

A Stable and Efficient Host Material Having Tetraphenylsilane for Phosphorescent Organic Light Emitting Diodes

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Abstract

A host material containing tetraphenylsilane, 9-(4-triphenylsilyl-(1,1',4,1'')-terphenyl-4''-yl)-9H-carbazole (TSTC), was synthesized for green phosphorescent organic emitting diodes. Ir(ppy)₃ based OLEDs using TSTC host and DTBT (2,4-diphenyl-6-(4'-yl)-1,3,5-triazine) hole blocking layer (HBL) showed the maximum external quantum efficiency of 19.8 %, the power efficiency of 59.4 lm and high operational stability with a half lifetime of 160,000 h at an initial luminance of 100 cd/m²

for green electrophosphorescent devices. The tetraphenylsilane moiety is expected to provide high LUMO level, thermal and chemical stability, and glassy properties,^{3,4} resulting in high efficiency and operational stability of a device. Ir(ppy)₃ based OLEDs employing the new host material and DTBT (2,4-diphenyl-6-(4'-triphenylsilyl-biphenyl-4-yl)-1,3,5-triazine) hole blocking layer (HBL) resulted in the maximum external quantum efficiency (η_{ext}) of 19.8% and the power efficiency (η_{p}) of 59.4 lm/W. High operational stability of $T_{1/2} = 160,000$ h at $L_0 = 100$ cd/m² was achieved using the host and BAq HBL.

1. Introduction

Good host materials in phosphorescent OLEDs should possess higher triplet energy than that of the guest molecule to prevent exothermic energy transfer from the emissive dopant to the host material and good morphological stability to improve the operational stability of the device. Among a number of materials which have been reported as the host for highly efficient green emitting phosphorescent devices, CBP is most common and widely utilized for green-emitting OLEDs, while Ir(ppy)₃ is the most popular dopant. Still, these green phosphorescent OLEDs are unable to achieve the desired high efficiency with high operational stability. Ir(ppy)₃ based OLEDs employing the BCP hole blocking layer result in low stability of half lifetime of <700 h at an initial luminance (L_0) of 600–1200 cd/m².^{1,2}

A new host material containing tetraphenylsilane, 9-(4-triphenylsilyl-(1,1',4,1'')-terphenyl-4''-yl)-9H-carbazole (TSTC) is synthesized and used as a host

2. Experimental

A new host material TSTC was synthesized via Suzuki–Miyamura coupling reaction.⁵

Absorption spectra of solutions were recorded with VARIAN Cary5000 UV–vis spectrophotometer from 250 to 700 nm. Photoluminescence (PL) spectra were measured in a system comprising a He:Cd CW laser (Melles-Griot 45MRS802-230) and a monochromator with a photomultiplier tube (Acton Research P2/PD-471). Phosphorescence spectra at 12 K were measured by using an ICCD camera (Princeton Instruments 7397-0005) with a Nd-YAG laser (Continuum Surelite 11-10) as the excitation source. Excitation laser power was few tens of μJ , which is close to the detection limit of phosphorescence emission. Cyclic voltammetry were carried out with a potentiostat (Princeton Applied Research model VSP) using a three electrode cell assembly comprising a Ag/Ag⁺ as

the reference electrode and Pt as the counter and working electrodes, respectively. Measurements were carried out in N₂-saturated N,N-dimethylformamide (for BCP and DTBT) and dichloromethane (for BAq, CBP, TSTC and Ir(ppy)₃) solution with tetrabutylammonium hexafluorophosphate (0.1 M) as a supporting electrolyte. The potential was calibrated with NPB as a reference. The HOMO level of the BCP and DTBT were obtained from the measurement of the LUMO level and the optical bandgap of the materials, respectively.⁴ Current density–voltage–luminescence characteristics of OLEDs were measured with a Keithley 2400 source meter and SpectraColorimeter PR650.

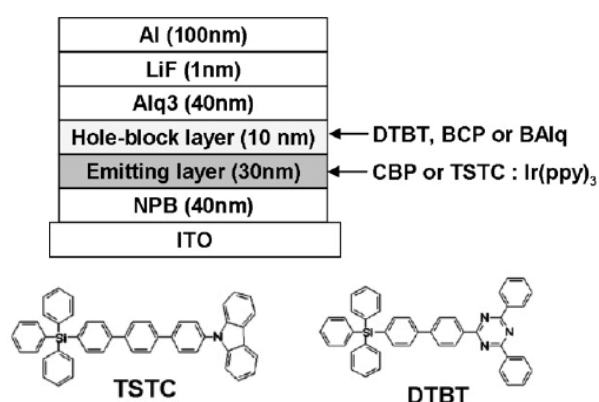


Figure 1. Structure of fabricated device and chemical structure of TSTC and DTBT.

