COMSOL CONFERENCE 2017 BOSTON

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Simulating Surface Plasmons at Metal Surfaces and its Application in Optoelectronic Devices with COMSOL Multiphysics

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Outline

❑ Introduction

- Surface plasmon polaritons (SPP)

❑ Simulation of SPP using COMSOL Wave Optics

- Prism coupling
- Scattering configuration (grating coupling)
- Explore SPP properties via scattering simulation

❑ Application examples

- Plasmon energy loss in OLED
- Surface plasmon-enhanced fluorescence spectroscopy (SPFS)

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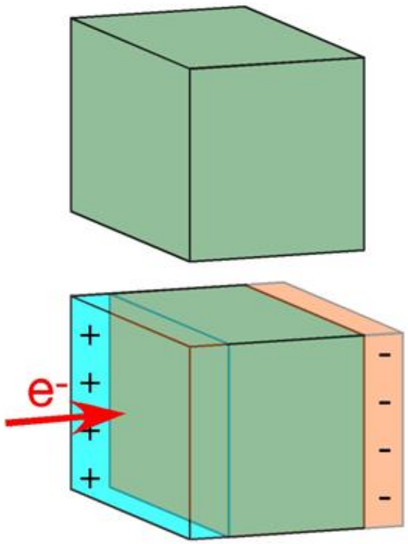
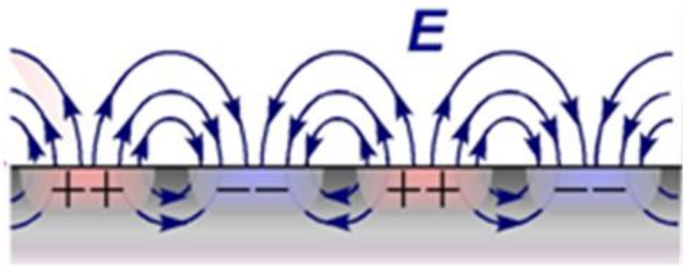
Bulk plasmons



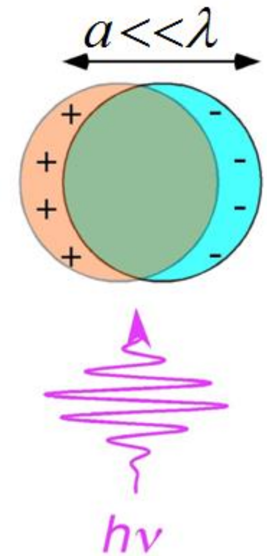
$$\omega_p^2 = \frac{ne^2}{\varepsilon_0 m^*}$$

Surface plasmon polaritons



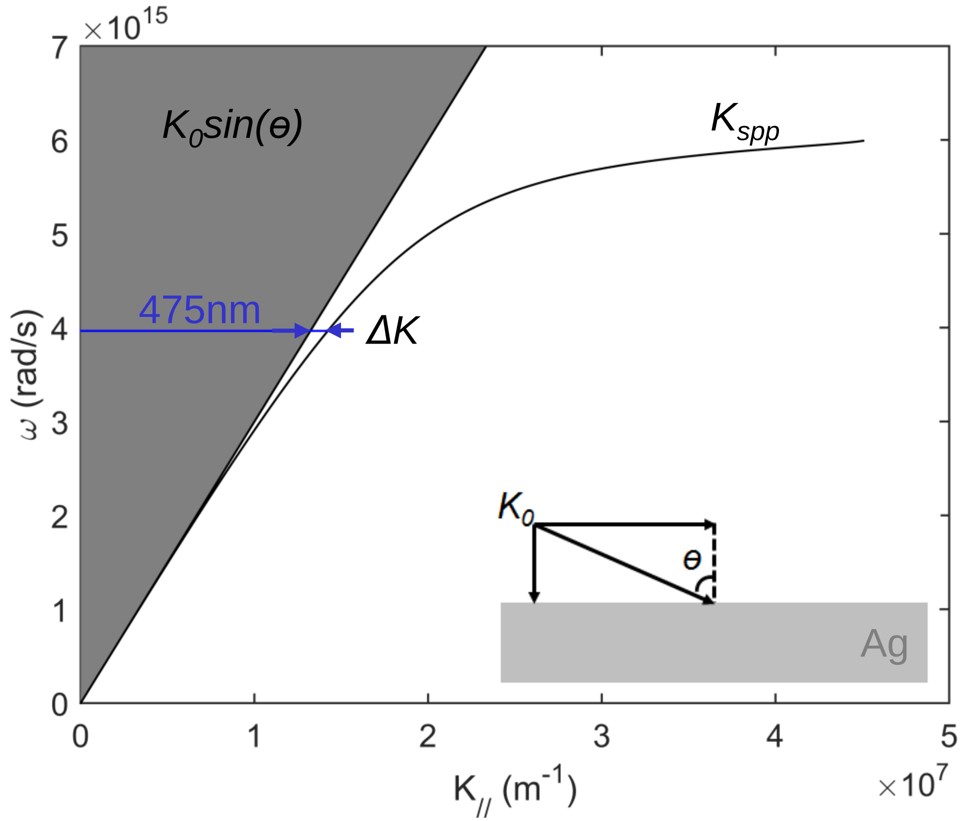
$$k_{SPP} = k_0 \sqrt{\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}}$$

Mie plasmons



$$\alpha = 4\pi a^3 \frac{\varepsilon_m - \varepsilon_d}{\varepsilon_m + 2\varepsilon_d}$$

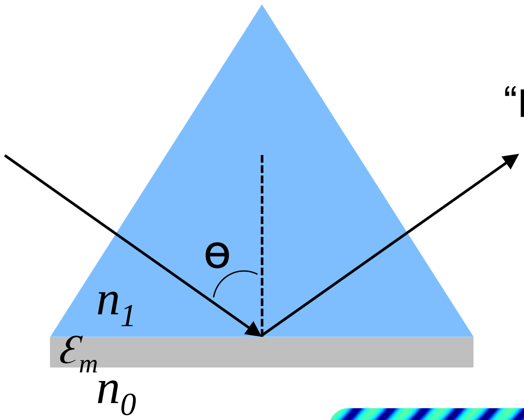
Surface plasmon polaritons – a guided surface wave



