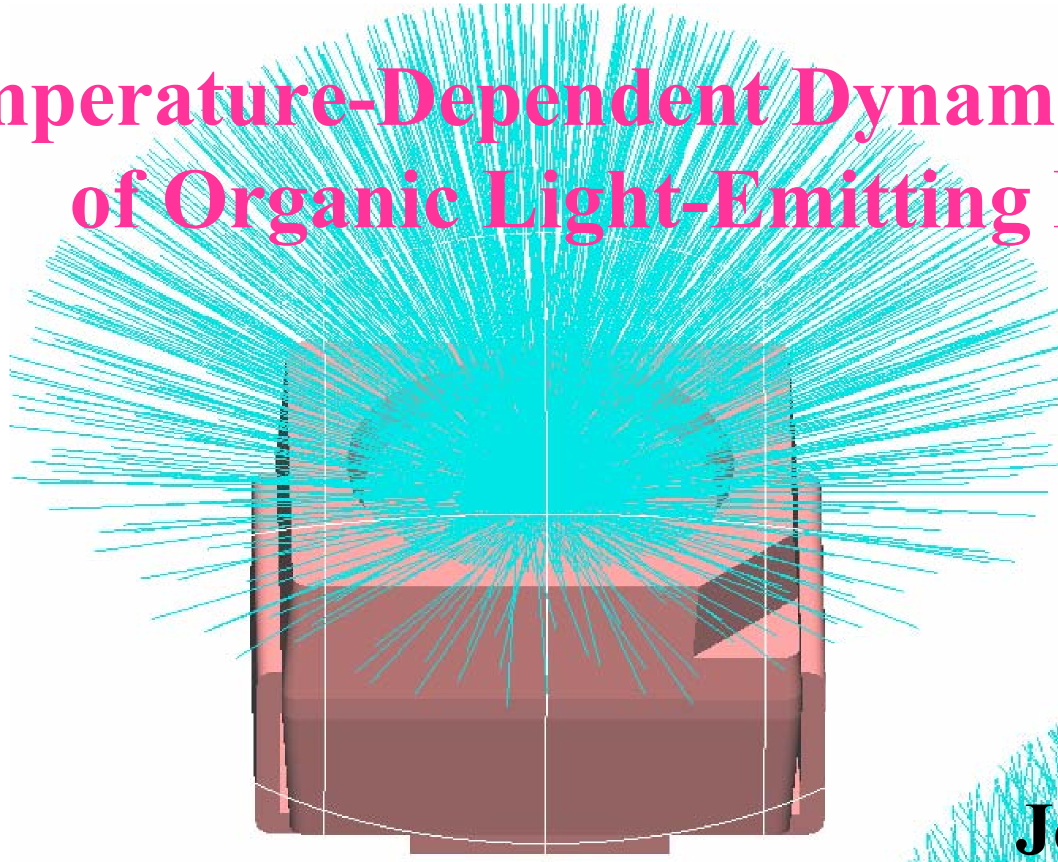
Temperature-Dependent Dynamic Behaviors of Organic Light-Emitting Diodes



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Outline

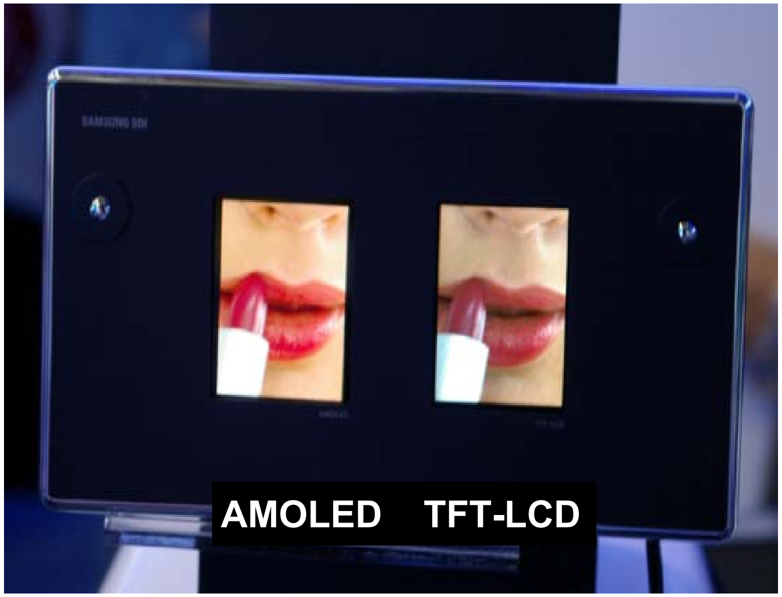
- Basic principle of operation
- Numerical model
- Simulation & Experiment results
- Overall conclusion

Organic Light-Emitting Devices:

- Low cost
- Self-emitting: require no backlight, reducing thickness
- Direct replacement for a conventional LCD
- Viewing angle up to 160 degrees
- Response of 1000 times faster than LCDs

