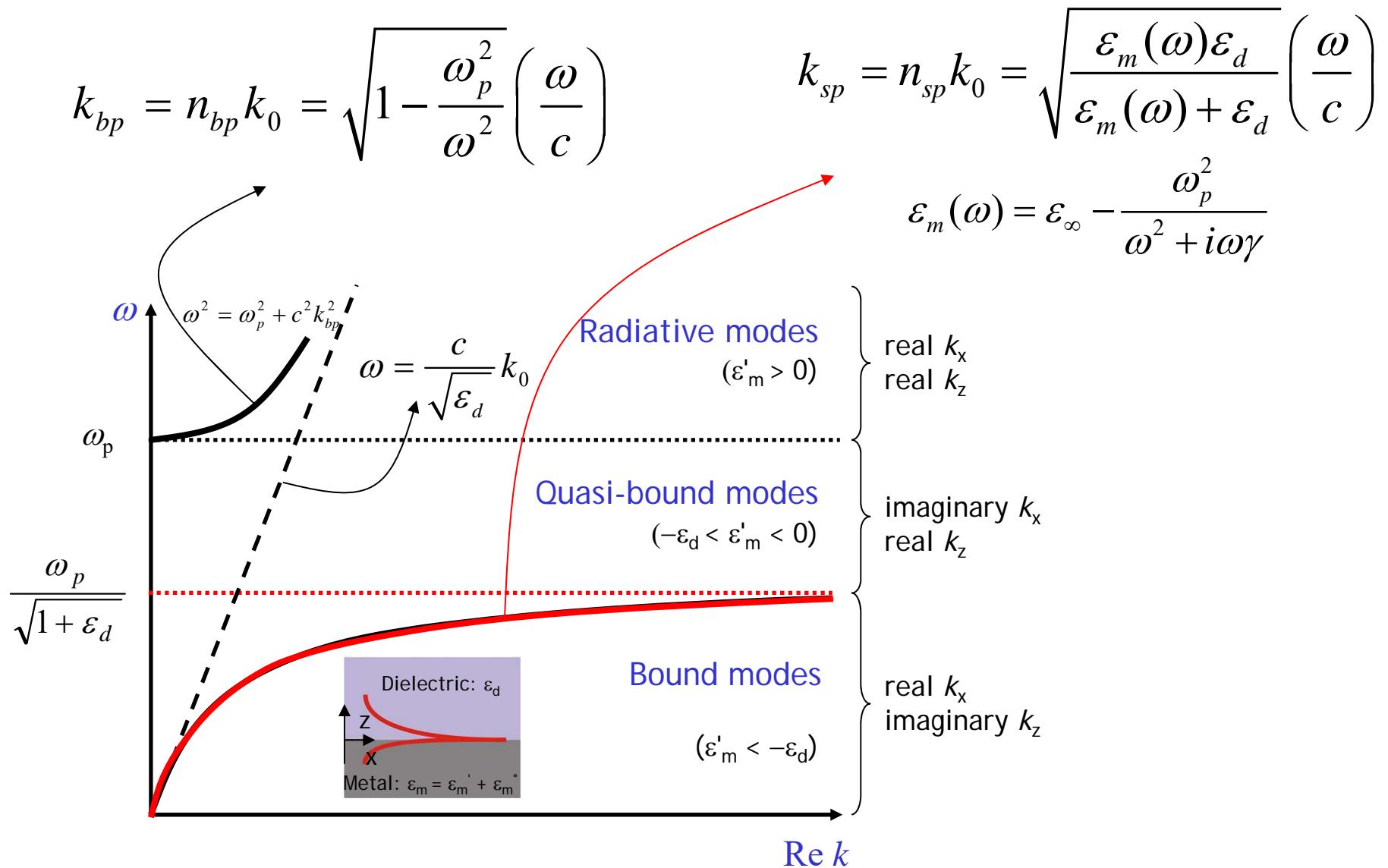


Excitation of surface plasmons



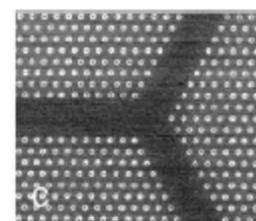
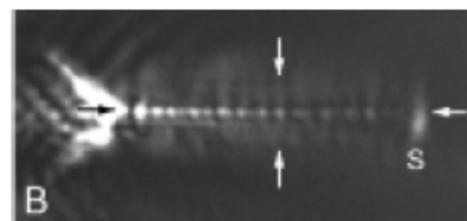
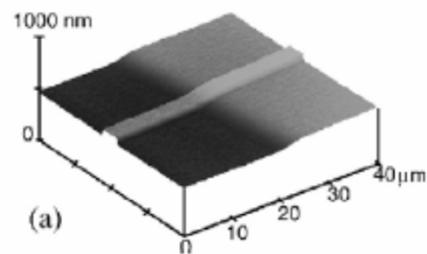
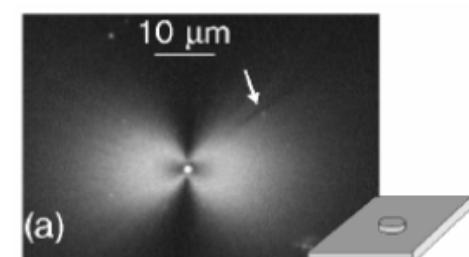
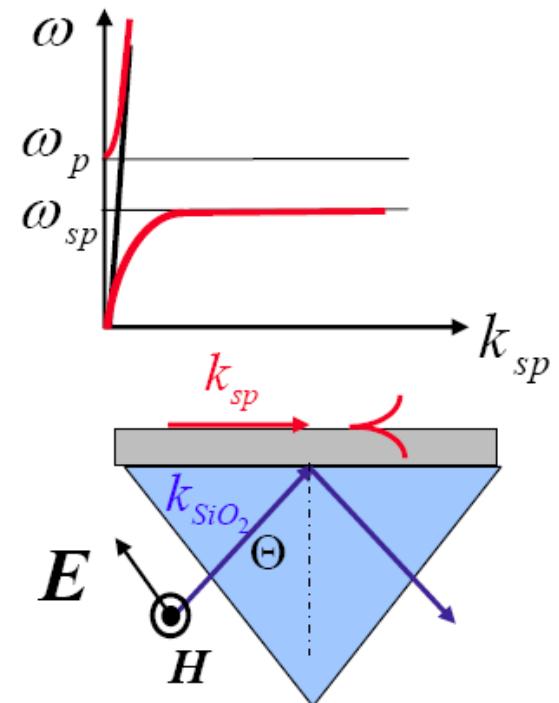
The dispersion relation for surface plasmons

