

## P-76: Efficient and Bright OLED based on Hexaphenylsilole

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### Abstract

OLED devices based on hexaphenylsilole (HPS) have been fabricated. These devices emit very bright greenish-blue light, up to 55,880 cd/m<sup>2</sup> at 16V. Emission starts at 2.6V, and reaches 100-cd/m<sup>2</sup> and 10,790-cd/m<sup>2</sup> at 5V and 10V respectively. The maximum electroluminescence (EL) efficiency and power efficiency are 20-cd/A and 12.8-lm/W, respectively. The maximum external quantum efficiency is 7%.

### 1. Introduction

Organic light-emitting diodes (OLED) are being investigated as alternatives to liquid crystals for realizing flat-panel displays (FPD) [1-2]. Much effort has been devoted to seeking for materials with high efficiency and high brightness. Although the phosphorescent dye is a mean to achieve high efficiency [3], it requires careful selection of host material to maximize the energy transfer from host to guest, i.e. the dye. The precise doping concentration needed complicates the device fabrication process. The dopant effect on device durability is also uncertain. So there is still a demand for OLED materials that can achieve high efficiency without doping. Many materials have been reported, and among which silole is an outstanding example.

The silacyclopentadienes or siloles are a group of Si-containing conjugated rings with novel molecular structures and unique electronic property [4]. Siloles possess low-lying LUMO energy levels associated with the  $\sigma^*-\pi^*$  conjugation arising from the interaction between the  $\sigma^*$  orbital of two exocyclic  $\text{-bonds}$  on the ring silicon and the  $\pi^*$  orbital of the butadiene moiety [5,6]. As a result, siloles can serve as efficient electron-transport materials in OLED devices [7]. The electron mobility of silole derivative has been proved to be  $\sim 100\times$  higher than Alq<sub>3</sub> [8]. The fixation of the labile *cis-cisoid* butadiene structure by the silicon atom gives a fluorene-like planar and rigid ring structure and the unique orbital interactions such as  $\sigma^*-\pi^*$  conjugation lower the LUMO energy levels [13]; 2,3,4,5-Tetraphenylsiloles have been reported as efficient blue emission candidates [9] And the 1,1-substituents on the silicon atom affect the absorption spectra of the siloles in a unique way. In other words, the electronic structures and properties of the siloles can be readily tuned by molecular engineering of the inductive effects of the 1,1-substituents [4]. 1-methyl-1,2,3,4,5-pentaphenylsilole (MPS) has been synthesized and used as emission layer in OLED devices. With optimal device structure, the external quantum efficiency of the MPS-base device is high as 8% [10], which is by far the highest for fluorescent OLED without dopant.

We have reported the interesting results of OLEDs by using one silole derivative of 1-methyl-1,2,3,4,5-pentaphenylsilole (MPS) [10]. In this report we wish to present data showing OLEDs based on another silole derivative, hexaphenylsilole (HPS), can achieve brightness of 55,880 cd/m<sup>2</sup> with a maximum quantum efficiency of

7%. The chemical structure is shown as the inset of Fig. 1. With one more benzene ring than MPS, HPS has stronger  $\pi$ -conjugation and is more stable, which is useful for improve the electron transport mobility, and resulting in better device performance.

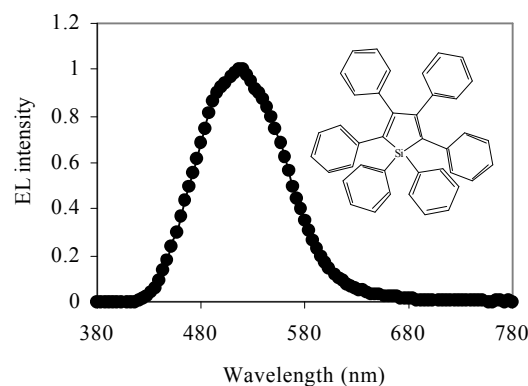


Figure 1. EL spectrum of HPS based OLED, inset is the chemical structure of HPS

### 2. Experimental detail

The OLED devices are fabricated in the usual manner with sequential evaporation of the constituents in a multi-source vacuum chamber. The substrates are indium tin oxide (ITO) glasses with a sheet resistance of 20–30  $\Omega/\square$ . The ITO glass substrates are cleaned by ultrasonic assisted detergent, deionized water sequentially, then drying in oven at 100°C. After 10 minutes of UV ozone cleaning, the glasses are transferred into vacuum chamber for device preparation. *N,N'*-Diphenyl-*N,N'*-bis(3-methylphenyl)-1,1'-biphenyl-4,4'-diamine (TPD) and tris(8-hydroxy-quinoline)aluminium (Alq<sub>3</sub>) were used as the hole- and electron-transport layers respectively in this device. HPS was used for emission layer. Additionally, copper phthalocyanine (CuPc) was used as the anode buffer layer. All the devices consist of the structure ITO/CuPc/TPD/HPS/Alq<sub>3</sub>/LiF-Al. All the chemicals, except for HPS mentioned above, are from Aldrich Company without further purification. Since the HPS has similar chemical structure with MPS [10], the optimal structure acquired with MPS is also used for HPS based OLED, which is 20nm, 50nm and 50 nm for CuPc, TPD, HPS respectively. In the study, the Alq<sub>3</sub> is varied from 0 to 10 nm, with the aim of optimizing the thickness of Alq<sub>3</sub> to get the best device efficiency. The device configuration is shown in Fig. 2.