Comparison with TFT-LCD

Viewing angle

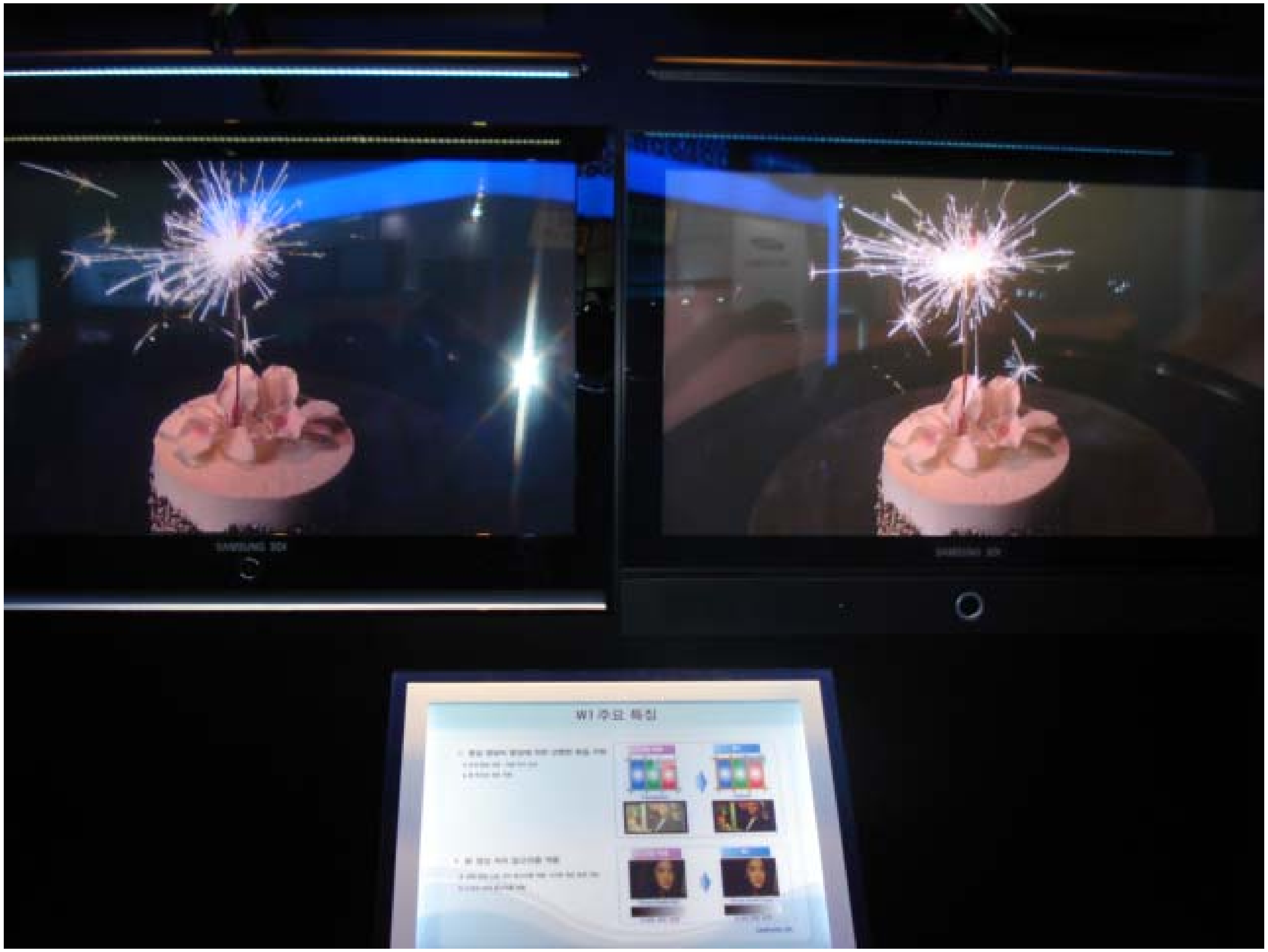


Power consumption

IMID 2006 display products by Samsung SDI

Color Representation

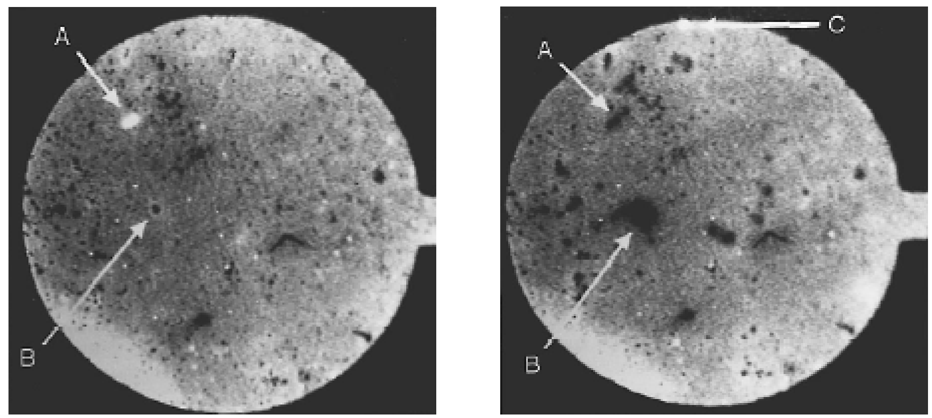
Outdoor



Indoor

IMID 2006 display products by Samsung SDI

Considerations for Long Lifetime

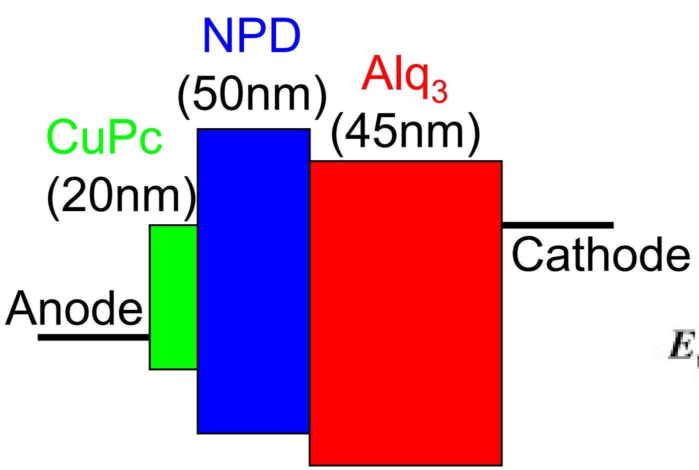


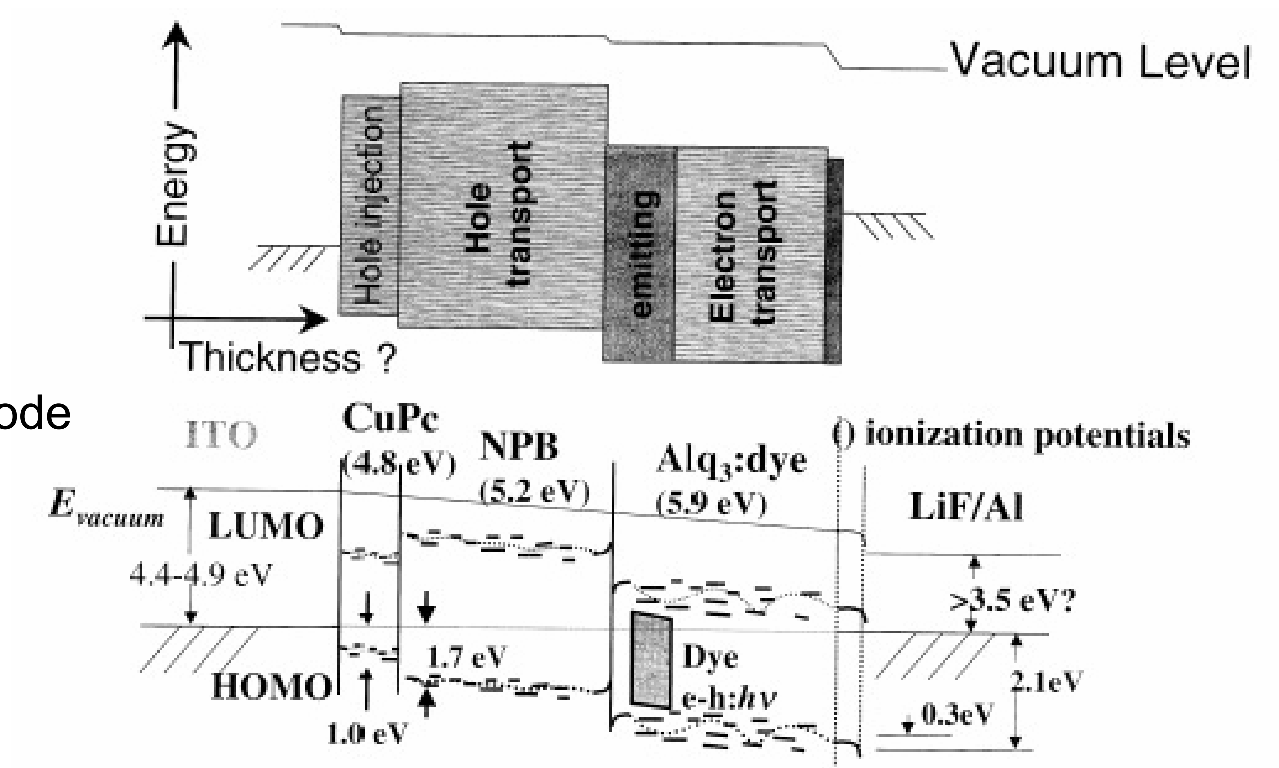
EL distribution

Unencapsulated 4min later

- Dark spot
  - impurity
  - defects
- Heat
  - glass transition temperature
- Electrochemical factors (stress)
  - device structure for balancing holes and electrons
  - doping
  - injection layers
  - surface quality between electrode and organic layers

Energy Band Diagram





Numerical Models (1D):

< Poisson’s equation >

$$\frac{\partial E(x,t)}{\partial x} = \frac{q}{\varepsilon}\left(p(x,t) - n(x,t) + N_D - N_A\right)$$

< Singlet exciton rate equation >

$$\frac{\partial S(x,t)}{\partial t} = \frac{1}{4} r(x,t) n(x,t) p(x,t) + D_s \frac{d^2 S(x,t)}{dx^2} - \frac{S(x,t)}{\tau_s} - Q(x)\frac{S(x,t)}{\tau_q}$$

