

CsN₃ as an air stable and low temperature evaporable novel n doping material for high efficiency and low driving voltage in organic light-emitting diodes

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Abstract

CsN₃ was developed as a novel n doping material with air stability and low deposition temperature. Evaporation temperature of CsN₃ was similar to that of common hole injection material and it worked well as a n dopant in electron transport layer. Driving voltage was lowered and high power efficiency was obtained in green phosphorescent devices by using CsN₃ as a dopant in electron transport layer. It could also be used as a charge generation layer in combination with MoO₃. In addition, n doping mechanism study revealed that CsN₃ is decomposed into Cs and N₂ during evaporation. This is the first work reporting air stable and low temperature evaporable n dopant in organic light-emitting diodes.

1. Introduction

Low driving voltage is important in organic light emitting diodes (OLEDs) to get low power consumption and there have been many studies to reduce driving voltage of OLEDs. The most effective method to reduce driving voltage is to apply p-i-n structure in OLEDs. P doped hole transport layer and n doped electron transport layer can induce ohmic contact between cathode and charge transport layer as well as high mobility.

Representative n doping materials are Li, Cs and Cs₂CO₃ and charge transfer from metal to organic materials such as Bphen and Alq₃ was observed¹⁻². However, all n doping materials are sensitive to moisture and oxygen and deposition process of n doping materials is unstable. In addition, all n doping materials could not be deposited at low temperature and they had to be evaporated at high temperature. Therefore, a new n doping material which is stable in

ambient condition and evaporable at low temperature has to be developed to apply p-i-n structure in real applications.

In this work, CsN₃ was developed as a new n doping material which can be handled in air and deposited at low temperature. Deposition mechanism of CsN₃ was investigated and device performances of CsN₃ doped green phosphorescent devices were compared with those of common devices without n doping. In addition, p-i-n and tandem structure of green phosphorescent device was fabricated by using MoO₃ and CsN₃ doped structure. This may be the first work reporting p-i-n structure which can be fabricated at low deposition temperature.

2. Results

Standard device structure used in this experiment was indium tin oxide(ITO, 150 nm)/N, N'-di(1-naphthyl)-N,N'-diphenylbenzidine(NPB, 10 nm)/4,4',4''-tris(N-carbazolyl)triphenylamine(TCTA, 30 nm)/TCTA: 1,3,5-tris(N-phenylbenzimidazole-2-yl)benzene(TPBI): tris(2-phenylpyridine)iridium(Ir(ppy)₃, 30 nm, 5 % doping)/4,7-diphenyl-1,10-phenanthroline(Bphen, 30 nm)/LiF(1 nm)/Al(200 nm). CsN₃ doped devices used Bphen(10nm)/Bphen:CsN₃(20 nm, 30 %) layer instead of Bphen/LiF layer. Al was directly deposited on Bphen:CsN₃ layer without LiF. MoO₃ doped NPB(30 %) was used as a p-doped layer in p-i-n devices. Device structures used in this work are shown in Figure 1. TCTA was an exciton blocking layer to block exciton diffusion from emitting layer to hole transport layer and Bphen was used both as an electron transport layer and an exciton blocking layer. Mixed host of TCTA:TPBI(50:50) was a host in

emitting layer. Current density-voltage-luminance characteristics of the devices were measured with Keithley 2400 source measurement unit and CS 1000 spectrophotometer. Deposition mechanism of CsN_3 was observed with X-ray photoelectron spectroscopy (XPS).

Cs is well known as a n doping materials and its doping in Bphen has been used as an effective way of n doping in electron transport layer. It has a work function of 2.3 eV and is suitable as a n dopant through electron transfer to Bphen with the lowest unoccupied molecular orbital (LUMO) of 2.8 eV. However, Cs is very reactive and sensitive to moisture and oxygen and its use is limited due to unstable deposition process and high temperature deposition. Therefore, a new stable material which can give n doping effect with electron transport material has to be developed which can be stably evaporated at low temperature. In addition, the n doping material has to be handled in ambient condition without decomposition.

To overcome several problems of Cs doping, a new method to achieve n doping with electron transport materials was developed. Instead of direct deposition of Cs, Cs doping can be achieved by evaporation of material which can liberate Cs during deposition. As a material which can liberate Cs during thermal deposition, CsN_3 was chosen because it is known to decompose into Cs and N_2 by thermal energy. In addition, it is very stable in ambient condition and it can be deposited at low temperature due to low bonding energy of CsN_3 .

Decomposition of CsN_3 has been reported to proceed according to following mechanism³.



