New Green Phosphorescent Organic Light Emitting Devices with the (TCTA/$TCTA_{0.5}TPBI_{0.5}$/TPBI):$Ir(ppy)_3$ Emission Layer

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Abstract

New green light emitting phosphorescent devices with host structure of TCTA[4,4',4''-tris(N-carbazolyl)-triphenylamine]/$TCTA_{0.5}TPBi_{0.5}$/TPBI[1,3,5-tris(N-phenylbenzimiazole-2-yl)benzene] were proposed and investigated according to the thickness combination of host layers and the doping level of $Ir(ppy)_3$[tris(2-phenylpyridine) iridium(III)].

1. Introduction

Though the internal quantum efficiency of phosphorescent organic light emitting diodes (PhOLEDs) theoretically reaches 100%, the practical value may be greatly lowered due to carrier injection loss, nonradiative relaxation of excitons, triplet-triplet annihilation at high current density, etc.[1-3] In addition , the triplet excitons have rather long lifetime so that they may diffuse to other layers by passing through the emission layer. This effect also deteriorates the electroluminescent characteristics and color purity due to the energy transfer and relaxation of excitons outside the emission layer. Therefore, the design of PhOLEDs which can confine triplet excitons in the emission layer is required to obtain high efficiency devices.

In a single host structure, excitons are generally formed around the outer part of emission region due to the band offset at the interface with carrier transport layer and carrier mobility difference in the emission region. Recently, various types of emission regions such as the simple mixed structure and the two stacked structure using double host materials have been reported in the PhOLEDs to improve the electroluminescent characteristics.[4-6] However, these devices with conventional double host structures still have some kinds of problems. In a device with the simple mixed double host structure, triplet excitons cannot be completely confined in the emission region because the exciton formation zone is extended over the entire emission region. Therefore, for the purpose of confinement of excitons in the emission region, the simple mixed device requires the establishment of exciton blocking layers[7,8] on both sides of emission layer, but the insertion of exciton blocking layers gives rise to several disadvantages such as increase of driving voltage, complicated process, and so on. On the other hand, a device with the two stacked double host structure has good confinement of excitons because the recombination of holes and electrons largely occurs around the interface of two host materials located in the central emission region, but it has still a problem that the exciton formation zone should not be wide enough to obtain high luminous efficiency due to the narrow accumulation of holes and electrons at the heterojunction.

In this study, high efficiency green PhOLEDs with the (TCTA/$TCTA_{0.5}TPBI_{0.5}$/TPBi):$Ir(ppy)_3$ emission layer were newly proposed in order to overcome these problems in conventional double host structures. That is, the structures with the intermixed layer of $TCTA_{0.5}TPBI_{0.5}$ between double host materials of TCTA and TPBI were fabricated and their optical and electrical properties were investigated.

2. Experimental Procedure

The substrates with ITO(indium tin oxide) anode of 12Ω/sq on glass were plasma-treated at 200W for 2 minutes with a DC bias of 37 V under 8 mTorr of O_2/Ar(0.5). The plasma treatment before deposition of the first organic layer reduces the energy barrier for hole injection from anode and remove surface contamination. It also improves the adhesion between the ITO and the organic layer. After the substrates were moved from the plasma chamber into the organic chamber, DNTPD[N-N'-diphenyl-N,N'-bis-[4-(phenyl-m-tolyl-amino)-phenyl]-biphenyl-4,4'diamine] with thickness of 500Å and NPB [N,N'-bis(1-naphthyl)-N,N'-diphenyl-1,1'-biphenyl-4,4'-diamine] with thickness of 300Å were successively deposited as

a hole injection layer and a hole transport layer on the ITO electrode, respectively.

In the formation of emission region, TCTA/ $TCTA_{0.5}TPBI_{0.5}$/TPBI host layers doped with 10% $Ir(ppy)_3$ with various thicknesses of TCTA in a range of 20 Å~100 Å on the condition of 90 Å-thick $TCTA_{0.5}TPBI_{0.5}$ and 300 Å-total thickness were prepared to determine the proper thickness combination of host layers. In a meanwhile, the doping variations of $Ir(ppy)_3$ with 3%, 6% and 9% were attempted in the structure of TCTA(80 Å)/ $TCTA_{0.5}TPBI_{0.5}$(90 Å)/TPBI(130 Å).

