

LOCALIZED SURFACE PLASMON RESONANCE ENHANCED EFFICIENCY OF POLYMER LIGHT EMITTING DIODES BY DOPING GOLD NANOPARTICLES

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Abstract: In this work, we aim to use the localized surface plasmon resonance (LSPR) effect of gold nanoparticles (Au NPs) to enhance the efficiency of standard polymer light emitting diodes (PLEDs). In order to improve the efficiency of PLEDs without changing its original structure design, we doped Au NPs into the PEDOT: PSS layer without changing its thickness. For optimizing this improvement, we increase the doping concentration of Au NPs from 5 vol.% to 15 vol.%. The optimal doping concentration was 15 vol.% and 35% efficiency improvement was finally achieved. The enhancement was originated from the LSPR effect of Au NPs, which was evidenced by the result of photoluminescence (PL) measurement.

Index Terms: LSPR, Au NPs, PLEDs, PEDOT: PSS

INTRODUCTION

In recent years, utilizing the LSPR effect of metal nanoparticles to increase the radiative emission rate of organic luminescent material has become a popular approach to improve the efficiency of organic light emitting diodes (OLEDs)^{1,2}. In order to obtain an effective efficiency enhancement, a well coupling between the LSPR spectra and the emission spectra of OLEDs is necessary. The LSPR properties of metal nanoparticles depends on its size, shape, surrounding environment and the metal material. Gold is always used as the material for nanoparticle to enhance OLEDs performance, because the LSPR frequency of Au NPs which is ranging from green to infrared region can match well with the green or red-light OLEDs. Furthermore, gold is hardly to be oxidized, so the Au NPs can maintain its LSPR properties after integrating it into the OLEDs fabrication process or with time pass by. In addition, Au NPs can be existed in a form of colloids by using chemical synthesis method, making it a promising technology to enhance the performance of solution-based polymer OLEDs.

In this work, we will investigate the influence of Au NPs with different concentration in PEDOT: PSS layer on the electrical and optical properties of green light PLEDs. For maintaining the same PEDOT: PSS layer thickness after doping Au NPs, the spin-coating speed for PEDOT: PSS solution doped with different amount of Au NPs colloids is different. Therefore, the electrical and optical differences after doping can be attributed to the effect of Au NPs³.

EXPERIMENT

Before the fabrication process of PLEDs, the PEDOT: PSS solution are mixed with 12 nm-diameter Au NPs

colloids with different concentration (5 vol.%, 10 vol.% and 15 vol.%). The mixed solutions then deposited onto the surface of O₂ plasma treated ITO-glass substrate by spin coating. The spin-coating speed is adapted with the Au nanoparticles concentration variation to maintain a 70 nm-thick PEDOT: PSS hole transport layer. Then the PFO solution was spin-coated onto the PEDOT: PSS layer with a speed of 6800 rpm for 30 seconds as emission layer OLEDs. Next, 1.5 nm-thick lithium fluoride and 100 nm -thick aluminum thin film were thermal deposited onto the emission layer respectively under a base pressure of 10⁻⁷ Torr. The final PLEDs structure was composed of PEDOT: PSS-Au NPs/PFO/LiF/Al multi-layers.

The sample for PL measurement will be doped with higher concentration of Au NPs than PLEDs sample. To achieve higher concentration, 50 vol.% of the solvent of PEDOT: PSS solution was evaporated and the rest of solution was mixed with a high concentration Au colloid in a ratio of 1: 1.

RESULT AND DISCUSSION

The Au NPs can play a role of traps in the hole transport layer and decrease the current density of PLEDs. As shown in Figure 1 (a), the current density of PLEDs without Au NPs at 12 V is 0.578 A/cm² which decreased to 0.488 A/cm² as the concentration of Au NPs increased to 5 vol.%. The current density will further reduce with increasing the doping concentration of Au NPs. The current reduction will be attributed to the trapping effect of Au NPs, which can be evidenced by the leakage current shown in Figure 1 (b). The appeared leakage current when PLEDs at negative bias is originated from the transportation of charges via traps in organic layer, so larger leakage current indicates the exist of higher concentration of traps. Hence, the increase of leakage current with the doping concentration of Au NPs can prove that the Au NPs will trap injected holes in PEDOT: PSS layer. The hole trapping effect of Au NPs in PEDOT: PSS layer is derived from the position of its Fermi level which is between the HOMO and LUMO of PEDOT: PSS⁴. This hole trapping effect may benefit for improving the disbalance of charges transportation in PLEDs and lead to the increase of emission efficiency.