Therefore, CsN_3 can be decomposed into Cs and gives off Cs during evaporation. Only Cs would be deposited on substrate during CsN_3 evaporation and it can work as a n dopant. To confirm Cs deposition on substrate, quartz crystal after CsN_3 evaporation was analyzed with XPS. XPS spectrum of CsN_3 deposited quartz crystal is shown in Figure 2. Cs_{3d5} and Cs_{3d5} peaks were observed at 737.6 eV and 723.2 eV, which were assigned to Cs and cesium oxide. If CsN_3 is deposited on quartz crystal without any decomposition, Cs and N_{1s} peaks should be observed in XPS data. However, there was no peak observed in

N_{1s} region around 400 eV. The disappearance of nitrogen peak in XPS indicates that only Cs was deposited on quartz crystal without any CsN_3 . Cesium oxide peak at 723.2 eV is due to partial oxidation of Cs during transfer of Cs coated quartz crystal from evaporation chamber to analysis chamber. Therefore, it can be expected that CsN_3 can have n doping effect through decomposition into Cs during film formation.

CsN_3 n doping material was stable in air and deposition temperature of CsN_3 was quite similar to that of common hole injection material based on aromatic amine. In addition, deposition process was quite stable compared with pure Cs deposition. Therefore, CsN_3 can play the same role as Cs as a n dopant and can be deposited stably at low temperature.

Device performances of Cs doped devices were investigated and current density of green device with CsN_3 doped electron transport layer was compared with common devices without CsN_3 . Figure 3 shows current density of green phosphorescent devices with CsN_3 doped electron transport layer. Current density was greatly improved by doping CsN_3 in electron transport layer and CsN_3 was effective as a n type dopant in organic light emitting diodes. P type doping in hole transport layer further increased the current density of green devices. Power efficiency of CsN_3 doped device was also improved and high power efficiency of 54 lm/W was obtained in p-i-n structure.

Tandem devices of green phosphorescent materials were also fabricated by using Bphen: CsN_3 /MoO₃ as a charge generation layer and efficiency was doubled and power efficiency was also improved. The Bphen: CsN_3 layer was effective as a n doped electron transport layer and it could also be used as a charge generation layer which can be fabricated stably at low processing temperature.

3. Conclusion

This is the first work reporting a novel CsN_3 n doping material which is stable in air and evaporable at low deposition temperature (<400 °C). The deposition temperature was quite similar to that of common organic hole injection material and its performance was comparable to other common n doping materials. This work solved the problem of air sensitivity and high deposition temperature of common n type doping materials.

4. Acknowledgements

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5. References

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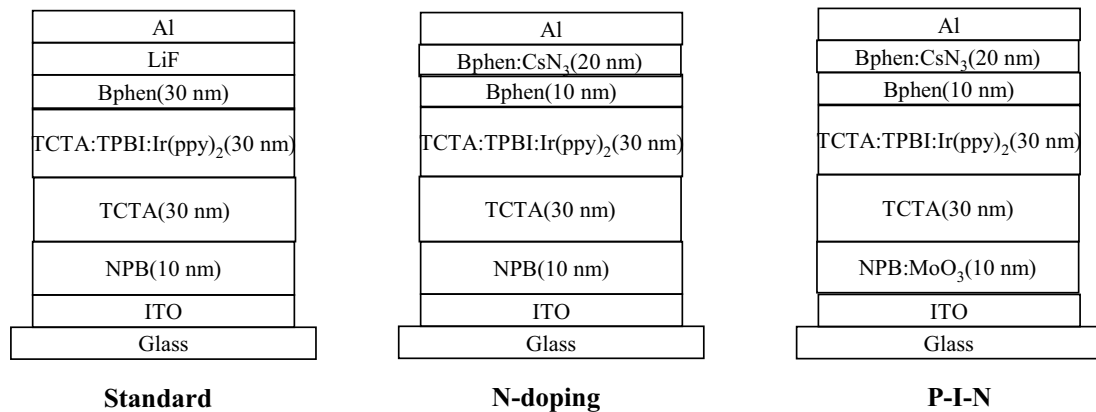


