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Improvement of roll-off in power efficiency for mixed single layer organic light emitting devices by co-doping

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ABSTRACT

Roll-off phenomena in power efficiency for rubrene-based mixed single layer organic light emitting devices is investigated. The evaluation of operational temperature demonstrates that Joule heating is not the main reason for roll-off in power efficiency with current density. Co-doping method through rubrene co-doping with some additive dopant, C6, DCJTB and Nile red, in mixed single layer are proposed for suppressing the roll-off in power efficiency. By co-doping suitable Nile red with rubrene, the efficiency roll-off is found to be largely improved in whole range of current density. Moreover, improved device performance is also realized even if with a 3 wt% fluorescent doping concentration. The improved performance is ascribed that there exists a competitive emission mechanism with respect to different dopant.

1. Introduction

Organic light-emitting devices (OLEDs) represent a promising technology for large, flexible, lightweight flat-panel displays [1]. Initial device with simple sandwiched configuration, however, sometimes does not show a sufficient performance for practical applications. Afterward, more complicated device architectures, such as multiple layer heterostructure consisting of separate electron and hole transporting layers [2,3] are developed and the device performance has been improved for practical commercialization. However, the heterojunction itself in the multilayer structures may limit the device stability which is deteriorated by the charge accumulation owing to the existence of higher electric field at heterojunction interface. The excitons are quenched and the lifetime is restricted by the high local electric field. A mixed organic layer structure, in which both the electron transport materials and the hole transport materials are evaporated in one layer, is very efficient in improving the performance by adjusting the mixing ratio [4,5]. In addition, doping of a fluorescent dye into the emission layer is also an important mean to realize high performance OLEDs [6,7].

In our past work [4], OLEDs with a mixed single layer were proposed and almost identical performance compared with stacked heterostructure device could be obtained. More important, the lifetime of the device operation was largely improved and the suppression of dark spots was also confirmed by evaluating the dark spots growth [8]. With optimized mixing ratio of tris-(8-hydroxyquinoline) aluminum (Alq_3) and 2,5-bis(6′-(2′,2″-bipyridyl))-1,1-dimethyl-3,4-diphenylsilole (PyPySPyPy), hole transport material 4,4′-bis[N-(1-napthyl)-N-phenyl-amion] biphenyl (α-NPD) and dopant material 5,6,11,12-tetraphenylnaphthacene (rubrene), the maximum power efficiency was improved to 3.45 lm/W for top-emission OLEDs [9].

In most OLEDs, the device efficiency including external quantum efficiency and power efficiency decreases monotonically with current density and it also occurred in our mixed single layer top-emission OLEDs. Our previous study demonstrated that the efficiency roll-off could be suppressed after co-doping two dyes in the emission layer [10]. The decrease in efficiency with current density has been attributed to several possible mechanisms, i.e., imbalance of electron and hole in emission layer, Joule heating produced during the electroluminescence process and non-radiative exciton quenching processes [11]. To our mixed single layer OLEDs,

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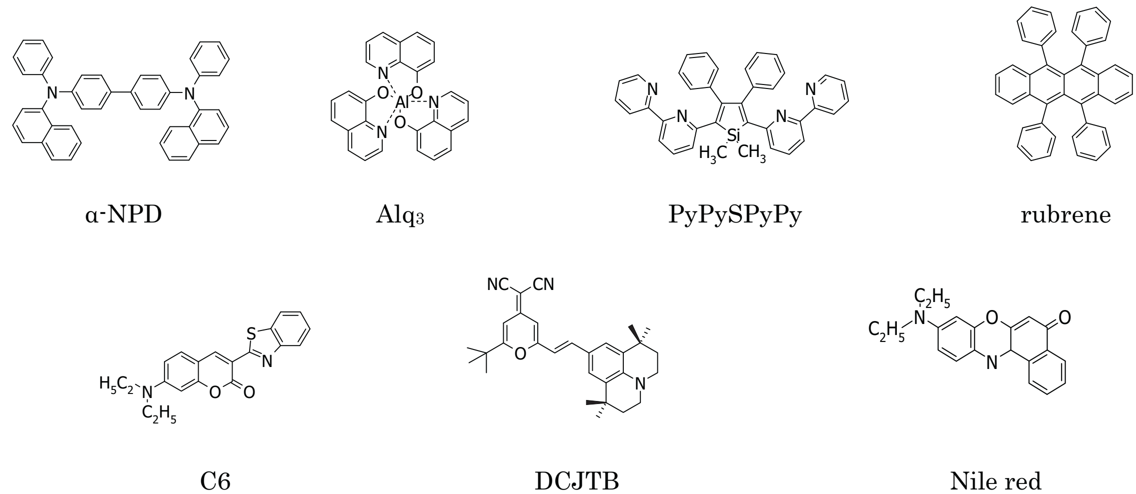

Fig. 1. The chemical structure of organic molecules upon investigation.

the mixing ratio of all organic materials is optimized under various conditions [9]. This rules out the imbalance of carriers as the main factor for the observed roll-off in efficiency. In this paper, we investigated the effects of environment temperature and exciton quenching on efficiency roll-off in a mixed single layer top-emission OLEDs, and searching for which is the main factor for the efficiency roll-off.

