

Charge Confinement and Interfacial Engineering of Electrophosphorescent OLED

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Abstract

Confinement of charge carrier and exciton is the essential factor for enhancing the efficiency and stability of the electrophosphorescent devices. The interplay between the properties of emitters and other adjacent layers are studied based on the physical interpretation with difference of energy level, charge carrier mobility, and corresponding charge-trapping behavior.

1. Introduction

Charge-balanced structure of OLED, both for small-molecular and polymeric type, has been essential for stable devices operation and higher efficiency, because device properties are strongly dependent upon the selection and interaction between multilayered organic functional materials. Doping of emissive dyes into the layer of fluorescent or phosphorescent host is most important technique for a color tuning and better device efficiency of OLED. Moreover, doped dyes act also as charge carrier-trapping site that can affect the carrier transport properties within device structure. Therefore, understanding and control of doped OLED structure can be essential for optimization of overall charge carrier balance, improved device efficiency, and lifetime enhancement.

2. Charge confinement structure by direct carrier trapping

Using fluorescent hosts doped with Rubrene, Murata *et al.* showed that emission zone exceeds the range of Förster energy transfer (which is smaller than 5nm) and carrier transport occurs via hopping on the dopant molecules at high concentration [1]. In case of direct charge carrier (electron-hole) recombination at

dopants, it is evident that emission zone is identical with recombination region (at least for fluorescence). However, if the energy transfer from the exciton of triplet host to dopant plays a role in the emission mechanism of doped device, initial electron-hole recombination should start at the interface of emission layer with either hole-transport or electron-transport layer, depending on the charge mobility of host molecule. At the fixed host-dopant combination, effective emission zone of OLED device with electrophosphorescent dopants can be controlled by the change of doping concentration as well as its spatial distribution. Previously, using the 4,4'-N,N'-dicarbazole-biphenyl (CBP) as host and fac-Tris(2-phenylpyridine) iridium(III) (Ir(ppy)₃) and iridium(III) bis(1-phenyl[quinolinato-N,C2']) acetylacetonate (pq₂Ir(acac)) as dopants having graded doping profile, we showed that device efficiencies are strongly dependent upon position of dopant-rich region and types of dopant. Biased (non-centered) recombination zone could be generated in an EML due to the different charge trapping characteristics.[2-3] Such behavior, as a result of shifted emitting zone by the doping-induced hole and electron trapping, was investigated even with the singlet dopants (short-lived exciton lifetime than triplet emitters) having different energy levels.[4]

A design of device architectures for the investigation of charge/exciton confinement, by applying the doping profiles in light emitting layer and exciton blocking layer are illustrated in figure 1, which might provide well-defined analytical interpretation under various environment of operation in the phosphorescent devices. Luminous efficiency and current density behavior was compared and explained by direct recombination and carrier hopping

between dopants, in connection with the change of energy levels for different dopant materials (red and green emitters). Through these approaches, we suggested the practical design schemes and physical interpretation for improving device efficiency and lifetime of both small-molecule, doped phosphorescent OLED.

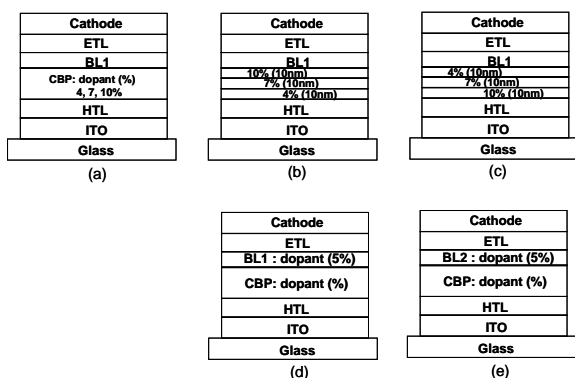


Fig. 1. Configuration of phosphorescent OLED device with stepwise doping profile in emitting layer (a) uniform doping concentration at light emitting layer (CBP) (b) 10nm-thick EML sub-region adjacent to HTL/EML interface was doped with 10%, followed by next 10nm with 7% doping, and 4% at 10nm adjacent to EML/BL interface (c) inversed sequence of stepwise, graded doping concentration, 4%, 7%, and 10% starting from HTL/EML interface. (d,e) describes the devices with doped hole (or exciton) blocking layers.

