

P-58 : Red OLEDs containing the dotted-line doped layer structure in its emitting region.

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Abstract.

We present an extremely high efficient red organic light-emitting diodes (OLEDs) using a fluorescent dye 4-(dicyanomethylene)-2-tert-butyl-6-(1,1,7,7-tetramethyljulolidyl-9-enyl)-4H-pyran (DCJTb) doped into an emitting region which consists of multiple pairs of a doped and an undoped layer. An emitting region of OLEDs composes of a tris-(8-hydroxyquinolino) aluminum (Alq₃) codoped with rubrene of 5% wt. or a mixture of Alq₃ and rubrene (1:1). The luminance yield of the codoped device and the mixed device are 6.5 cd/A and 9.2 cd/A at 10 mA/cm², respectively. We have considerably improved the luminance yields of red OLEDs as much as ~90% at 10 mA/cm² compared with that of the device doped with only DCJTb. We attribute it to both the emitting assist dopant (rubrene) and the dotted-line doping structure in an emitting region of OLED.

1. Introduction.

For the development of organic full color displays, red organic light emitting devices (red OLEDs) still needs to be improved further to increase emission efficiency and color purity.

In general, a doping system, which is composed of a host material (Alq₃) and a red dopant (DCJTb), is used in red OLEDs in order to enhance luminous efficiency [1]. However, this doping system does not produce pure red emission with high luminance yield due to the poor energy transfer from a host to a guest or the concentration quenching of excitons on dopant molecules.

To circumvent to this problem, a codoping system has been proposed. A codoping system is composed of a red dopant (DCJTb) and an emitting assist dopant (rubrene or quinacridone) in the emitting layer. In fact, enhancement in a luminance yield by using a codoping system or a DLD structure in an emission region of red OLED has been reported [2~5]. Also, the emission process mechanism for codoping system has been discussed [6~8].

We have fabricated extremely high efficient red OLEDs containing dotted-line doping structure in its emission layer. The emission layer is composed of multiple pairs of an undoping layer and a doping layer which is composed of DCJTb and rubrene.

The structures of the red OLED studied in this experiment are

as follows :

ITO / α-NPD: 40nm / Alq₃+3% wt. DCJTb +5% wt. Rubrene /
 Alq₃ : 30nm / MgAg : 150nm

and

ITO / α-NPD : 40nm / (Alq₃+3% wt. DCJTb +5% wt. Rubrene /
 Alq₃ + 5% wt. Rubrene)_n : 30nm) / Alq₃ : 30nm / MgAg : 150nm

or

ITO / α-NPD : 40nm / (Alq₃+3% wt. DCJTb +50% wt. Rubrene /
 Alq₃ + 50% wt. Rubrene)_n : 30nm) / Alq₃ : 30nm / MgAg : 150nm

Fig. 1 shows a schematic diagram of the structure of the red OLEDs having DLD structure in its emission layer.

