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Surface plasmon-enhanced localized electric field in organic light-emitting diodes by incorporating silver nanoclusters

Ying-Chung Chen [a], Chia-Yuan Gao [a], Kan-Lin Chen [b], Chien-Jung Huang [c,*]

[a] Department of Electrical Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan
[b] Department of Electronic Engineering, Fortune Institute of Technology, Kaohsiung, Taiwan
[c] Department of Applied Physics, National University of Kaohsiung, Kaohsiung, Taiwan

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ABSTRACT

The influence of silver nanoclusters (SNCs) on the performance of organic light-emitting diodes is investigated in this study. The SNCs are introduced between the electron-injection layer and cathode alumina by means of thermal evaporation, resulting that different absorption peaks of SNCs were formed. A higher luminance and electron-injection ability are obtained when the mean cluster size is 34 nm. The surface-enhanced Raman scattering spectroscopy reveals that the localized electric field around the SNCs is enhanced, resulting in an increase in electron injection from cathode electrode.

1. Introduction

Organic light-emitting diode (OLED) has displayed significant potentiality in the application of lighting and display, which is mainly because of its low power consumption. So far, the efficiency of device is not optimal, so many researchers are still trying to improve the efficiency of device by different means, e.g., doping phosphorescence material into the emitting layer [1,2], blocking hole with hole-blocking layer [3–6], or improving the hole/electron balance by increasing electron injection [7–9], which is to improve the efficiency of device. The efficiency of OLED can be improved, but these methods increased the complexity of device structure which increased the fabrication time and cost of device.

Recently, it has drawn a lot of attention that the surface plasmon resonance effect (SPRE) of metal nanocluster is applied to OLED which is mainly because of surface plasmon-enhanced luminescence of OLED being enhanced. In recent reports on both organic and inorganic light-emitting diodes, the coupling process between surface plasmons and radiated light is rapider than spontaneous recombination of excitons [10,11]. Therefore, the exciton lifetime in surface plasmon resonance (SPR) devices is considerably reduced. Furthermore, spontaneous emission rate of exciton is inversely proportional to the exciton lifetime [12]. In other words, emission efficiency is increased with the subtraction in the exciton lifetime. Besides, a thin silver layer was incorporated as an interlayer between the electron-transport layer and the electrode which can improve the efficiency of OLEDs [13]. However, the cause of improving the efficiency has not yet been studied in detail. In this article, the silver nanoclusters (SNCs) were introduced between electron-injection layer (EIL) and cathode, and it was also observed that how SPR wavelength of different mean cluster sizes of SNCs influenced for the enhancement of device efficiency. In addition, a different viewpoint in surface plasmon-enhanced luminescence by a theory of surface-enhanced Raman scattering (SERS) is presented.

2. Experimental

The schematic structure of OLEDs is shown in Fig. 1. Indium tin oxide (ITO) coated on glass with a sheet resistance of 10 Ω/sq was used as the starting substrate. The substrate was cleaned with acetone, methanol and deionized water, and then dried with nitrogen gas. After cleaning process, the substrates were loaded into a thermal evaporator. Afterward, N,N′-bis-(1-naphthyl)-N,N-dipheny1,1′- bipheny1 -4-diamine (NPB; 35 nm), tris-(8-hydroxyquinoline) aluminum (Alq_3; 40 nm), 4, 7-dipheny1-1, 10-phenanthroline (BPhen; 10 nm), lithium fluoride (LiF; 0.5 nm), SNCs (× nm) and aluminum (Al; 100 nm) were deposited. NPB and BPhen were used as the hole and electron transporting layers, respectively. Alq_3 was used as emitting layer. LiF, Al and ITO were used as EIL, cathode and anode, respectively. To obtain the absorption peak of SNCs being the closest to the photoluminescence (PL) peak of Alq_3, the mean cluster size of the SNCs was

* Corresponding author. Tel.: +886 7 5919475; fax: +886 7 5919357.
E-mail address: chien@nuk.edu.tw (C.-J. Huang).

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changed from 15 to 43 nm. Furthermore, the different mean cluster sizes of SNCs were deposited on top of glass substrate in order to measure SERS. During the deposition, the base pressure of the chamber was maintained as low as 2.4×10^{-6} Torr. The active area of the device was $6 \times 6\,mm^2$. The deposition rates of all organic materials were maintained at 0.01 nm/s, except for the Al that deposition rate was 0.5 nm/s. In addition, the SNCs were fabricated by thermal evaporation of silver slug. The deposition rate of SNCs is 0.01 nm/s. Besides, the different mean cluster sizes of SNCs are obtained by different deposition time. The deposition time for the mean particle sizes of 15, 24, 34, 43 nm is 100, 200, 300, and 400 s, respectively. The thickness of the layers is controlled by using a quartz–crystal monitor. The current density–voltage (J–V) characteristics and luminance–voltage (L–V) of the devices were measured by using a Keithley 2400 (Keithley instruments Inc, USA) and a PR-655 (Photo Research Inc, USA), respectively. The SERS and absorption spectrum were measured by using a BWII RAMaker

