# Simulating Plasmon Effect in Nanostructured OLED Cathode Using COMSOL Multiphysics

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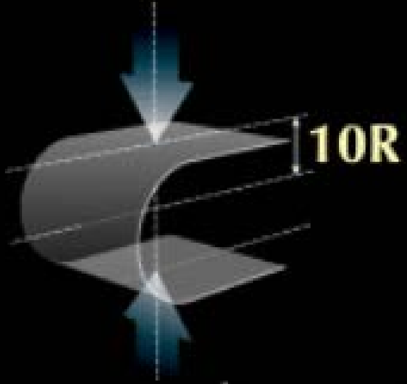
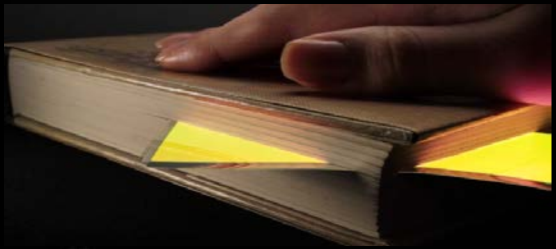
*Konica Minolta Laboratory USA Inc.*

10/08/2015

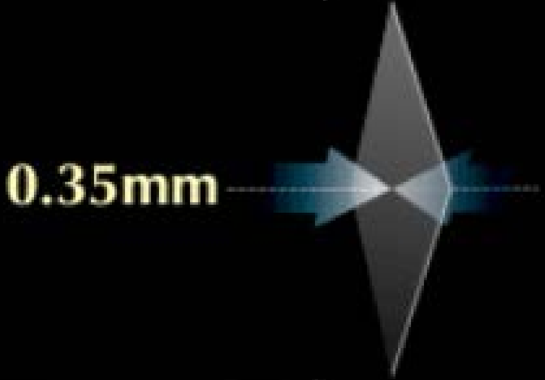
# Konica Minolta OLED lighting

Flexible

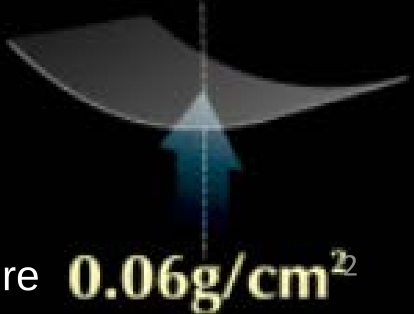


Thin




Lightweight




One piece of cutting-edge technology creates the future

# Konica Minolta OLED lighting

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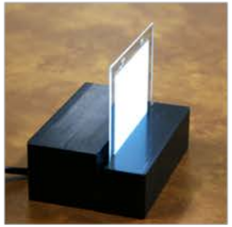
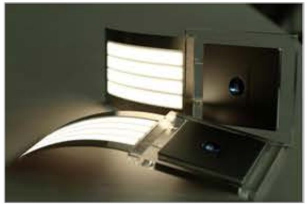
**Prototype**



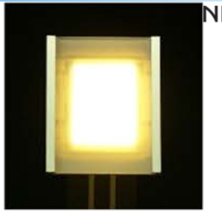
All-phosphorescent OLED with world-record performance @SID2007