- Useful for describing plasmon excitation & propagation

Coupling light to surface plasmon-polaritons

- Using high energy electrons (EELS)
- Kretschmann geometry
- Grating coupling
- Coupling using subwavelength features
- A diversity of guiding geometries

$$k_{\parallel, SiO_2} = \sqrt{\epsilon_d} \frac{\omega}{c} \sin \theta = k_{sp}$$



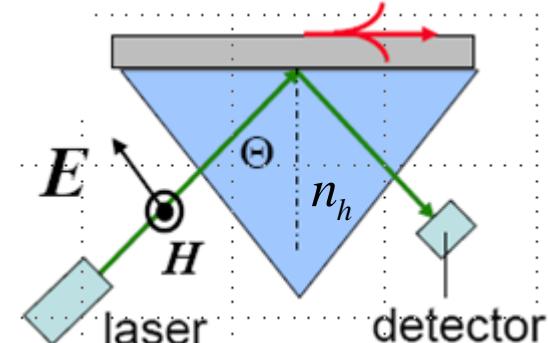
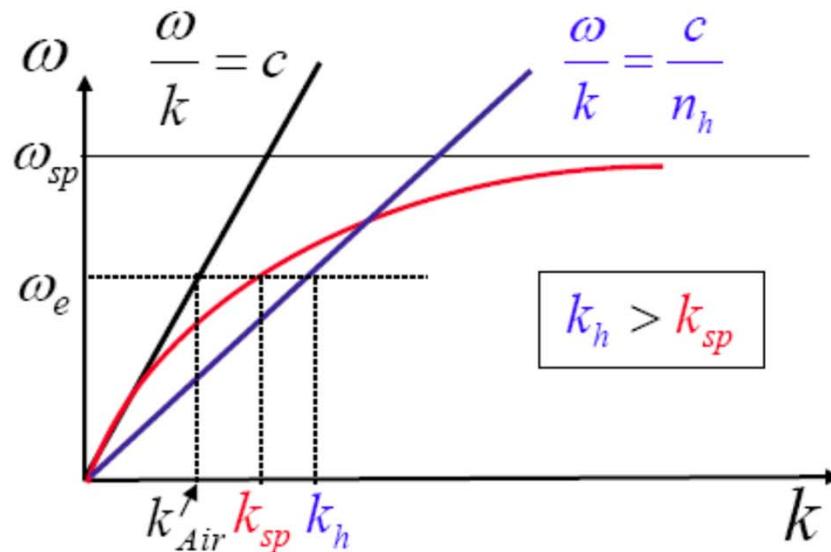
Excitation Surface-Plasmon Polaritons (SPPs) with Light

Problem SPP modes lie below the light line

- No coupling of SPP modes to far field and vice versa (reciprocity theorem)
- Need a “trick” to excite modes below the light line

Trick 1: Excitation from a high index medium

- Excitation SPP at a metal/air interface from a high index medium $n = n_h$



- SPP at metal/air interface can be excited from a high index medium!
- How does this work in practice ?

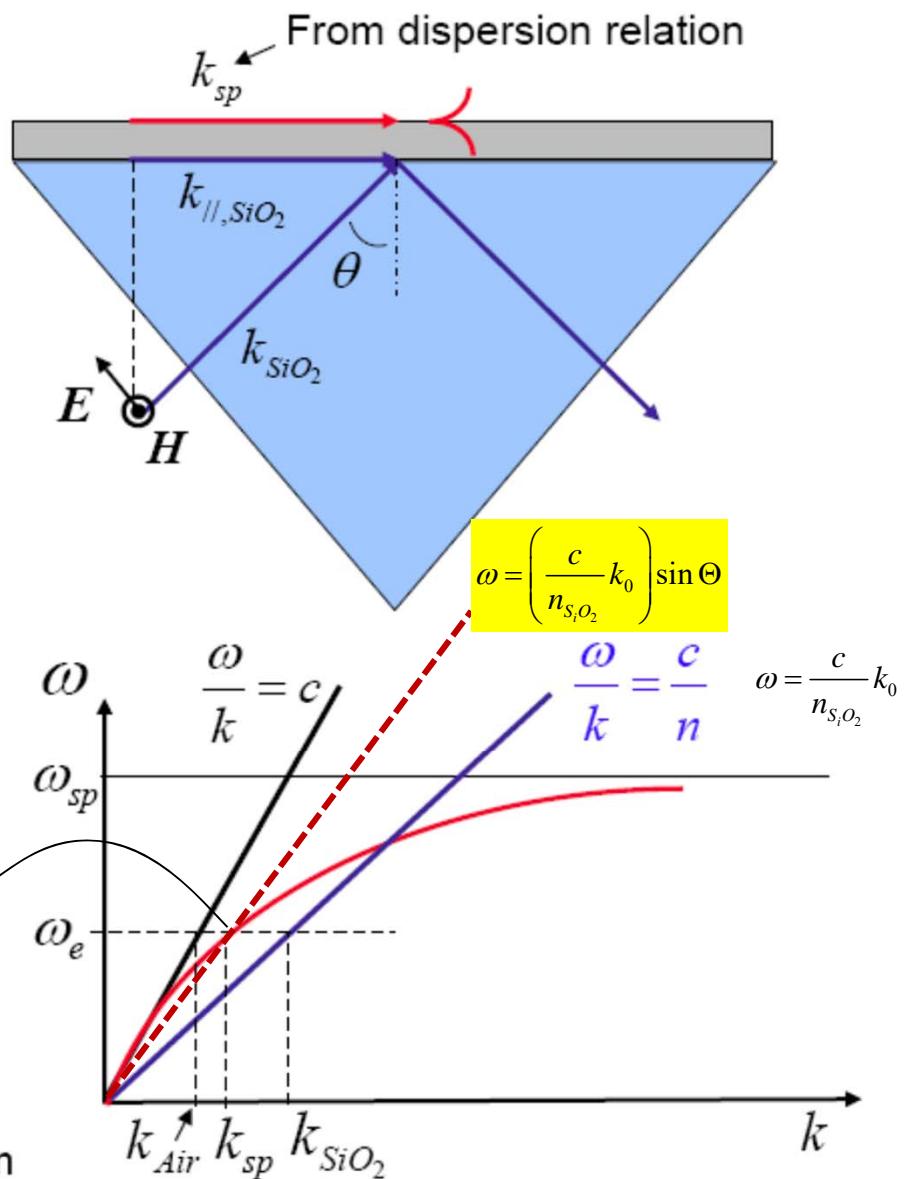
Excitation Surface-Plasmon Polaritons with Light

