Model of tip-sample near-field interaction

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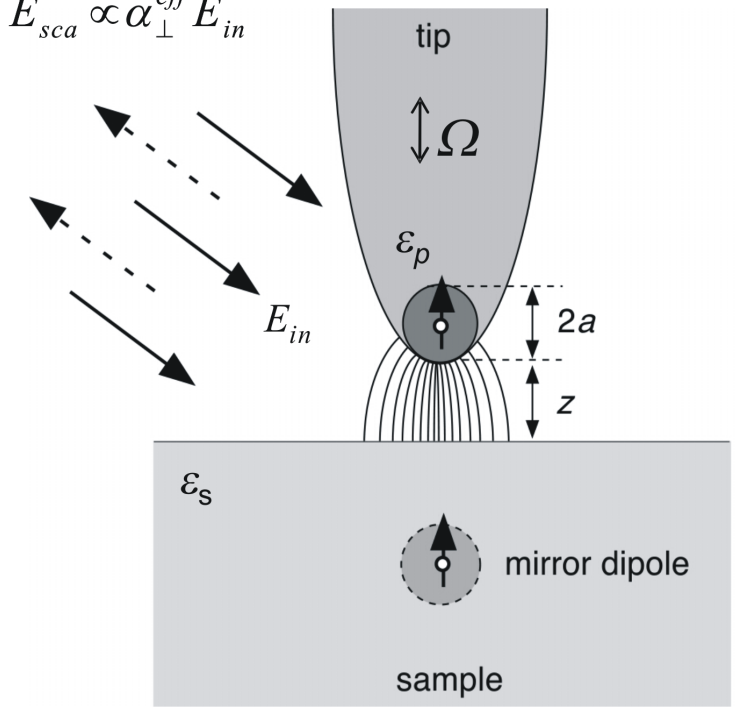
Far-field scattering:

$E_{sca} \propto \alpha_{\perp}^{eff} E_{in}$



Polarizability of the tip: $\alpha = 4\pi a^3 \frac{(\varepsilon_p - 1)}{(\varepsilon_p + 2)}$

Effective polarizability of tip and sample:

$$\alpha_{\perp}^{eff} = \frac{\alpha(1+\beta)}{1 - \frac{\alpha\beta}{16\pi(z+a)^3}}$$

$$\beta = \frac{1-\varepsilon_s}{1+\varepsilon_s}$$

Nonlinear term

- The point dipole, induced by the incident field at the tip apex, is compounded with the mirror dipole to give an effective polarizability.
- The scattered field can be originated from the surface EM wave, enabling s-SNOM to provide the field amplitude at surface.

