Effect of thickness of a CuI hole injection layer on the properties of organic light emitting diodes

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Abstract—We report the influence of the thickness of a copper iodide (CuI) hole injection layer (HIL) on the performance of organic light-emitting diodes (OLEDs) with tris-8-hydroxyquinoline aluminum (Alq\textsubscript{3}) active layer and aluminum cathode layer. The investigation of structural and morphological properties of thermally evaporated CuI thin films indicates that they are amorphous. OLEDs with the ITO/CuI/Alq\textsubscript{3} structure [17,18] and metals with high work functions [11] are promising for practical applications in organic light emitting devices.

Display technologies that utilize organic light-emitting diodes (OLEDs) were commercialized at the end of the last century and have been continually developed until the present time [1-3]. One active direction of current research is the synthesis and characterization of new hole-injection and electron-injection materials. Hole injection layers (HIL) and electron injection layers (EIL) enhance the luminescence current efficiency of OLEDs [4-6]. For example, polyaniline [7], poly(3,4-ethylenedioxythiophene) (PEDOT) [8-9], metal phthalocyanines [10] and metals with high work functions [11-12] are successfully used as HILs. These materials decrease the hole injection barrier between the anode and the organic active layer.

Recently we have reported that CuI thin films can be used as effective HILs in the pentacene-based photovoltaic structures [13], as an efficient injection layer of holes from the ITO anode in a light-emitting diode structure based on Alq\textsubscript{3} [14], and solid-state dye-sensitized solar cells [15].

CuI thin films deposited by thermal evaporation are on average 80% transparent over the 400–800nm wavelength range [13]. CuI material has low cost and therefore is promising for practical applications in organic optoelectronic devices.

The aim of this work is to characterize the structural and morphological properties of CuI thin films and to investigate the influence of the thickness of the CuI hole

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The results of the current density-voltage study are shown in Fig. 3. J-V curves of the ITO/CuI/Alq3/PEGDE/Al devices with a different CuI thicknesses were fit using a trap-charge limited current (TCLC) model [1]:

\[
J_{\text{TCLC}} = N_c \mu q \left( \frac{e \varepsilon_0}{N_c q (l + 1)} \right)^{1/2} \left( \frac{2l + 1}{l + 1} \right)^{1/2} \frac{V^{l+1}}{d^{2l+1}}
\]

where \( \mu \) is the charge carrier mobility, \( q \) is the charge, \( d \) is the device thickness, \( \varepsilon \) is the relative dielectric constant, \( \varepsilon_0 \) is the vacuum permittivity, \( N_c \) is the density of states at the conduction band minimum, \( N_t \) is the trap density. In Eq. (1) \( l = E_t/k_b T \), where \( E_t \) is the characteristic trap energy, \( T \) is the operation temperature, and \( k_b \) is the Boltzmann’s constant.

The results of the TCLC model analysis lead to the conclusion that the CuI layer decreases the number of charge traps and enhances the hole injection properties of OLEDs. The insertion of the CuI layer into the structure leads to a decrease of \( l \) from 5.7 to 5.2. We attribute this change to the elimination of interface charge traps at the interface with Alq3 [1]. The CuI layer also improves hole injection properties of the devices. As shown in Fig. 4, this improvement is associated with the decrease of a potential barrier for holes at the Alq3 interface [1].

The efficiency of OLEDs was also improved by introducing of CuI hole injection layers [14]. As shown in Fig. 5, an increase of CuI thickness from 0 to 12 nm leads to an increase of luminance from 3000 cd/m² to 4000 cd/m² at a current of 200 mA/cm².
Improving the OLED performance can be explained by the improvement of the electron-hole balance in the active Alq3 layer. In turn, this increases the distance between the recombination region and the interface with the anode, and decreases non-radiative energy transfer [23]. An increase of CuI thickness beyond 12 nm deteriorates the device performance due to an increase of the series resistance and resulting Joule heating. Therefore, the 12 nm thickness of CuI hole injection layers was found to be optimal for the performance of ITO/CuI/Alq3/PEGDE/Al organic light-emitting devices.

We found that the CuI thin films prepared by thermal evaporation on substrates held at room temperature are amorphous. We investigated the effect of the thickness of the CuI hole injection layer of electrical and light-emitting properties of the ITO/CuI/Alq3/PEGDE/Al organic light-emitting devices. J-V curves of the OLEDs were approximated using a trap-charge limited current density model. It was shown that the efficiency of OLEDs can be improved by introducing of CuI hole injection layers up to a thickness of 12 nm. Further increasing of the CuI thickness deteriorates the device performance due to increased series resistance and resulting Joule heating.

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