All-phosphorescent OLED by R2R solution-process @Light+Building2010

Large area OLED using new printable anode @CEATEC Japan 2012

Flexible OLED panel demonstration @LIGHTING FAIR 2013



The world's most efficient OLED lighting panel @SID2014

~2000 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015

**Product & Business**

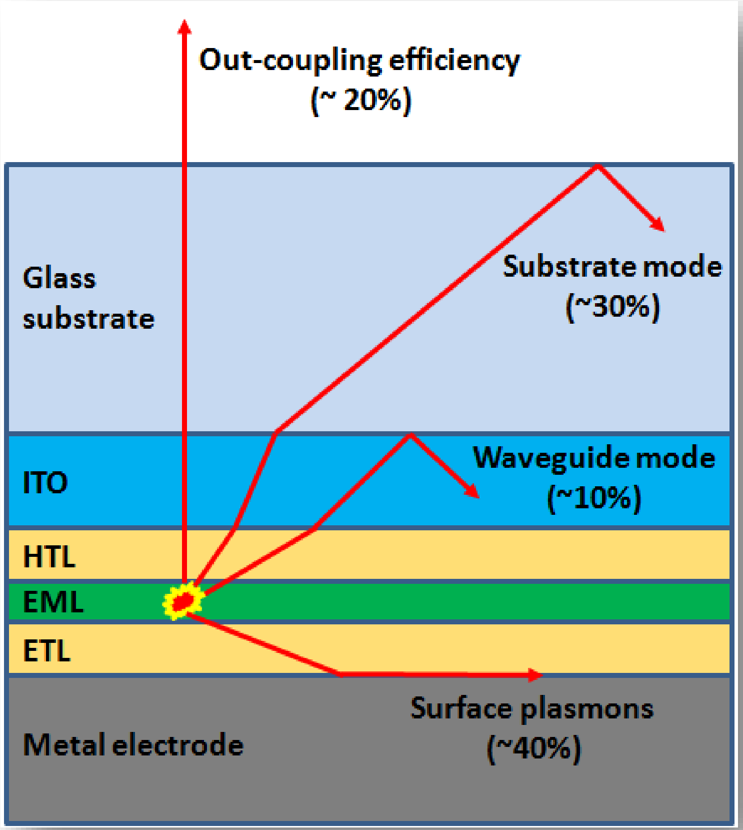
Symfos

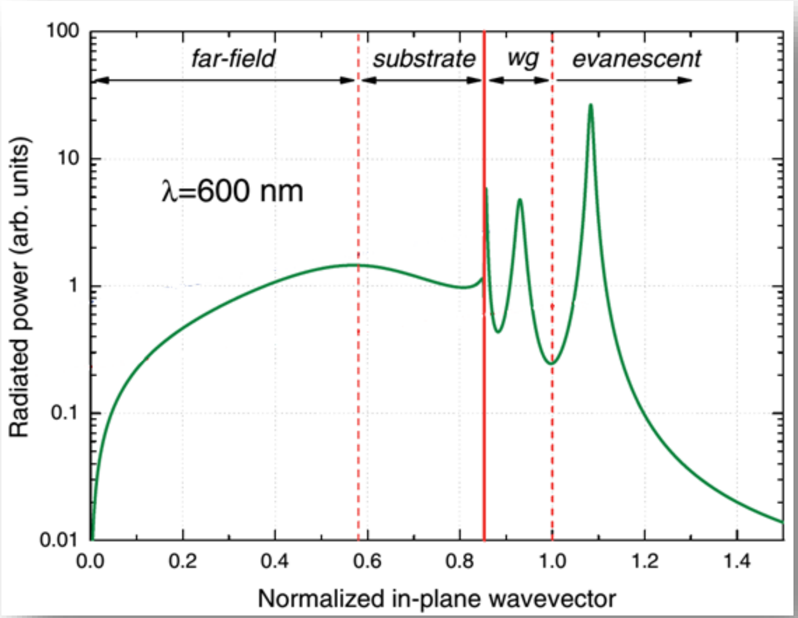
World's first all-phosphorescent white OLED product" Symfos OLED-010K"

Mass production for plastic substrate flexible OLED lighting panel

World's first flower illumination

# Multilayer structure and light out-coupling of OLED

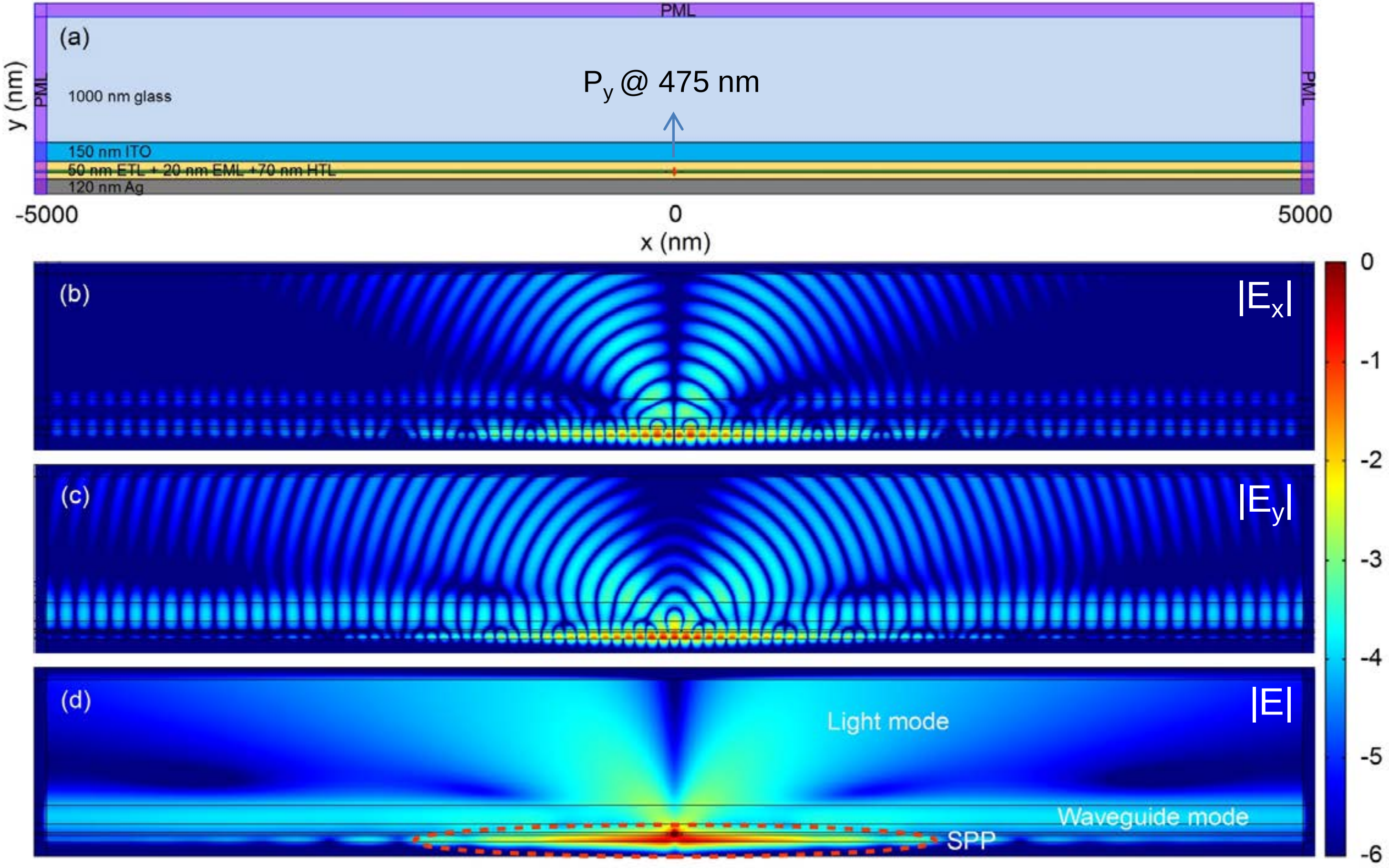



Typical power distribution spectrum of an OLED viewed in the k-space*

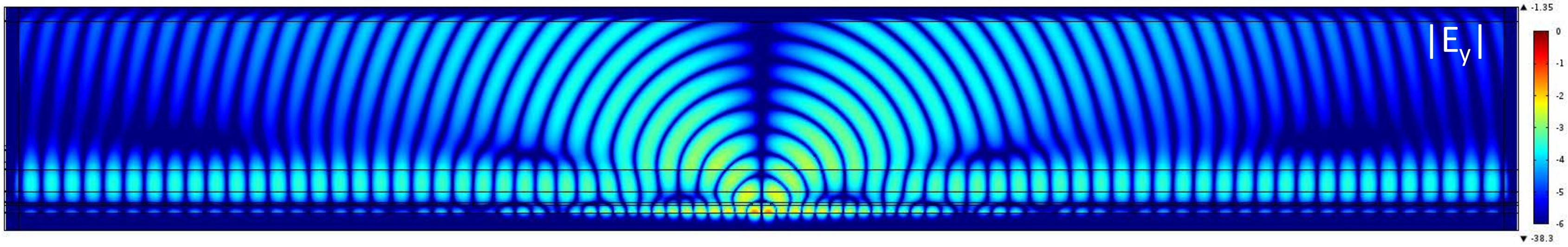
*Reineke et al., Rev. Mod. Phys. 85, 1245–1293 (2013)