Reproduced from Dr. Keilmann

Schematic layout of *s*-SNOM

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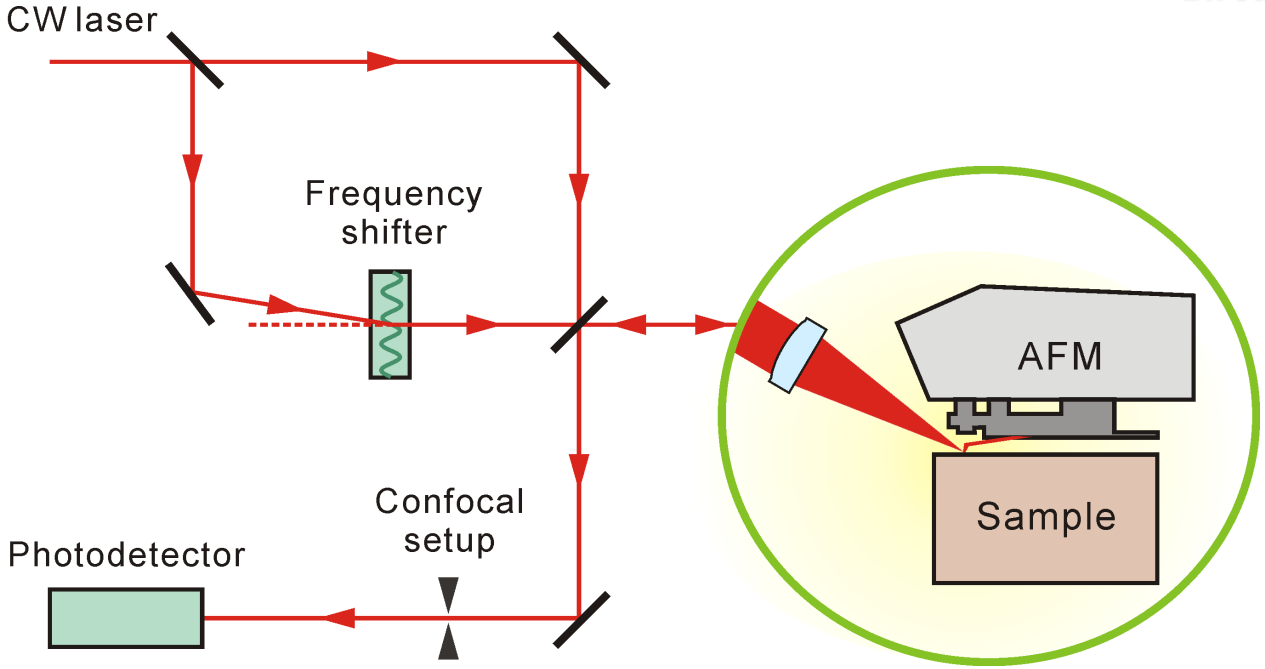

$$S_{\text{det}} \propto I_{sca} + I_{ref} + 2\sqrt{I_{sca} \times I_{ref}} \cos\left[(\Delta + n\Omega)t + \varphi\right], \quad I_{sca} \sim 10^{-6} I_{ref}$$

- The interferometric setup measures amplitude and phase of the scattered radiation.
- A heterodyne detection scheme is adopted to facilitate the detection of amplitude and phase.
- The cross term is amplified by the reference beam.
- The higher harmonic term is recorded to extract the near-field signal based on the nonlinear dependence of the effective polarizability on the tip-sample sample