< Drift-Diffusion equation >

$$\frac{\partial n(x,t)}{\partial t} = \frac{1}{q}\frac{\partial J_n(x,t)}{\partial x} - r(x,t) n(x,t) p(x,t)$$

$$\frac{\partial p(x,t)}{\partial t} = -\frac{1}{q}\frac{\partial J_p(x,t)}{\partial x} - r(x,t) n(x,t) p(x,t)$$

$$J_n(x,t) = q\mu_n(x,t) n(x,t) E(x,t) + kT\mu_n(x,t)\frac{\partial n(x,t)}{\partial x}$$

$$J_p(x,t) = q\mu_p(x,t) p(x,t) E(x,t) - kT\mu_p(x,t)\frac{\partial p(x,t)}{\partial x}$$

Langevin recombination rate model

< Luminance >

$$L(t) = \frac{683}{\pi}\frac{\eta_{abs}}{n^2_{sub}} h\nu P(t)$$

< Boundary conditions >

$$\int_0^L E(x,t)dx = V_{bias} - V_{bi}, \qquad t \geq 0$$

$$J = AT^2 \exp(-\phi_B / kT) \exp f^{1/2} - qn(x)S(E)$$

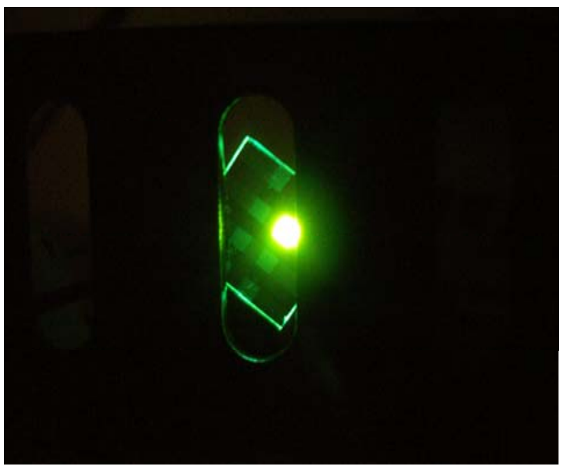
< Field- and temperature-dependent mobility >

Poole-Frenkel type mobility model

$$\mu\left(E(x,t),T\right) = \mu_0(T)\exp\left(\sqrt{\frac{E(x,t)}{E_0}}\right)$$

