Organic Electronics 57 (2018) 1–6

Contents lists available at ScienceDirect

Organic Electronics

journal homepage: www.elsevier.com/locate/orgel

The application of the nanostructure aluminum in the blue organic light-emitting devices

Yadong Liu[a,*], Yan Zhao[b], Haihao Zhang[a], Xinchao Song[a], Jihua Zhou[a], Zhisheng Wu[a], Jie Zhang[a], Wangjun Guo[a], Yuhua Mi[a]

[a] Xi'an Modern Chemistry Research Institute, Xi'an, 710065, PR China
[b] Xi'an Horological Research Institute of Light Industry Corporation Ltd, Xi'an, 710061, PR China

ARTICLE INFO

Keywords:
HAT-CN
Nanostructure
The microcavity effect
The surface plasmon effect
OLED

ABSTRACT

A composition of aluminum (Al)/1,4,5,8,9,11-hexaazatriphenylene-hexacarbonitrile (HAT-CN) was adopted on the ITO anode of organic light-emitting diodes (OLEDs). With changing the thickness of this anode nanostructure Al, a whole continuous nanofilm or discontinuous nanoparticles would be formed on the ITO surface which can be used to improve the performance of the blue-emitting device. An optical microcavity would be formed by the whole continuous Al nanofilm at the thickness of 15 nm combined with the cathode Al film, which could narrow the emission spectra and enhance the blue emission intensity from the 4,4′-bis(9-ethyl-3-carbazovinylene)-1,1′-biphenyl (BCzVBi). A deep blue electroluminescent (EL) emission with an EL efficiency of 5.7 cd/A at a current density of 20 mA/cm^2 at saturated blue Commission International de l'Eclairage (CIE) coordinates of (0.137, 0.112) was obtained, of which the full width at half-maxmium (FWHM) of 49 nm was narrower 30% than the reference device with the increased EL intensity. And while the formed discontinuous nanoparticles was optimized at the thickness of 3 nm, the surface plasmon (SP) effect of the Al nanoparticles was utilized to increase the EL efficiency up to 7.5 cd/A which was 36% higher than the reference device at a current density of 20 mA/cm^2, and along with the slightly changed CIE coordinates of (0.156, 0.210).

1. Introduction

Ever since the efficient and small molecular OLED was reported for the first time by Tang and VanSlyke in 1987 [1]. There has been widespread research and commercial interest on the applications in next-generation flat panel displays and solid-state lighting [2,3]. Nowadays, although this technology has been certainly applied in market, a significant improvement in its efficiency is still needed, particularly for the blue emission device [4,5]. Many technologies have been made to ameliorate the performance of OLEDs, including the application of the metal nanostructure used into device [6–33]. The metal nanostructure can be formed as nanofilm or nanoparticles.

Generally, the metal nanofilm was utilized as a semi-transparent light-output mirror electrode, it could combine with the highly reflective back mirror electrode to constitute an optical microcavity of wavelength size. This microcavity was demonstrated to narrow emission spectra and thus improve color saturation for display applications and to enhance the luminance of OLEDs [6–11]. Commonly, the metal materials such as Al [12], Ag [13], Au [14], Pt [15]have been investigated for the promising semi-transparent anode. The metal oxides of WO_3 [16], MoO_3 [17], and V_2O_5 [18]have been extensively used as buffer layer to increase the work function of the anode.

Meanwhile, the metal nanoparticles could be adopted to enhance luminescence of OLED through SP effect. The SP are the collective oscillations of free electrons in metal nanopaticles at the interfaces between the metal and dielectric [19–21], which can also be potentially applied to molecular sensing [22], organic solar cells [23,24], electrochromic devices [25]. Commonly the metal materials of Al [26], Ag [27], Au [28]formed as nanoparticles have been used. An evanescent field would be formed by SP extends into the dielectric, which could enhance the absorption/emission efficiency by mutually influencing with the penetrated light and nearby molecule [23,26,29], but the range of the evanescent field reported in the references had obviously variance [30–33]. Arunandan Kumar reported that 2.8 times enhancement in EL intensity of device when the gold nanoparticles had been introduced at a distance of 5 nm from emissive layer [31]. Hyangki Sung reported that the external quantum efficiency was increased 27% with silver nanoparticles at a distance of 40 nm from emissive layer [32]. Tomohiro Fukuura reported that a luminescence efficiency increased 4.5 times with silver nanoparticles layer at a distance of 50 nm