R. Hillenbrand and F. Keilmann, Phys. Rev. Lett. ***85****, 3029 (2000).*

Spatial resolution

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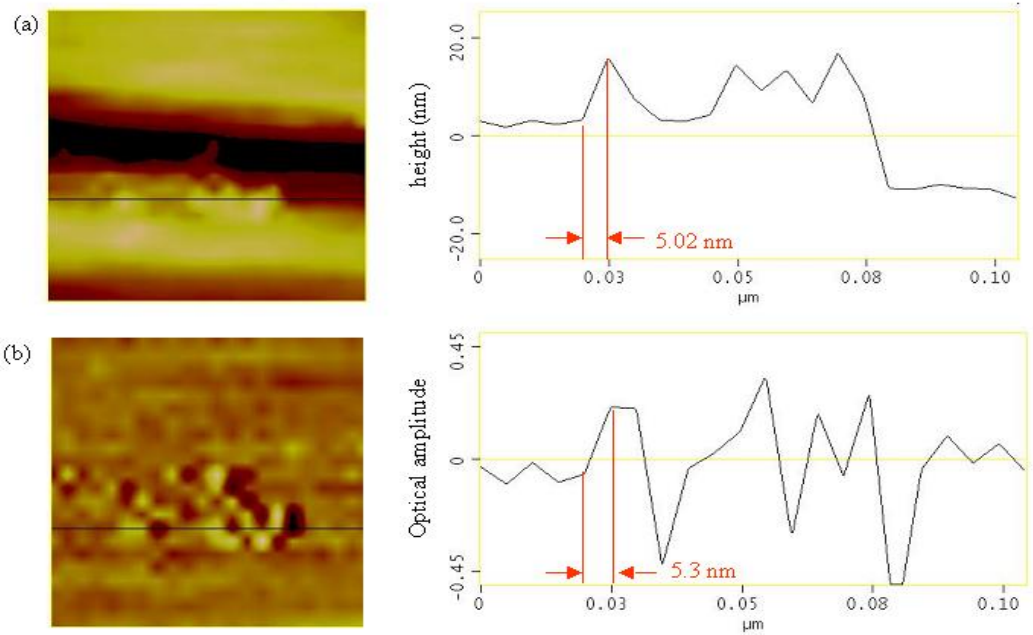
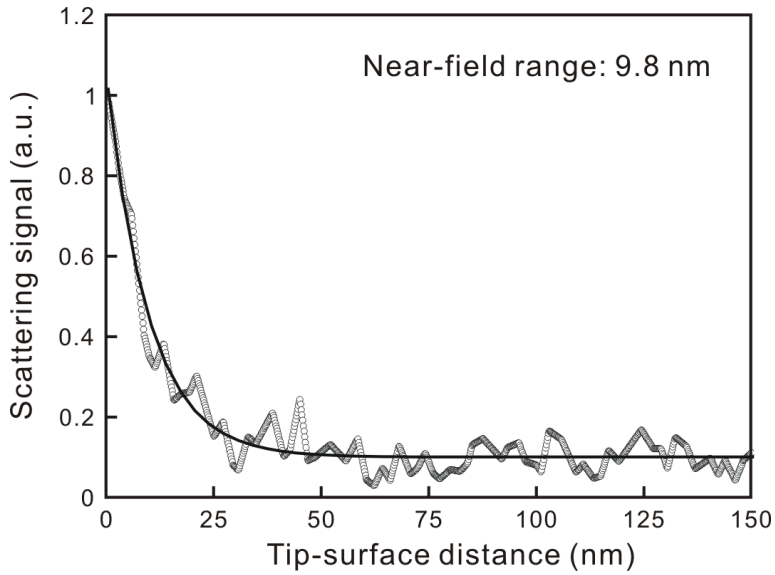
AFM image



***s*-SNOM image**



Lateral resolution: 5 nm

Vertical resolution: 10 nm

- The *s*-SNOM achieves ~5 nm resolution, suitable for the near-field studies of plasmonics.