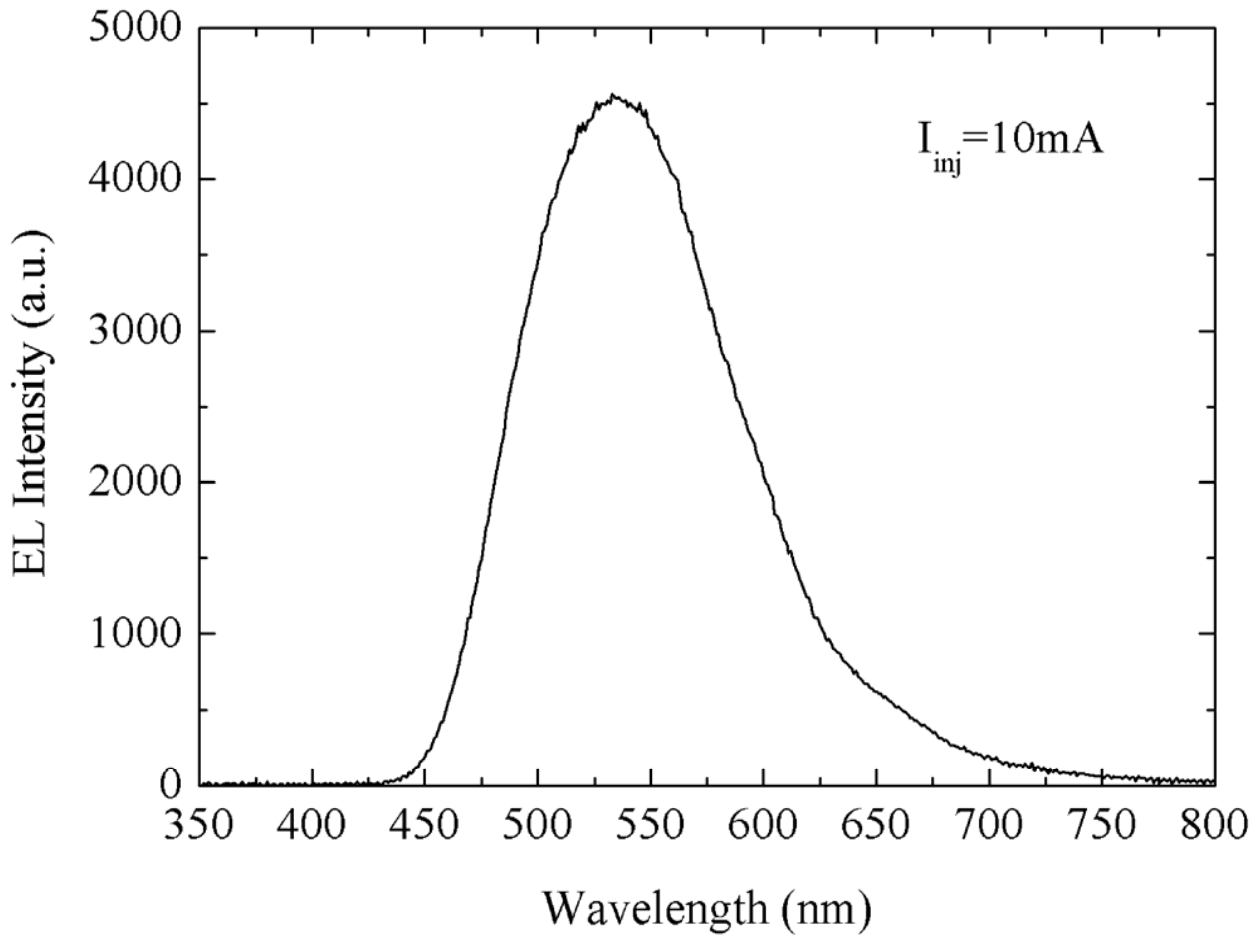
NPD-Alq$_3$ OLED

NPD-Alq$_3$ OLED
under EL test



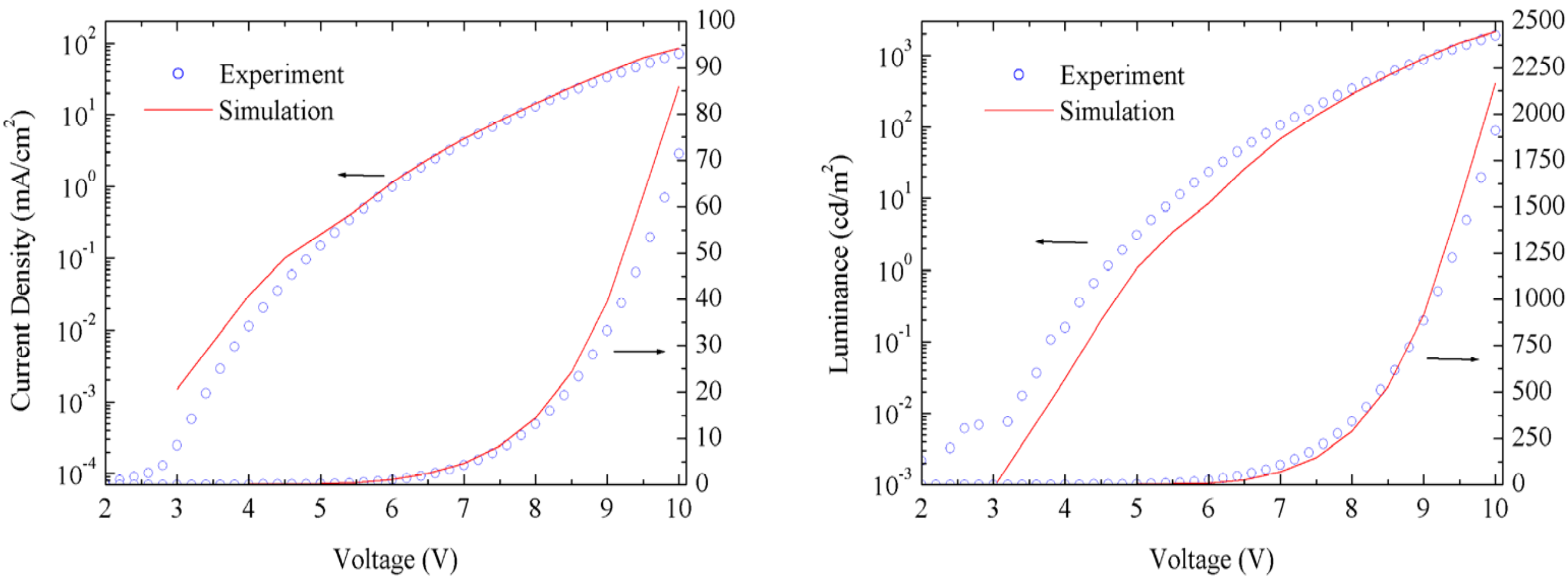
Vacuum Evaporation System
at Kyoto Univ.