* Corresponding author.
E-mail address: ndyadong@126.com (Y. Liu).

https://doi.org/10.1016/j.orgel.2018.02.029
Received 7 November 2017; Received in revised form 10 February 2018; Accepted 19 February 2018
Available online 21 February 2018
1566-1199/

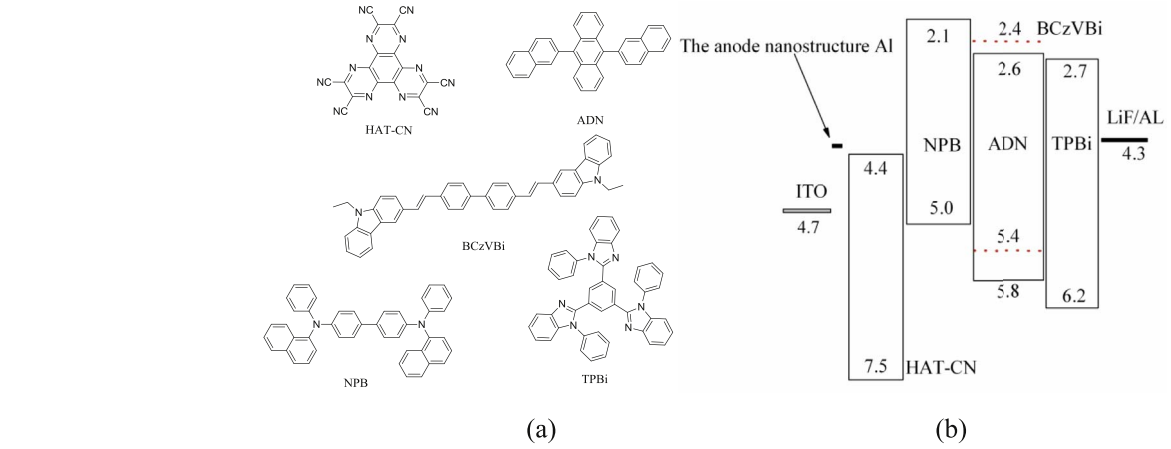

Fig. 1. (a) Schematic structures of the materials used in our work; (b) energy level diagrams of the materials used in the devices.

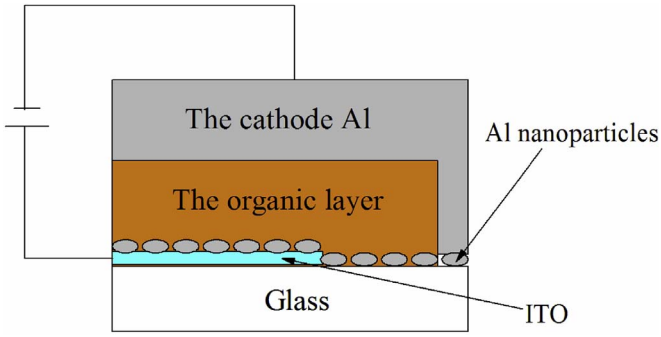

Fig. 2. Schematic device structure used to confirm whether the anode nanostructure Al assembled as a whole continuous nanofilm or not.

