Developing High-Performance OLED Materials with Diverse Properties for Various Display Makers

Lichang Zeng, Entao Sun, Jinhua Huang, Zhipeng Wang* and*Song Liu
Beijing Eternal Material Technology Co., Ltd., Beijing, China
Gu'an Eternal Materials Technology Co., Ltd., Gu'an, Hebei, China
***E-mail*: zenglc@eternalmt.com (*Lichang Zeng*)**

Abstract
Our efforts in developing novelhigh-performance ETL and R prime materials are presented. These new materials are tailor-designed for our customers to improve the performance of their AMOLED display products.

Author Keywords:
Electron-transporting materials; prime layer materials

1. Introduction

Over the past decade, OLED has established a commanding positionin displays for smart phones，smart watches and TVs. Although OLED possesses many aspects of inherent excellence, such as high color gamut, ultimate high contrast and aesthetic form factors, its wide adoption would not be possible without the many years of joint efforts from both industry and academic institutes [1]. The rising of many AMOLED display makers and fast expansion of manufacturing capacity in Korea and China effectively brings this beautiful display screen accessible for ordinary people. In the upper stream of the OLED industry, a number of chemical companies keep coming out with various highly efficient and stable electroluminescent materials to meet ever-growing performance requirements from end customers. The multi-layer architecture of OLED, on the other hand, provides a wide horizon of business opportunities for materials providers.

Though modern AMOLED displays generally adopt the same arrangement of the numerous active organic layers, individual display makers might have different specific requirements for each active layer in different products. One of these apparently contradicting requirements might have originated inunique choices of materials for each active layer by different display manufacturers.Various application intentions of displays further complicate the prerequisites in materials selection. The pre-selection of one active layer materials (e.g. hole-transporting layer, HTL) could necessitate a special set of properties from the other layers, *e.g.* electron-transporting layer (ETL), hole-blocking layer (HBL), electron-blocking layer (EBL) and emission layer(EML), to arrive at balanced charge transportation and recombination to maximize the device performance. In this work, we report our efforts on developing tailored design ETL and red EBL materials (Red prime, R') for our customers.

2. Experimental

Materials preparation:All new materials were synthesized from commercially available intermediates, and purified by column chromatography and vacuum sublimation. The purity (>99.9%) of final products were guaranteed by high performance liquid chromatography (HPLC) with a C18 column. The chemical structures were verified by H^1-NMR and high-resolution Mass Spectroscopy (HRMS). The highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) levels of compounds were measured by cyclic voltammetry in dimethyl formamide with ferrocene (HOMO = −4.8 eV) as internal standard. The glass transition temperatures (T_g) were recorded with differential scanning calorimetry, and all new materials discussed below have T_g> 105 C.

Device fabrication and characterization:All devices were fabricated by vacuum thermal evaporation under high vacuum (<10^{-6} torr) in a cluster-type 3-chamber OLED fabrication tool. The overall deposition ratesfor organic layers and metal electrodes were controlled at 0.1 and 1 nm/s, respectively. The active area of 9 mm^2 for all OLED devices was defined by ITO pre-etching in conjunction with electrode deposition shadow mask.

3. Results and Discussion

We set out our materials development focusing on ETL for blue fluorescent OLED, where both efficiency and lifetime improvements are desperately needed in OLED display industry. The new materials are evaluated in our first standard bottom-emission device structure, Device Structure A:

ITO/HT1:p-Dopant (100:3)(10 nm)/ HT1(100 nm)/B'1(5 nm)/BH1:BD1 (100:5) (20 nm)/HBL1 (10 nm)/ ET:LiQ (100:150) (25 nm)/Mg:Ag (100:10)(20 nm)/Ag (80 nm)

Except for ETL materials, all materials in Device Structure A were acquired from commercial sources. BH1 and BD1 are high-performance host and

fluorescent blue dopant, respectively. Our first round of ETL development produces ET-106, which enable 5% and 20% increment in efficiency and lifetime, respectively, compared with our earlier generation ETL, ET57, as presented in Table 1.

Table 1: Energy levels and Relative performance of ET57 and ET106. The voltage (*V*), efficiency (*LE*) and lifetime (*LT*) were all recorded at 1000 nits and normalized to that of ET57. Both materials were evaluated in Device Structure A.

ETL Materials	Energy Levels		Relative Performance		
	HOMO (eV)	LUMO (eV)	*V* (%)	*LE* (%)	*LT* (%)
ET57	−5.68	−2.92	100	100	100
ET106	−6.24	−2.69	101	105	120

Apparently, the deeper HOMO level and shallower LUMO level of the new ETL are favorable for efficiency improvement. Following this molecular design approach, we developed a library of ETL materials, their performance data are summarized in Figure. 1.

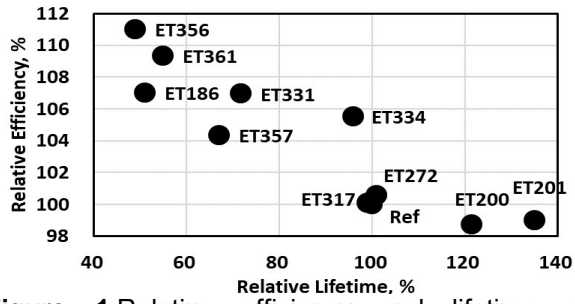

Figure 1. Relative efficiency and lifetime of selected ETL materials *vs*. our Ref ETL evaluated in Device Structure A.