Figure 1. Device structures of CsN₃ doped devices

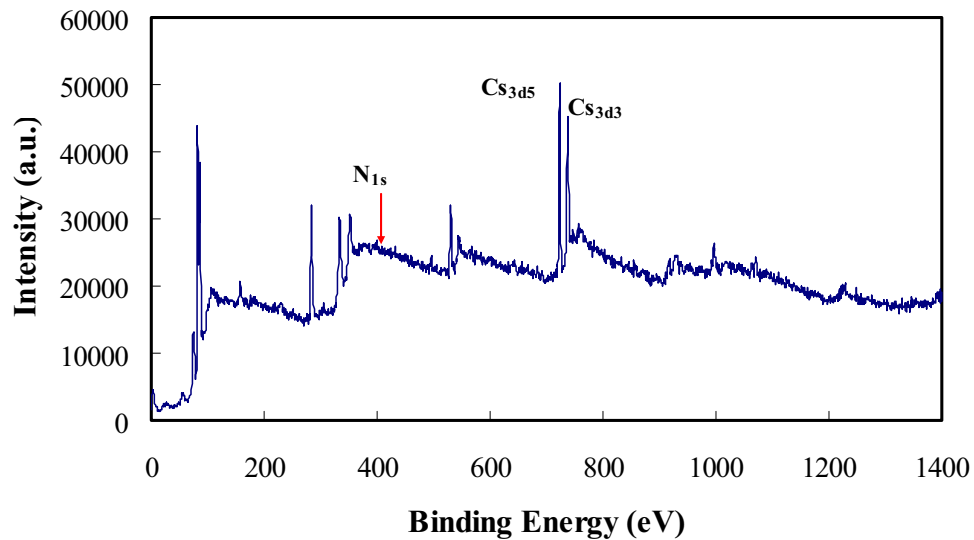


Figure 2. X-ray photoelectron spectroscopy data of CsN₃

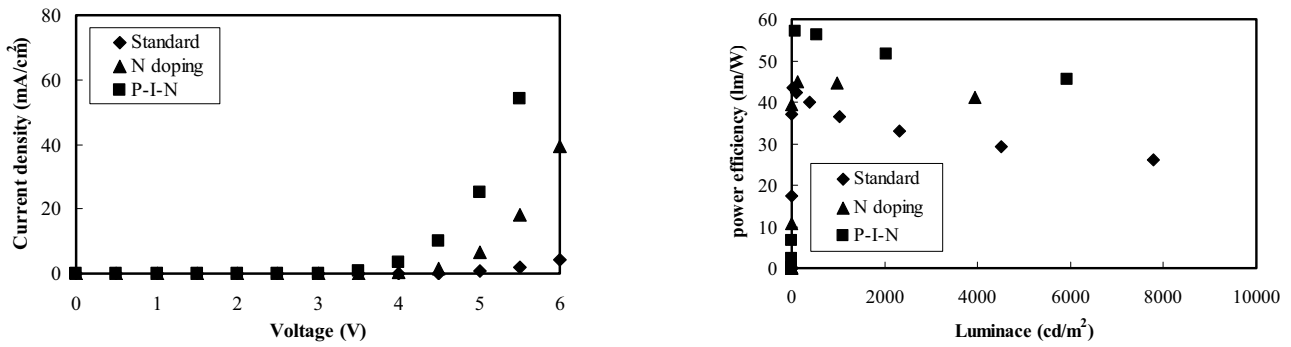


Figure 3. Current density-voltage-luminance curves of CsN₃ doped devices

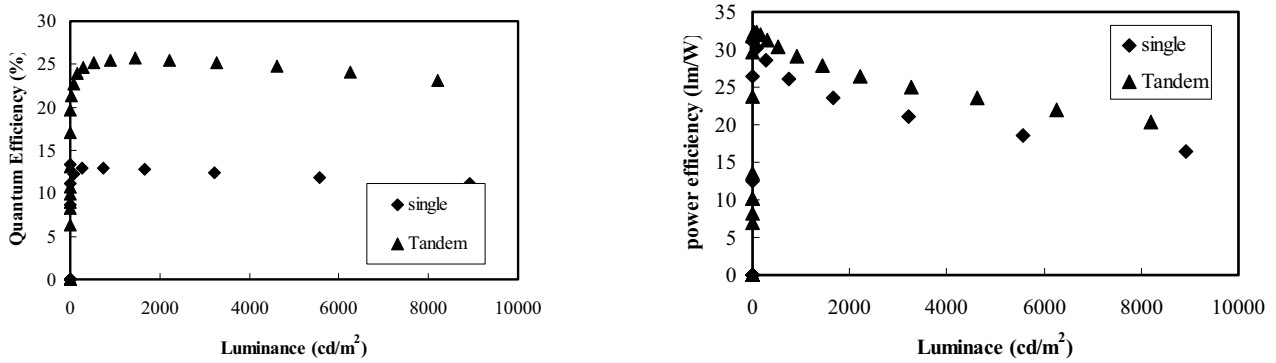


Figure 4. Quantum efficiency and power efficiency of CsN₃ doped tandem devices