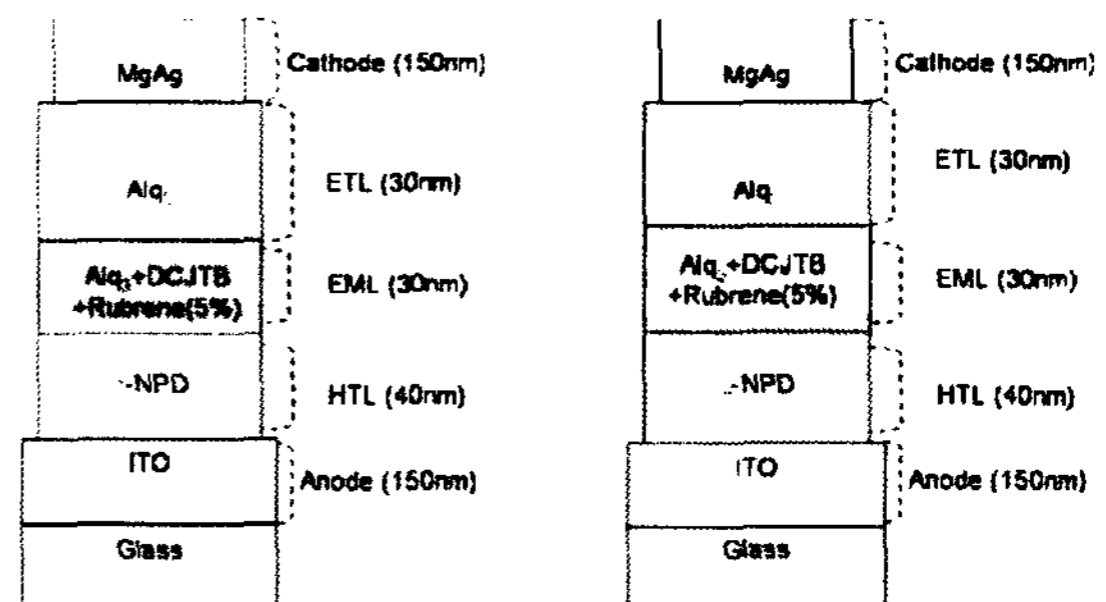


Fig.1-a A schematic diagram of the red OLEDs with DLD structure.

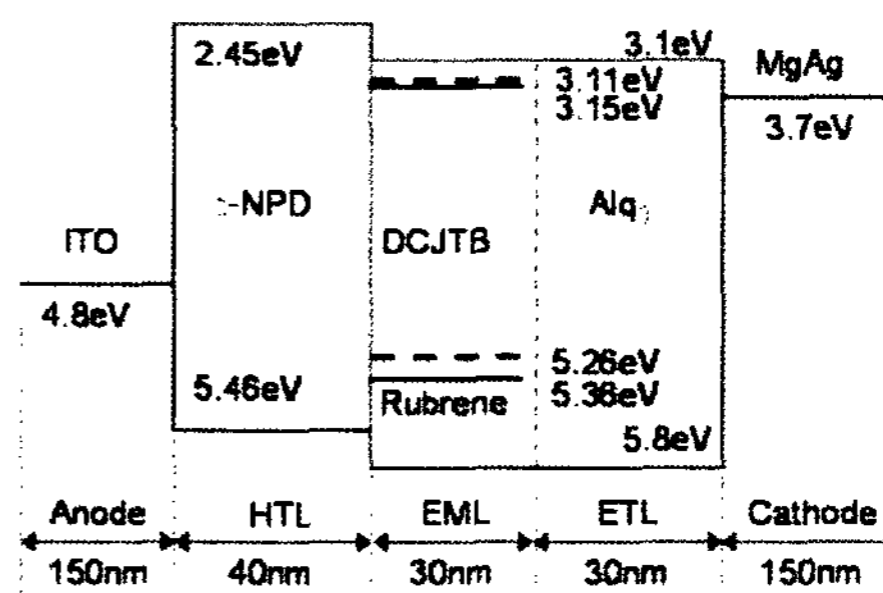


Fig. 1-b. A schematic energy band diagram of the red OLEDs with DLD structure in its emissive region.

We also suggest a possible emission process mechanism for codoping system with DLD structure based on our experiment data.

2. Experimental

The sheet resistance of ITO/glass substrate was used about $15\Omega/\square$. Prior to deposition, the ITO substrate was cleaned by sonication and oxygen plasma treatment. The OLEDs were fabricated by EPI organic molecular beam deposition (OMBD) system on an indium-tin-oxide (ITO) coated glass substrate. The base main chamber pressure has been kept under 2×10^{-10} torr by CTI Cryo8 pumping system. N,N' -di(naphthalene-1-yl)- N,N' -diphenyl-benzidine (α -NPD) for hole transport material, Alq_3 for electron transport material, DCJTB for red dopant material, and rubrene for emitting assist dopant material are loaded in different effusion cells equipped with each shutter and are evaporated separately. The deposition rate was controlled by Eurotherm temperature and power controller system, and the quartz crystal thickness monitor. The doping concentration of DCJTB was controlled to 3% (wt ratio). The emitting area was $2 \times 2 \text{ mm}^2$. A cathode layer (MgAg) was deposited by a separated vacuum vapor deposition system keeping a high vacuum of $\sim 10^{-6}$ torr.