2. Experimental

In mixed single layer top-emission OLEDs, aluminum–neodymium alloy (AlNd, Al:Nd = 98:2, Kobelco Research Institute) is selected as a cathode in order to flatten the electrode surface and avoid the short-circuiting. Thin gold film is used as a semitransparent anode. The device has a structure of AlNd/PyPySPyPy + Alq_3 + α-NPD + rubrene (100 nm)/MoO_3 (50 nm)/Au (20 nm). The weight ratio of organic material in a mixed single layer is optimized with PyPySPyPy:Alq_3:α-NPD:rubrene = 25:50:25:3. Glass substrate used is alkaline earth boro-aluminosilicate glass (Corning 1737). Mixed organic materials were evaporated at a pressure of 4×10^{-6} torr at a rate of 1–3 Å/s. The device area is 2 mm × 2 mm. For investigating the co-doping effects, coumarin 6 (C6), 4-dicyanomethylene-6-cp-julolidinostyryl-2-tert-butyl-4H-pyran (DCJTB) and phenoxazone (Nile red) were doped with rubrene into mixed single layer. Fig. 1 shows the chemical structure of organic molecules upon investigation. Device characteristics are measured using semiconductor parameter analyzer (HP 4155B) and luminance meter (Topcon BM-3). For evaluating the effects of environment temperature, device characteristics are measured under vacuum at temperature range between −20 and 100 °C.

3. Results and discussion

3.1. Effects of environment temperature on efficiency roll-off

Although higher power efficiency was obtained at lower current density in a mixed single layer top-emission OLEDs, the power efficiency decreased with a ratio of 76.4% from 1 to 100 mA/cm^2. We firstly evaluate the effects of operational temperature on efficiency roll-off through measuring the device characteristics with varied temperature (−20 to 100 °C) under vacuum.

Fig. 2(a) and (b) shows the current density vs voltage (*J*–*V*), and power efficiency vs current density voltage (η–*J*) characteristics of devices at different temperature. The power efficiency increases with temperature from −20 to 100 °C in whole current range. Table 1 shows the detailed device parameter with varied temperature. The roll-off ratio in power efficiency from 1 to 100 mA/cm^2 is also calculated as shown in Table 1. The power efficiency at 100 mA/cm^2 increases from 0.95 to 1.58 lm/W with increasing of temperature. However, roll-off ratio in power efficiency is not changed. The driving voltage of device is lowered with temperature. For example, it decreases from 9.2 to 5.1 V at 100 mA/cm^2. In addition, the device luminance shows little changes under varied temperature. In our previous study, hole and electron injections to the mixed organic layer are both ascribed to be the Schottky thermionic emission mechanism [12]. With increasing of temperature, Schottky thermionic emission current increases owing to

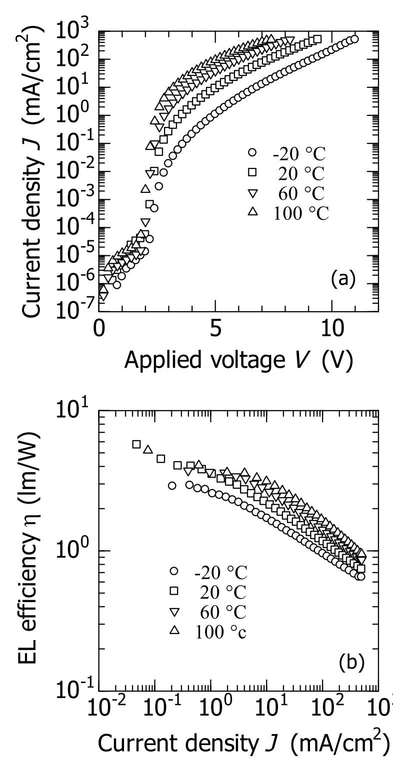

Fig. 2. Current density vs voltage (*J*–*V*) (a) and power efficiency vs current density voltage (η–*J*) characteristics (b) of rubrene-only doped device at different temperature.