Theoretical analysis of charge carrier injection and transport in QLED layers

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1. Introduction

A theoretical analysis on carrier injection and transport through layers of QLED device was attempted assuming dynamic equilibrium of trapping and detrapping charge carriers. Assuming traps in exponential or Gaussian energy distribution, the effect of parameters on the current-voltage relationship for the device was investigated. The energy level and distribution of charge traps, Schottky barrier, and the ratio of de-trapping rate constant to the trapping rate constant were found to affect the current-voltage relationship significantly in the charge transport layer. The results suggest that the parameters must be modulated simultaneously in order to achieve a charge balance in the QD layer of the QLED device.

2. Theory of Charge Injection and Transport through QLED layers

When carriers are injected into a charge transporting layer from an electrode, the carrier distribution could be described by the Poisson's equation as in eqn. 1)

$$\frac{dF(x)}{dx} = \frac{q[p(x)+p_t(x)]}{\varepsilon} \qquad (1)$$

where F(x) is an electric field, q is a carrier of the current carrier, p(x) is the density of free carrier carriers, $p_t(x)$ is the density of trapped carrier carriers, and ε is a dielectric constant of the layer.

By combining equations of continuity, Poisson's equation and trap energy distribution, and integrate over the whole thickness, a self-consistent electric field that satisfies the Poisson's equation is obtained as follows[1]:

$$\int_0^d dx = \frac{\varepsilon\varepsilon 0}{q}\int_{F(0)}^{F(d)} \frac{1}{\frac{J}{q\mu F(x)}+\int_{-\infty}^{0}\frac{H_b}{kT_c}\exp(\frac{E}{kT_c})\frac{1}{1+\frac{\gamma q\mu F\exp(\frac{E}{kT})}{J}}}dF(x) \qquad (2)$$

With the boundary condition,

$$V = \int_0^d F(x)dx \qquad (3)$$

J-V curves can be obtained using the numerical integration process, following a similar procedure described in a previous study[2].

A. Effects of Trap Density on J-V relationship

The effects of trap density on the J-V curves are calculated and shown in Fig. 1. When the trap density is higher than $1x10^{17}$ cm^{-3}, a distinctive TFL region with a stiff slope was calculated to appear. Further increase in trap density lengthens the TFL current range and the TFL voltage, V_{TFL}. V_{TFL} was increased ~ 2 orders of magnitude as the trap density was increased 3 orders of magnitude from 1016 cm-3 to 1019cm-3.

This result implies that the control of trap density is very critical in achieving the charge carrier balance in the QLED device and in lowering the turn-on voltage (or threshold voltage) of the device.

B. Effects of Field Effect Mobility on J-V relationship

The effects of field effect mobility of the charge transport layer on the J-V curve are shown in Fig. 2. When the mobility was varied from 10^{-6} cm^2/Vs to 10^{-3} cm^2/Vs for the calculation, the current density was increased proportionally without changing the shape of the J-V curve, shifting the curves in the vertical direction as noted from the figure. The change in mobility does not influence the slope and regions of the J-V curves, instead, the current density was calculated to increase propositional to the increase in the mobility as expected from Mott-Gurney's law where current density increases linearly with the mobility. These results suggest that the change in carrier mobility would not improve the charge balance over the whole operation range since the change in the mobility would shift the J-V curve in the vertical direction, without affecting the shape of the curves.

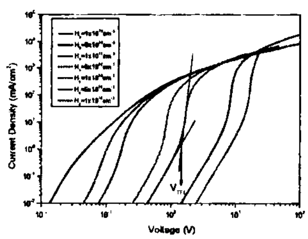

Figure 1: Effect of trap density on J-V relationship

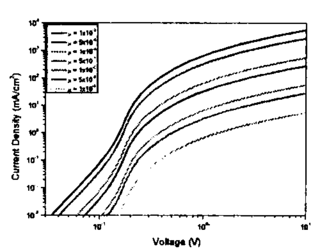

Figure 2: Effect of field effect mobility on J-V relationship

3. References

[1] M. A. Lampert, Physical Review **103,** 1648 (1956).

[2] P. Kumar, S. Jain, V. Kumar, S. Chand, and R. Tandon, Journal of Physics D: Applied Physics **41,** 155108 (2008).