# Visualizing field distribution in OLED in real space

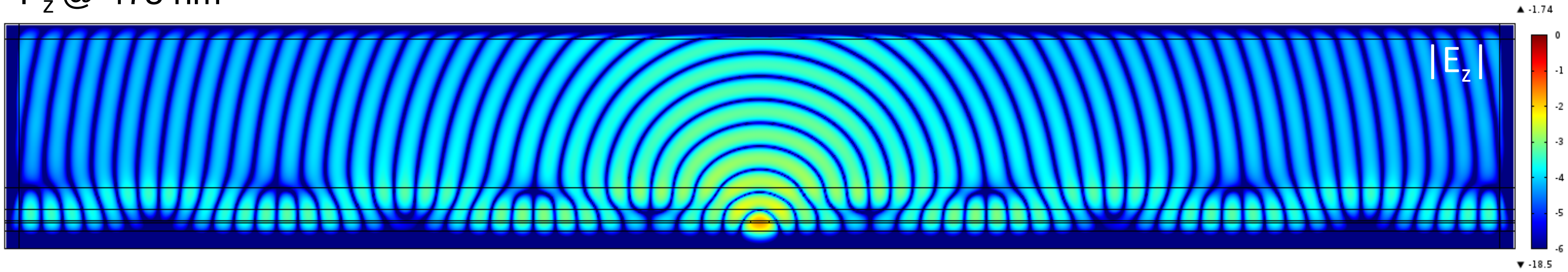


# Visualizing field distribution in OLED in real space

$P_x$ @ 475 nm

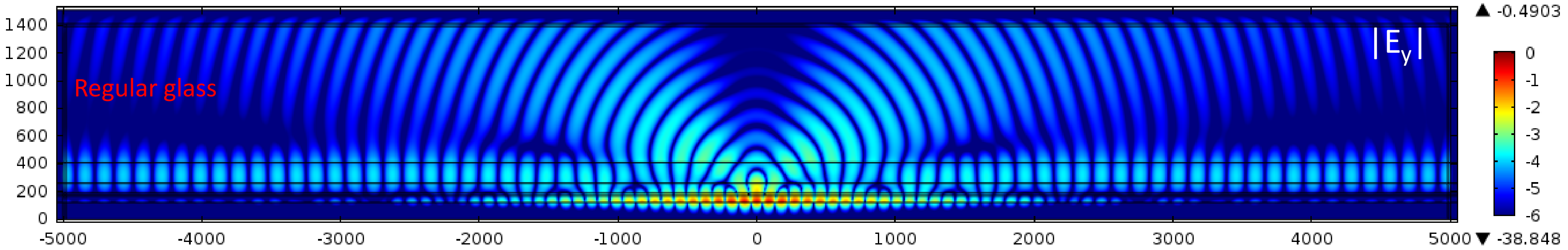


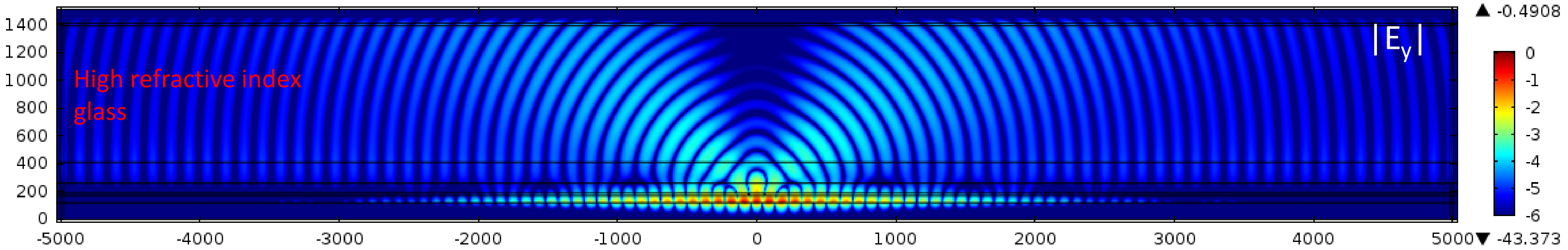

$P_z$ @ 475 nm




- SPP coupling is less for horizontally oriented dipole emission.
- No SPP coupling for *s*-polarized case in 2D.

