[0027] **FIG. 6** shows the light output vs. current for a ZnPc electron injecting interface layer as compared with a CuPc electron injecting interface layer where the efficiency η of the CuPc device was 0.23% and the ZnPc device was 0.15%.

[0028] **FIG. 7** shows the transmission (T), reflection (R) and absorption (A), as a function of wavelength (nm), of an OLED having an ITO cathode and CuPc electron injecting interface layer.

[0029] **FIG. 8** shows the I-V characteristics of a standard prior art OLED having a metallic Mg:Ag cathode layer with the higher set of values at 0 hours and the lower set of values at 180 hours.

[0030] **FIG. 9** shows the I-V characteristics of an OLED having an ITO cathode and a CuPc electron injecting interface layer with the higher set of values at 0 hours and the lower set of values at 60 and 180 hours.

[0031] **FIG. 10** shows the light output vs. current for devices having CuPc injection layer thicknesses from about 30 Å up to about 120 Å. These devices show a quantum efficiency η of about 0.1%.

[0032] **FIG. 11** shows the I-V characteristics of the devices of **FIG. 10**.

[0033] **FIG. 12** shows the current-voltage characteristics of a 0.4 mm diameter non-metallic-cathode-containing TOLED ("MF-TOLED") and a reference TOLED grown in the same vacuum cycle.

[0034] **FIG. 13** shows a schematic illustration of the non-metallic-cathode-containing TOLED structure.

[0035] **FIG. 14** shows the summed optical output power from top and bottom surfaces vs. drive current of the non-metallic-cathode-containing TOLED ("MF-TOLED") and reference TOLED in **FIG. 12**. The luminance at the maximum current density measured corresponds to 2000 cd/m^2.

[0036] **FIG. 15** shows the electroluminescence spectra from both the top and bottom device surfaces with a fit (solid line) to the top emission spectrum using the calculation method described herein.

[0037] **FIG. 16** shows the proposed simplified energy level diagram of a non-metallic-cathode-containing TOLED. D_{ss} indicates the density of surface states.

[0038] **FIG. 17** shows digitally reproduced photographs that were taken of the non-metallic-cathode-containing TOLED and the conventional TOLED.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0039] The present invention will now be described in detail for specific preferred embodiments of the invention, it being understood that these embodiments are intended only as illustrative examples and the invention is not to be limited thereto.

[0040] The present invention is directed to a novel cathodes comprised of an electrically conductive non-metallic layer which forms a low resistance electrical contact with a semiconductive organic layer. Such cathodes may be employed in a wide range of electrical devices. In particular, since the cathodes of the present invention may be fabricated from highly transparent materials, such cathodes have particular benefit for use in organic optoelectronic devices such as OLEDs, solar cells, photodetectors, lasers and phototransistors. S. R. Forrest, *Chem. Rev.* 97, 1793 (1997). In an optoelectronic device having at least one electron transporting layer (ETL) comprised of an electron transporting material and at least one hole transporting layer (HTL) comprised of a hole transporting material, the cathode is identified as the electrode on the ETL side of the device and the anode is identified as the electrode on the HTL side of the device. In an OLED, for example, the cathode may be referred to as the electrode that injects electrons into the ETL and the anode as the electrode that injects holes into the HTL. Injecting holes into the HTL is equivalent to extracting electrons from the HTL.

[0041] Each electrode of an OLED may typically be present as a layer that is in direct contact with the adjacent HTL or ETL, dependent on whether the electrode functions as an anode or cathode, respectively. Alternatively, it was disclosed in copending Ser. No. 08/865,491 that an additional organic layer may be included between the anode and the organic HTL. Such an additional layer, which was referred to as a protection layer or a hole-injection-enhancement layer, was disclosed to function as a protection layer for protecting the underlying organic layers during deposition of the electrode layer and/or as an enhancement layer for enhancing the hole-injection efficiency of the anode. For example, Ser. No. 08/865,491 disclosed that a protection layer, for example, of a phthalocyanine compound, such as zinc phthalocyanine (ZnPc) or copper phthalocyanine (CuPc), or PTCDA, could be deposited on top of the organic HTL so as to protect the organic layer during the subsequent sputter deposition of the ITO anode layer. Ser. No. 08/865,491 further disclosed that the protection layer could in some cases enhance the hole-injection efficiency of the hole-injecting anode.

[0042] Because of the combination of high electrical conductivity and low work function, which is provided by certain metals, practically useful optoelectronic devices such as OLEDs containing a cathode/organic-layer interface have until now been comprised of metallic cathode materials that inherently have a high reflectivity as well as modest absorption of optical radiation, even though the performance of such optoelectronic devices tends to be adversely affected by the high reflectivity of the metallic cathode layers. In optoelectronic devices such as OLEDs for which a high transparency is desired, semi-transparent metallic cathode layers are typically prepared using very thin metallic layers. Nevertheless, the metal's high reflectivity, which is inherently related to the high electrical conductivity of the metallic cathode materials, still causes significant losses in the overall performance of the device, for example, in producing a reduced quantum efficiency for the overall device.

[0043] One of the surprising aspects of the present invention is the fact that an electrically conductive non-metallic material has been to be found to be capable of forming a low-resistance electrical contact with an organic layer, wherein the electrically-conductive-non-metallic-layer/semiconductive-organic-layer interface, hereinafter "cathode/organic layer interface", is capable of efficiently injecting electrons form the non-metallic cathode layer, through the semiconductive organic layer of the cathode/organic layer interface, and then into the adjacent ETL of a practi-