The Au NPs doped in PEDOT: PSS not only influence the electrical properties of PLEDs but also can enhance the emission intensity of PLEDs. As shown in Figure 2 (a), the luminance at 0.5 A/cm² for PLEDs without Au NPs were

19570 cd/m^2 and it will increase to 25850 cd/m^2 as the doping concentration of Au NPs increased to 15 vol. %. The presented 32% emission enhancement was attributed to the coupling between the LSPR of Au NPs and the PFO molecule. As shown in Figure 3 (a), over 90% of the PL spectra of PFO was overlap with the LSPR spectra of Au NPs, so most of the photon emitted by PFO can induce LSPR in Au NPs. The LSPR effect will give rise to a strong electric field around the Au NPs. According to the Fermi's golden rule, this strong electric field can increase the radiative emission rate of PFO⁵. Consequently, the total light emission will be enhanced. This effect can be evidenced by measuring the PL intensity of PLEDs. As shown in Figure 2 (b), the PL intensity of PFO will increase more and more intense with increasing the doping concentration of Au NPs in PEDOT: PSS. When the doping concentration increase to 0.18 mg/ml, 20% PL intensity enhancement can be obtained. This enhancement is not as high as we expected, which is lower than the electroluminescence (EL) enhancement. The reason for this difference is originated from the small range of near field around Au NPs, meaning that only part of the PFO molecule can be affected by the strong near field. Moreover, the Au NPs doped in PEDOT: PSS is randomly dispersed, so only part of the Au NPs will be emerged in the interface of PEDOT: PSS and PFO. This assumption can be observed in Figure 4 where the roughness of PEDOT: PSS increase with doping concentration. Therefore, not all of the EL enhancement comes from the LSPR effect of Au NPs. Part of the EL enhancement can come from the improvement of charges transportation imbalance. As a result, 35% emission efficiency enhancement can be finally achieved.

CONCLUSION

In summary, 12-nm-diameter Au NPs were dispersed in

PEDOT: PSS by doping different concentration (5 vol. %, 10 vol. % and 15 vol. %). By tuning rotation speed of spin-coating, the PEDOT: PSS-Au NPs hybrid film with same thickness can be formed. It is found that the electric property of the hybrid film is a little worse than the pure PEDOT: PSS film, but 32% of luminance enhancement and 35% of efficiency enhancement still can be achieved. According to the PL measurement, this efficiency enhancement is attributed to the LSPR effect and hole trapping effect of Au NPs.

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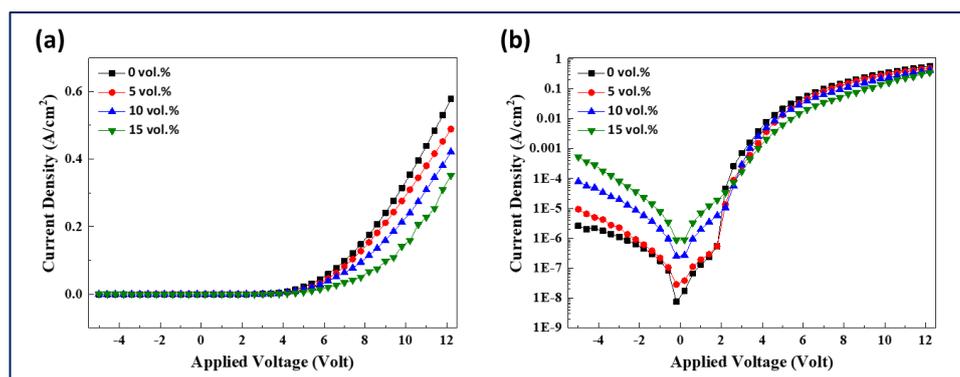


Figure 1. (a) Linear current density and (b) semi-log current density as a function of voltage for PLEDs with different concentrations of Au NPs doped in PEDOT: PSS layer.