Material contrast

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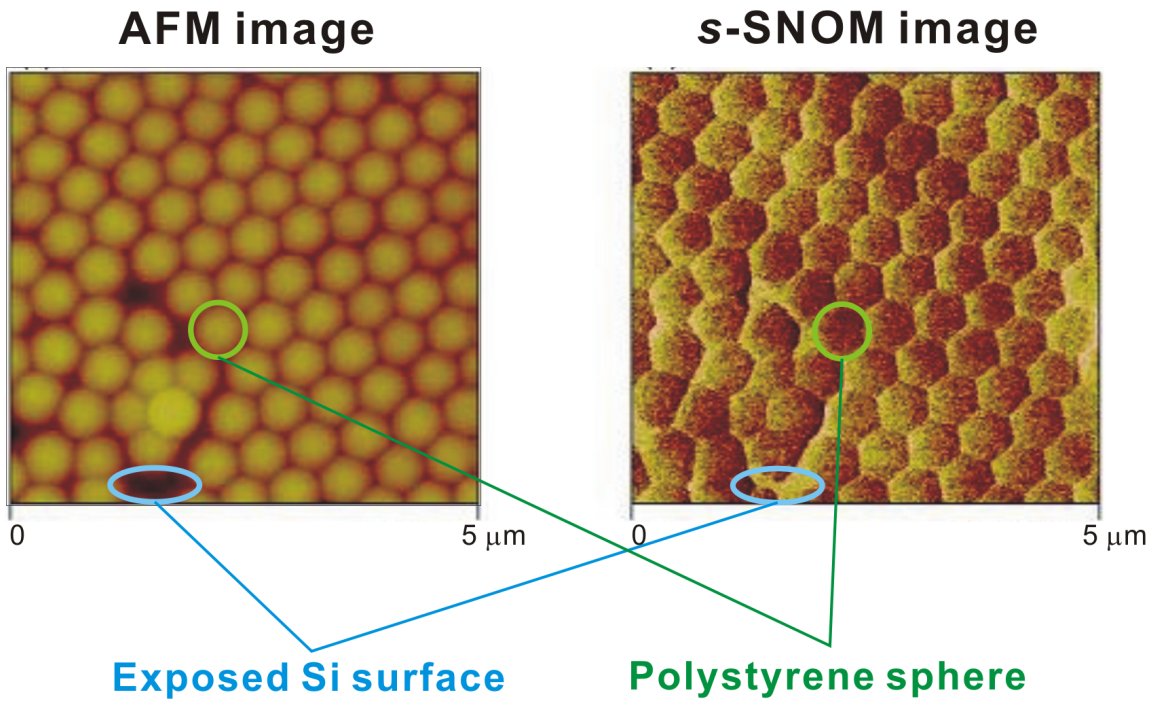
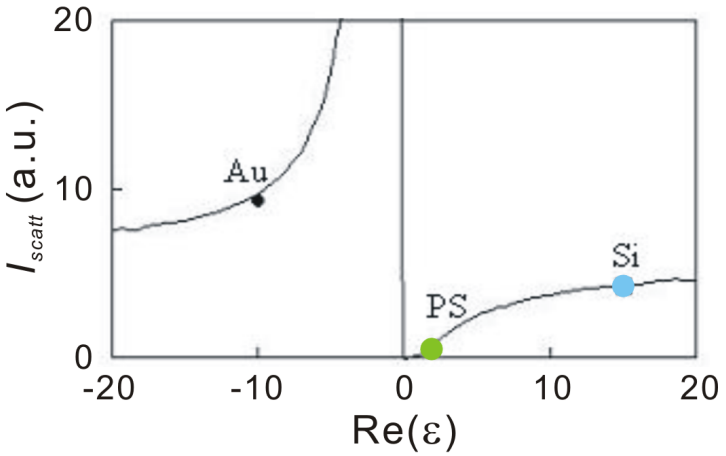
Polystyrene sphere on Si(111)





- **Detection limit of Δn: 0.02**

k-space analysis of single nanohole image-1

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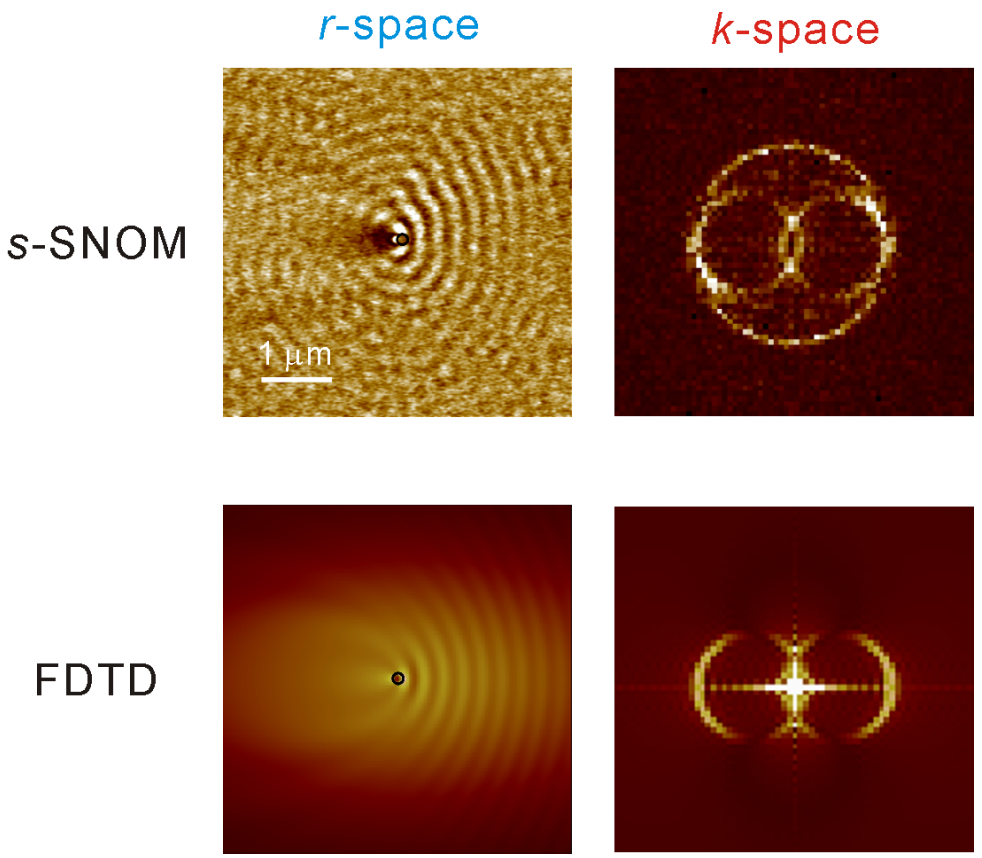
200 nm Ag film
Hole diameter: 150 nm
l_{ex} = 532 nm