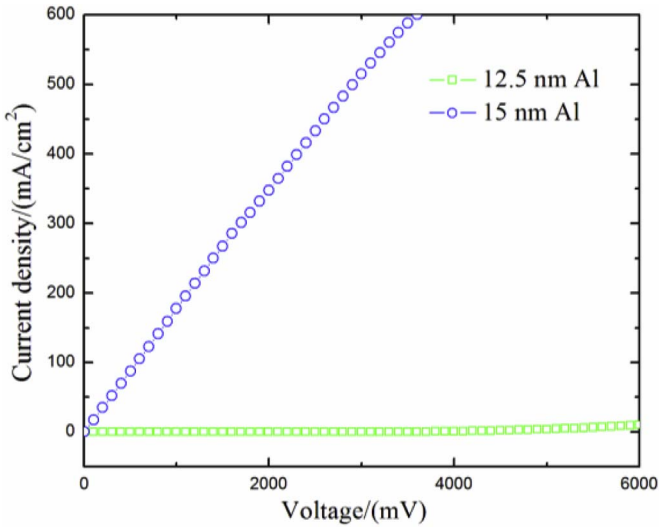

Fig. 3. J-V characteristics of the certification devices with the anode nanostructure Al at the thickness of 15 nm and 12.5 nm.

from emissive layer [33].

In our work, a composition of Al/HAT-CN was successfully adopted on the ITO surface to improve the performance of the blue device based on BCzVBi emission. This anode nanostructure Al was formed as continuous nanofilm or discontinuous nanoparticles via changing the thickness. At the thickness of 15 nm, the microcavity effect played a crucial role in the device to increase the emission intensity with excellent deep-blue CIE coordinates (x = 0.137, y = 0.112) at a current density of 20 mA/cm^2, along with the FWHM of 49 nm which was narrower 30% than the reference device. And while the thickness of the anode nanostructure Al was 3 nm, the SP effect of Al nanoparticles increased the EL efficiency up to 7.4 cd/A which was 35% higher than that of the reference device at a current density of 20 mA/cm^2, with blue CIE coordinates (x = 0.156, y = 0.210) decided by the slightly changed emission spectra.

2. Experimental details

The devices used in our work were fabricated on patterned ITO-coated glass substrates with a sheet resistance of 15 Ω/sq which were routinely cleaned in an ultrasonic bath with distilled water, ethyl alcohol, and acetone. Then the substrates were treated by O_2 plasma under conditions of 1.3×10^{-2} Pa at 75 W for 20 min. All the layers, including the anode nanostructure Al and the cathode Al, were grown by thermal evaporation at the base pressure of $< 3 \times 10^{-4}$ Pa. The deposition rate was 0.1 nm/s for all organic materials used in our work, and 0.01 nm/s for LiF along with the anode nanostructure Al. Without breaking the vacuum after the deposition of the organic layers, the Al cathode was deposited at a rate of 1 nm/s. All the materials used in our experiments were purchased by commercially without further purification. The devices used here with a configuration of ITO/Al (d nm)/HAT-CN (20 nm)/NPB (60 nm)/ADN: BCzVBi (wt.6%, 35 nm)/TPBi (20 nm)/LiF (1 nm)/Al (100 nm). The device structure and molecular structures are shown in Fig. 1. The weight ratio of ADN: BCzVBi films was optimized and fixed at 3:47 in this work. Using DC voltage bias with Keithley2400, the current density-voltage-luminance (J-V-L) characteristics have been measured with a luminance meter (DLM-1000S). And the EL spectra of the emission were measured by OPT-2000 instruments. The UV–vis absorption spectrum was recorded with Lambda 750 UV/VIS/NIR spectrophotometer of PerkinElmer. The scanning electron microscope (SEM) was obtained using Quanta 600 FEG of FEI. The simulation of the EL spectra was calculated by MATLAB 8.3. All measurements were carried out under ambient conditions at room temperature without encapsulation.

3. Results and discussion

The formation of discontinuous nanoparticles or continuous nanofilm of the anode nanostructure Al was determined by the thickness. Clearly when the anode nanostructure Al assembled as a whole continuous nanofilm on the ITO surface, with which an optical microcavity would be formed by combining the cathode Al film. So foremost, to confirm the condition when the anode nanostructure Al had assembled as a whole continuous nanofilm, a certification device was designed with a configuration shown in Fig. 2. It can be comprehended that the organic layer would be shorted out if the Al nanoparticles connected as