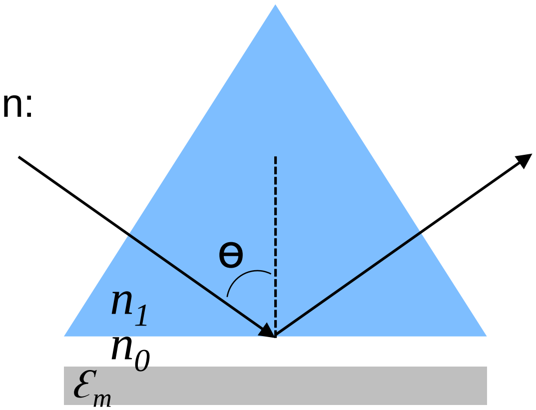
- ❑ Transverse magnetic (TM, or *p*-polarized) mode – H_z, E_x, E_y
- ❑ "Phase-matching" (ΔK) condition for SPP excitation

SPP excitation – prism coupling

Kretschmann-Raether

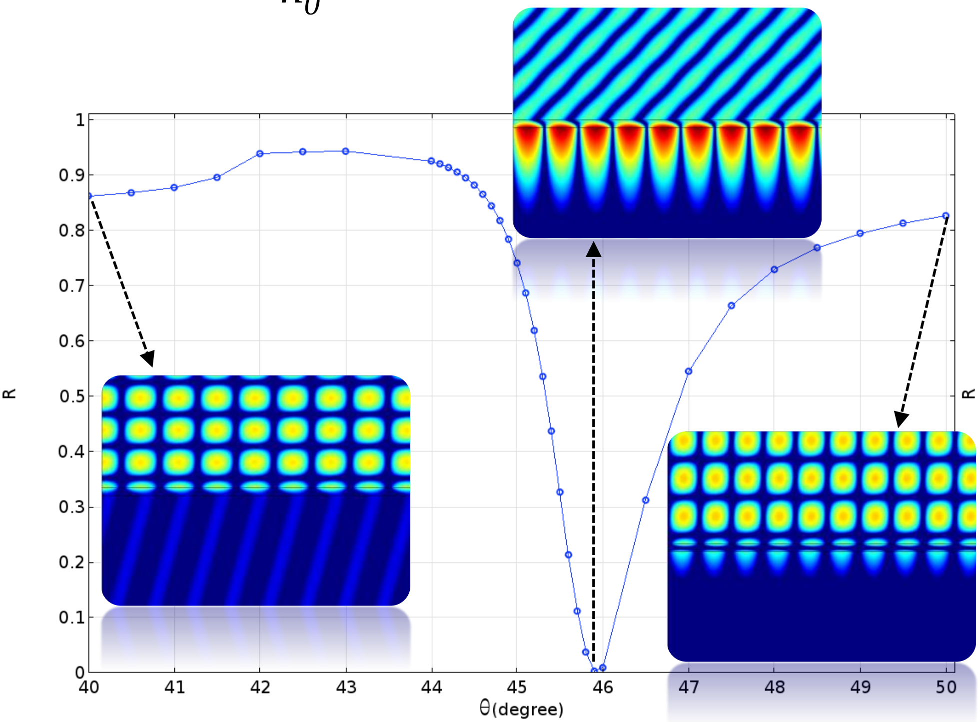


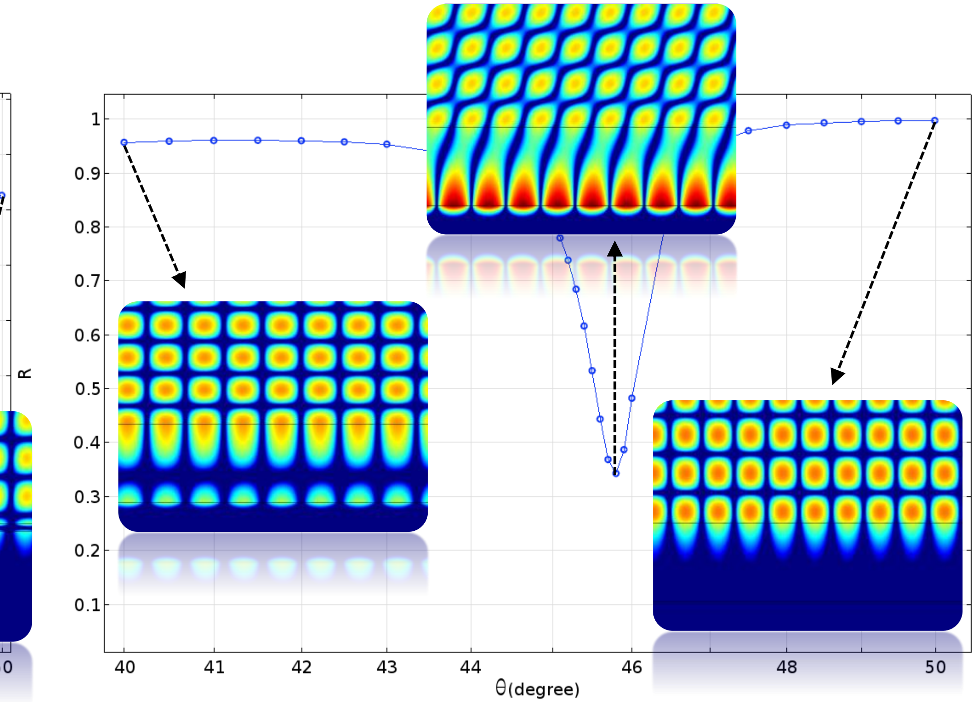
Otto



"Phase-matching" condition:

$$n_1 k_0 \sin(\theta) \approx k_{spp}$$



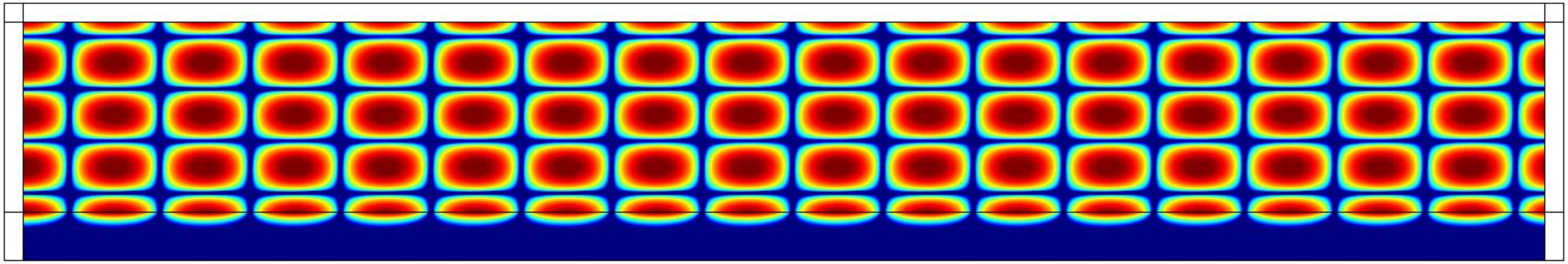


Yushanov, et al, COMSOL Conference 2012

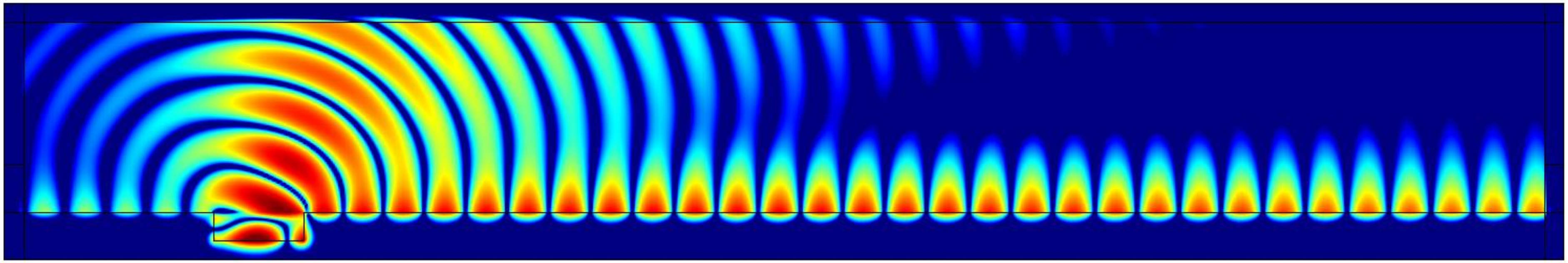
SPP excitation – scattering

Symmetry breaking by discontinuity/defect provides a broad spectrum of spatial frequency, allowing the phase matching (Δk) to be attained for SPP excitation.

(1) Full-field simulation w/o the slit to generate incident field for step 2 (ɵ = 30°).

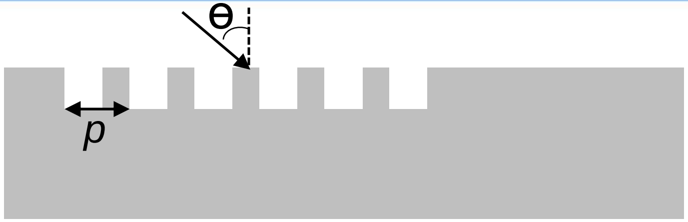


(2) Scattered-field simulation with the output from step 1 as the incident field.



Scattering configuration enables the local excitation of SPP and opens the way for further study on its wave properties such as attenuation, interference, focusing, etc.

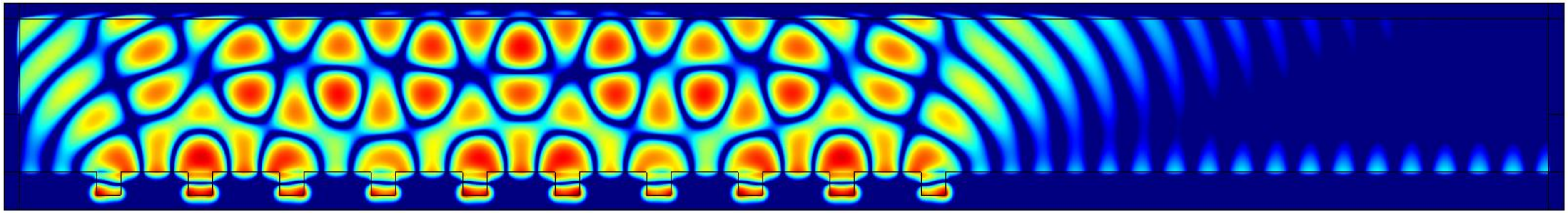
SPP excitation – grating coupling



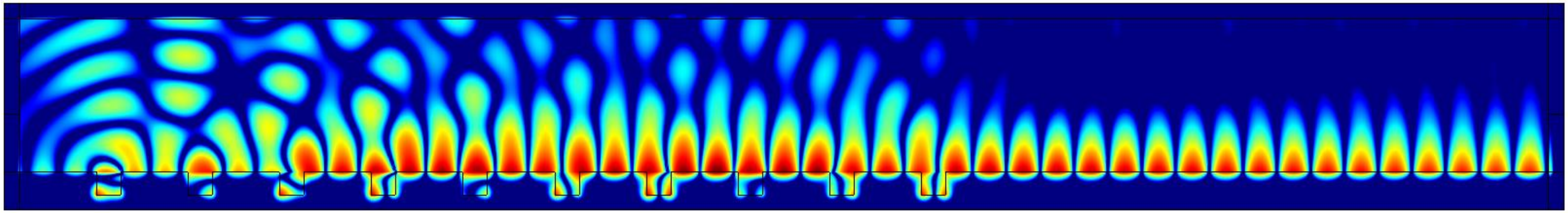
Finite grating is a special case of scattering configuration, with resonance:

$$k_0 \sin(\theta) \pm m \cdot (2\pi / p) = k_{spp}$$

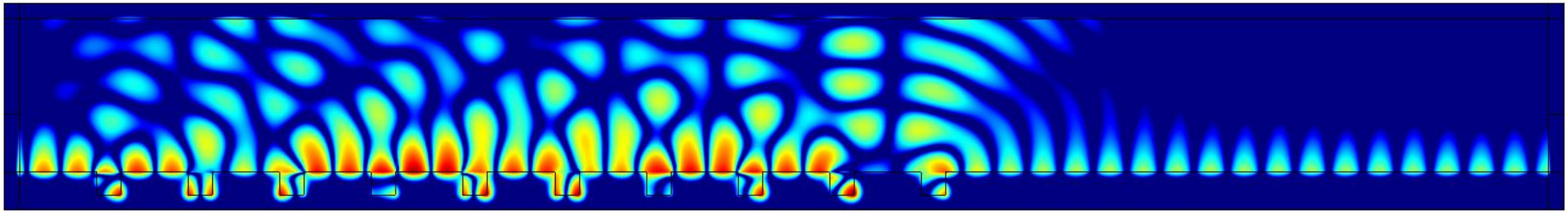
θ = 0°



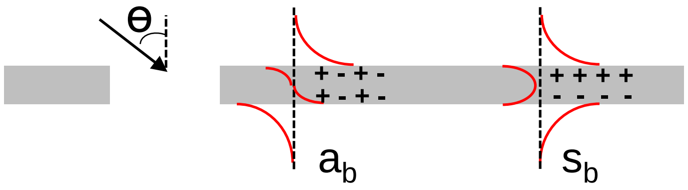
θ = 16.5° (resonance)