And then, Balq [bis(2-methyl-8-quinolinolato)(p-phenylphenolato)aluminium(Ⅲ)] and SFC137 [proprietary material coded by SFC co.] were used as a hole blocking layer and an electron transport layer, respectively. Finally, 10 Å-thick LiF and 1200 Å-thick Al were successively deposited as a cathode.

3. Results and discussion

The electrical properties of the devices were investigated using a Polaronix M6100 I-L-V test system (McScience). The optical properties such as luminance, emission spectrum and CIE color coordinates were evaluated using a CS-1000 spectro-radiometer (Konica Minolta) in a dark room.

Figure 1 showed the luminance-voltage characteristics of the devices according to the thickness variation of TCTA in a range of 20 Å~100 Å with the constant thicknesses of $TCTA_{0.5}TPBI_{0.5}$ (90 Å)and total emission region(300 Å). The doping level of $Ir(ppy)_3$ was fixed as 10% for all the devices in Figure 1.

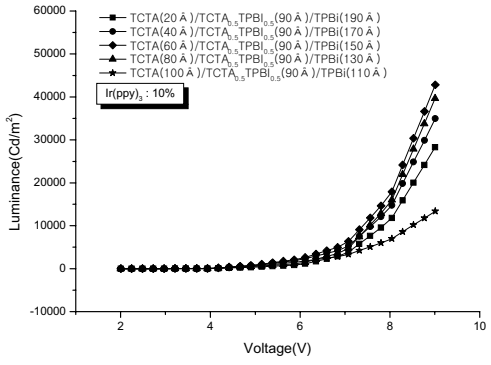

Fig. 1. Luminance–voltage characteristics with different thickness combination of host layers.

Among the experimental devices according to the variation of TCTA thickness, the highest luminance was obtained in the device with emission structure of TCTA(60)/$TCTA_{0.5}TPBI_{0.5}$(90 Å)/TPBI(150 Å) which showed a luminance of 42,800 cd/m^2 at 9V. The luminances of other devices with TCTA thicknesses of 20 Å, 40 Å, 80 Å and 100 Å were 28,300 cd/m^2 34,900 cd/m^2, 39,600 cd/m^2 and 13,400 cd/m^2 at 9V, respectively.

The current efficiency can be calculated by the equation of (L/J) if the current density-voltage and luminance-voltage relationships are known, where L (cd/m^2) and J (A/m^2) are luminance intensity and current density, respectively. Figure 2 showed the current efficiency versus luminance curves of the devices according to the thickness variation of TCTA.

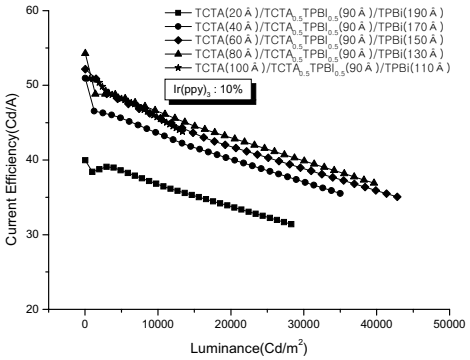

Fig. 2. Current efficiency-luminance curves with different thickness combination of host layers.

Unlike the luminance-voltage characteristics, the best current efficiency-luminance characteristics was obtained in the device with emission structure of TCTA(80)/$TCTA_{0.5}TPBI_{0.5}$(90 Å)/TPBI(130 Å). The current efficiencies of the fabricated devices with TCTA thicknesses of 20 Å, 40 Å, 60 Å, 80 Å and 100 Å were 36.5 cd/A, 43.5 cd/A, 45.7 cd/A, 46.3 cd/A and 45.5 cd/A under a luminance of 10,000 cd/A, respectively. The maximum current efficiency of the device with emission structure of TCTA(80)/$TCTA_{0.5}$ $TPBI_{0.5}$(90 Å)/TPBI(130 Å) was 54.2 cd/A under a luminance of about 50 cd/m^2.

The luminance-voltage characteristics of the devices with host structure of TCTA(80)/$TCTA_{0.5}$ $TPBI_{0.5}$(90 Å)/TPBI(130 Å) were shown in Figure 3 according to the $Ir(ppy)_3$ doping of 3%, 6% and 9%. In Figure 3, the highest luminance was obtained in the device with $Ir(ppy)_3$ doping of 9%. The luminances of the devices with $Ir(ppy)_3$ doping of 3%, 6% and 9%

were 41,500 cd/m^2, 46,600 cd/m^2 and 57,600 cd/m^2 at 9V, respectively.