We further found that the performance of ETL materials are critically dependent on the materials selection of other layers. Replacing HT1 with another commercially available HT2, which is known to improve device lifetime in many occasions, in conjunction with our proprietary high-performance HBL materials (HB333), we constructed a second bottom-emission device structure, Device Structure B:

ITO/HT2:p-Dopant (100:3) (10 nm)/ HT2 (100 nm)/B'1 (5 nm)/BH1:BD1 (100:5) (20 nm)/HB333 (10 nm)/ ET:LiQ (100:100) (25 nm)/Mg:Ag (100:10)(20 nm)/Ag (80 nm)

Table 2 summarizes the performance of our two newly developed ETL materials, ET201 and ET356, evaluated in both Device Structure A and Device Structure B. It is clear that both ETL materials show much improved performance in Device Structure B. It is worth noted that the lifetime of ET356 is increased by 3 folds, surpassing that of ET201.

A closer look at the efficiency-luminance curve (Figure 2.) found that the efficiency at low luminance was improved for device with ET356 as ETL. This improvement of efficiency at low luminance is especially desirable for RGB side-by-side devices to achieve high-quality gray scale [2].

Table 2: Performance of ET201 and ET356 evaluated in Device Structures A and B. Voltage (*V*) and current efficiency (*LE*) were recorded at 1000 nits. Lifetime (*LT97*) was recorded as the time the device luminance decays to 97% of initial value under constant current density at 20 mA/cm^2, and was normalized to that of Device Structure A with ET201 as ETL

Device Structure	ETL Materials	*V* (V)	*LE* (cd/A)	*LT97* (%)
A	ET201	3.72	9.30	100
	ET356	3.55	9.80	43
B	ET201	3.61	9.95	112
	ET356	3.69	10.23	121

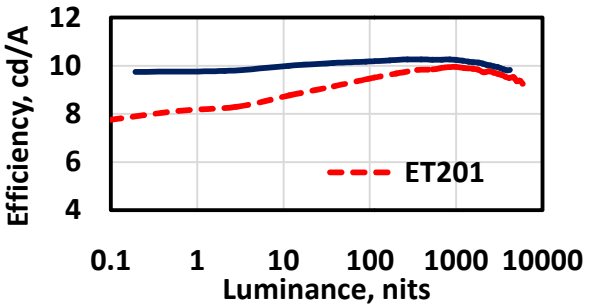

Figure 2. Luminance-dependent efficiency of ET201 and ET356 evaluated in Device Structure B.

Though ET201 could be a better choice than ET356 for customers adopting Device Structure A due to the apparently better stability of the former materials, customers adopting Device Structure B might prefer ET356 as their ETL materials.

In parallel to the ETL materials development, a series of hole-transporting compounds were also developed asEBL (R Prime, R') materials for red phosphorescent OLED. These materials were evaluated in our red bottom-emission device structure, Device Structure C:

ITO/HT1:p-Dopant (100:3) (10 nm)/ HT1 (100 nm)/R' (90 nm)/RPH1:RD1 (100:3) (40 nm)/HB1 (10 nm)/ ET201:LiQ (100:150) (25 nm)/Mg:Ag (100:10)(20 nm)/Ag (80 nm)

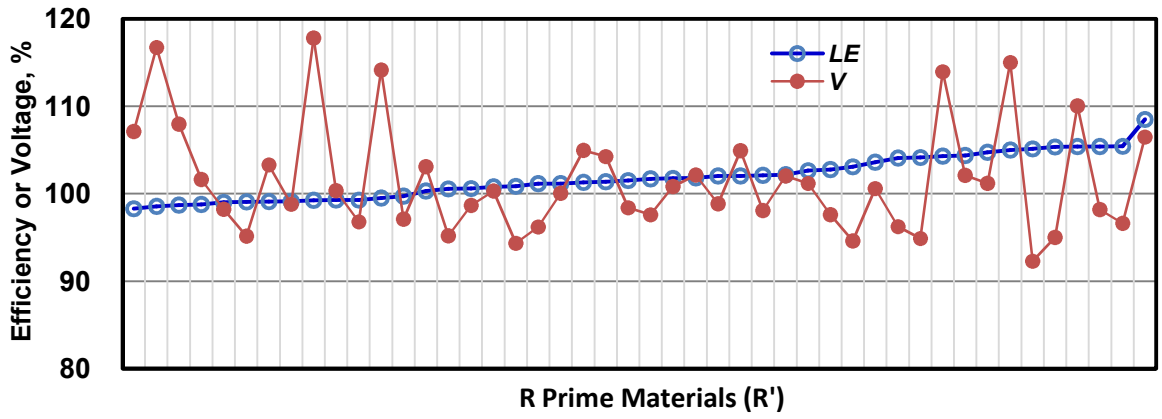

Figure 3. Relative efficiency and voltage of selected R Prime materials (R') *vs*. our reference R' evaluated in Device Structure C. Each vertical pair of solid and hollow circles represent one R'. The solid connecting lines are presented for guidance.

RPH1 and RD1 are commercially available high-performance host and phosphorescent red emitter, respectively. The relative performance of selected R' materials are summarized in Figure 3. Numerous novel materials demonstrate higher efficiency than our standard R', HT64, albeit with various voltage shifts. Further evaluation of these materials in different device structures are under wayand will be reported in the future.

4. Conclusions

In summary, we have developed a library of novel ETL and R prime materials tailored designed for our customers. The performance of these materials could be dependent on device structure, which might be different for various display manufacturers or display products. A few of materials selected from this library are adopted by our customers for mass production. We believe R&D efforts like ours are particularly beneficial to advancing the OLED industry.

Acknowledgment

We are grateful to Beijing Eternal Material Technology Co., Ltd. for financial and technical support.

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