The effect of oxygen doping on organic light emitting diodes by oxygen plasma treatment

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Abstract

By the oxygen plasma exposure to the organic light-emitting diodes, the turn-on voltage decreased from 10.5 to 7 V and luminance increased from 470 to 852 cd/m^2. Synchrotron radiation photoelectron spectroscopy results showed that during oxygen plasma exposure, oxygen ions were diffused into organic layer and induced *p*-type doping effect.

1. Objectives and Background

Copper phthalocyanine (CuPc) represent an interesting organic semiconductor suitable for the fabrication of photodetectors, solar cells, gas sensors and organic light emitting diodes (OLEDs).[1]-[3] Although the interaction of oxygen with CuPc is an important phenomenon occurring in organic semiconductor electronic devices, still little is known about charge transfer between CuPc and an oxygen molecule.

In this work, we report the enhancement of electroluminescent property of OLEDs by using oxygen doping into CuPc by O_2 plasma exposure. Synchrotron radiation photoemission spectroscopy (SRPES) and ultraviolet photoemission spectroscopy were used to examine the doping effect of oxygen plasma exposure on CuPc.

2. Results

Glass was used as the starting substrate. As a cathode, Al was deposited on the substrate. The sample was loaded into a thermal evaporator and tris(8-hydroxyquinoline)aluminum, 4,4'-Bis[N-(1-naphthyl)-N-phenylamino]biphenyl, and CuPc were deposited in sequence. Finally, 30-nm-thick Au film was chosen as an anode. Then, the fabricated OLED was exposed to O_2 plasma with a power of 25 W under 100 mTorr to dope oxygen into CuPc layer. The exposing time of O_2 plasma was 0, 1, 3, and 5 s. The current density-voltage and luminance-current density characteristics of the devices were measured.

Device	S1	S2	S3	S4
Operation voltage @ 100 mA/cm^2	15.5 V	14.3 V	10.0 V	9.5 V
Luminance @ 150 mA/cm^2	375 cd/m^2	398 cd/m^2	596 cd/m^2	680 cd/m^2

Table 1. Current density-voltage and luminance-current density characteristics of OLEDs as a function of the oxygen plasma exposure time.

Table 1 show the current density-voltage and current density-luminance characteristics of the four types of devices. S1 refers to the as-deposited OLEDs. S2, S3, and S4 are the OLEDs exposed to oxygen plasma for 1, 3, and 5 s. For the untreated device (S1), the operation voltage at a current density of 100 mA/cm^2 was 15.5 V. It decreased to 9.5 V when the device was treated with O_2 plasma for 5 s (S4). The luminance value also increased with O_2 plasma treatment.

The Figure 1(a) and (b) showed the SRPES core level spectra (C 1*s,* O 1*s*) spectra of CuPc surface of S1 and S4 samples. The charge transferred from oxygen ion to the CuPc molecule during oxygen plasma treatment. In particular, charge transfer influences mainly the pyrrolic rings and center of the CuPc molecule.

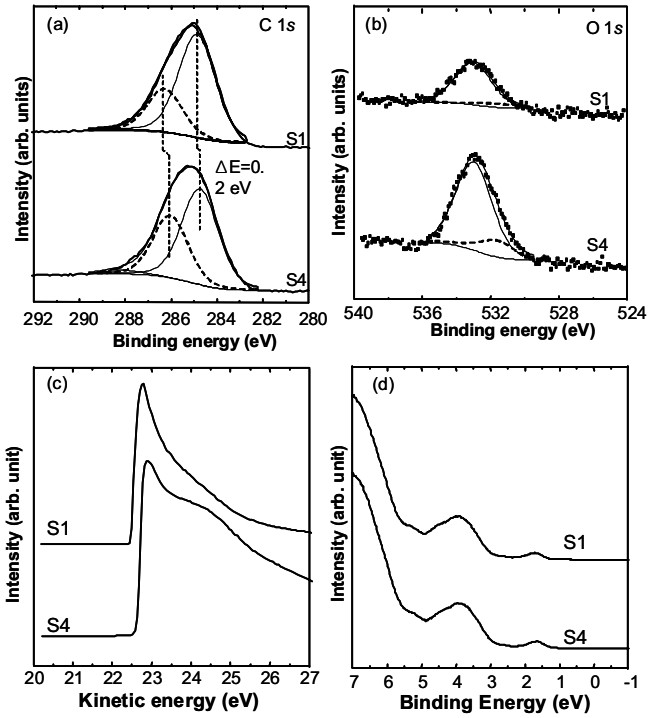

Figure 1. SRPES (a) C 1s core level, (b) O 1s core level, (c) secondary cut-off (d) valence band spectra of bare CuPc and O_2 plasma exposed CuPc

The valence band spectra of bare CuPc (S1) and oxygen plasma exposed CuPc (S4) are shown in Figure 1(d). In the case of S1, the energy difference between the highest occupied molecular orbital (HOMO) of CuPc and E_F is 0.48 eV. For the S4, the energy difference is 0.28 eV. It is previously reported that oxygen atoms could be diffused into CuPc film and act like *p*-type dopant. When the CuPc was exposed to oxygen plasma, oxygen ion adsorbed to CuPc and induced charge carrier donation by chemical dissociation. In this process, a charge transfer from the oxygen ion to the CuPc molecules occurs, changing the electronic properties of the organic film; in particular, the central part of the molecule. These transferred charges induce *p*-type doping effect, the shift of the Fermi level toward the HOMO state of CuPc, which could be detected by measurement of the valence band spectra. Thus, the hole injection barrier, the energy difference between the work function of anode and the HOMO level of organic layer, reduced by 0.20 eV for the S4. Therefore, the operation voltage at the current density of 100 mA/cm^2 of OLEDs using oxygen plasma treatment decreased from 15.5 V to 9.5 V.

3. Conclusion

We have investigated the oxygen doping effect on CuPc film by oxygen plasma exposure. The operation voltage at the current density of 100 mA/cm^2 of OLED exposing oxygen plasma decreased from 15.5 V to 9.5 V. SRPES spectra showed that oxygen was diffused into CuPc film and it induced *p*-type doping effect. The Fermi level of CuPc was shifted to HOMO level by 0.20 eV. Thus, the oxygen plasma treatment lowered the potential barrier for hole injection from Au anode to CuPc, enhancing the electroluminescent property of OLEDs.

4. Acknowledgements

This research was financially supported in part by the Ministry of Commerce, Industry and Energy (MOCIE) and Korea Industrial Technology Foundation (KOTEF) through the Human Resource Training Project for Regional Innovation.

5. References

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