Nanoscopio óptico con resolución de profundidad

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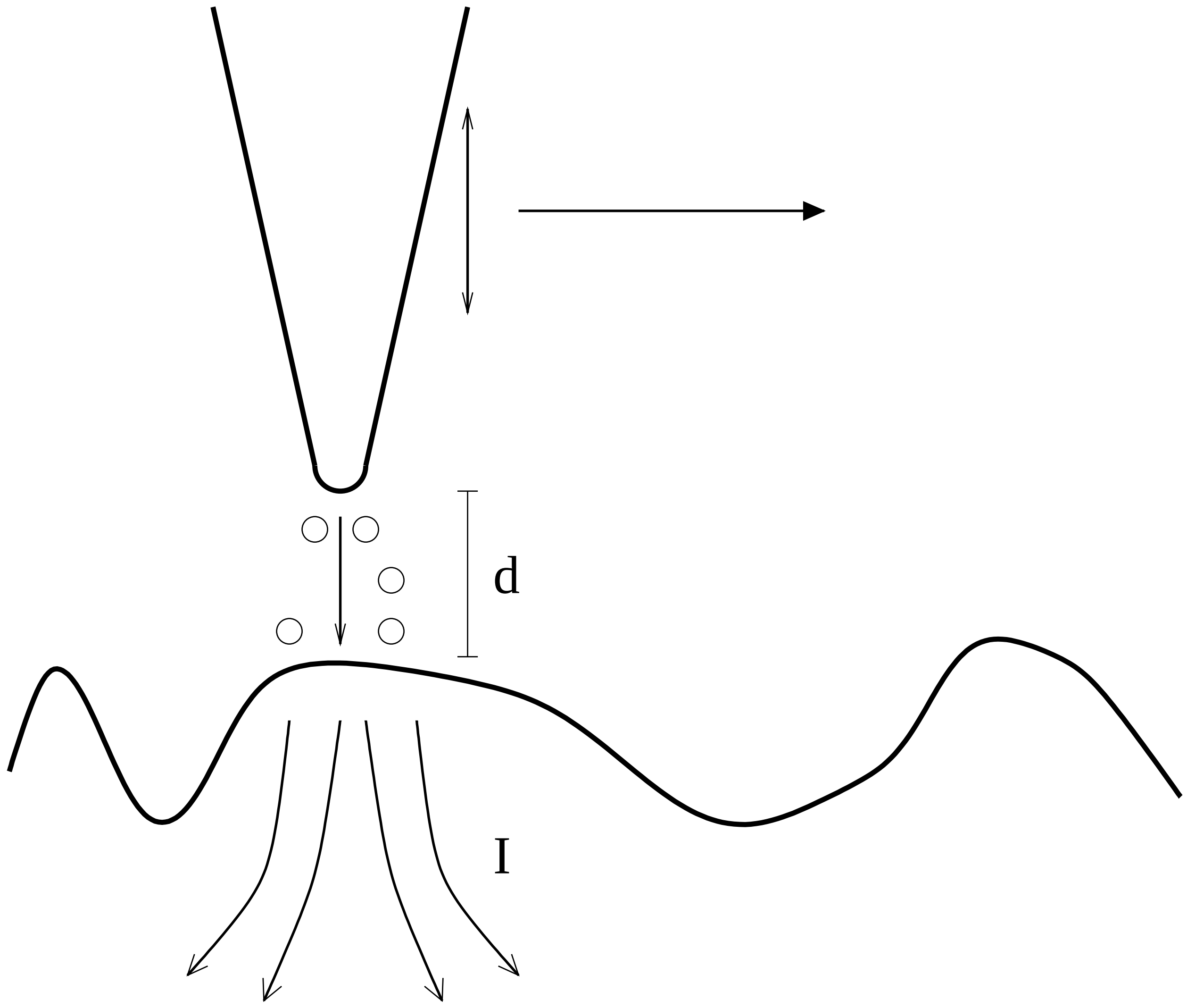
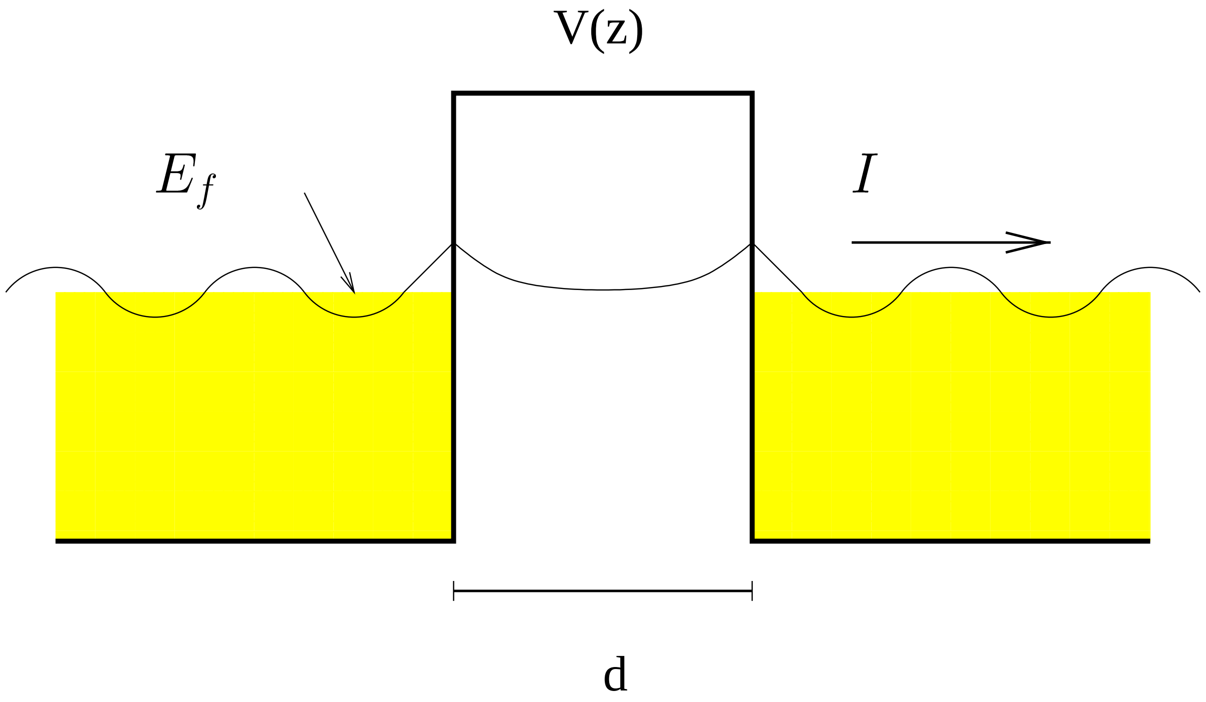
Tunneling Microscopy