θ = 30°

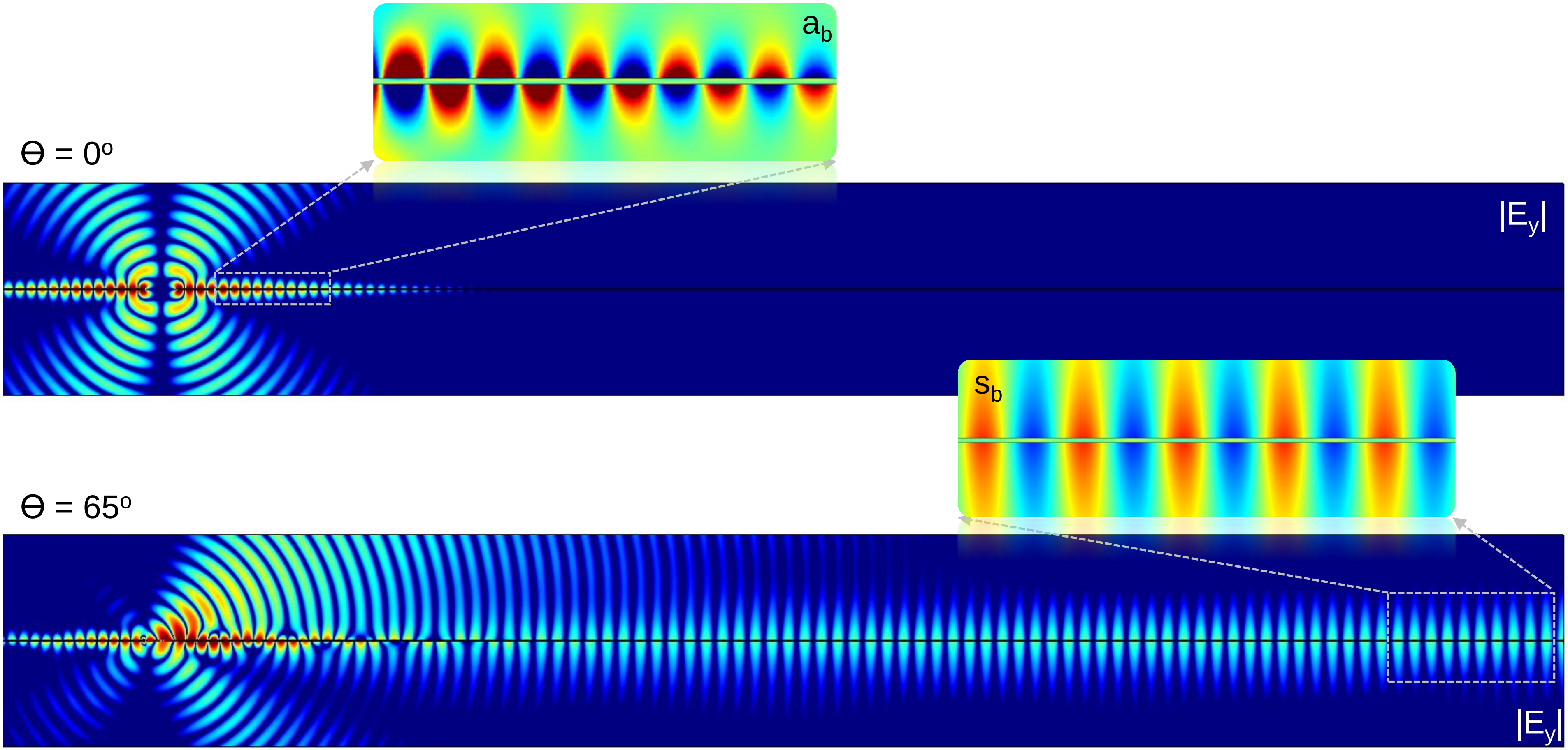


Coupled SPPs at thin metal film



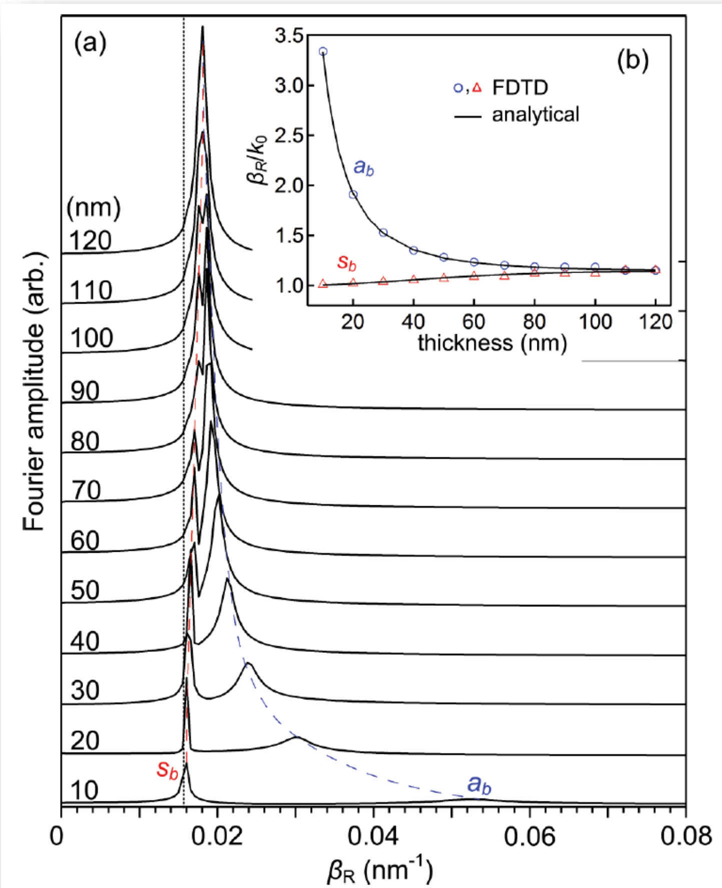
SPPs at the two interfaces of thin metal film interact to form two coupled SPP modes:

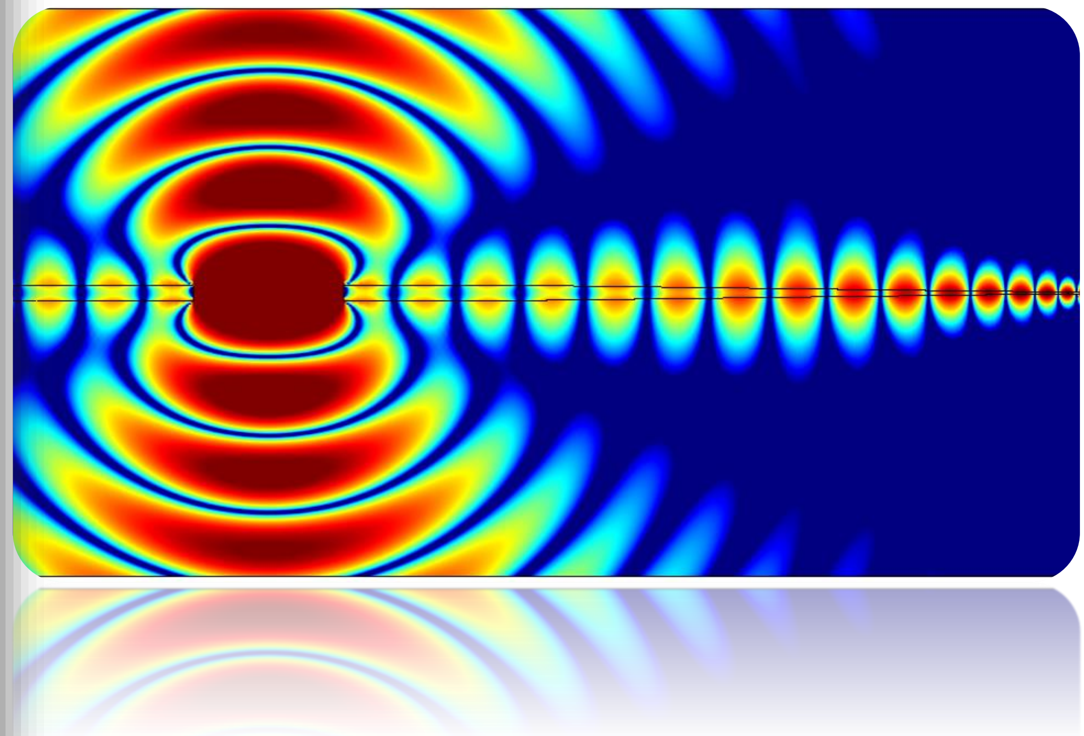
- Anti-symmetric bound mode (a_b): strong confinement, strong damping (short range SPP).
- Symmetric bound mode (s_b): weak confinement, small damping (long range SPP).



Adiabatic focusing of SPP by thin wedge

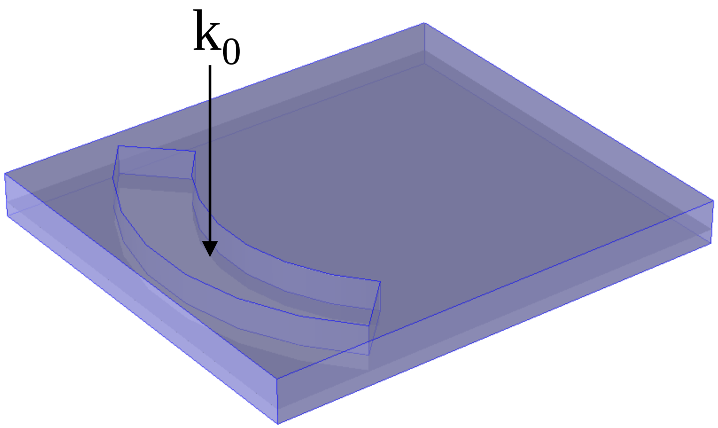
The dispersion with respect to film thickness leads to adiabatic focusing of the thin film coupled SPP in a wedge structure.



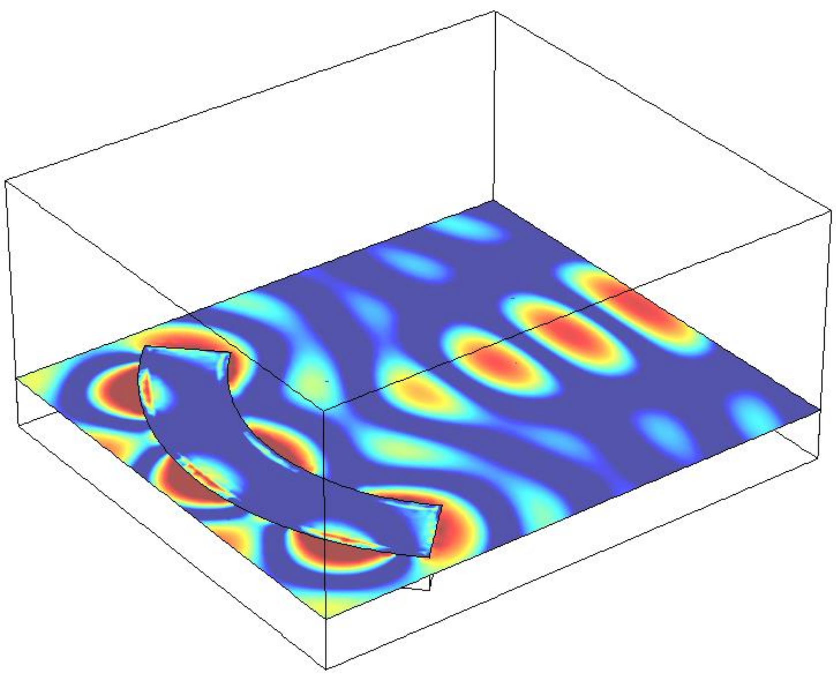


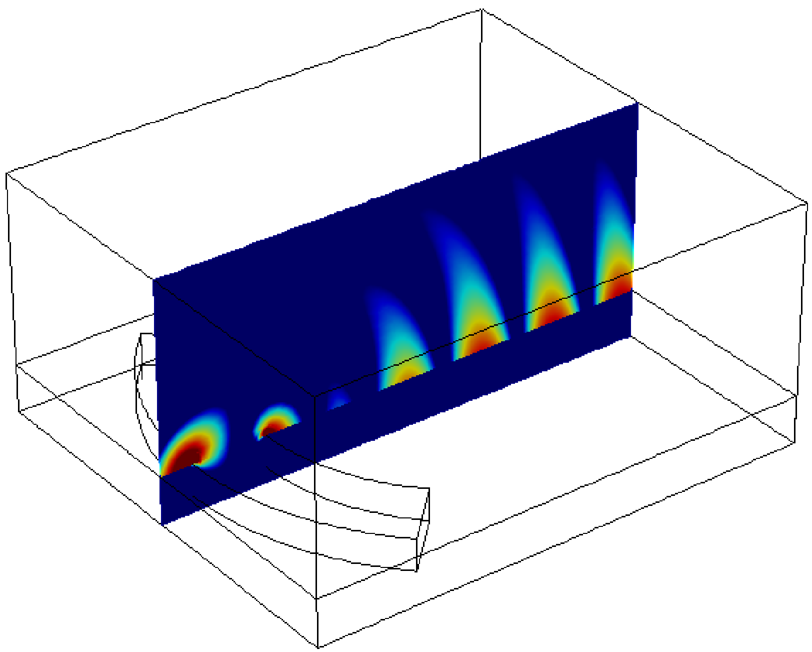
Wang, et al, PHYSICAL REVIEW B **86,** 165408 (2012)

SPP focusing lens



Engineering the wave front of SPP by 2D arrangement of local coupling structures.