Kretschmann geometry (Trick 1)

- Makes use of SiO_2 prism
 - Create evanescent wave by TIR
 - Strong coupling when $k_{\parallel,\text{SiO}_2}$ to k_{sp}
- ↓
- Reflected wave reduced in intensity

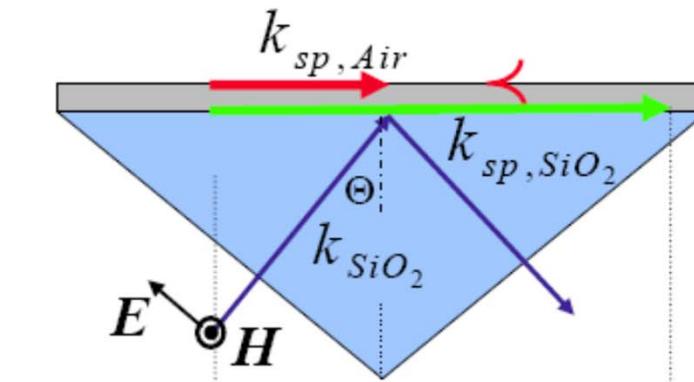
$$k_{\parallel,\text{SiO}_2} = (n_{\text{SiO}_2} k_0) \sin \Theta = k_{sp}$$

Note: we are matching energy and momentum

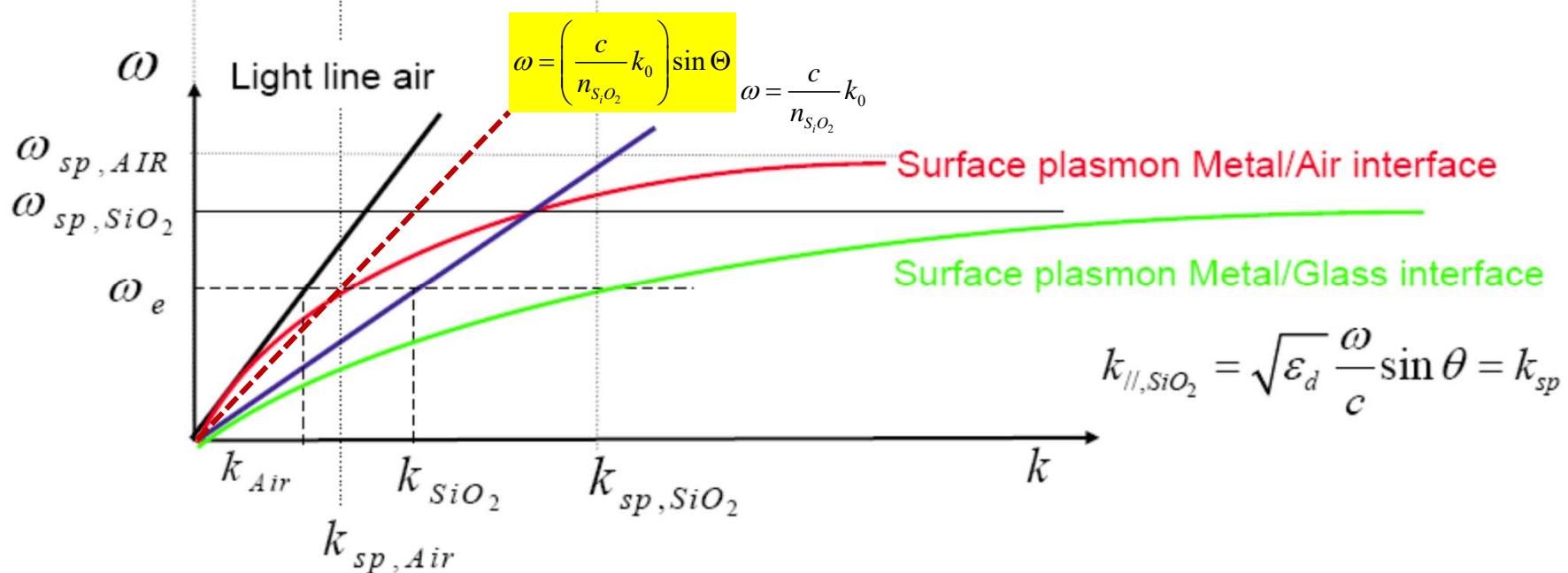


Surface-Plasmon is Excited at the Metal/Air Interface

Kretschmann geometry



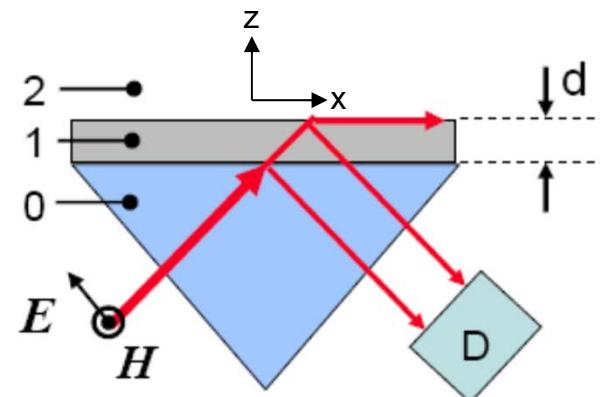
- Makes use of SiO_2 prism
- Enables excitation surface plasmons at the Air/Metal interface
- Surface plasmons at the metal/glass interface can not be excited!



