in forming good electron injecting contacts. However, when CuPc is replaced with PTCDA, there is a significant increase in V_T to 20V.

[0065] The sum of the output optical power emitted from both top and bottom device surfaces as a function of the current is shown in **FIG. 14** for the same devices as in **FIG. 12**. The total external quantum efficiencies of the devices are similar at $\eta=(0.38\pm0.05)\%$. Their luminance at 10 mA/cm^2 is ~200 cd/m^2, increasing to 2000 cd/m^2 at 10 mA/cm^2, corresponding to the maximum drive current indicated in **FIG. 14**. The ratio of the power emitted from the top to that emitted from the bottom substrate surface of the non-metallic-cathode-containing TOLED is $r=1.0\pm0.05$.

[0066] Due to the relatively large difference between the complex index of refraction of CuPc and the other organic materials in the non-metallic-cathode-containing TOLED, there is some broadening of the output electroluminescence spectrum measured from the top, relative to the bottom device surface, as shown in **FIG. 15**. Using the known complex indices of refraction for each layer in the device, and assuming that the radiative, dipolar cm6 molecules are uniformly distributed in the emissive layer, r was calculated as a function of wavelength (λ). A fit to the top surface spectrum was obtained by multiplying the emission from the substrate by $r(\lambda)$. The fit closely matches the normalized, measured output spectra **(FIG. 14)**, with the remaining discrepancies between calculation and experiment due to the neglect of dispersion in the CuPc.

[0067] While the I-V characteristics of devices employing CuPc or ZnPc cathodes were similar, η of the ZnPc device was 30% lower than that of the CuPc device. In sharp contrast to the CuPc and the ZnPc cathodes, however, the devices with PTCDA in the cathode had quantum efficiencies that were only about 1% that of the CuPc devices. This indicated very poor electron injection into the ETL employing PTCDA cathodes, consistent with the I-V data.

[0068] The elimination of semi-transparent metal films from the TOLED results in a significant increase in the total optical transmission. This is readily apparent from the digitally reproduced photographs that were taken of the non-metallic-cathode-containing TOLED arrays and the conventional TOLED arrays, as shown in **FIG. 17**. The arrays were placed on a white background having a grid of black dots for contrast. The devices were illuminated from underneath and are indicated by the arrows at about 0.2-0.4 cm for the conventional TOLED arrays and at about 1.3-1.6 cm for the non-metallic-cathode-containing TOLED arrays, respectively. The photographs in **FIG. 17** show the non-metallic cathodes of the present invention are featureless due to the absence of any metal in the electrode whereas conventional TOLEDS have a faint grey appearance due to the metallic cathodes. The non-metallic-cathode-containing TOLED arrays could be detected only if the digitally Measurements of the non-antireflection-coated device optical transparency shown in **FIG. 7** indicate a transmission of 0.85 ± 0.05, which corresponds to a 35% increase over the conventional OLED. The reflection and absorption of the non-metallic-cathode-containing TOLED are also plotted in **FIG. 7,** where the primary source of absorption is due to the CuPc Q bands, B. H. Schechtman and W. E. Spicer, *J. of Mol. Spec.* 33, 28 (1970), which peak at λ=620 nm and 665 nm.

[0069] Without being limited to the theory of how the present invention works, it is believed that during the initial stages of ITO deposition, damage-induced states are produced in what is herein referred to as a damage layer at the cathode/organic film interface. In contrast to the prior art understanding of high efficiency electron injecting electrodes, C. W. Tang and S. A. VanSlyke, *Appl. Phys. Lett.* 51, 913 (1987), which required energy band alignment of the lowest unoccupied molecular orbital (LUMO) of the ETL with the Fermi energy of a low work function metal, it is believed herein that the damage layer is responsible for providing improved electron-injection properties for non-metallic cathodes comprised of materials that do not have the matching Fermi energy level that is typically provided by a low-work-function metal.

[0070] The improved electron-injection properties of the highly transparent non-metallic cathodes may be understood in terms of the proposed energy band diagram in **FIG. 16**. The ionization potentials (IP), which are defined as the vacuum lever to HOMO distance, and optical energy gaps (E_g) are taken from A. Rajagopal, C. I. Wu, and A. Kahn, 1997 *Fall Mtg. Of Mat. Res. Soc.*, paper J1.9; and K. Seki, *Mol. Cryst. Liq. Cryst.* 171, 255 (1989). Since the ionization potential (IP) of CuPc lies between the work function of ITO and the IP of A-NPD, CuPc lowers the barrier to hole injection into the HTL. In contrast, there is a large barrier (1.6 eV) to electron injection at the ITO/CuPc interface, in spite of the fact that this electrode is disclosed herein to efficiently inject electrons whenever this electrode is prepared in accord with the resent invention. This apparent contradiction is consistent with previous reports, S. R. Forrest, L. Y Leu, F. F. So, and W. Y. Yoon, *J. Appl. Phys.* 66, 5908 (1989), of efficient hole injection using anodes consisting of PTCDA capped with ITO. In this case, hole injection is achieved although the barrier from ITO into PTCDA is 2.1 eV. Values for the ionization energies (defined as the vacuum level to HOMO distance) are from A. Rajagopal, C. I. Wu, and A. Kahn, *J. Appl. Phys.* 83, 2649 (1998) and K. Seki, *Mol. Cryst. Liq. Cryst.* 171, 255 (1989). While these authors suggest that the vacuum level may not be flat between organic heterojunctions, as shown in **FIG. 4**, this does not change our conclusions and hence has been omitted for simplicity.

[0071] Efficient electron injection in the presence of a large energy barrier suggests that the barrier is effectively reduced due to the electrode deposition/formation process. When the ITO is sputtered onto the CuPc surface, the Cu can form a Cu—O bond via an exothermic reaction, F. F. So and S. R. Forrest, *J. Appl Phys.* 63, 442 (1988), thereby inducing a high density of midgap or surface states, D_{ss}, as shown in **FIG. 16**. These states, whose density decreases away from the ITO interface, provide small energy "steps" which can easily be surmounted by the injected electron. These data and the resulting model are in contrast to previous suggestions that low work function metals are required for efficient electron injection. The residual energy barrier may account, in part, for the small increase in V_T for the non-metallic-cathode-containing TOLED as compared with TOLEDs not having the non-metallic cathodes of the present invention.

[0072] Evidence that such damage is effective to produce the non-metallic cathode of the present invention only when the damage is restricted to the CuPc layer was obtained by reducing the CuPc layer thickness from 60 Å to 30 Å. This