] This means that if a transparent OLED is desired, such as for stacked layers of a full-color SOLED or the