- Through Fourier transform, the obtained *k*-space image exhibits one large circle and two center-shifted small circles and does not agree with the one obtained with FDTD method.

Y.-C. Chang et al., Opt. Exp. 16, 740 (2008).

Scattered field contributions from a single nanohole

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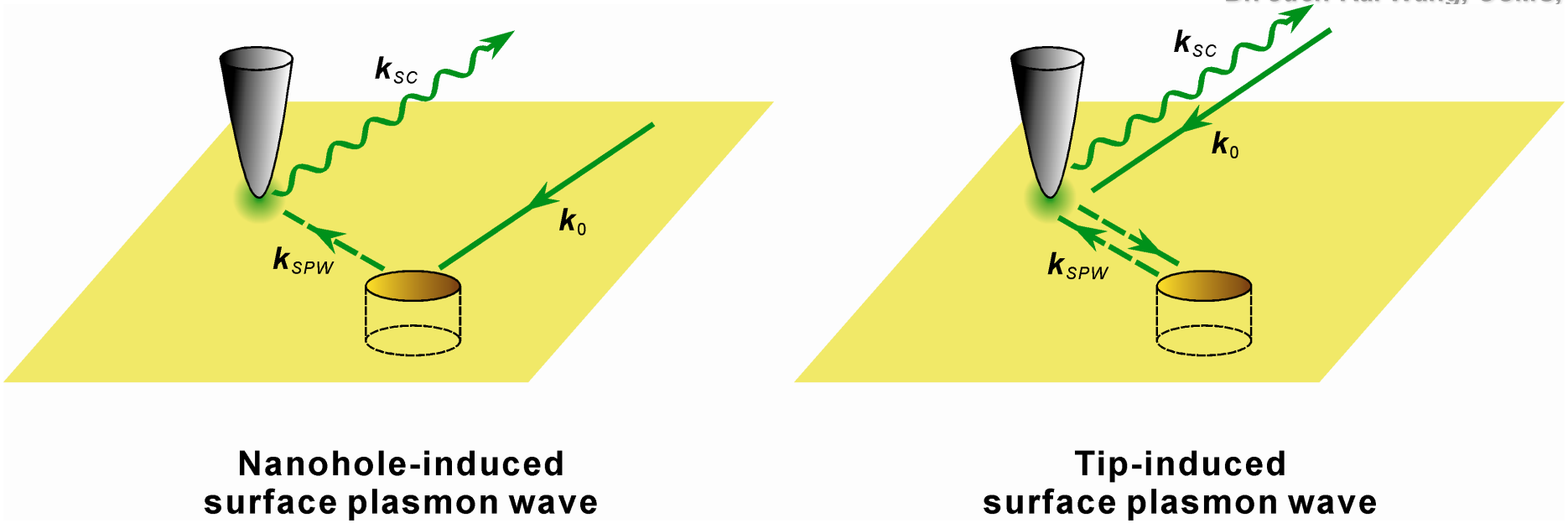