3. Results and discussion

The HOMO level of the material measured by the cyclic voltammetry technique was 6.0 eV, which is almost the same as the CBP. The energy gap of the TSTC film obtained from the absorption edge of the spectra was 3.5 eV, which is higher than that of CBP (3.2 eV). As a result, the LUMO level of the TSTC is higher (0.3 eV) than CBP. It is interesting to note that the TSTC emits fluorescence at longer wavelength than CBP even though the HOMO–LUMO energy gap of TSTC is higher than the CBP film. The triplet energy level (E_T) of TSTC host estimated from the phosphorescence peak was 2.4 eV. The E_T of TSTC host is lower than that of commonly used CBP host ($E_T = 2.56$ eV) and similar to that of green phosphorescent dopant such as Ir(ppy)₃ ($E_T = 2.42$ – 2.46 eV).^{6,7} Even though the triplet energy level of the TSTC host is a little lower than the Ir(ppy)₃ dopant, it does not reduce the light emitting efficiency very much by the energy transfer as will be demonstrated

by high efficiency using the host material.

The maximum η_{ext} and η_p with TSTC host and DTBT HBL are much higher than those of commonly used CBP host and BCP HBL, respectively, as shown in Figure 2(a). When we employ TSTC host and DTBT HBL, the peak η_{ext} and η_p reaches to 19.8%, while the control devices adopting CBP host and BCP HBL showed the peak η_{ext} of 14.5%. The devices with DTBT and BCP hole blocking layers with the same host gave higher efficiency than BAq especially at low current densities, which can be explained by better hole blocking ability of DTBT and BCP coming from the lower HOMO levels than BAq.⁸

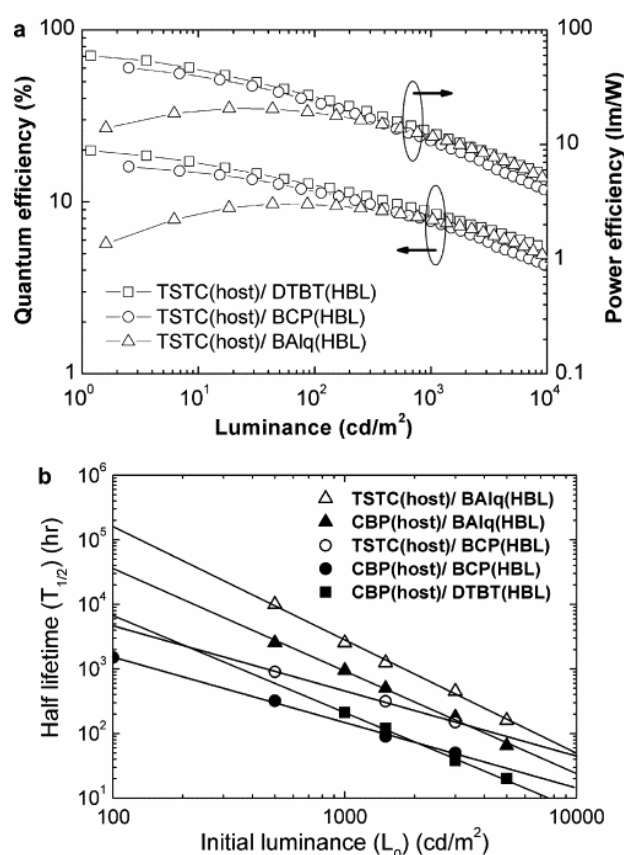


Figure 2. (a) The external quantum efficiency and power efficiency of OLEDs as a function of luminance using 6 wt.% Ir(ppy)₃:TSTC as the emitting layers with three different hole–block layers, respectively. (b) The time for the luminance to decay to half of initial luminance ($T_{1/2}$) vs initial luminance (L_0). Extrapolated lifetime of 160,000 h at 100 cd/m² can be obtained for TSTC(host)/BAq(HBL) based device.

5. References

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The stability of the devices using various HBLs and EML hosts was examined at various luminances of 100–5000 cd/m² under constant currents at room temperature and the results are shown in Figure 2(b). The operational lifetime of the devices differ by more than two orders of magnitude depending on hole blocking and host materials. The devices with the BA1q hole blocking layer gave the longest lifetime among the three HBLs even though the devices with the BCP and DTBT HBLs show higher efficiency than BA1q HBL. The devices using the TSTC host show much longer lifetime than the devices with CBP host if the same HBL is employed for the devices. For instance, the device with the TSTC host and BA1q HBL shows $T_{1/2} \sim 10,000$ h at $L_0 = 500$ cd/m² which is much longer than 2550 h obtained from the device with the CBP host and BA1q HBL. The result is a significant improvement over that reported by Watanabe et al. of $T_{1/2} \sim 4000$ h at $L_0 = 570$ cd/m² for an Ir(ppy)₃ based device.⁶

The half lifetime of phosphorescent OLEDs with the BA1q HBL was estimated to be $T_{1/2} = 160,000$ for TSTC host when extrapolated to $L_0 = 100$ cd/m² using $T_{1/2} \propto (1/L_0)$, which is much longer than 37,000 h for the CBP host.

4. Summary

The tri-phenyl silane moiety in TSTC host improved thermal stability and glassy property resulting in the increase of operational stability. It is interesting to note that the slope in the log $T_{1/2}$ vs log L_0 plot is smaller for the devices with BCP than the devices with other HBLs of DTBT and BA1q₃, where the latter devices give almost the same slope in the figure. Furthermore the devices with the TSTC host give almost five times improvement in the lifetime regardless of the initial luminance and the hole blocking material in the devices. Those observations need more study to understand and are under investigation now. Since the device stability is one of the most serious problems in OLEDs.

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