The emission spectra were measured with Acton spectroscopy system. The current-voltage and the brightness-voltage characteristics were measured by Keithley model 236 source-measure unit and model 485 autoraging picoammeter for measuring current from Oriol UV-enhanced Silicon Detector (model 71608) respectively. All measurements were carried out at room temperature under ambient atmosphere.

3. Results and discussion

Fig.2 shows the normalized electroluminescent (EL) spectra of a series of 6 OLEDs fabricated under the same deposition parameters and condition. The measurement has been done at the current density 10 mA/cm^2 and at room temperature. While the position of the EL spectrum peak of the device D-1 is 610 nm , those of the other devices are varied from 610 nm to 615 nm . They show slightly a red shift with decreasing the numbers of DLDs. The full width at half maximum (FWHM) of the each EL spectrum has nearly same value of $\sim 60 \text{ nm}$.

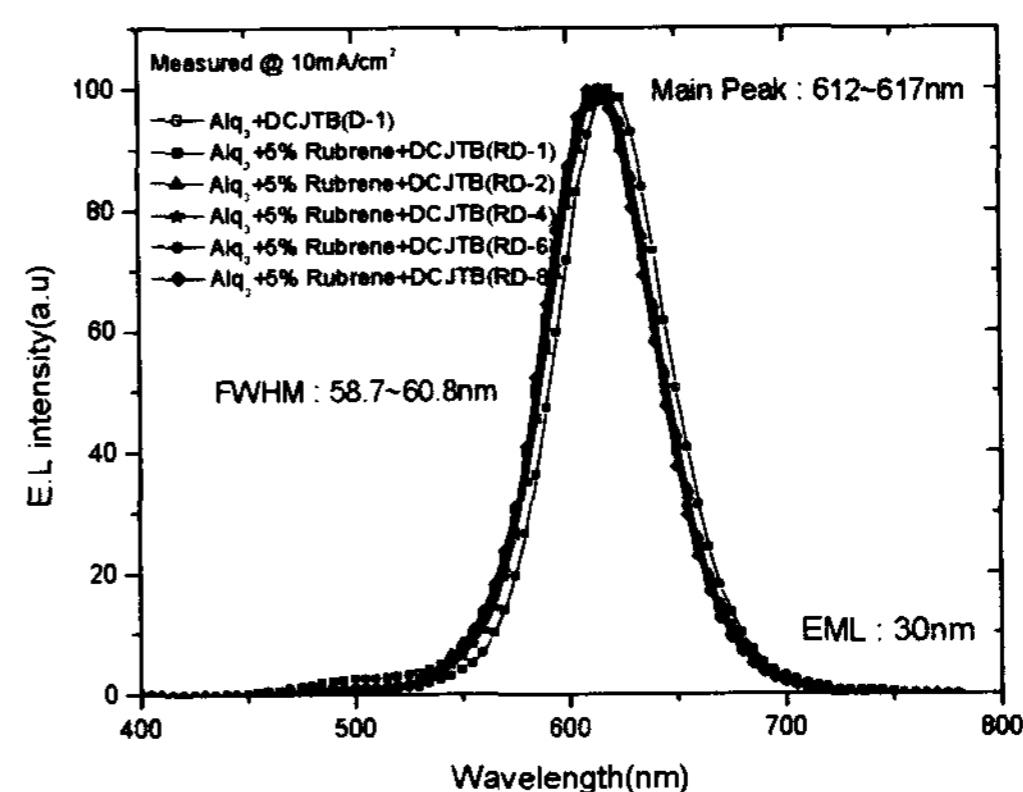


Fig.2 The electroluminescent (EL) spectra of the devices codoped with DCJTB and rubrene.

From the EL spectra, we can see the very small emission shoulders around the EL peak of Alq_3 at $\sim 520 \text{ nm}$. These peaks come from the emission of excitonic states of molecules Alq_3 inside or outside of the emission layers. The shoulder of the device D-1 doped with only DCJTB is bigger than those of other devices (RD1~RD6) codoped with rubrene and DCJTB. The shoulders of the devices codoped with rubrene and DCJTB are getting larger with increasing numbers of DLDs. This is attributed to it that the energy transfer did not occur less and less with increasing numbers of DLDs in emission layers of devices.