Nanohole-induced surface plasmon wave

Tip-induced surface plasmon wave

$$E_{hole-SPW} = A_{hole-SPW}(\boldsymbol{r})\exp\left[i\left(-k_0 \sin\theta \boldsymbol{i}\cdot\boldsymbol{r} + k_{SPW}\cdot r + \phi\right)\right]$$

$$E_{tip-SPW} = A_{tip-SPW}(\boldsymbol{r})\exp\left[i\left(2k_{SPW}\cdot r + \phi'\right)\right]$$

$$k_{SPW} = k_0\sqrt{\varepsilon_{air}\varepsilon_{Ag}/\left(\varepsilon_{air}+\varepsilon_{Ag}\right)}$$

- Nanohole-induced and tip-induced surface plasmon waves
- Both waves contribute to the detected scattering radiation of *s*-SNOM.

Y.-C. Chang et al., Opt. Exp. 16, 740 (2008).

k-space analysis of single nanohole image-2

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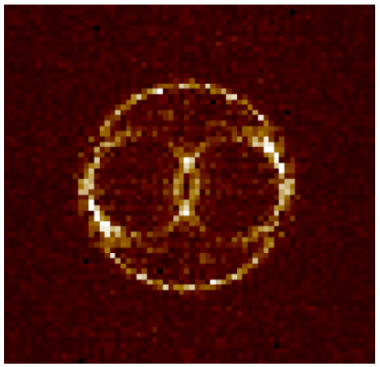
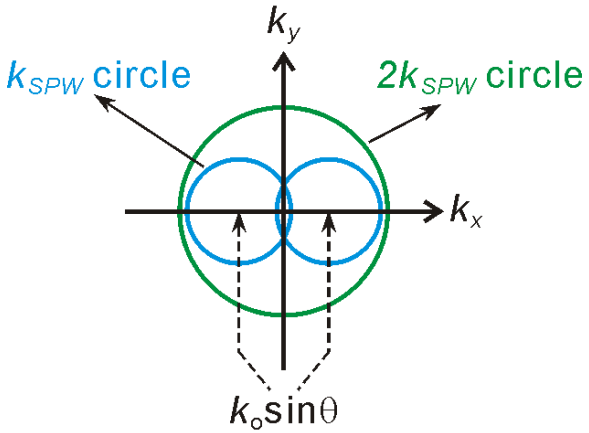
200 nm Ag film
Hole diameter: 150 nm
λ_{ex} = 532 nm

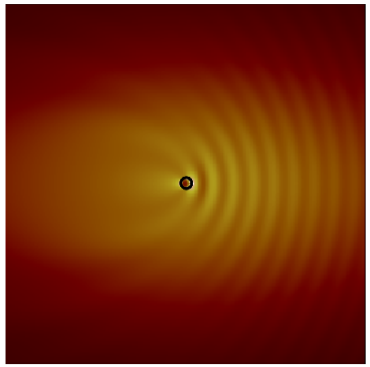
k-space

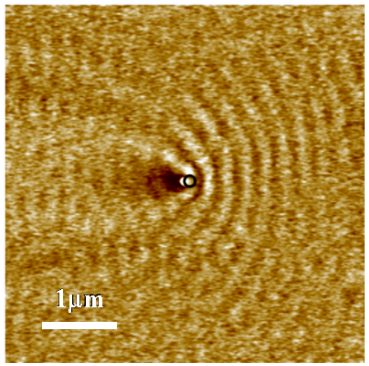
s-SNOM





FDTD





s-SNOM image
w/o $2k_{SPW}$ circle

- The s-SNOM image without the $2k_{SPW}$ circle matches with the image calculated without the tip.

Y.-C. Chang et al., Opt. Exp. 16, 740 (2008).