Tunnel Current



$$\kappa \propto \sqrt{V_0 - E_f}$$

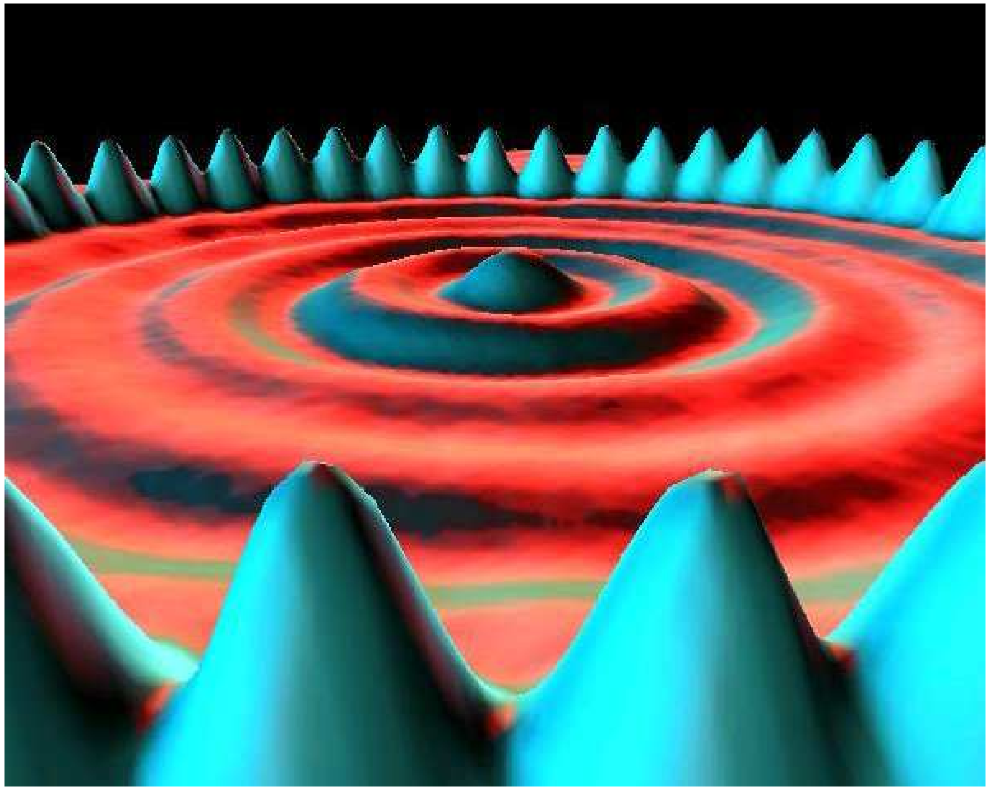
$$I \propto e^{-\kappa d}$$

STM view of quantum corral

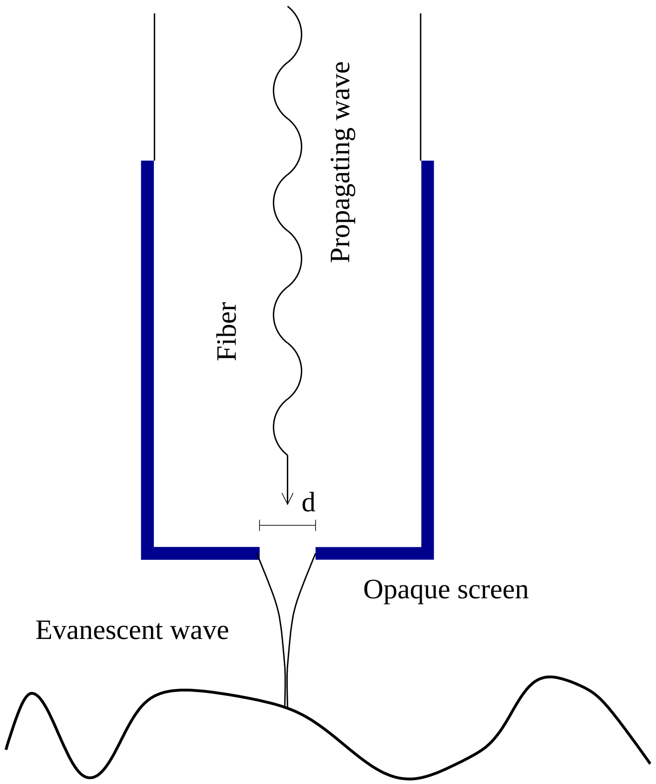
M.F. Crommie, C.P. Lutz, D.M. Eigler,

Science **262**, 218-220 (1993).

Fe/Cu(111)



Scanning Near Field Optical Microscope



$$\nabla^2 \vec{E} = -\frac{\omega^2}{c^2}\vec{E}$$

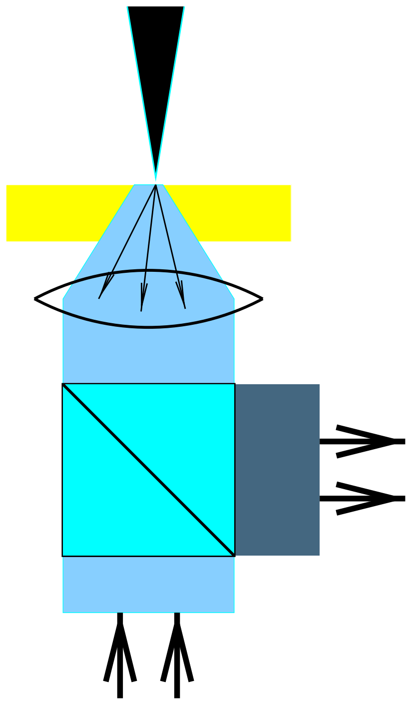
$d \ll \lambda \Longrightarrow$

$$\begin{aligned} \frac{d^2}{dz^2}E &= -\nabla_{\|}^2 E - \frac{\omega^2}{c^2}\vec{E} \\ &\sim \frac{E}{d^2} - \frac{E}{\lambda^2} \\ &\sim \frac{E}{d^2} \end{aligned}$$

$\Longrightarrow$ exponential decay with scale d.

SNOM

- Subwavelength resolution
- Evanescent near fields
- Problems with aperture microscope
  - Small signal
  - Penetration into metal; poor resolution
- Alternatives
  - Tip
  - Two photon fluorescence
  - Raman scattering
  - ...

