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Polymeric Optical Devices with Printable and Flexible Electrode

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Abstract

Flexible light-emitting devices have been developed utilizing polymeric materials by solution process. Fluorene-type polymer and silver nano materials were used as light-emitting and electrode materials, respectively. Inserting thin layer between electrode and semiconducting layer drastically improves carrier injection resulting into improved light-emitting efficiency. All solution processed light-emitting diodes and transistors have been developed by solution process.

1. Introduction

Organic semiconductors have attracted considerable attention due to their simple fabrication process, as well as their potential applications for electronic and optoelectronic devices. In particular, optoelectronic devices fabricated by solution processing have been demonstrated for large area and flexible devices. Recently, organic light-emitting diodes (OLEDs) and organic light-emitting transistors (OLETs) have been extensively studied in view of their applications in low-cost, large-area, flexible electronics. OLETs are multifunctional devices that combine the light emission from an OLED with the switching properties of a field-effect transistor in single device architecture.

Poly(alkylfluorene), one of the liquid-crystalline semiconducting polymers, exhibits blue emission and various unique aspects. Since fluorene-type polymers have efficient light emission, relatively high mobility, and ambipolar conduction [1], they can be used as light-emitting material in light-emitting diodes and transistors. Polymer light-emitting diodes have been fabricated utilizing silver nano-ink electrode by solution process [2].

Indium-tin-oxide (ITO) is often used as transparent electrode material, however, it contains rare earth material and it suffers gradual destruction of successive impact. For flexible electrode with flexible and durable bending and twisting operation, silver-nanowire (AgNW) transparent conductive film was employed as alternate transparent electrode. AgNW electrode was tested as source and drain electrode of OLETs [3].

2. OLEDs with Silver Nano-ink Electrode

Light-emitting diodes have been fabricated utilizing a fluorene-type block copolymer, poly(9,9-dioctyl fluorene-co-benzothiadiazole) (F8BT) as light-emitting material supplied by Sumitomo Chemical Co., Ltd. A conjugated polymer, poly(9,9-dioctyl fluorene-co-*N*-(4-butylphenyl)-diphenylamine) (TFB) and a conjugated polyelectrolyte, poly[(9,9-di(3,3'-*N,N*'-trimethylammonium) propylfluorenyl-2,7-diyl)-alt-co-(9,9-dioctylfluorenyl-2,7-diyl)] diiodide salt (PFN) have been tested as buffer layer to the emissive layer.

In this study, the incorporation of a Cs_2CO_3: conjugated polyelectrolyte blended interfacial layer between silver (Ag) cathode and the emissive layer have been tested in order to realize all-solution processed polymer light-emitting diodes. Schematic of device structure tested in the experiment is shown in Fig 1.

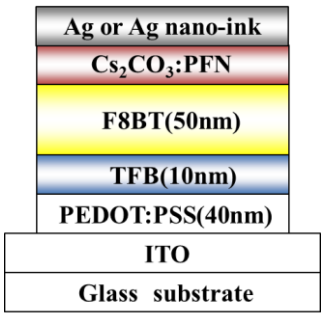


Fig. 1 Schematic of light emitting diode with silver (Ag) electrodes.

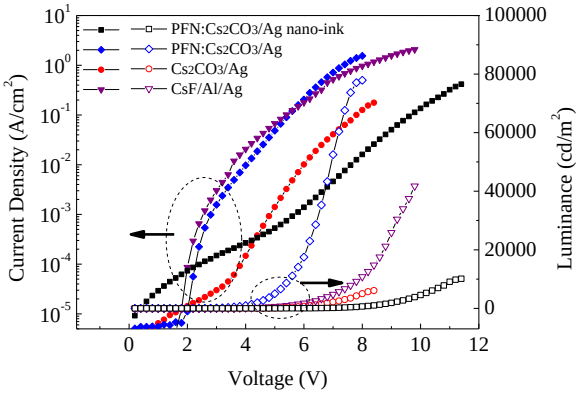


Fig. 2 Current density-voltage-luminance characteristics of OLEDs with various cathode structures.

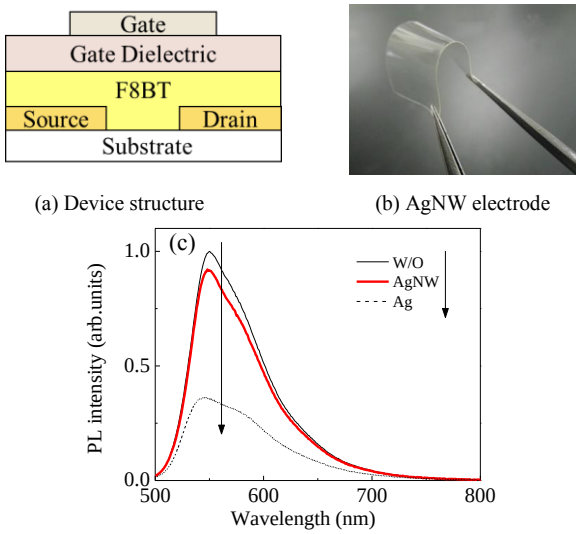
Various buffer layers inserted between Ag electrode and organic layer have been tested as shown in Fig. 2. Using 2-ethoxyethanol as the main solvent, Cs_2CO_3 and Cs_2CO_3:PFN were formed as buffer layers by spin-coating on the F8BT layer. An ultrathin Cs_2CO_3 layer was spin-coated from a 0.5 mg/ml 2-ethoxyethanol solution. The Cs_2CO_3:PFN layer was obtained using Cs_2CO_3:PFN solutions in a 2:1 weight ratio. The typical thickness of Cs_2CO_3:PFN layer was10 nm.