# Reducing waveguide mode by high index substrate

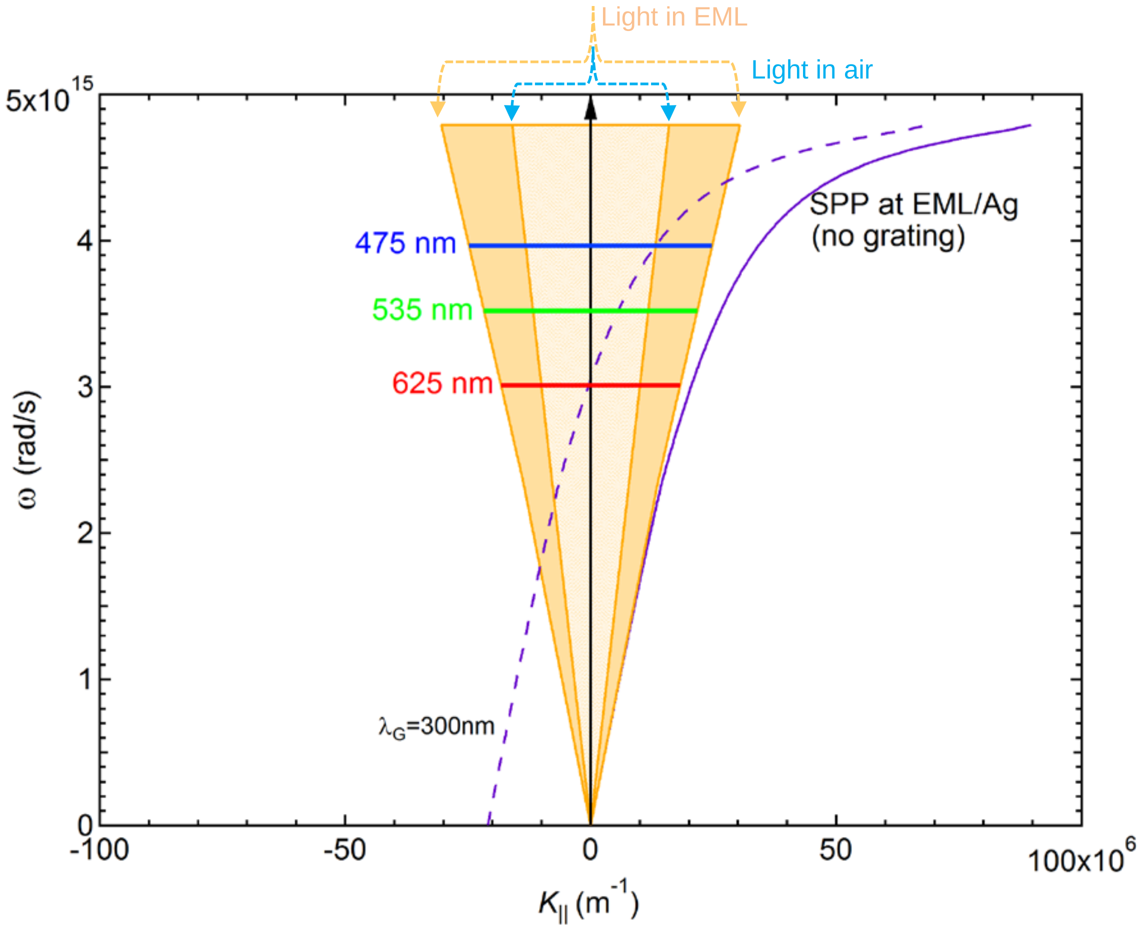


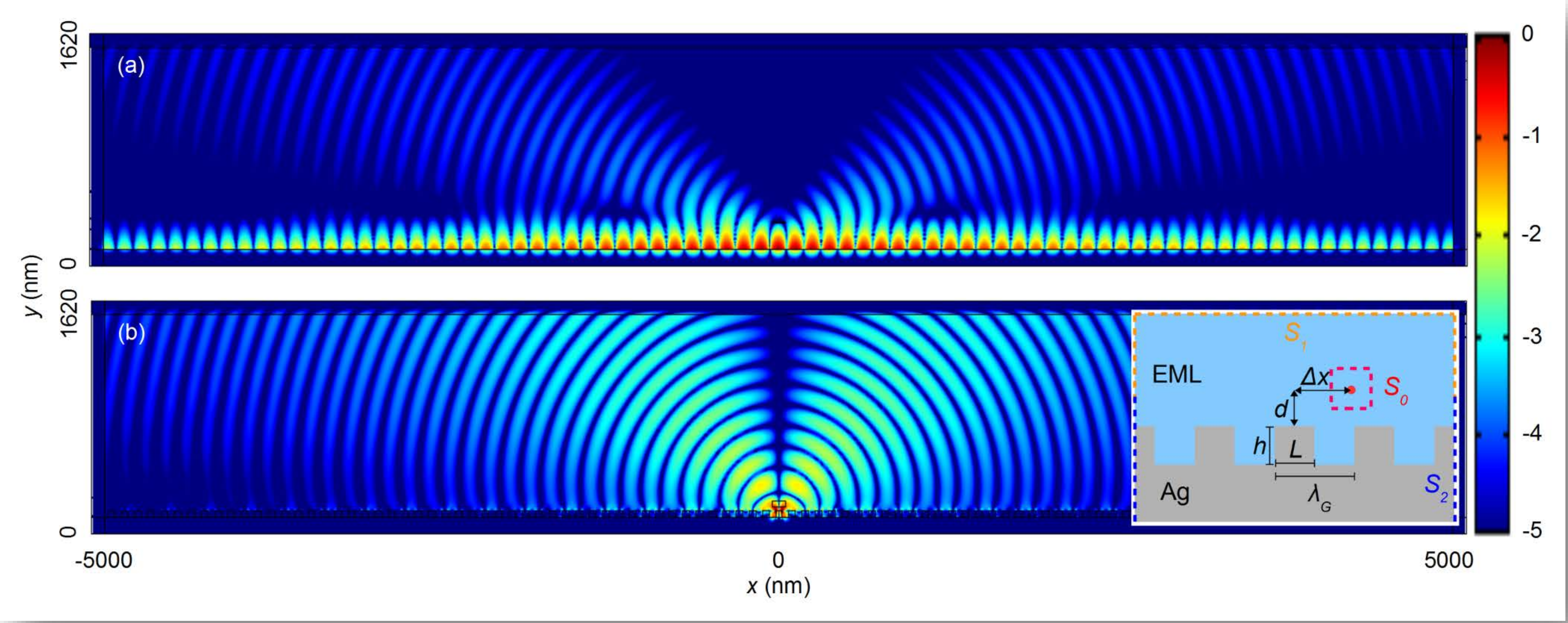

- $P_y$ @ 475 nm.

- Strategy of enhancing light extraction efficiency of OLED:
plasmon mode → waveguide mode → substrate mode → air mode.