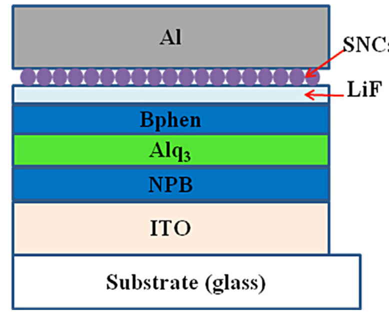

Fig. 1. Schematic device structure of the OLED with SNCs.

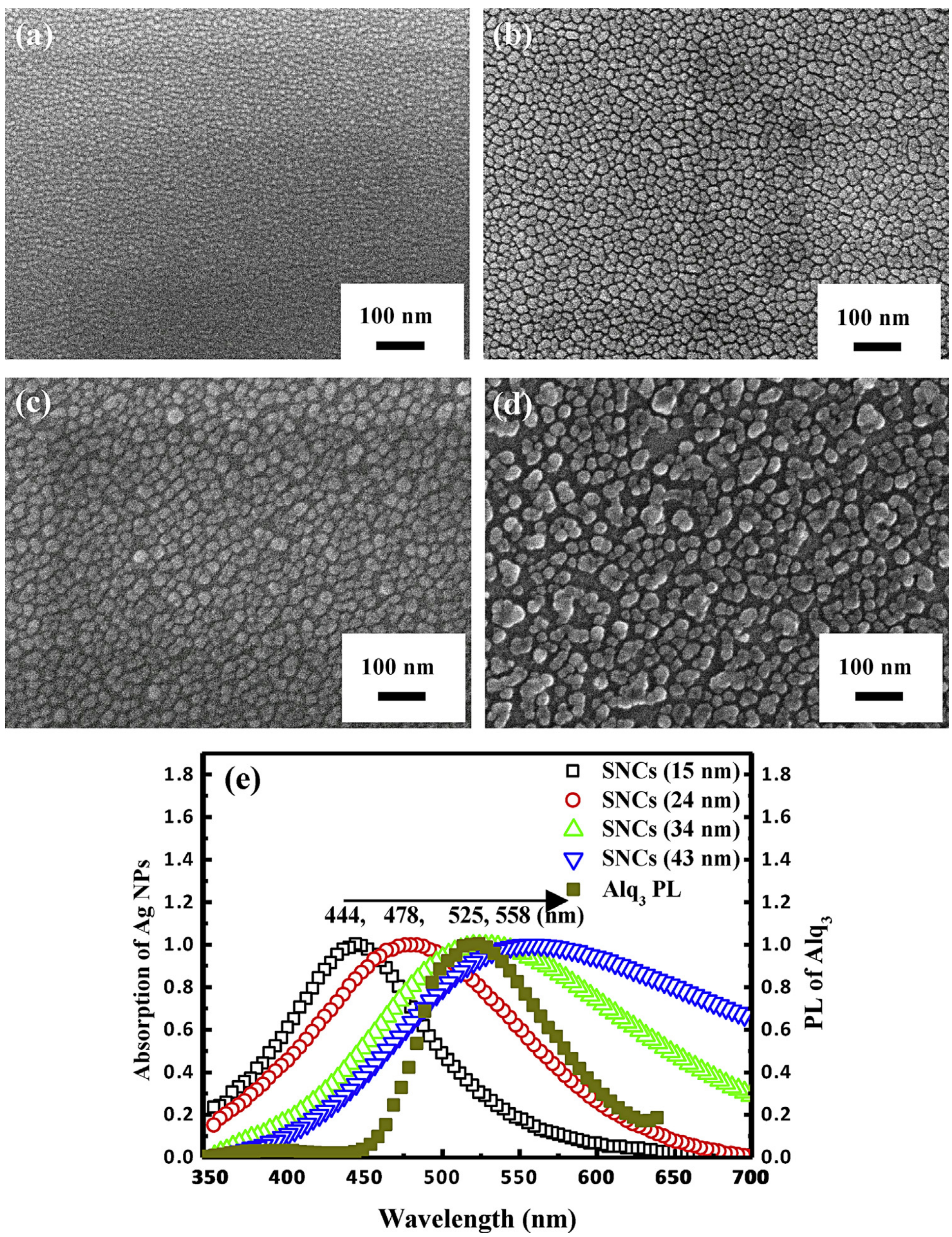

Fig. 2. The SEM images of SNCs at (a) 15 nm, (b) 24 nm, (c) 34 nm, and (d) 43 nm. (e) Normalized absorption spectra of the SNCs with different mean cluster sizes and PL spectrum of the Alq_3.