EL Spectrum

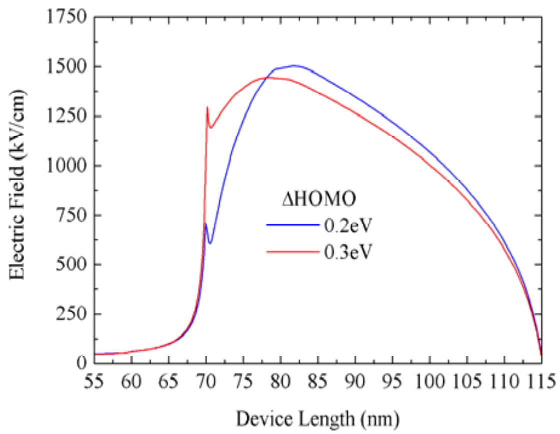


EL Intensity (a.u.)
5000
4000
3000
2000
1000
0
350
400
450
500
550
600
650
700
750
800
Wavelength (nm)
I inj =10mA

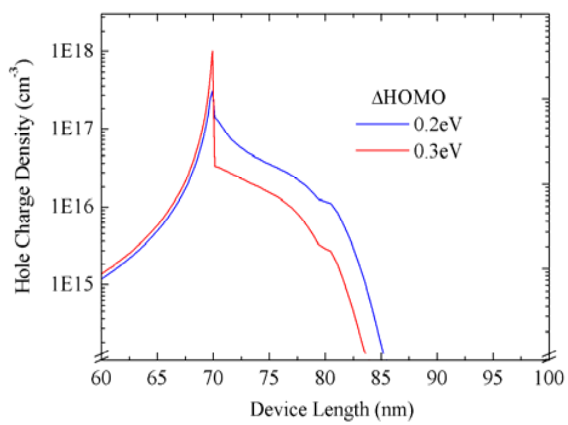
Validation of Numerical Model



Simulation Results
-Effects of ΔHOMO-

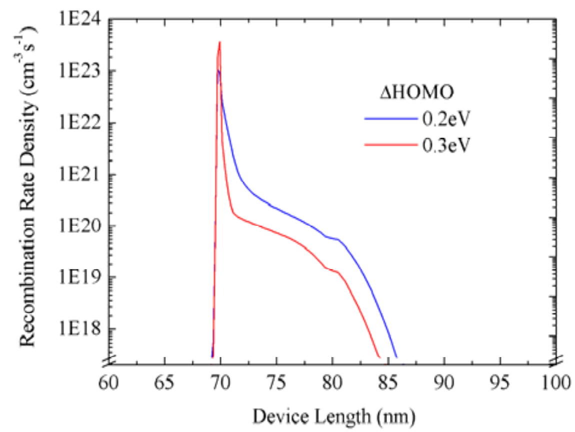


Electric Field



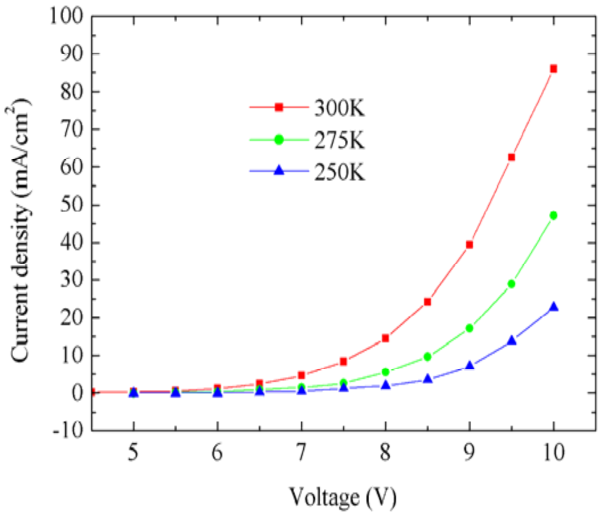
Hole charge density

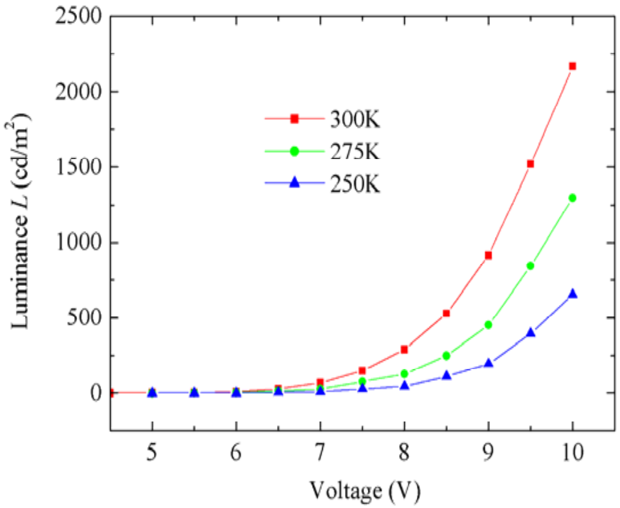
Recombination rate

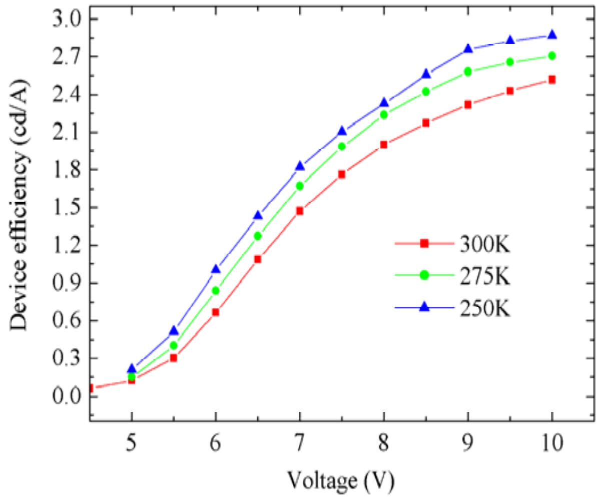


- **Similar behaviors for ΔLUMO**

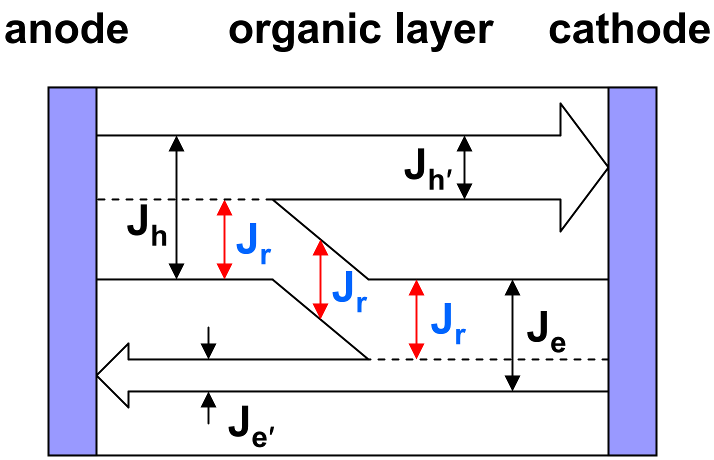
Temperature-Dependent Device Performances