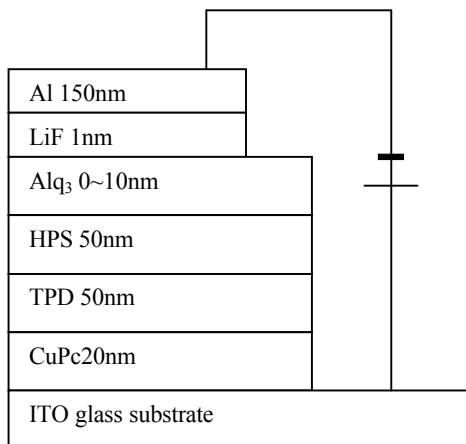


Figure 2. HPS based OLED device configuration

Both the EL and PL spectra are measured by a PR650 photometer. Current and voltages to the device are automatically recorded to give the current-voltage curves and luminance-current density curves, according to which the efficiencies can be calculated. External quantum efficiency is calculated with the output photon flux divided by carrier density passing through the whole device.

### 3. Results and discussions

Fig. 1 shows the EL spectrum of HPS-based OLED. It peaks at 520nm and is shifted to longer wavelength as compared to the HPS PL spectrum, which is at 496nm, as illustrating in Fig. 3. This shift is attributed to the insertion of Alq<sub>3</sub> and a weak micro-cavity effect from the electrodes of the OLED device.

The HPS-based OLED is very sensitive to the Alq<sub>3</sub> thickness in device performance, similar to the result of MPS-based OLED devices. The OLED device efficiencies change with the Alq<sub>3</sub> thickness is plotted in Fig. 4. When no Alq<sub>3</sub> involved, the device efficiency is very low, and the threshold is as high as 6V, resulting in an ultra low power efficiency of 0.12 lm/W. When a ~3nm thick layer of Alq<sub>3</sub> inserted between HPS and cathode, the threshold is dramatically lowered to 2.6V, and the device efficiency is increased to a high value of 12.8 lm/W.

This ~100 times improvement is not due entirely to the lower threshold voltage, but mainly due to the cathode interface modification with Alq<sub>3</sub>. The electron injection is greatly enhanced with a barrier-reducing layer, which in this case is Alq<sub>3</sub>. As mentioned before in the case of our MPS study, Al/LiF/Alq<sub>3</sub> forms an excellent electron injector. The way this composite layer serves to enhance electron injection in particular when Alq<sub>3</sub> is not the emission layer [10]. The trend observed in Fig. 4 in HPS is very similar to the case of MPS. The dependence of EL efficiency on Alq<sub>3</sub> thickness in HPS provides further evidence that the Alq<sub>3</sub>LiF/Al layer is an excellent composite electron injector.

Upon careful examination of Fig. 4, it is seen that the dependence on Alq<sub>3</sub> thickness of HPS-based OLED devices is not as sharp as that of MPS-based OLED. That is also reasonable because HPS has one more benzene-ring, resulting in a stronger  $\pi$ -conjugation. Stronger  $\pi$ -conjugation will cause red shift for both absorption

and PL spectrum of HPS than MPS, as illustrated in Fig. 3. The inter-molecular force between HPS and Alq<sub>3</sub> is also different, implying that the barrier-reducing dipole required for Alq<sub>3</sub> is also different. That is the reason why 7nm is optimal for MPS based OLED device, and only 3nm is thick enough for HPS based OLED devices.