Quantitative Description of the Coupling to SPP's

Calculation of reflection coefficient

- Solve Maxwell's equations for
- Assume plane polarized light
- Find case of no reflection
- Solution (e.g. transfer matrix theory! 😊)



$$R = \left| \frac{E_r^p}{E_0^p} \right|^2 = \left| \frac{r_{01}^p + r_{12}^p \exp(2ik_{z1}d)}{1 + r_{01}^p r_{12}^p \exp(2ik_{z1}d)} \right|^2$$

where r_{ik}^p are the amplitude reflection coefficients

Plane polarized light

$r_{ik}^p = \left(\frac{k_{zi}}{\epsilon_i} - \frac{k_{zk}}{\epsilon_k} \right) / \left(\frac{k_{zi}}{\epsilon_i} + \frac{k_{zk}}{\epsilon_k} \right)$

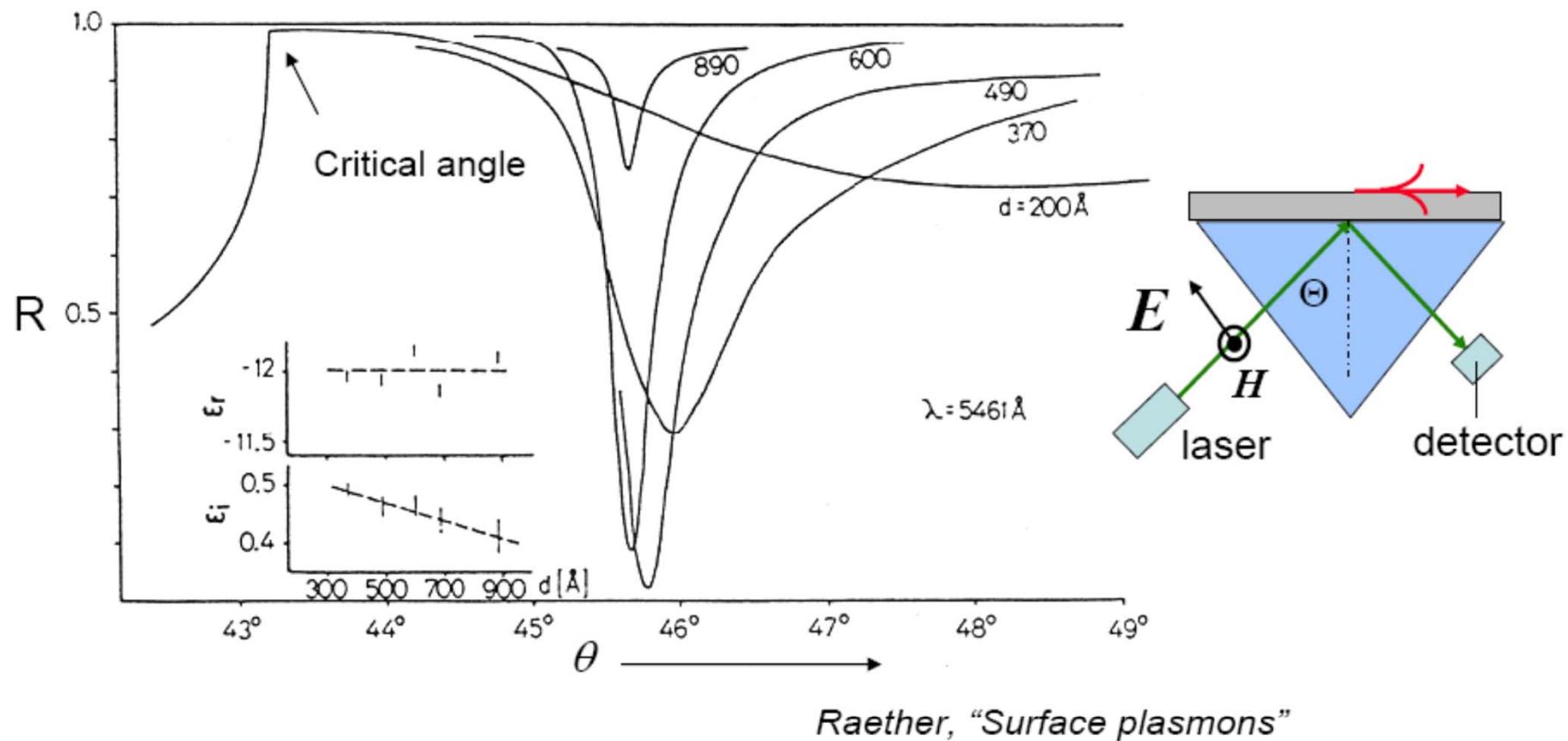
Also known as Fresnel coefficients (p 95 optics, by Hecht)

Notes: Light intensity reflected from the back surface depends on the film thickness

There exists a film thickness for perfect coupling (destructive interference between two refl. beams)

When light coupled in perfectly, all the EM energy dissipated in the film)

Dependence on Film Thickness



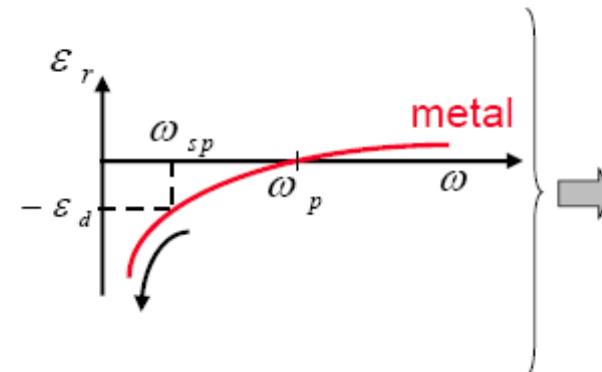
Raether, "Surface plasmons"

- Width resonance related to damping of the SPP
- Light escapes prism below critical angle for total internal reflection
- Technique can be used to determine the thickness of metallic thin films