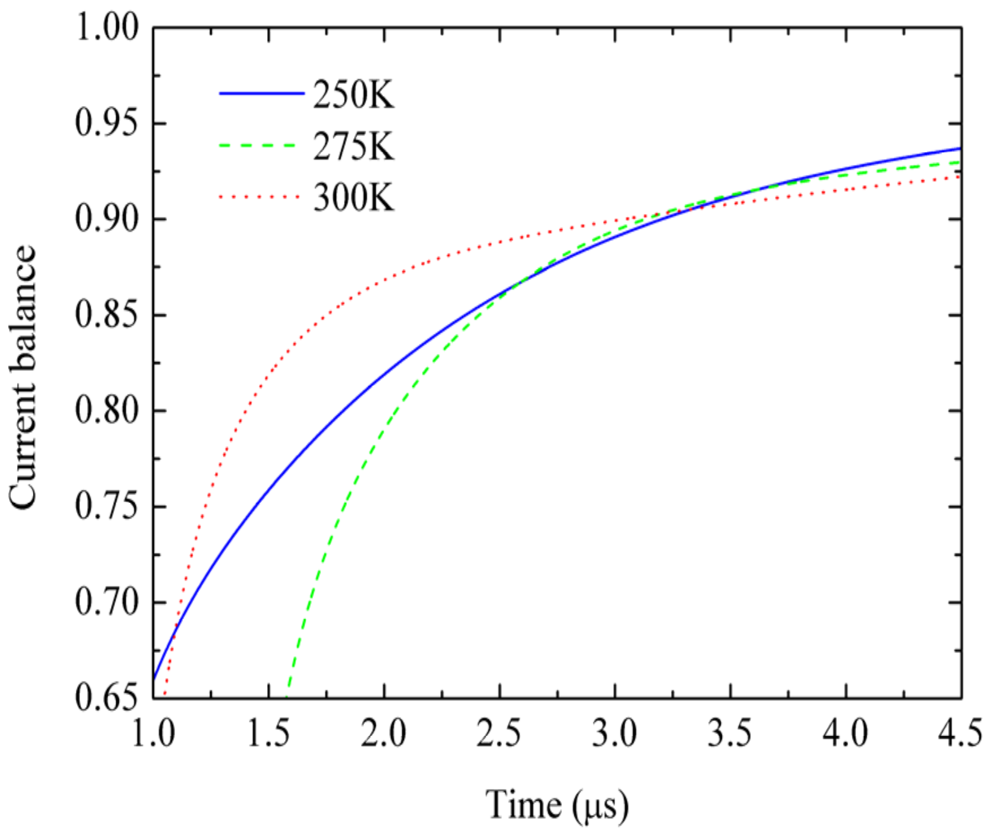


Temperature-Dependent Current Balance=J_r/J



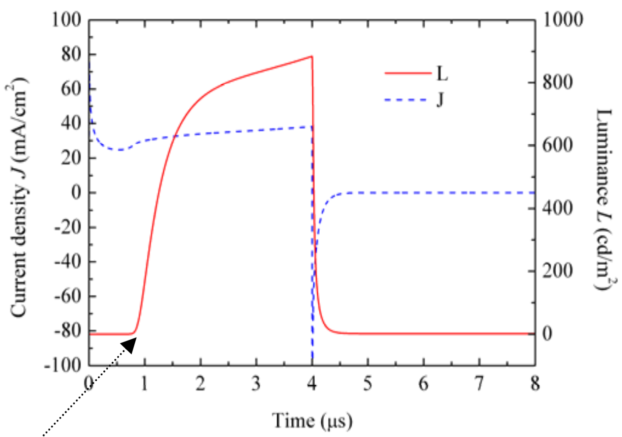
$$J=J_h+J_{e'}=J_e+J_{h'}$$

$$J_r=J_h-J_{h'}=J_e-J_{e'}$$



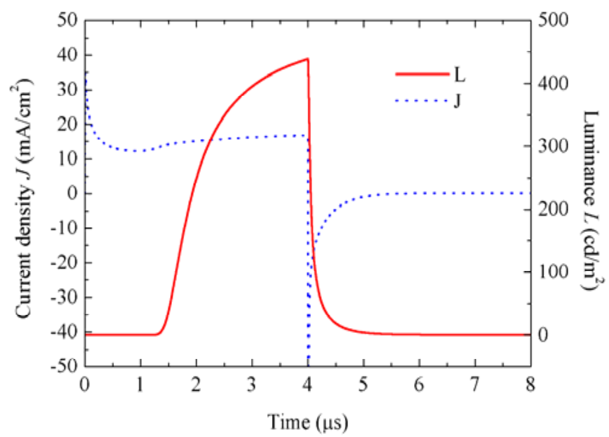
Temperature-Dependent Dynamic Behaviors of OLED

Bias=9V



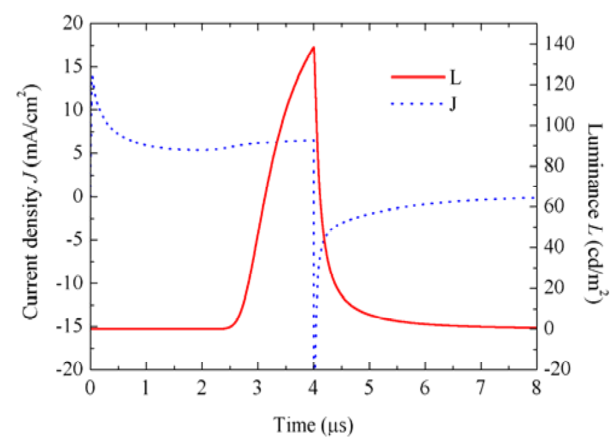
T_d

300K (0.8μs)