Giving Shape to Ideas

Konica Minolta OLED lighting

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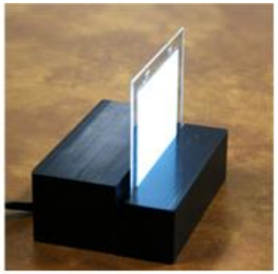
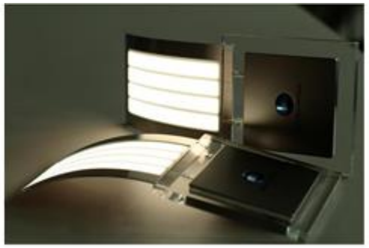
Prototype



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

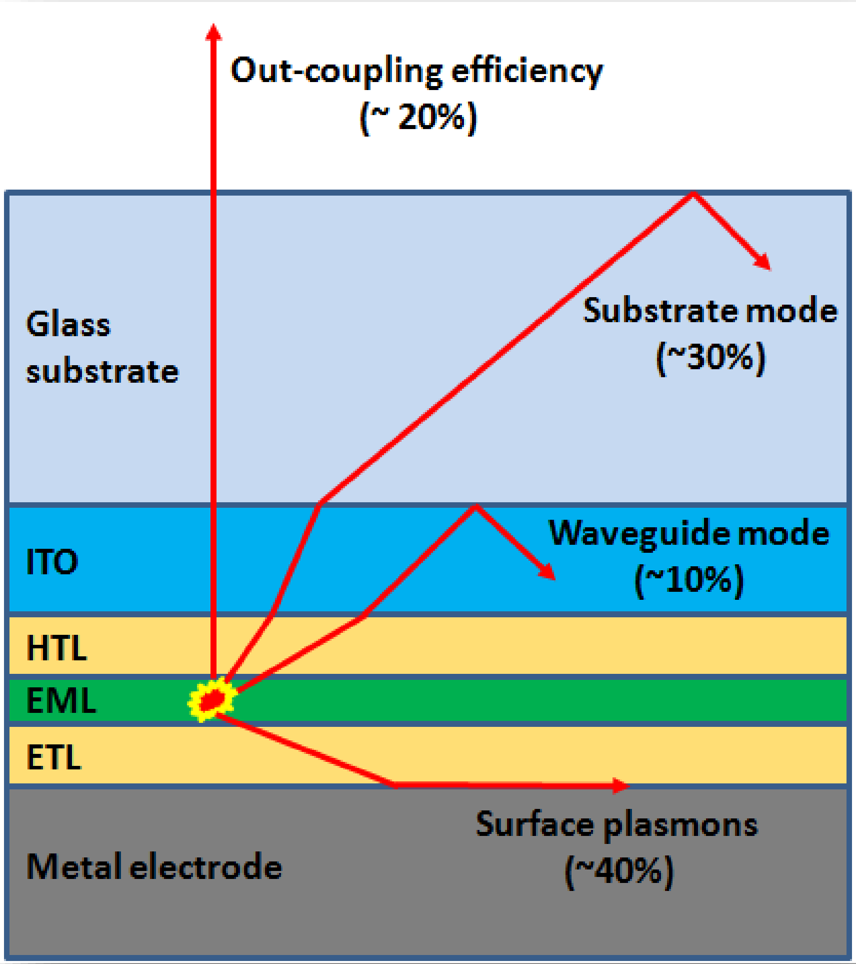
Symfos

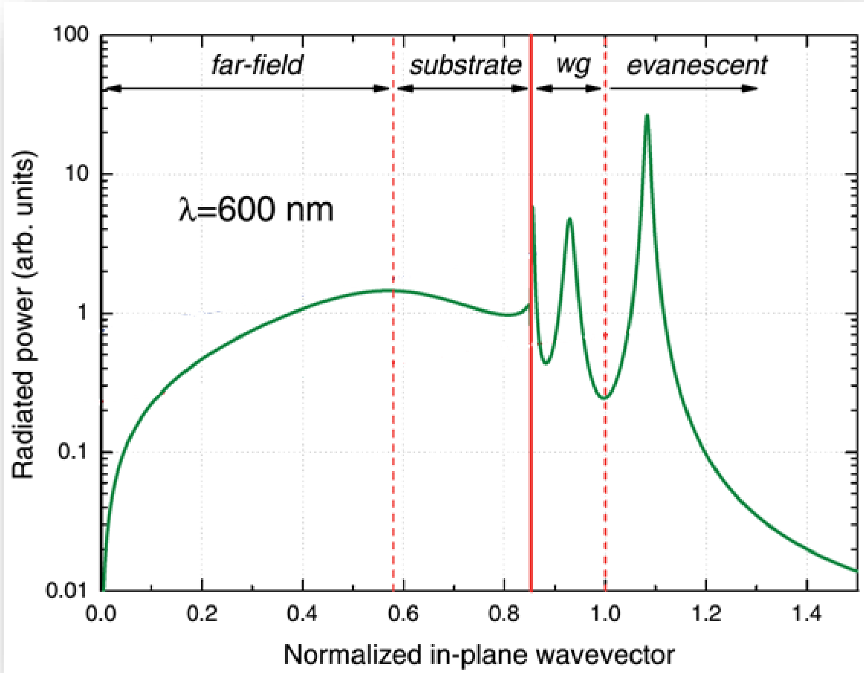
World's first all-phosphorescent white OLED product" Symfos OLED-010K"