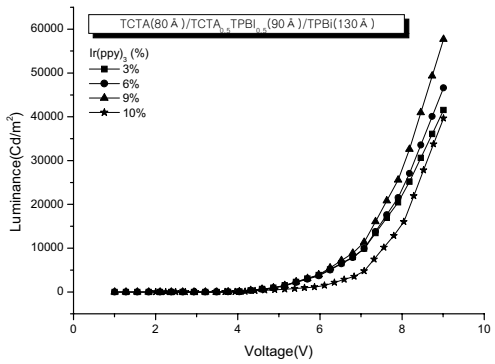

Fig. 3. Luminance versus voltage characteristics according to the doping level of $Ir(ppy)_3$.

Figure 4 showed the current efficiency versus luminance curves of the devices according to the doping variation of $Ir(ppy)_3$. The best current efficiency-luminance characteristics were obtained with almost same curves in a doping range of 6%~10%, showing the maximum value of about 55%. The current efficiencies of the devices with $Ir(ppy)_3$ doping of 3%, 6% and 9% were 44.1 cd/A, 46.8 cd/A and 46.8 cd/A under a luminance of 10,000 cd/A, respectively.

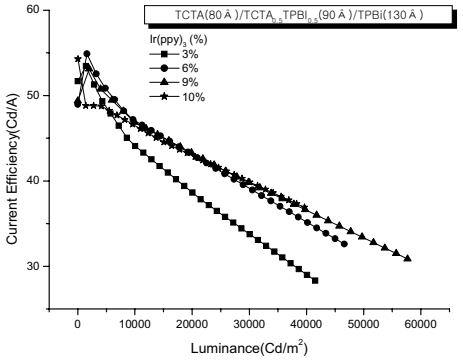

Fig. 4. Current efficiency versus luminance curves according to the doping level of $Ir(ppy)_3$.

Considering the properties of both luminance and current efficiency, the optimum thickness of TCTA in the device with emission structure of TCTA/$TCTA_{0.5}$ $TPBI_{0.5}$/TPBI could be thought to be 60 Å~80 Å on the condition of 90 Å-$TCTA_{0.5}TPBI_{0.5}$ and 300 Å-total layer, and the doping level of $Ir(ppy)_3$ to be 6%~9%. It is believed that the current efficiency of 55 cd/A obtained in our experiments should be one of the highest values ever achieved from the green light PhOLEDs.

The central wavelength and color coordinates measured from the electroluminescent spectra and CIE (Commission Internationale de I'Eclairage) chart were 513nm and (0.31, 0.62), respectively. The electroluminescent spectra and CIE color coordinates of the fabricated devices were almost identical regardless of emission layer treatments.

The good electroluminescent characteristics in this study could be obtained from the appropriate realization of each layer thickness and doping level in the emission structure of (TCTA/$TCTA_{0.5}TPBI_{0.5}$/TPBI):$Ir(ppy)_3$ which can provide effective triplet confinement and sufficient exciton formation space.

4. Summary

We have fabricated and evaluated new green light emitting phosphorescent devices with the emission structure of (TCTA/$TCTA_{0.5}TPBI_{0.5}$/TPBI):$Ir(ppy)_3$. In order to investigate the optimum thickness of each host layer and $Ir(ppy)_3$ doping level in the emission region, the devices with various thicknesses of TCTA in a range of 20 Å~100 Å on the condition of 90 Å-$TCTA_{0.5}TPBI_{0.5}$, 300 Å-total thickness, and 10%-$Ir(ppy)_3$ were firstly prepared. And then, the doping variations of $Ir(ppy)_3$ with 3%, 6% and 9% were attempted in the structure of TCTA(80 Å)/$TCTA_{0.5}$ $TPBI_{0.5}$(90 Å)/TPBI(130 Å).

From the experimental results, we could conclude that the optimum thickness of TCTA in the device with emission structure of TCTA/$TCTA_{0.5}TPBI_{0.5}$/TPBI would be 60 Å~80 Å and the optimum doping level of $Ir(ppy)_3$ would be 6%~9%. The good electroluminescent characteristics in this study may be resulted from the proper treatment of each layer thickness and doping level in the emission region as well as the adoption of new intermixed double host of (TCTA/$TCTA_{0.5}TPBI_{0.5}$/TPBI):$Ir(ppy)_3$ providing the effective triplet confinement and sufficient exciton formation space.

5. Acknowledgments

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6. References

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