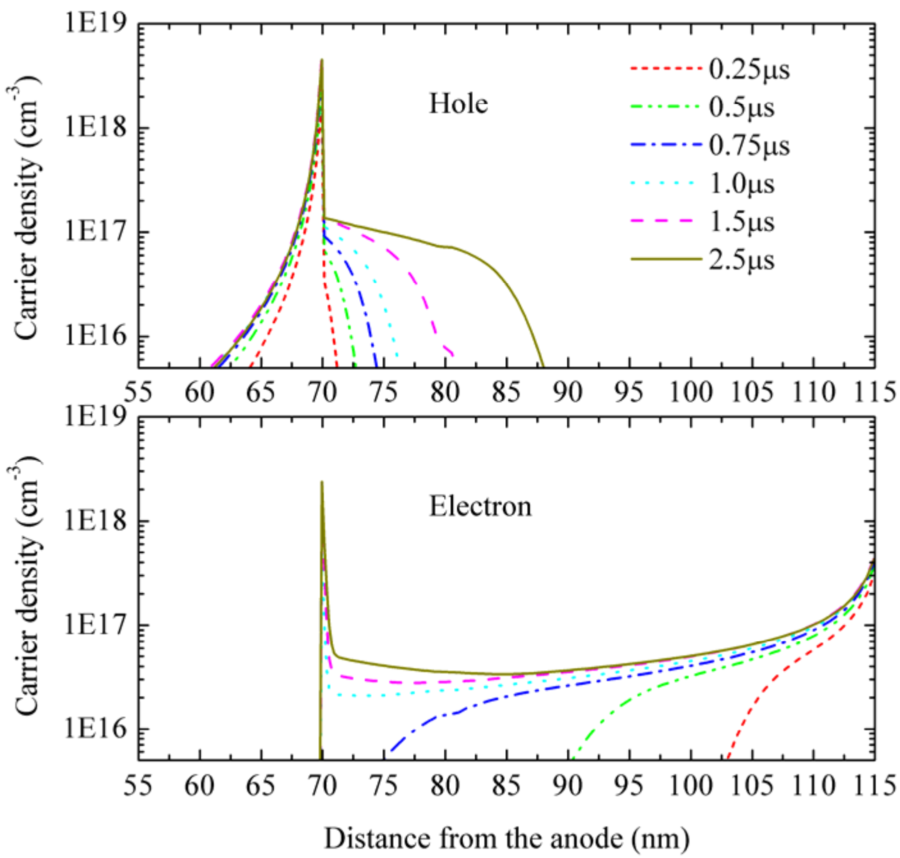


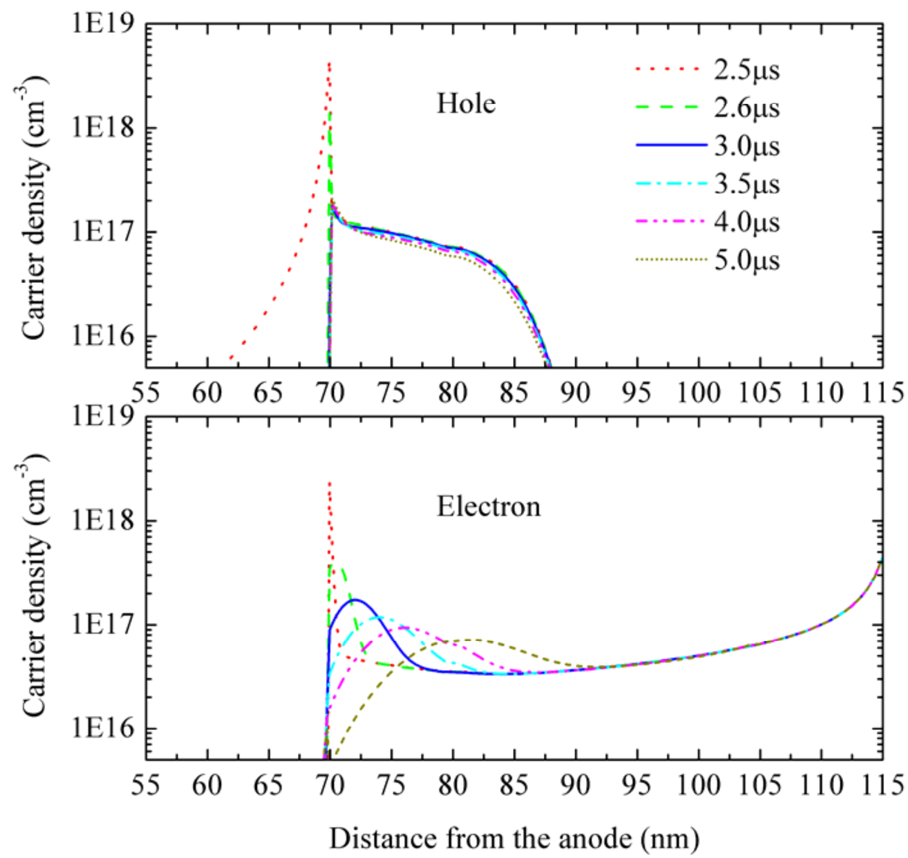
275K (1.31μs)

250K (2.4μs)