Quantitative Description of the Coupling to SPP's

Intuitive picture: A resonating system

- When $|\epsilon_m'| \gg 1$...well below ω_{sp} :

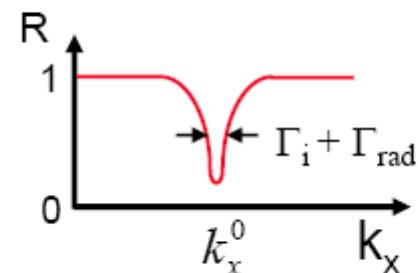


- and $|\epsilon_m''| \ll |\epsilon_m'|$...low loss...

$$(\gamma \ll \omega) \leftarrow \epsilon_r(\omega) = \epsilon_\infty - \frac{\omega_p^2}{\omega^2 + i\omega\gamma} = \left(\epsilon_\infty - \frac{\omega_p^2}{\omega^2 + \gamma^2} \right) + i \left(\frac{\omega_p^2\gamma}{\omega^3 + \omega\gamma^2} \right)$$

→ Reflection coefficient has Lorentzian line shape (characteristic of resonators)

$$R = 1 - \frac{4\Gamma_i\Gamma_{rad}}{\left[(k_x - k_x^0)^2 + (\Gamma_i + \Gamma_{rad})^2 \right]}$$

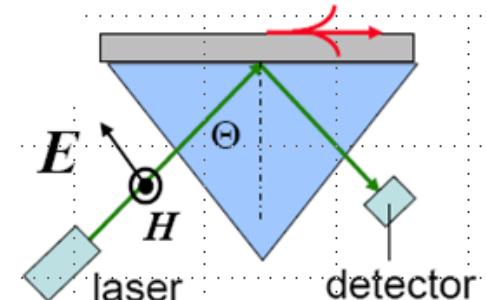


Where Γ_i : Damping due to resistive heating

Γ_{rad} : Damping due to re-radiation into the prism

k_x^0 : The resonance wave vector (maximum coupling)

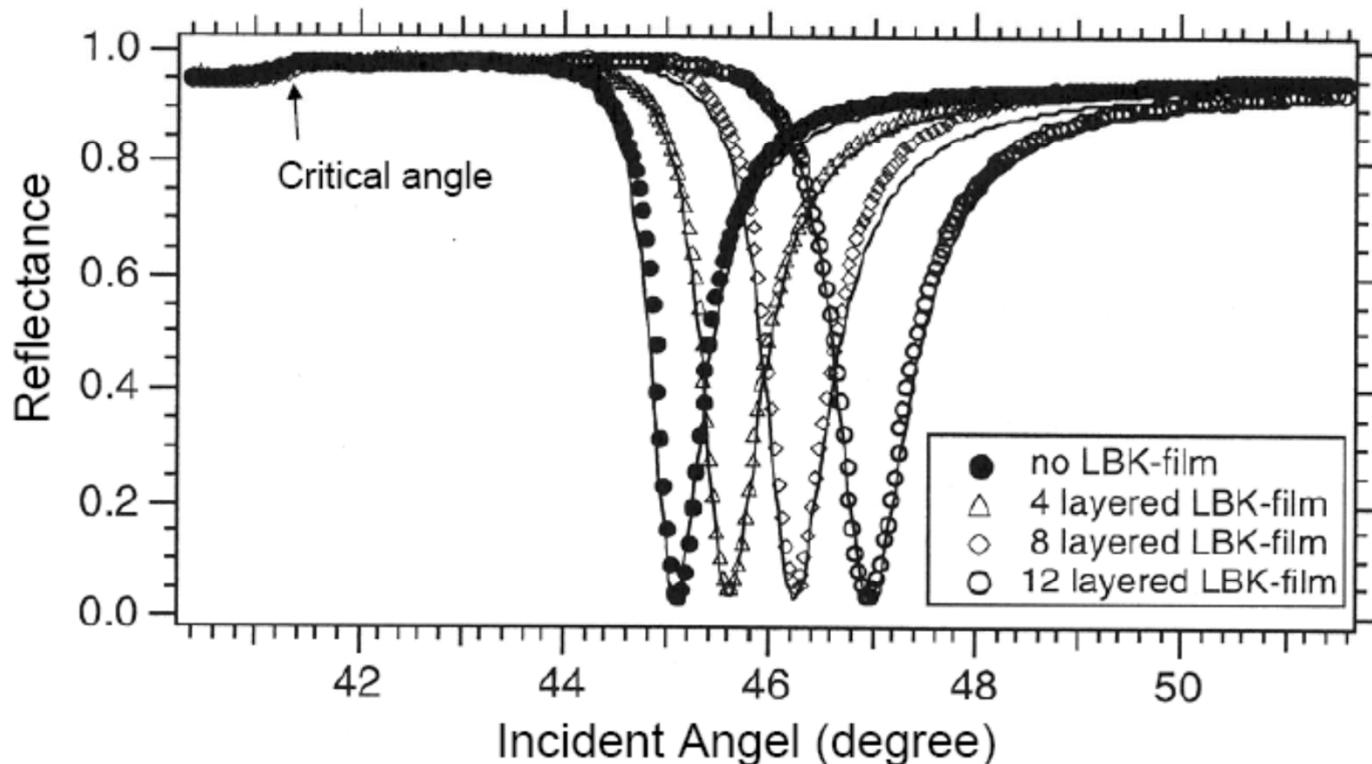
Note: R does to zero at resonance when $\Gamma_i = \Gamma_{rad}$



Current Use of the Surface Plasmon Resonance Technique

Determination film thickness of deposited films

- Example: Investigation Langmuir-Blodgett-Kuhn (LBK) films



- Coupling angle strongly dependent on the film thickness of the LBK film
- Detection of just a few LBK layers is feasible

Hiroshi Kano, "Near-field optics and Surface plasmon Polaritons", Springer Verlag

Excitation Surface-Plasmon Polaritons with Gratings (trick 2)

Grating coupling geometry (trick 2)

- Bloch: Periodic dielectric constant couples waves for which the k-vectors differ by a reciprocal lattice vector \mathbf{G}