The plots of luminance yield versus current density for the devices studied in this work are shown in Fig.3.

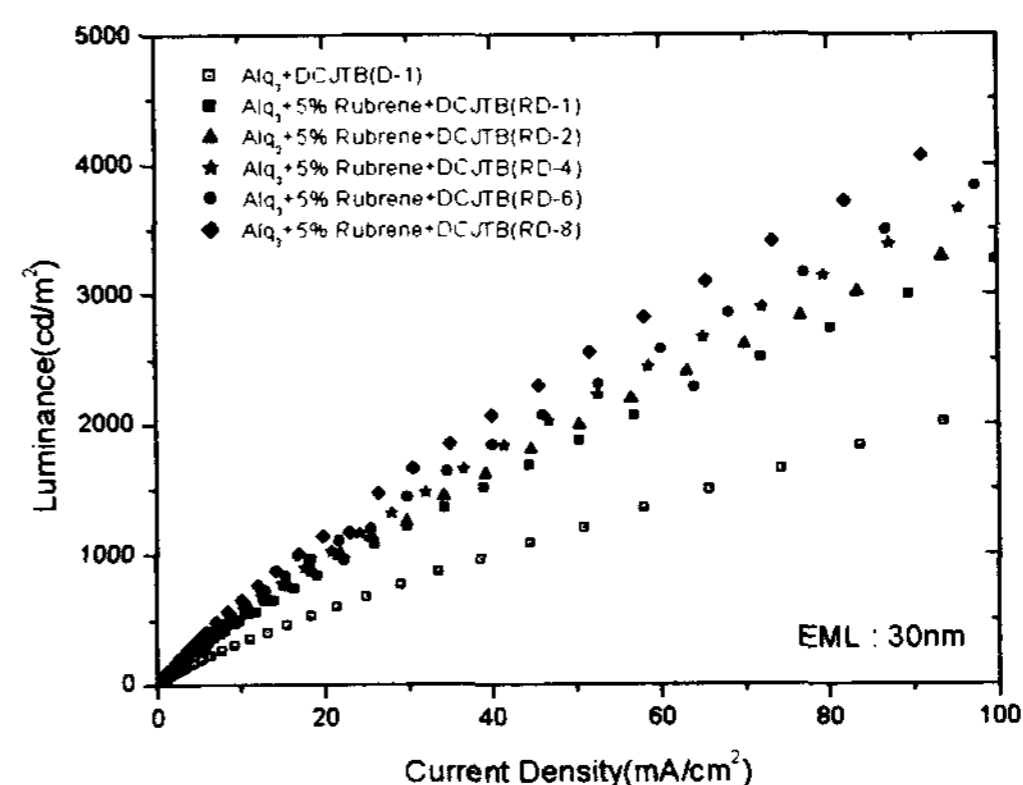


Fig.3. A plot of luminance yields versus current density for the devices studied in this experiment.

The luminance of all samples RD-n ($n=1,2,4,6,8$) codoped

with rubrene and DCJTb molecules is much brighter than that of D-1 doped with only DCJTb. In addition, the luminance intensity increases with increasing numbers of DLD layers. While the luminance measured at 10mA/cm² of sample RD-1 is 487 cd/m², that of sample RD-8 is 576 cd/m², which is bigger by ~18% than 487 cd/m². Those mean that both the rubrene molecules and the DLD structure in emission region play an important role in emission process.

We suppose that there are three possible emission processes for the red OLEDs investigated in this work. Those are as follows. (1) Injected carriers combine on the host molecules Alq3 and then form excitons on Alq3 sites. This exciton is transferred from Alq3 to the assist dopant rubrene molecules by the non radiative Forster energy process. And then this exciton continues to transfer from rubrene to DCJTb and produce the red light ; two-step energy transfer process. (2) Injected carriers combine on the mixed host rubrene molecules and form excitons. This excitonic energy is transferred to DCJTb, and the DCJTb molecules produce the light. (3) Injected carriers through Alq3 or rubrene molecules are sequentially trapped on the DCJTb molecules and form excitons. These excitons produce the light.

