Positioning of nano-sized noble metal aerosols in an organic light-emitting diode for enhanced quantum efficiency

H.-K Sung[1], J.-C. Lee[2], J.-K. Lee[1], C. Kim[2], and M. Choi[1]

[1]Global Frontier Center for Multiscale Energy Systems, School of Mechanical and Aerospace Engineering, Seoul National University, 151-744, Korea
[2]Program in Nano Science and Technology, Graduate School of Convergence Science and Technology, Seoul National University, Seoul 151-742, Republic of Korea
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Presenting author email: hksung@snu.ac.kr

We report a method of incorporating aerosol gold nanoparticles (Au NPs) into an organic layer without any damage to the surrounding organic materials and its application to fabricating an Au NP-embedded organic light-emitting diode (OLED) for enhanced external quantum efficiency (EQE).

An Au NP layer has been successfully incorporated in the middle of organic layer by means of aerosol method adopting a dry and low-temperature process. This has enabled us to investigate the influence of the position of an Au NP layer on the performance of a fluorescence OLED. Here, four distances (d = 10, 20, 30 and 40 nm) of the Au NP layer away from the emissive layer were tested.

The structure of the Au NP-embedded OLED was ITO/NPB (50 − d nm)/Au NPs/NPB (d nm)/Alq3 (50 nm)/LiF (0.5 nm)/Al (100 nm). To fabricate the Au NP-embedded OLEDs, substrates were moved between a vacuum thermal evaporator and a homemade electrostatic precipitator (ESP) installed inside a nitrogen (N_2) glovebox. The ESP was connected to a homemade spark discharge generator (SDG) so that Au NPs generated by the SDG were led to the ESP by a N_2 carrier gas and collected on the substrate on which an organic layer was previously deposited by vacuum thermal evaporation (VTE). We adopted pin-to-plate configuration for the SDG (Han, 2012), and the geometric mean diameter and the geometric standard deviation of the Au NPs were measured as 6.0 nm and 1.43, respectively. The surface coverage density of the Au NP layer was found to be 1900 particles per μm^2 on average. In addition, for comparison, various Au NP layers were fabricated with a conventional vacuum thermal evaporation method at d = 20 nm by changing the deposition rate and thickness.

Figure 1 shows that the Au NP layers were formed well inside the NPB layers by either the SDG-ESP or VTE. However, a few Au NPs were observed to penetrate into the bottom organic layer when VTE was used, which was not observed when the SDG-ESP was used.

Figure 2 shows the external quantum efficiency-current density (*EQE-J*) characteristics. It is noted that all the Au NP-embedded OLEDs fabricated by VTE exhibited poor EQE compared to the reference device, while those by the SDG-ESP showed larger EQE than the reference device. Interestingly, the EQE was enhanced most when the Au NP layer was located at d = 20 nm (increased 37 %) among the Au NP-embedded OLEDs fabricated by the SDG-ESP. It was attributed to hole trapping into the Au NPs. According to the position of the positively charged Au NPs due to the trapped holes, the charge balance and the exciton formation rate improved competitively, and, consequently, the EQE was maximized for the device with d = 20 nm.

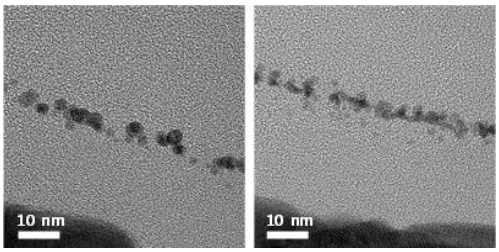

Figure 1. Cross-sectional TEM images of the OLEDs incorporating the Au NPs fabricated using the SDG-ESP (left) and VTE (right).

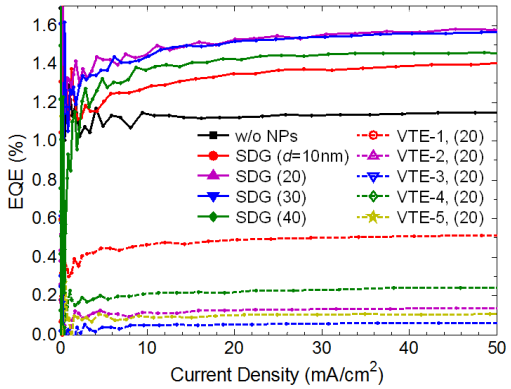

Figure 2. *EQE-J* characteristics of the OLEDs without Au NPs, with the Au NP layer fabricated using the SDG-ESP with different values of d, and with the Au NP layer introduced at d = 20 nm fabricated using VTE with different deposition rates and thicknesses.

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