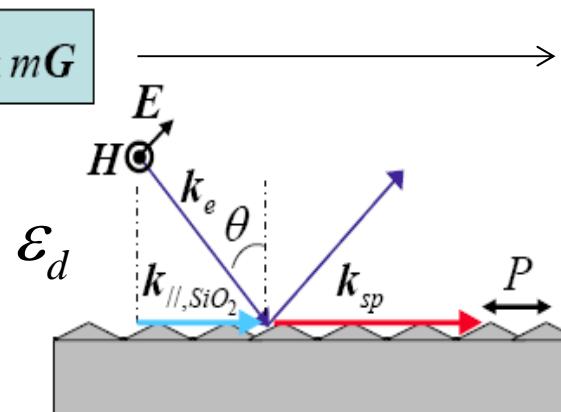
- Strong coupling occurs when

$$\mathbf{k}_{\parallel,SiO_2} = \mathbf{k}_{sp} \pm m\mathbf{G}$$

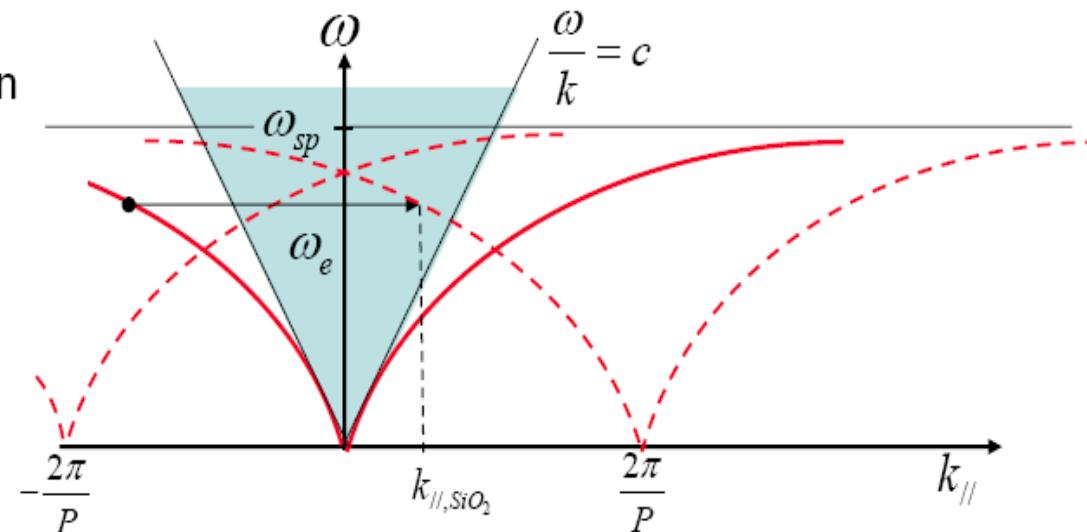
$$\mathbf{k}_{sp} = \mathbf{k}_{\parallel,d} \pm m\mathbf{G}$$

where: $\mathbf{k}_{\parallel,SiO_2} = |\mathbf{k}_e| = \sqrt{\epsilon_d} \frac{\omega}{c} \sin \theta$

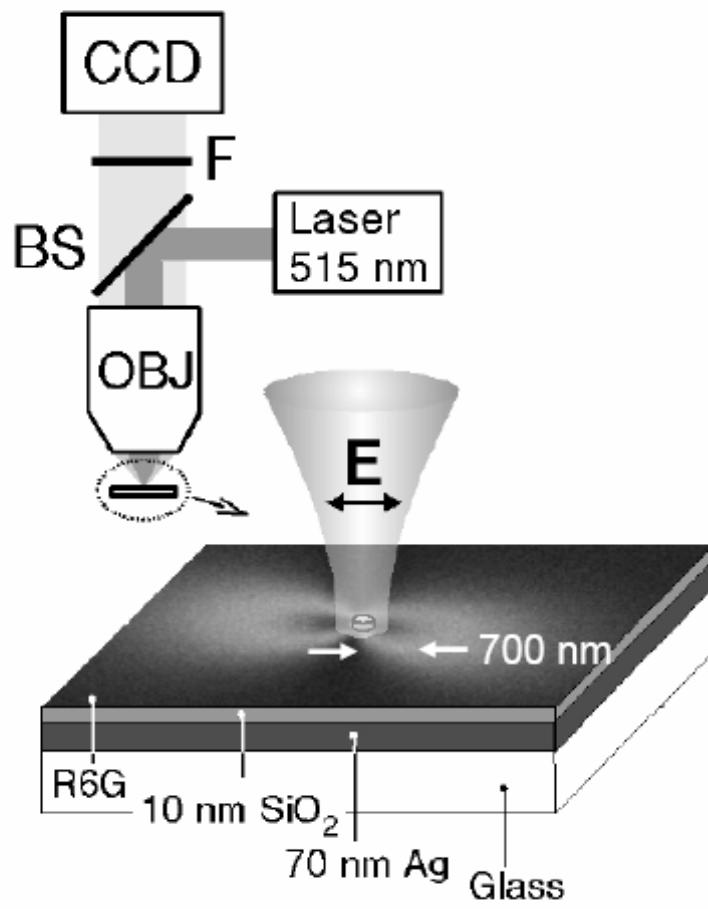
$$\left\{ \begin{array}{l} \mathbf{k}_{sp} = \frac{\omega}{c} \left(\frac{\epsilon_m \epsilon_d}{\epsilon_m + \epsilon_d} \right)^{1/2} \\ |\mathbf{G}| = 2\pi/P \end{array} \right.$$