Fig.4. shows the plots of the luminance yield as a function of the current density for the OLEDs codoped with 5% rubrene + 3%DCJTb in its emission region.

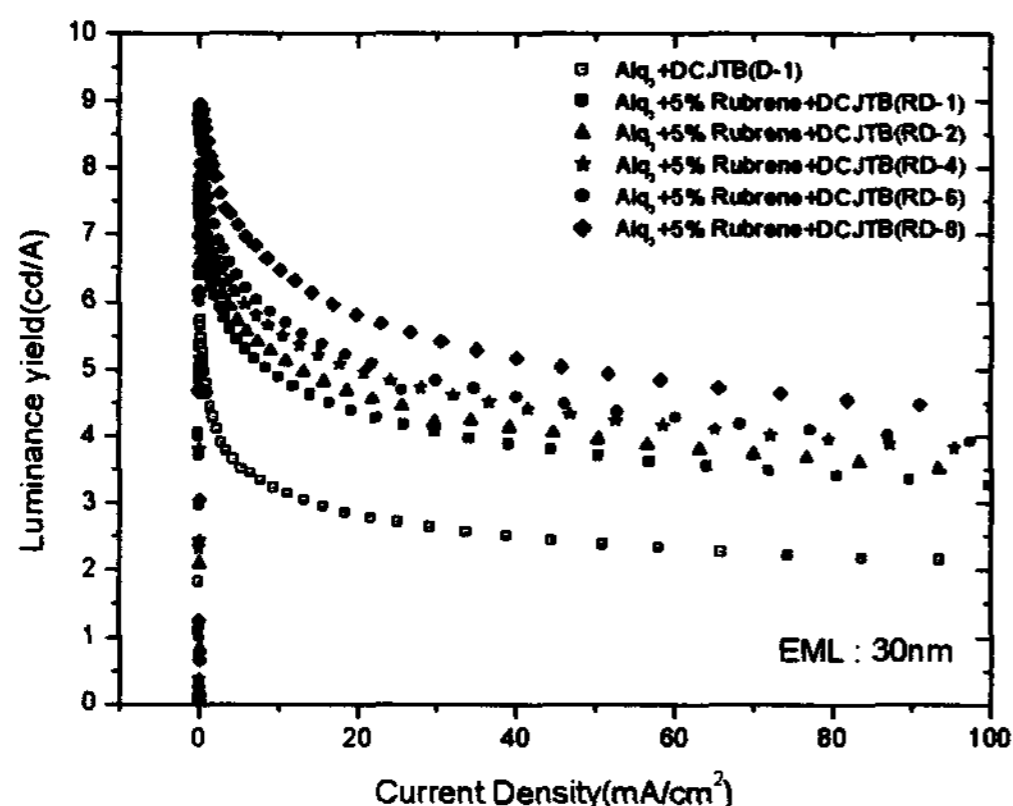


Fig.4. A plot of luminance yields versus current density for devices D-1 and RD-n.

From this figure, we observe that the luminance yields of the samples RD-n (n=1,2,4,6,8) increases as the numbers of DLD layers increase and the total thickness of doping layers decrease. The luminance yields measured at 10mA/cm² of sample RD-1 and RD-8 are 4.88 cd/A and 6.52 cd/A, respectively. The total thickness of doping layers of RD-1 and RD-8 are 30nm and 16nm, respectively. These results may be explained by the fact that the process (3) dominates process (1) although both processes play an important role in light emission.

On the other hand, the luminance yield of the sample RD-1

codoped with 5% rubrene and 3% DCJTb molecules is 4.90 cd/A while that of D-1 doped with only DCJTb is 3.18cd/A. It is thought that this enhancement is attributed to the fact that the process (1) dominates process (3).

Fig.5. shows the plots of the luminance yield as a function of the current density for the OLEDs with the mixed host 50% rubrene + 50% Alq3 in its emission region.