# Reducing SPP coupling by nanograting electrode

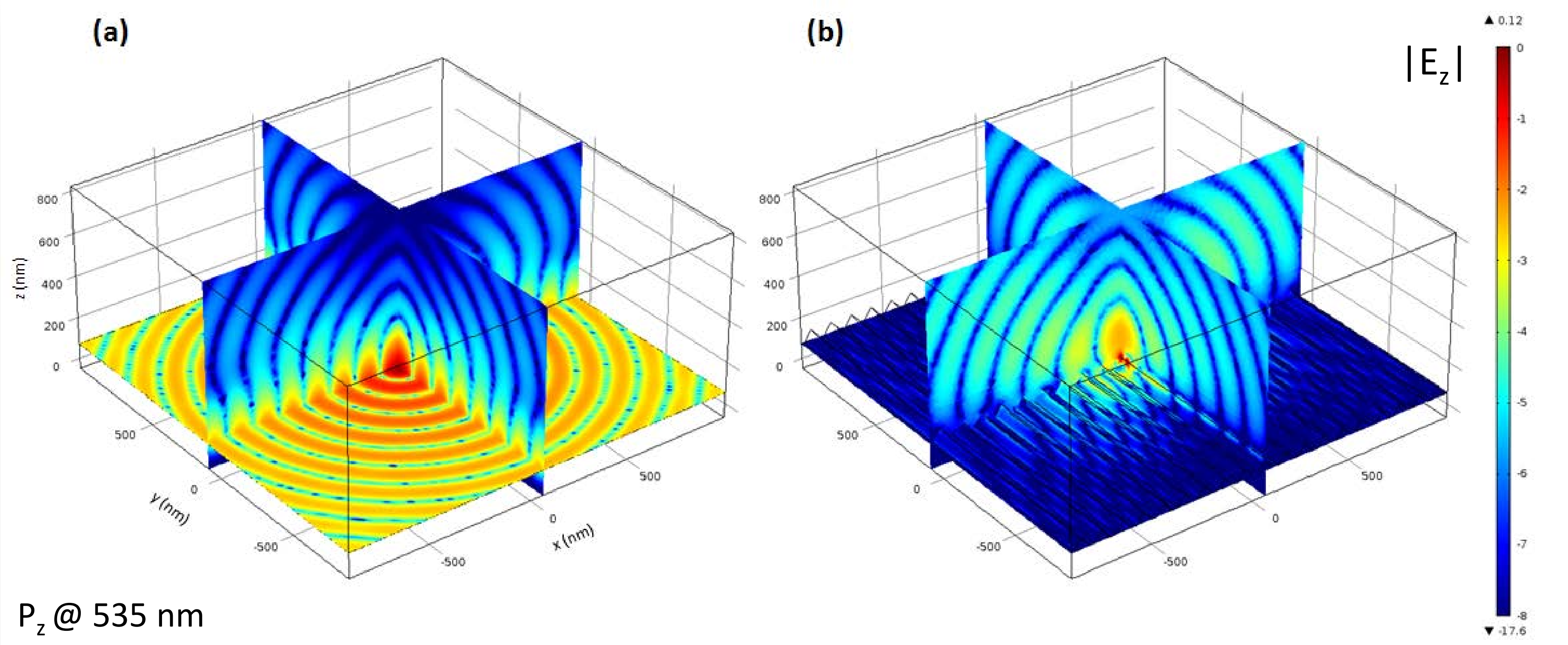


# Reducing SPP coupling by nanograting electrode



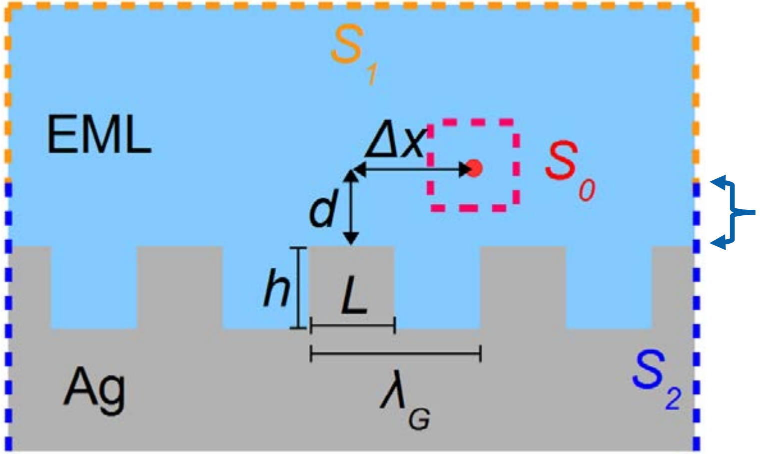

- Simplified model – Ag/EML two layer.
- $P_y$ @ 535 nm.
- Grating: $\lambda_G$ = 100 nm, L = 50 nm, h = 50 nm, d = 50 nm, Δx = 0.

# Reducing SPP coupling by nanograting electrode




- 3D capable, but memory intensive and time-consuming

# Power flow analysis




SPP evanescent field ($e^{-1}$)

$$P_{total} = \int (\vec{E} \times \vec{H}) \cdot d\vec{S}_0$$

$$P_{light} = \int (\vec{E} \times \vec{H}) \cdot d\vec{S}_1$$

$$P_{plasmon} = \int (\vec{E} \times \vec{H}) \cdot d\vec{S}_2 + \int (\vec{J} \cdot \vec{E}) \cdot dV_{Ag}$$