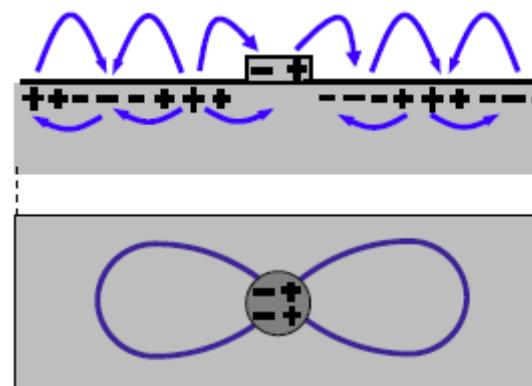
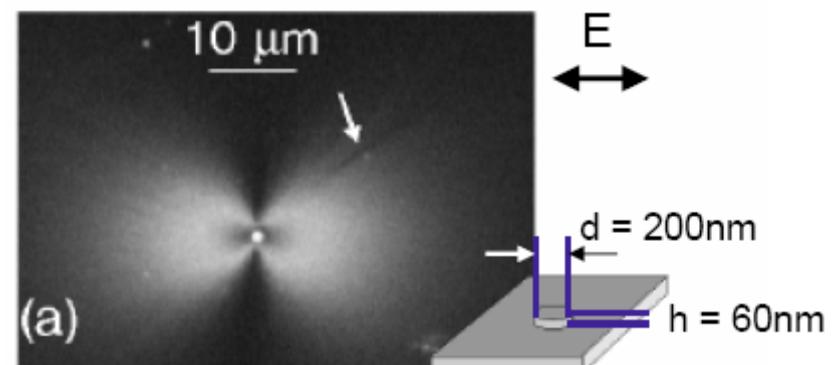
- Graphic representation



Excitation Surface-Plasmon Polaritons with Dots (Trick 3)



Dipolar radiation pattern



E-fields

Radiation

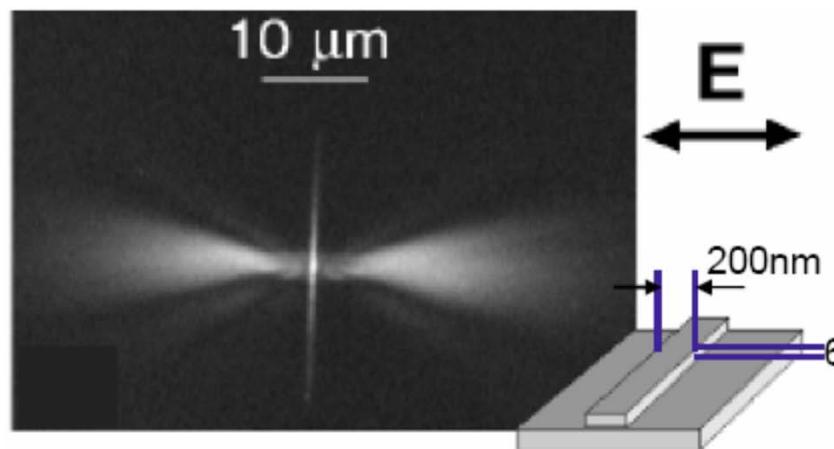
- Strong coupling: $k_{\parallel, \text{SiO}_2} = k_{sp} \pm \Delta k_{dot}$

Spatial Fourier transform of the dot contains significant contributions of Δk_{dot} values upto $2\pi/d$

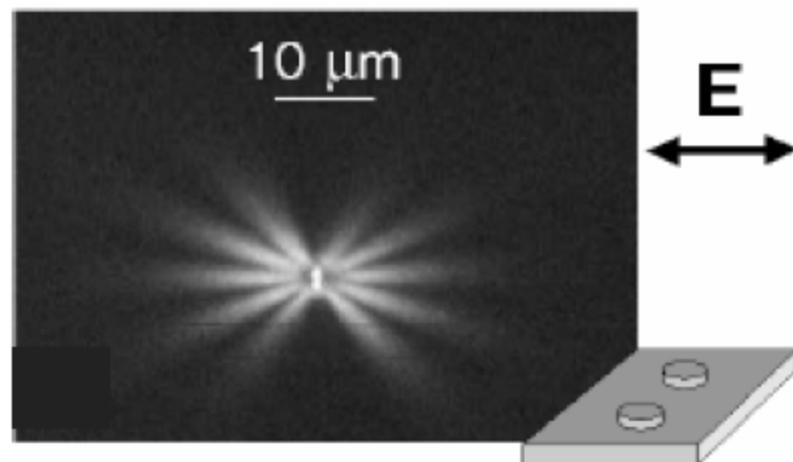
H. Ditlbacher, Appl. Phys. Lett. 80, 404 (2002)

- Dipole radiation in direction of charge oscillation!
- Reason: Plasmon wave is longitudinal

Other Excitation Geometries



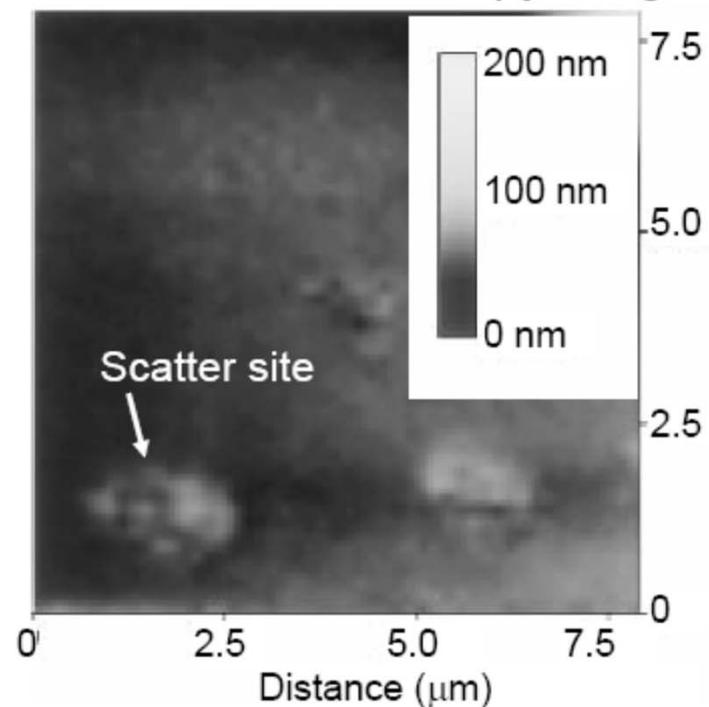
- Radiation pattern more directional
- Divergence angle determined by spot size
- Illumination whole line → radiation \perp to line



