Optical capturing kinetics of deep level defects in Alq3-based organic light emitting diodes

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The extensive development in organic semiconductor materials including conjugated polymers and small molecules has allowed their applications in optoelectronic devices such as emissive full-color display.[1] Since the amorphous structure of the polymers is known to contain defects, however, these defects affect the electrical and optical properties of the organic-devices. For large-size industrial applications, the device performance using these derivatives is considered as limited because of their lack of stability. The defects introduce deep levels within the bandgap of the emissive polymer.[2] The carriers captured by a defect site cannot participate in the transport process, thus reducing the efficiency of devices. Some of the defects form deep levels that deteriorate the created excitons and radiative recombination center participating in the emission process. Therefore, it is very important to have a clear understanding of the influence of defects of organic film on the performance of OLEDs. In this work, we have investigated the defect states behaviors in Alq3-based organic films on the electrical characteristics of the films. In addition, the defect states will be discussed to be distinctly classified using the model of the optical capture kinetics of charge carriers.

The used organic layers were Alq3-based blue OLED, fabricated with DNTPD(75nm)/NPB(15nm)/ MADN+BCzNBi(30nm)/Alq3(25nm)/LiF(10nm) structure. To characterize the deep level defects, we have utilized the photoinduced current transient spectroscopy (PICTS) measurement. During PICTS measurement with the UV light pulse of 365 nm, transient current signals (repetitive optical current pulse) were detected with a fast current amplifier. The amplified transient signal was processed with a 16-bit A/D converter and a computer. During the PICTS measurement, measuring temperatures were increased at rate of 1 K/min and the photocurrent transients after an optical pumping are analyzed at a fixed rate window in the time ranges from 10 μsec to 10 msec.

From the PICTS measurement for the OLED structures, as shown in Fig.1, we found two electron deep levels, denoted as the P1 and the P2 traps, at 80K and 250K, which are located at the activation energies of 0.28 eV and 0.45 eV below the lowest unoccupied molecular orbital (LUMO) edge, respectively. To investigate the optical capture kinetics of charge carriers in deep traps, the optical filling pulse study during PICTS measurement was done. The PICTS spectra of the P2 trap were obtained with varying pulse width. The P2 intensityl increases gradually with the increasing pulse time and then the intensity is saturated above 20 msec. And the P2 peak position moves to low temperature as the increasing pulse time.

Figure 2 shows the variation of normalized trap occupancies and activation energies of the P2 trap as a function of the optical filling pulse time in the range from 10 μsec to 10 msec. As the optical pulse time increases, the intensities of PICTS signals for the P2 trap is shown to increase logarithmically with the filling pulse duration, which shows the optical capture kinetics like the extended defect in the layer. The logarithm fitting of the amplitudes indicates that the deep trap could be indeed related to a linear array of traps as an extended trap. Thus, we found the defects might be either in the vicinity of molecular dangling bond(MDB)-trap or at linearly arranged defects between backbone.

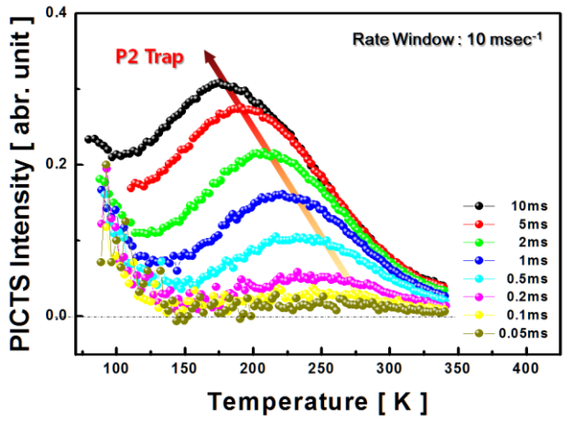

Fig.1 PICTS spectra as a function of the filling optical pulse width..

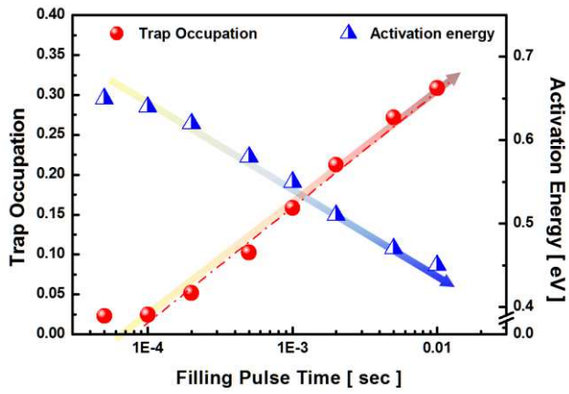

Fig. 2 Variation of the P2 trap occupations and activation energies as a function of the optical filling pulse width in a range of of 10 μsec ~10 msec

As shown in Fig. 2, the activation energy reduces from 0.64eV to 0.45eV as increase of the optical filling pulse width from 10 μsec to 10 msec, respectively. The low energy shift according to the optical pulse duration could be explained as extended trap model, as represented. Assuming that the energy state of the P2 trap is degenerated with identical cross sections and degeneracy factors in the bandgap, the trap energy level can be broaden like an energy band or extended states. In the case of the short pulse duration, only a part of the P2 trap could be occupied by carrier and the activation energy level to the LUMO state from the P2 trap is larger. When the P2 trap is fully occupied with the long pulse, the average activation energy reduces, resulting in the lower shift of the PICTS peak in temperature. This confirms that the P2 trap is degenerated and attributed to not a point defect state, but extended states.

[1] J.H. Burroughes et al., Nature, **347**, 539(1990).
[2] E.J.W.List et al., Adv. Mater., **14**, 374(2002).

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