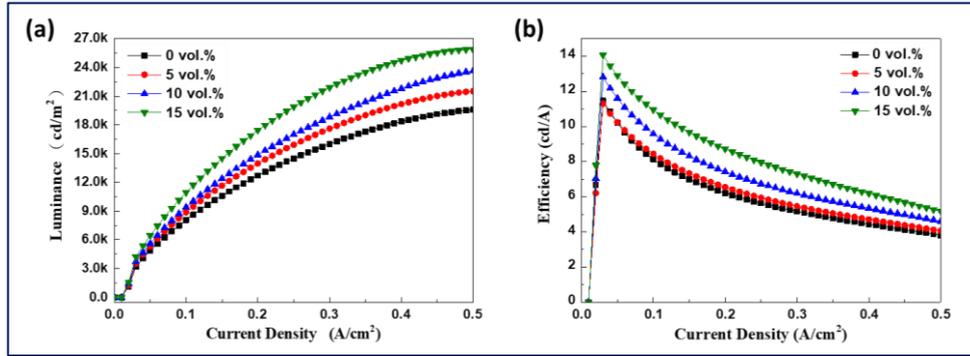


Figure 2. (a) Luminance versus current density curves and (b) the efficiency versus current density curves for the PLEDs with different Au NPs concentrations in PEDOT: PSS layer.

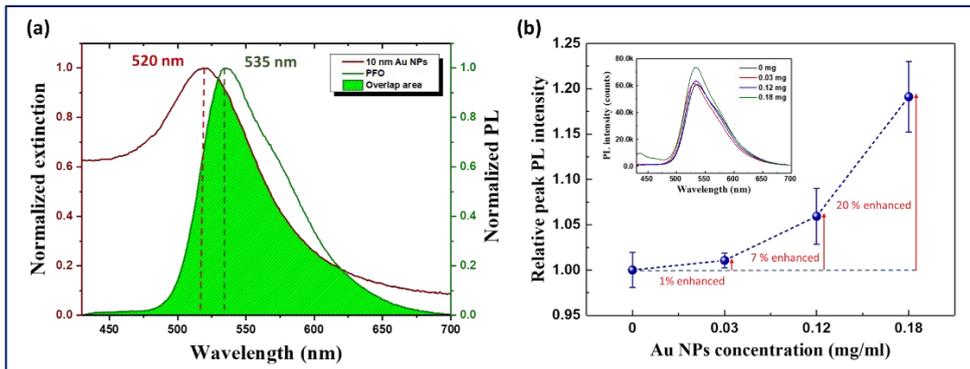


Figure 3. (a) Normalized extinction spectra of Au NPs and PL spectra of PFO; (b) the average peak PL intensity distribution for sample with different Au NPs concentration in PEDOT: PSS.

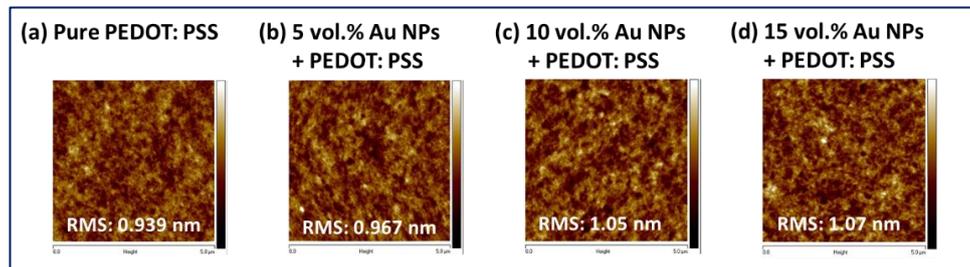


Figure 4. AFM surface morphology of PEDOT: PSS (a) without of Au NPs and (b) with 5 vol.%, (c) 10 vol.% and (d) 15 vol.% Au NPs.