Mass production for plastic substrate flexible OLED lighting panel

World's first flower illumination

Plasmon energy loss in OLED

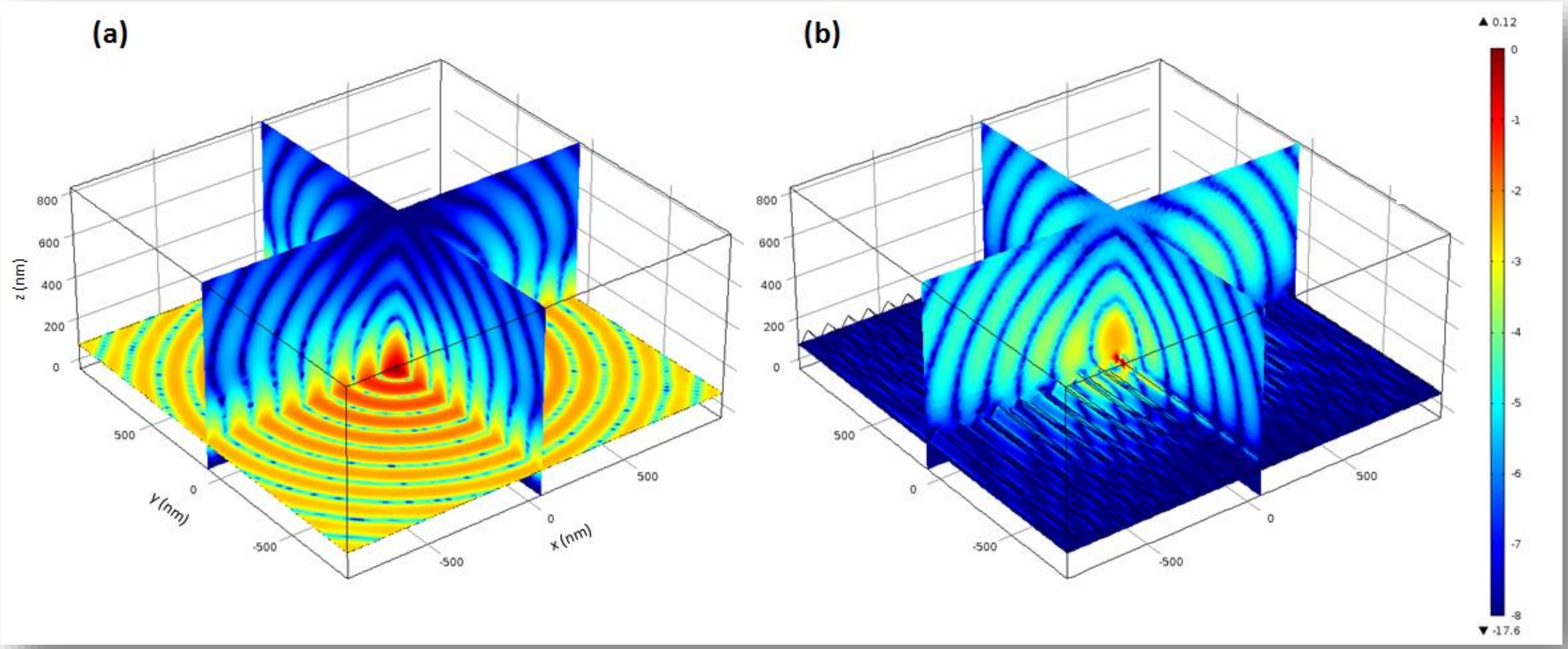


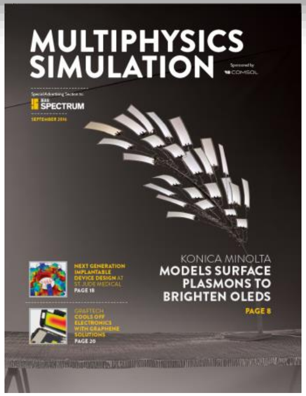


Typical power distribution spectrum of an OLED viewed in the k-space*

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

Reducing plasmon loss in OLED by nanostructured cathode





"Let there be light: a brighter future for OLED",
IEEE Spectrum, September 2016