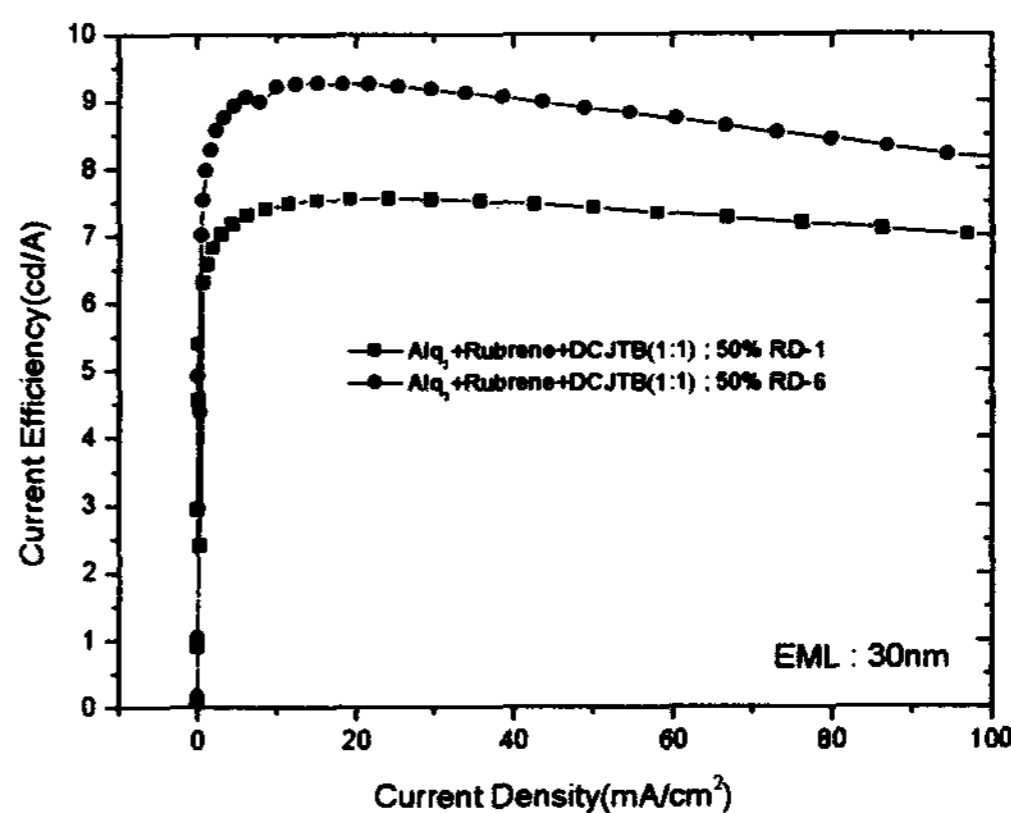


Fig.5. A plot of luminance yields versus current density for devices 50% RD-1 and 50% RD-6.

The luminance yield measured at current density 10mA/cm² of sample 50% RD-6 is 9.25cd/A, which is bigger by 25% than that of sample 50% RD-1 whose luminance yield is 7.34cd/A. The total thickness of doping layers of RD-1 and RD-6 are 30nm and 16.4nm, respectively. Likewise the above, these results may be explained by the fact that the process (3) dominates the process (2) or the process (1).

Also, we can observe that the luminance yield of the device 50% RD-6 is greatly improved as much as ~190% (9.25 cd/A : 3.18 cd/A) compared with that of the device D-1 doped with only DCJTb. We attribute it to all process (1), (2), and (3). That is, both the mixed host material (rubrene+Alq3) and the dotted-line doping structures in the emission region of red OLEDs have an important role in the emission process of red OLEDs.

4. Conclusions

We have successfully fabricated extremely high efficient red organic light-emitting diodes (OLEDs) using a fluorescent dye. The luminance yield of the codoped device and the mixed device are 6.5 cd/A and 9.2 cd/A at 10 mA/cm², respectively. This enhancement in luminance yield is attributed to both the emitting assist dopant (rubrene) and the dotted-line doping structure in an emitting region.

5. References

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