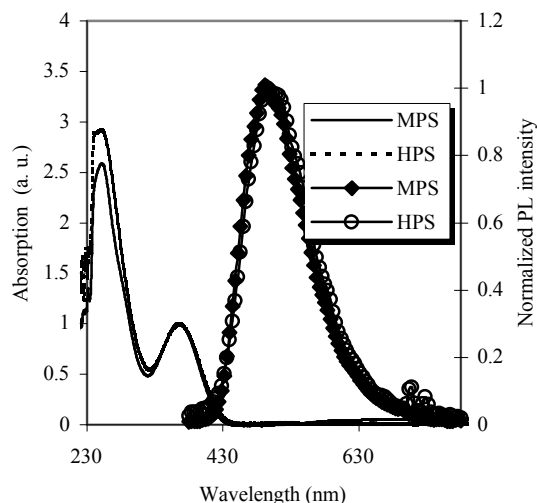


Figure 3. Absorption and PL spectra of HPS in comparison with MPS

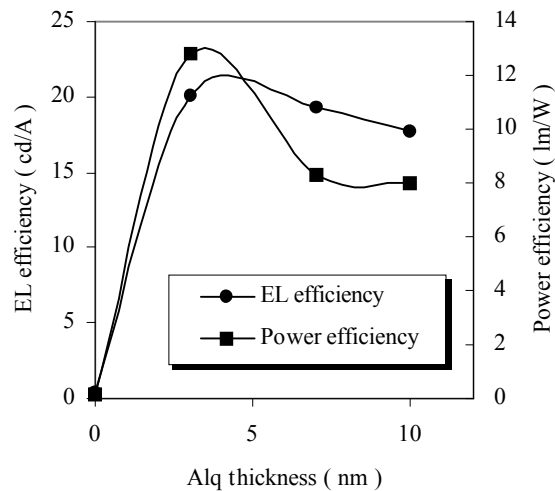
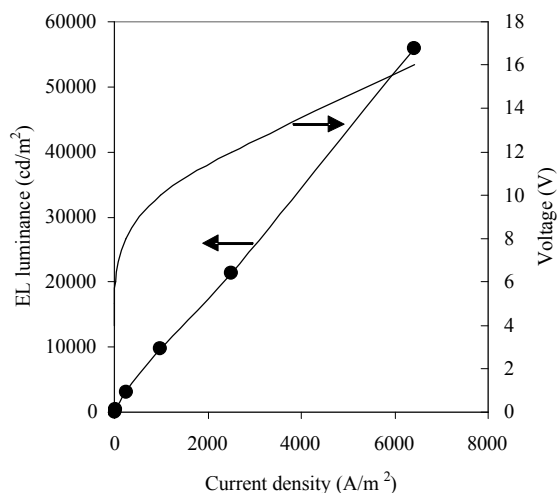


Figure 4. The dependence of EL efficiency and power efficiency of HPS-based device on Alq<sub>3</sub> thickness

Because the silole has ~x100 higher electron mobility than Alq<sub>3</sub> [8], excessive Alq<sub>3</sub> layer, thick than the barrier-reducing required

thickness, will cause additional voltage drop, and increase threshold and decrease the device efficiency as a result. Repeatable experimental results show that the 3nm thick Alq<sub>3</sub> is thick enough to form an efficient electron injector together with LiF and Al, but not too thick to induce additional voltage drop on it.

With the optimal 3nm Alq<sub>3</sub> layer, the device performance is shown in Fig. 5. Both the current-voltage curve and luminance-current density curves are shown. The emission can be detected by unaided eye at 2.6V, and reaches 100cd/m<sup>2</sup> at 5V. The brightness reaches 55,880cd/m<sup>2</sup>, when the voltage is only 16V. The peak power efficiency is 12.8 lm/W, the maximum EL efficiency is 20cd/A, and the peak external quantum efficiency is 7%. This power efficiency is so far the best for dopant free OLED devices, and the external quantum efficiency is also comparable to our former published results of MPS [10]. The brightness is so far the highest for the OLED devices based on silole derivatives.



**Figure 5. The luminance-voltage-current density curve of HPS-based OLED device with optimal structure**

Apparently this improvement on the device brightness is caused by silole derivatives, since all the other layers and device structure are kept the same in both silole based OLED devices. With methyl group replaced by a benzene ring, the  $\pi$  electron conjugation will be stronger, and affects the nature of the emission process. The high brightness also can be attributed to the improved stability of HPS in chemical structure.

The improvement on power efficiency is attributed to the better electron injection with an ultra thin Alq<sub>3</sub>, which serves as electron injector together with LiF and Al. The optimal Alq<sub>3</sub>

thickness difference, 3nm for HPS and 7nm for MPS, might be due to the organic/organic interface between silole and Alq<sub>3</sub>, where the chemical property variation caused by substituent affects the dipole layer formation of Alq<sub>3</sub>. With stronger interaction of HPS and Alq<sub>3</sub>, the required OLED forming dipole layer is thinner than that for MPS-based OLED device. The thinner Alq<sub>3</sub> results in a lower OLED operating voltage and higher power efficiency.

## 4. Conclusion

In conclusion, a new silole derivative, hexaphenylsilole (HPS), was synthesized. Devices with HPS as emission layer were fabricated and characterized. The optimal device emits very bright greenish-blue light, up to 55,880cd/m<sup>2</sup> at 16V. Emission starts at 2.6V, and reaches 100-cd/m<sup>2</sup> and 10,790-cd/m<sup>2</sup> at 5V and 10V respectively. The maximum electroluminescence (EL) efficiency and power efficiency are 20-cd/A and 12.8-lm/W, respectively. The maximum external quantum efficiency is 7%, and maximum measured brightness is 55,880-cd/m<sup>2</sup>. This proves that HPS is a promising material to realize bright and efficient dopant-free OLED device.

## Acknowledgements

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## 5. References

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