3. Role of charge confinement in the electrophosphorescent devices

For a study of the effect of charge/exciton confinement on the efficiency and lifetime behavior, phosphorescent green and red-emitting devices with different hole/exciton blocking layers were characterized. Generally, device lifetimes are strongly determined by the materials used. In the general multi-layered organic phosphorescent devices, the role of charge transport and blocking layers is to confine originally formed exciton within the doped emission layer and its interface, so that the pure emission can be maintained at the designed narrow region of multi-layered devices. Figure 2 represents example of blocking layer-dependent light emitting behavior; the power efficiency (lm/W) of devices composed of red [tris[1-phenylisoquinolinato- C_2,N] Iridium(III); Ir(piq)₃, (a)] and green [Ir(ppy)₃, (b)] dopants doped in CBP, with different blocking structures. In case of red device efficiency, highest efficiency was obtained

with BALq as blocking layer. Generally, increase of emission spectrum at around 460nm-centered peak (blue region) could be responsible for such a reduced red efficiency and deviation of color coordinate from pure red emission. Unlike red devices, light emission of green phosphorescent devices using Ir(ppy)₃ dopant were not very sensitive to the difference of blocking layer structure and their energy levels. Figure 2(b) shows the power efficiency of green devices [5]

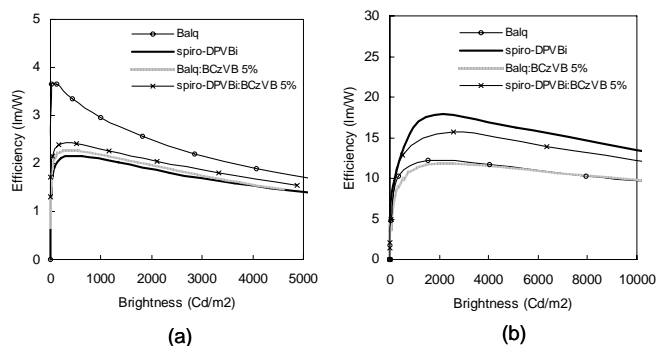


Fig. 2. Power efficiency plotted with luminance for (a) red and (b) green electrophosphorescent device with different charge/exciton blocking material and their doping configuration.

Ir(piq)₃ and Ir(ppy)₃ in CBP matrix are different in their charge-trapping characteristics, and such difference can be a origin of sensitivity of device properties on the charge/exciton blocking behavior. Details of charge-trapping characteristics can be therefore, even more important than the contribution of energy transfer in light emitting mechanism of triplet emitters. Precise results on the charge carrier mobility, exciton diffusion, and their correlation with device properties will be presented in detail.

Furthermore, balanced charge carrier mobility of the light emitting layer is one of the most feasible method to achieve higher efficiency and longer lifetime of phosphorescent OLED. Figure 3 shows the design scheme of double host light emitting layer for better charge/exciton confinement. Although some of the design may not provide the pure color emission of the used dopant due to the possible formation of excimer and interfacial exciplex, use of multiple host materials with different charge mobility and position of energy level in connection with effective blocking layers can significantly improve the light emitting efficiency and stability of phosphorescent devices. Results of feasible studies and route to efficient white device fabrication will be briefly described.

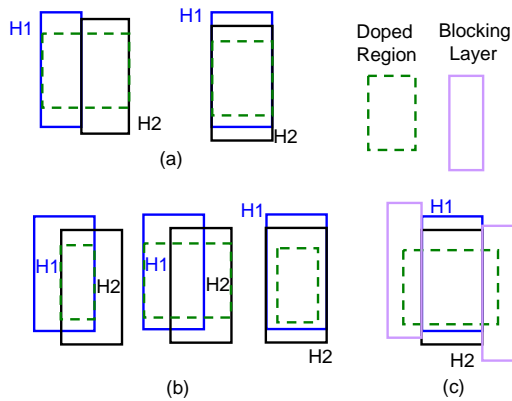


Figure 3. Schematic diagram of light emitting layer composed of double light emitting host. (a) simple bi-layer and mixed heterojunction (b) complicated heterojunction (c) heterojunction with blocking layers.

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4. References

1. Murata, H.; Merritt, C.D.; Kafafi, Z.H. *IEEE J. sel. top. quant. elec.* **4**, 119 (1998)
2. B. D. Chin, M. C. Suh, M.-H. Kim, S. T. Lee, H. D. Kim, H. K. Chung. *Appl. Phys. Lett.* **86**, 133505 (2005)
3. B. D. Chin, S.H.Lee, J.K.Kim, S.T.Lee, *Eurodisplay '05 Technical Digest*, (SID International Sym.) p195 (2005)
4. F. Nüesch, D. Berner, E. Tutis, M. Schaer, C. Ma, X. Wang, B. Zhang, L. Zuppiroli, *Adv. Func. Mater.* **15**, 323 (2005)
5. B. D. Chin and C. Lee. *Adv. Mater.* in press (2007)