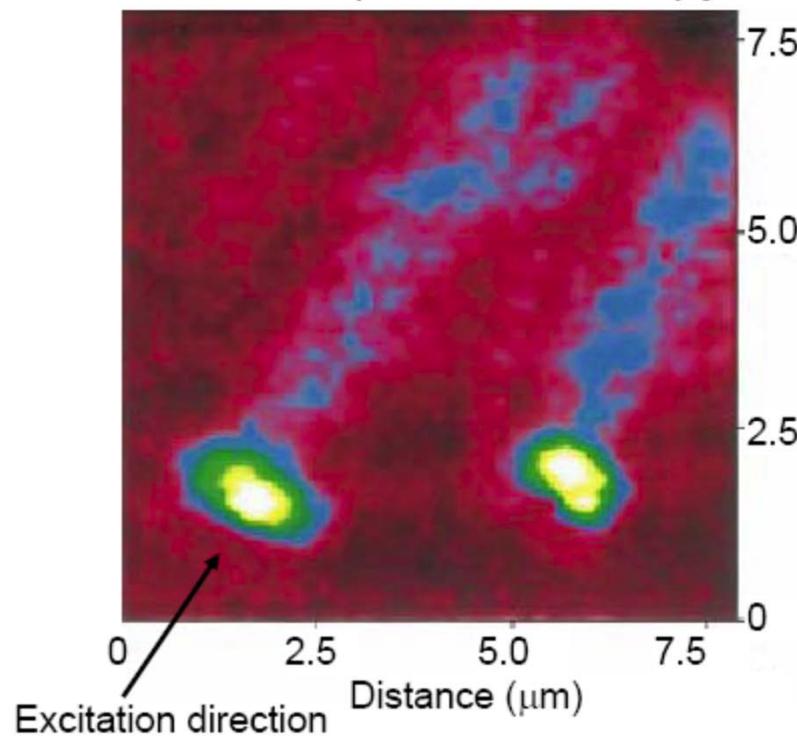
- Pattern results from interference 2 dipoles

Excitation Surface-Plasmon Polaritons from a Scattering Particle

Atomic Force Microscopy Image

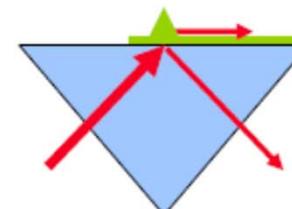


Near-field Optical Microscopy Image



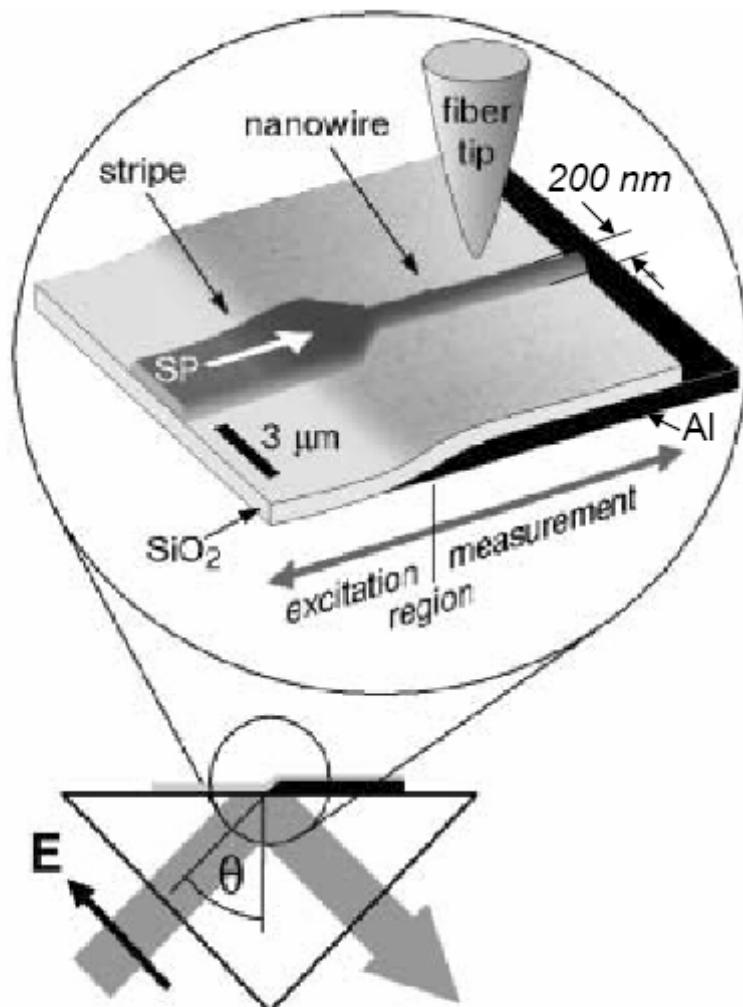
- Scattering site created by local metal ablation with a 248 nm Excimer laser ($P=200 \text{ GW/m}^2$)
- Scattering site brakes translational symmetry
- Enables coupling to SPP at non-resonant angles

I.I. Smolyaninov, Phys. Rev. Lett. 3877 (1996)

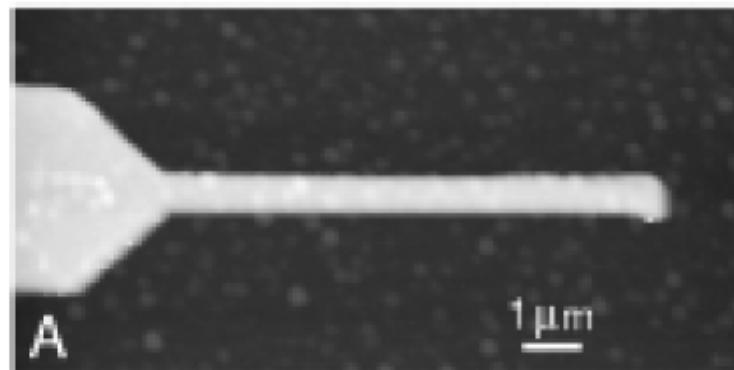


Excitation SPPs on stripes with $d < \lambda$

Excitation using a launch pad



Atomic Force Microscopy image



Near Field Optical Microscopy image