Spatial Distribution of Carrier Density

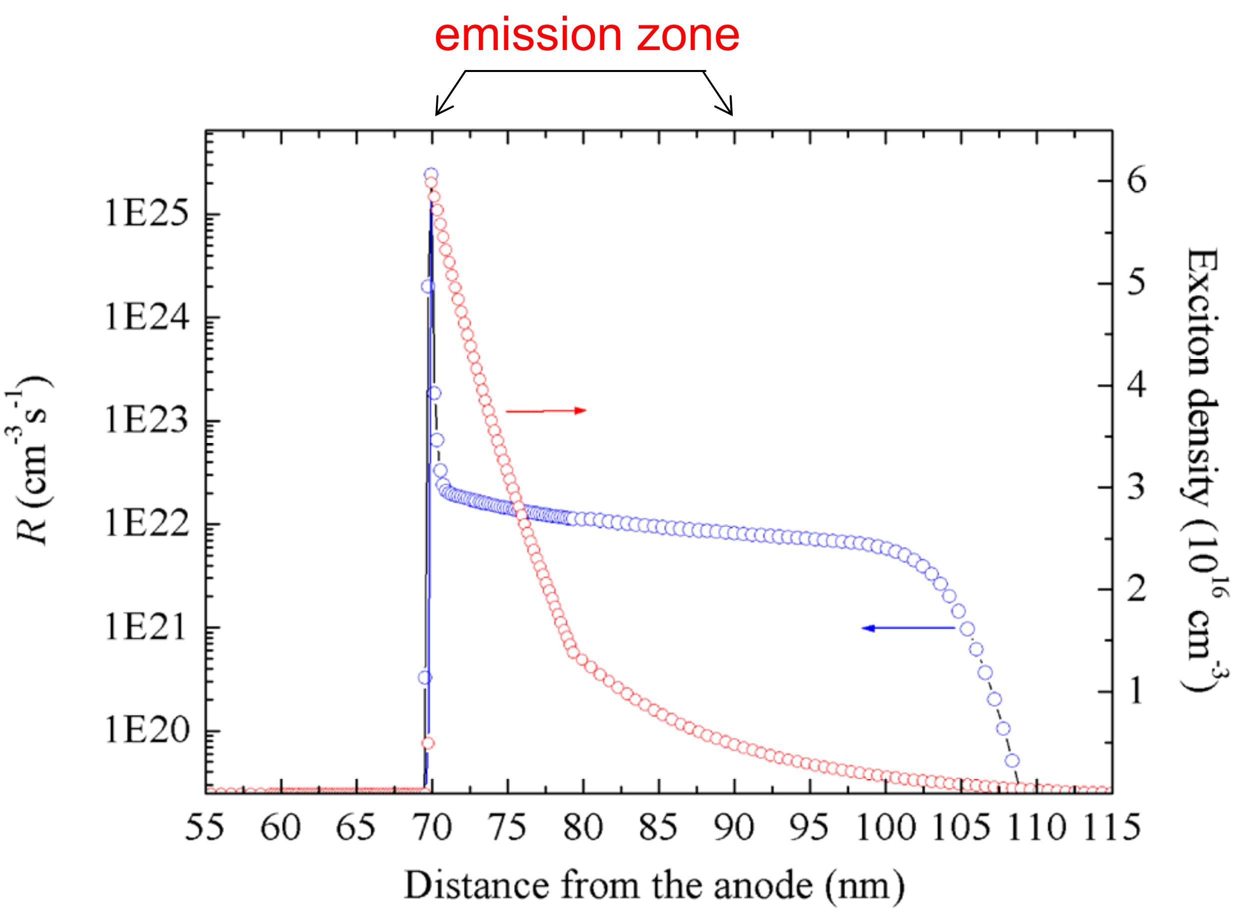




Turn-on cycle (charge)

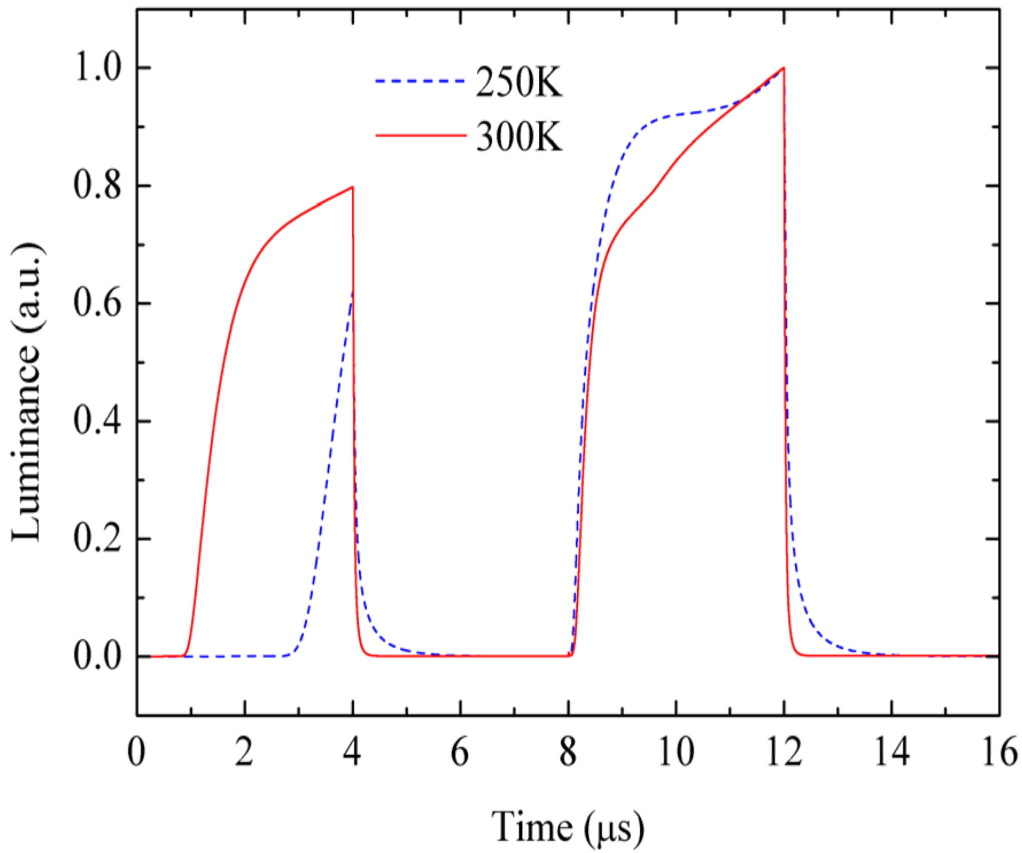
Turn-off cycle (discharge)

Exciton Distribution



Dirac delta function (“seed exciton”) → Diffusion

Response to a Train of Voltage Pulses



Summary

- The luminance decreases and the turn-on voltage increases as the temperature decreases due to a reduction in thermally activated hopping speed.
- It delays not only the startup of EL upon turn-on of OLEDs, but also the discharge upon turn-off.
- The device efficiency is increased with decreasing temperature due to enhanced charge-balance factor.
- The pulse-to-pulse interference by the space charge effects is more significant at lower temperatures.