The devices with Cs_2CO_3/Ag and CsF/Al exhibited the maximum luminance of approximately 6,000 and 40,000 cd/m^2. This approach improves the maximum luminance of

approximately 80,000 cd/m^2 with maximum current efficiency of 10.6 cd/A, and 10,000 cd/m^2 with maximum current efficiency of 3.9 cd/A for the devices with vacuum deposited Ag and Ag nano-ink cathode, respectively. It is clarified that the buffer layer prevents Ag nanoparticles from penetrating into the emissive layer, resulting in yellow–green emission from F8BT. We also demonstrate the possibility of all-solution processed polymer light-emitting diodes utilizing solution-processed Cs_2CO_3:conjugated polyelectrolyte buffer layer and Ag nano-ink.

3. OLETs with AgNW Electrodes

In order to realize light-emitting devices with flexible, durable bending and twisting operation, OLETs with AgNW electrodes coated on polyester film have been fabricated and tested. Schematic of device structure and AgNW electrode on plastic film are shown in Fig. 3(a) (b).



(a) Device structure (b) AgNW electrode

(c) PL spectra of F8BT films

Fig. 3 (a) Device structure of an OLET with AgNW source/drain electrodes. (b) Optical micrograph of patterned AgNW. (c) PL spectra F8BT films fabricated on quartz glass, AgNW-coated film and Ag-coated quartz glass substrates.

Fluorene-type block copolymer F8BT and poly(methyl methacrylate) (PMMA) were used as an active layer and a gate dielectric, respectively. The polymeric layers were spin coated onto a patterned AgNW as source and drain electrodes. The channel length and width are 0.15 and 2 mm, respectively.

AgNW electrode has transparency of more than 90 % in the visible region, which is comparable to the ITO electrode. AgNW electrode has more durable bending and twisting operation under successive impact operation compared with ITO electrode. Photoluminescence (PL) intensity from an F8BT film formed on quartz substrate, AgNW coated polymer film and Ag-coated quartz substrates were compared. The PL intensity and PLQY of the F8BT film fabricated on the AgNW coated film were almost the same as those on the quartz substrates and even higher than those on Ag-coated substrates as shown in Fig. 3(c). This suggested that the suppression of PL quenching does not originate in the material properties of Ag but rather in the nano sized structure of AgNW with a geometric aperture.

Ambipolar characteristics were obtained from an OLET with AgNW source/drain electrodes. For a device with AgNW, yellow-green emission was observed as shown in Fig. 4. The emission site depended on the applied gate voltage. For the electron enhancement mode, OLETs fabricated in this study emitted light close to the source electrode at the lower gate voltage because holes were injected from the drain electrode and hole current dominated. As the gate voltage was increased, the electron injection was accelerated and then the emission site moved from source to drain side in the channel region. At the higher gate voltage, the channel was dominated by electrons and light is emitted close to the drain electrode. The maximum value of light emission occurred close to electrodes. It is found that reducing exciton quenching near the AgNW source/drain electrodes leads to light emission at the lower and higher gate voltages. Utilizing AgNW electrode, flexible, light-emitting devices with durable bending and twisting operation under successive impact operation are obtained.

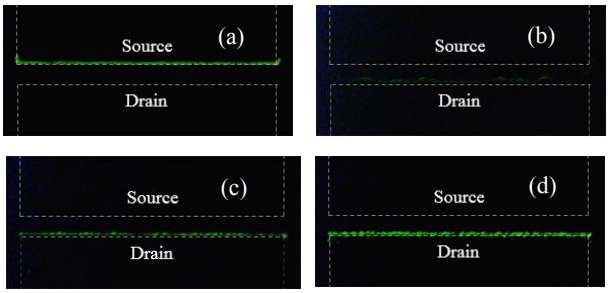


Fig. 4 Optical images of the light emission for different gate voltage of (a) 0 V, (b) 60 V, (c) 90 V and (d) 150 V for OLET with AgNW. .

4. Summaries

Fabrication and characteristics of polymeric light-emitting devices with Ag nano-ink and AgNW have been discussed. The results show that light-emitting diodes and light-emitting transistors with poly(alkylfluorene) derivatives can be applicable to flexible and printable devices.

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