*Plasmon loss* (%) = $P_{plasmon}/P_{total}$

# Total emission power

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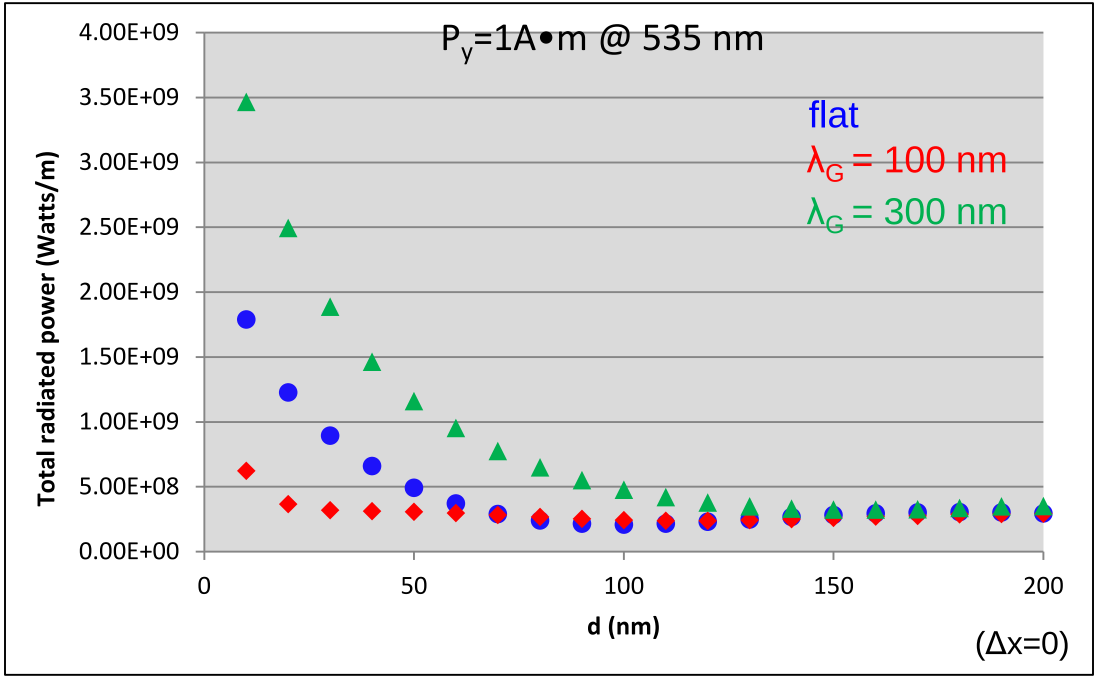
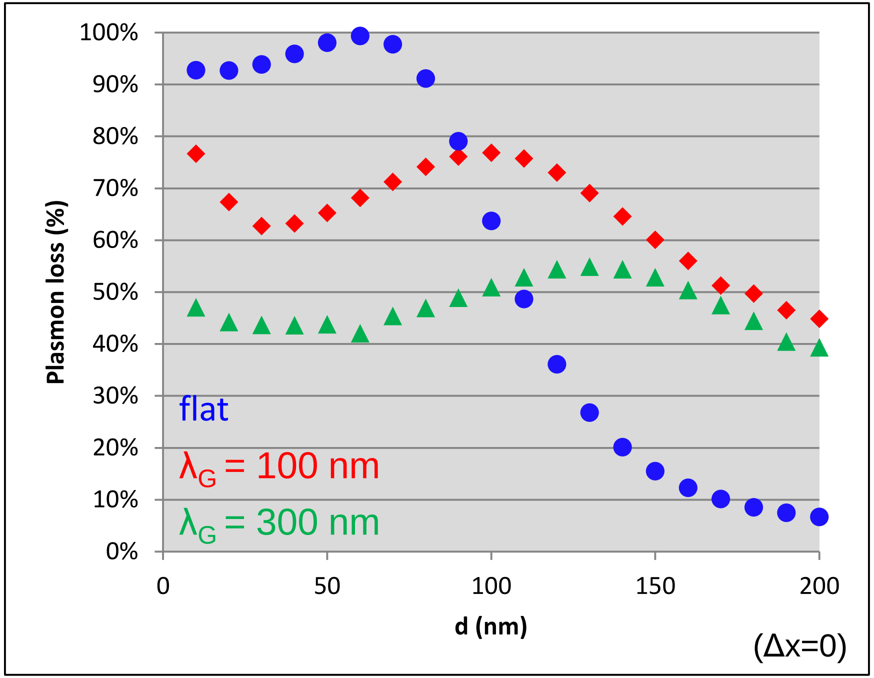
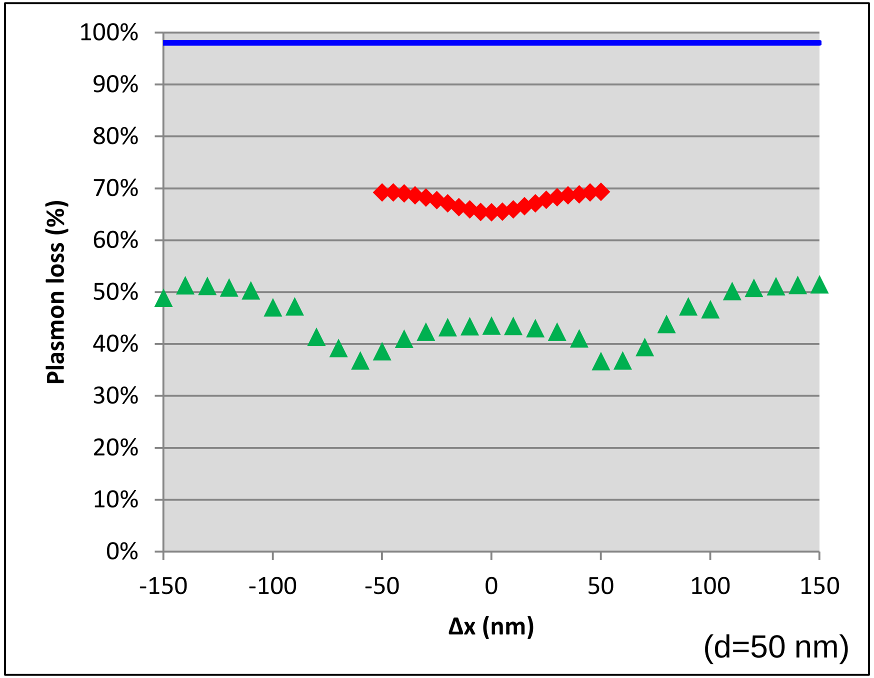



- Total emission power correlates with the decay rate of the molecular emitter and the internal quantum efficiency (IQE) of OLED.
- For all-phosphorescent OLED, the IQE is ~100%; only the percentage of plasmon loss is concerned.