Wang, et al, COMSOL Conference 2015

Surface plasmon-enhanced bio-sensing

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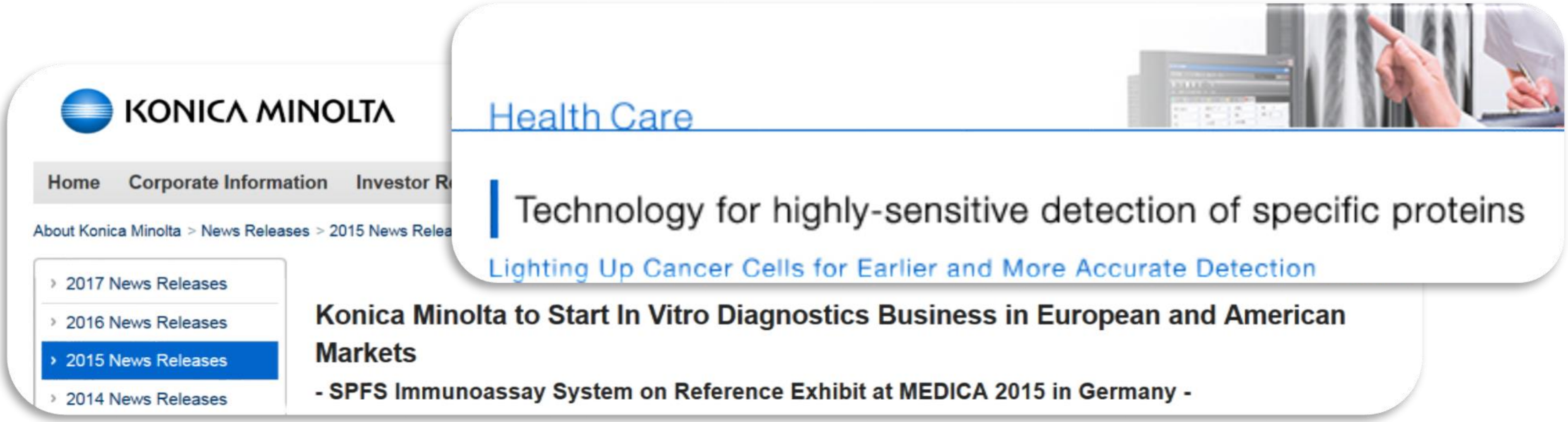
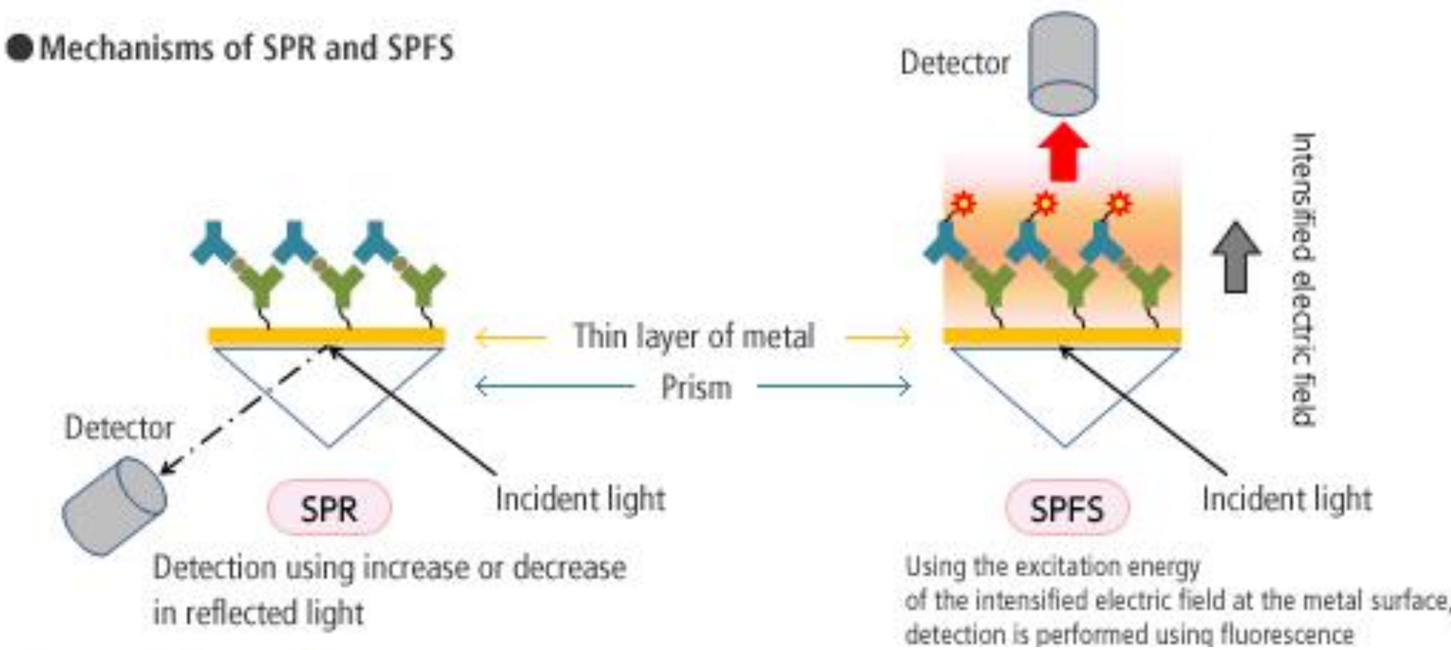
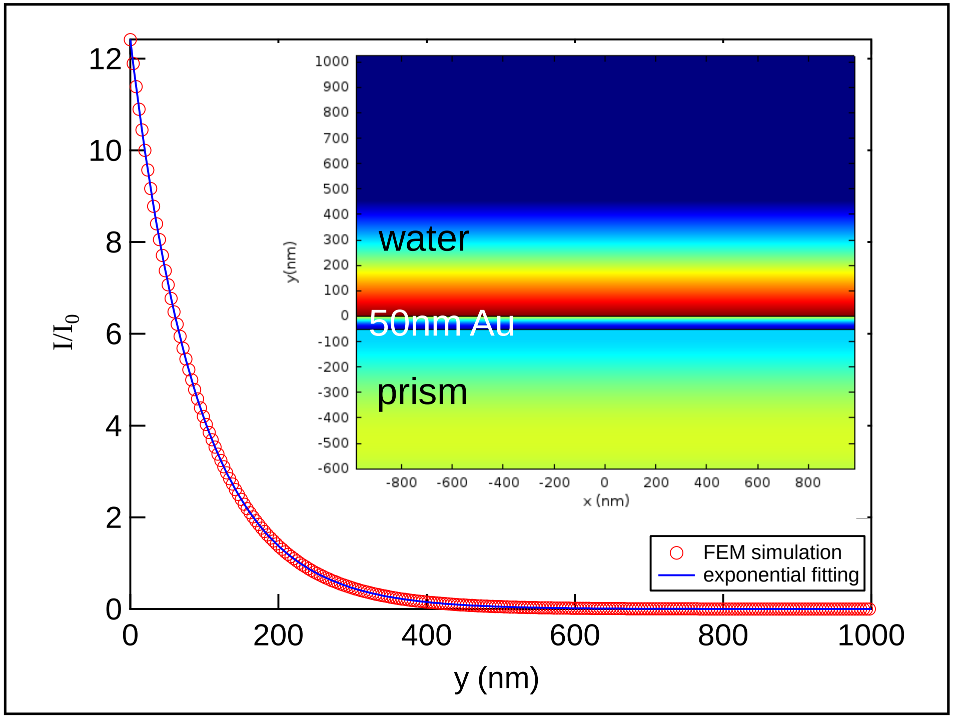
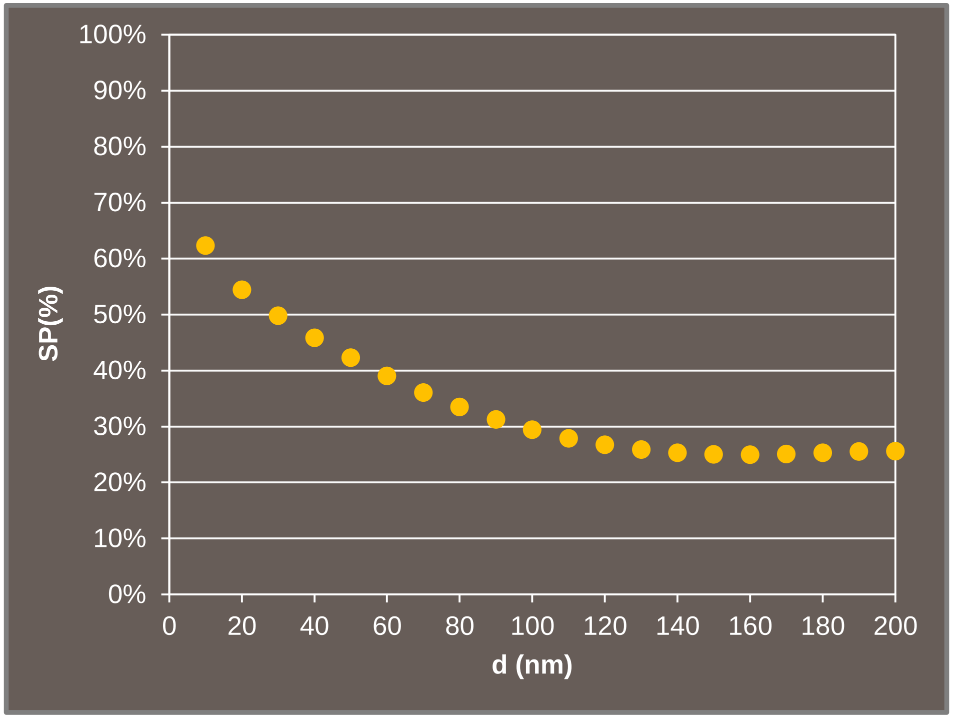




Trade-off btw SP-enhanced excitation and -quenched emission in SPFS





Excitation field enhancement

SP quenching of fluorescence emission

Thank You!
QUESTIONS?

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