# Plasmon loss – vertical dipole

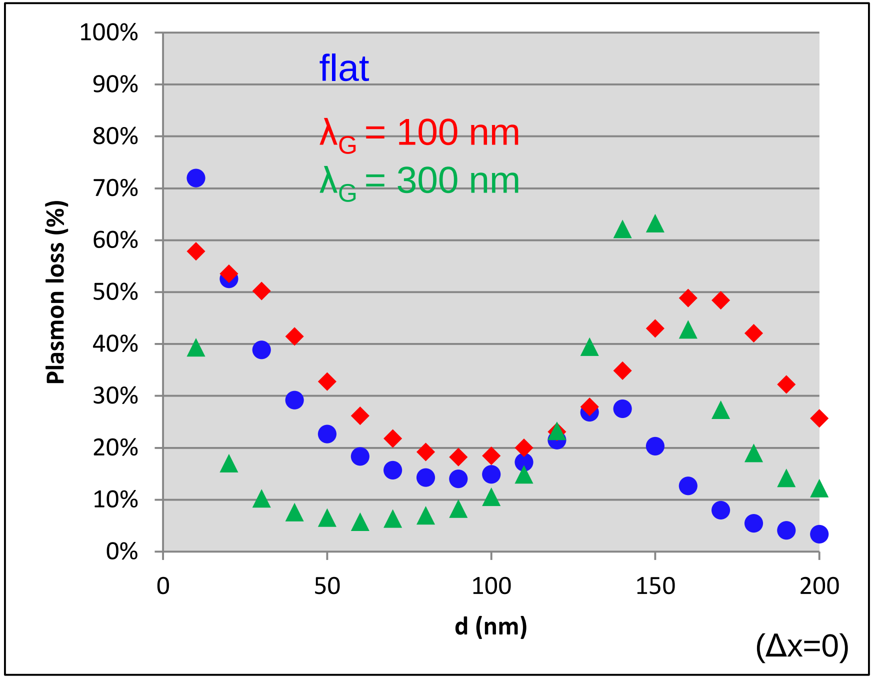
$P_y$ @ 535 nm

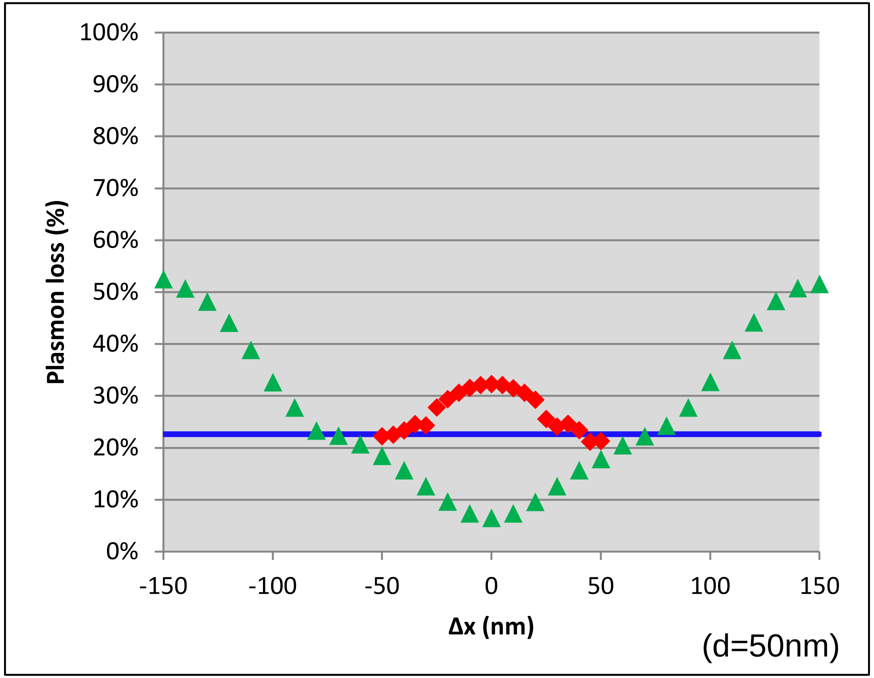


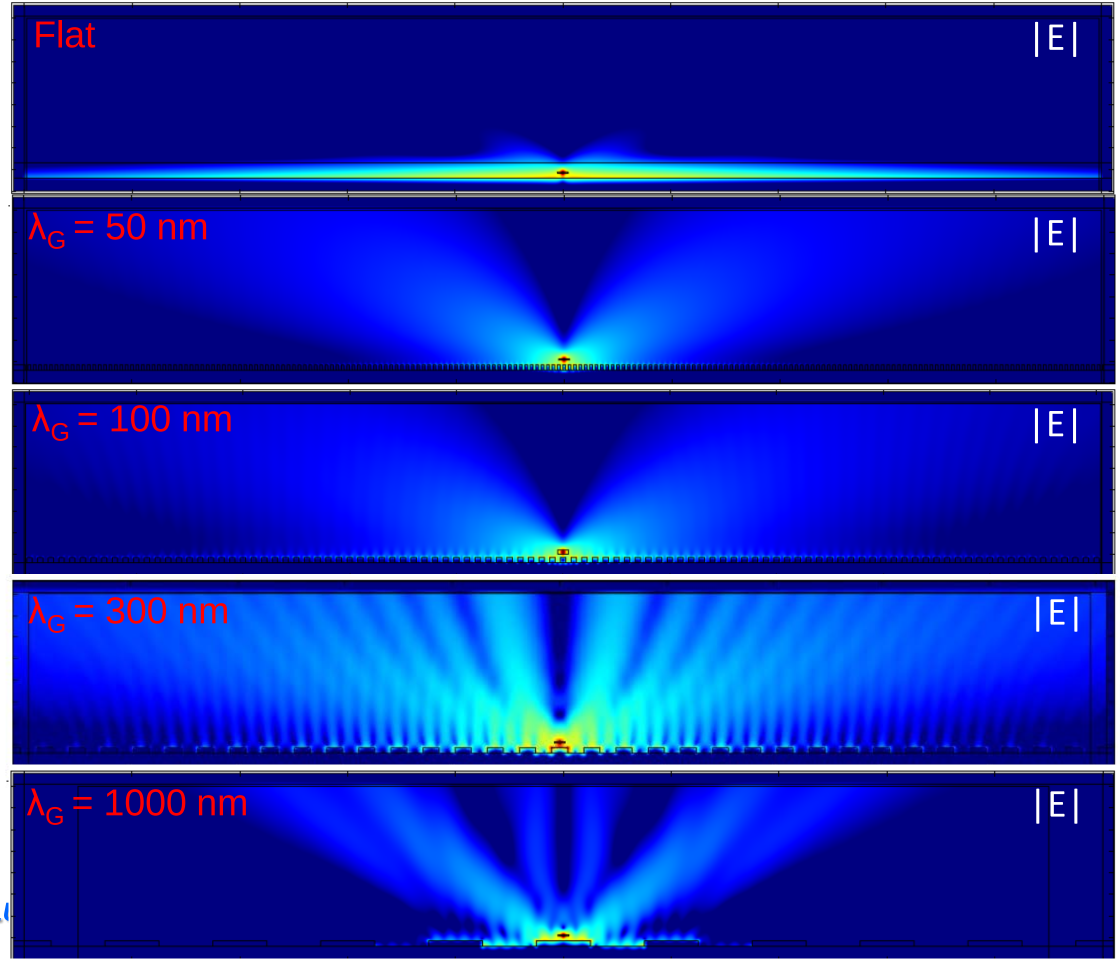
# Plasmon loss – horizontal dipole

$P_x$ @ 535 nm



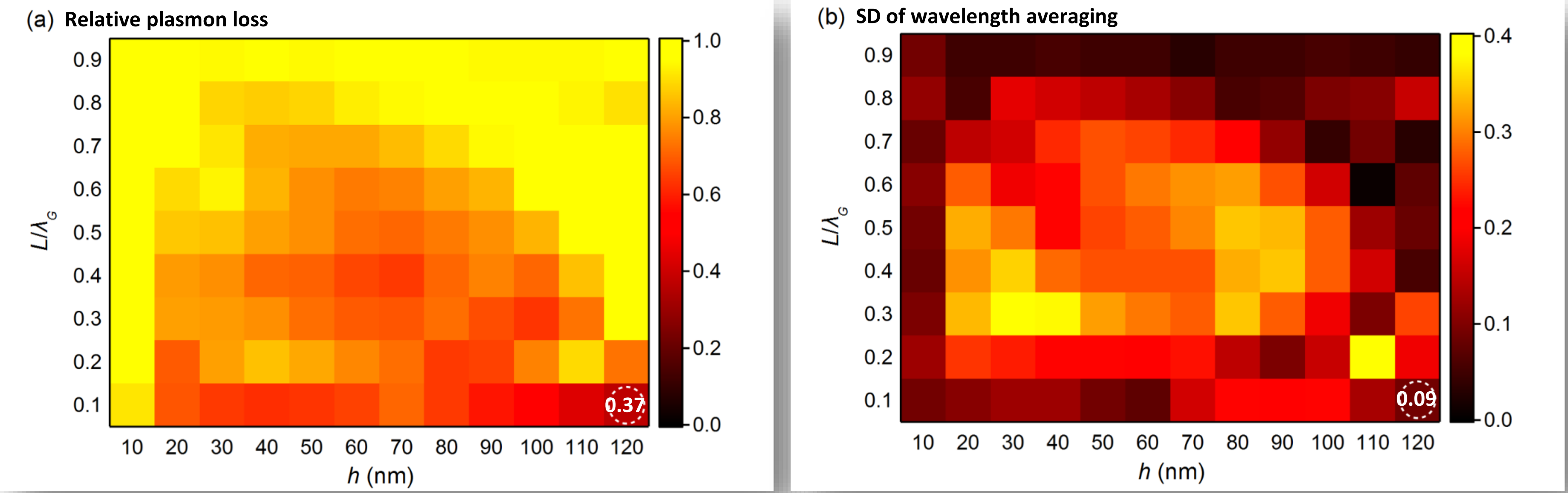



# Effect on emission pattern




- $P_y$ @ 535 nm.
- $\Delta x = 0$, d = 50nm, h=50nm, $L/\lambda_G = ½$.
- Large grating may lead to structured directional emission.
- Subwavelength grating – metasurface.

# Parametric study




- Relative ratio of plasmon loss - grating with respect to flat.
- $\lambda_G$ = 100nm, d = 50 nm.
- Average of 2 horizontal positions: $\Delta x = 0$, $\Delta x = \lambda_G/2$.
- Average of $P_x$ and $P_y$.
- Average of 3 emission wavelength: 475 nm, 535 nm, 625nm.
- COMSOL Multiphysics® Cluster Sweep – parallel!

# Summary

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- ❑ Mode distribution and plasmon coupling effect in OLED were modeled using COMSOL Multiphysics®, which can simulate the optical effect caused by arbitrary subwavelength nanostructures.

- ❑ Reduction of plasmon loss in OLED by ~ 50% over broadband emission is promising by nanostructured metal cathode.

# Acknowledgement

❑ HLUS

Dr. Jun Amano

Dr. Po-Chieh Hung

❑ Stanford University

Prof. Mark Brongersma

Mr. Majid Esfandyarpour

❑ Konica Minolta Inc. (Japan)

Mr. Toshihiko Iwasaki

Mr. Masahiro Imada

OLED group

Simulation group

Thank you for attention