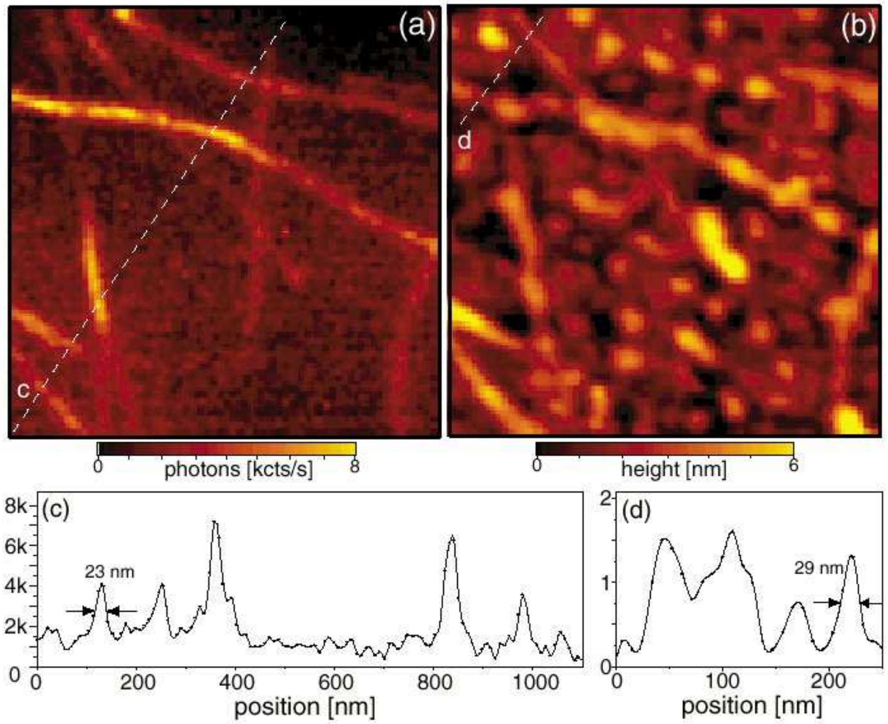


Nano Raman

Achim Hartschuh, Erik J. Sánchez, X. Sunney Xie, and Lukas Novotny

Phys. Rev. Lett. **90**, 095503 (2003)

Single wall C nanotubes/SiO_2

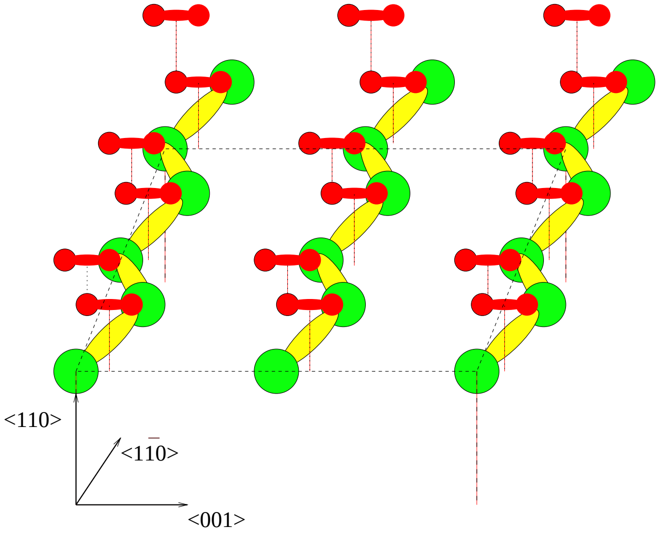


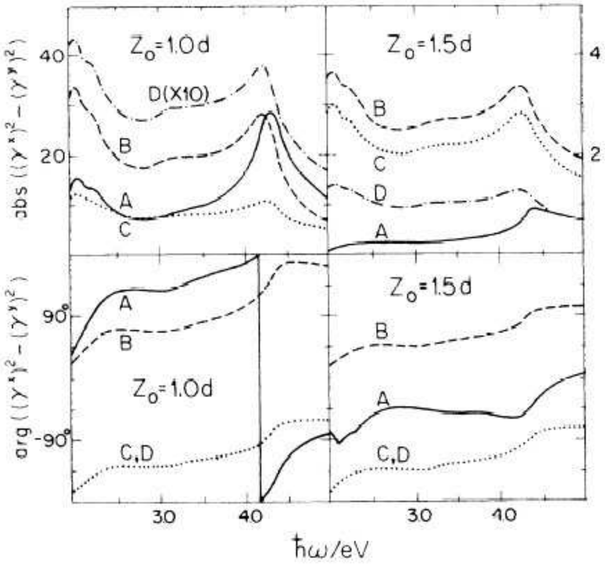
Atomic resolution?

W. Luis Mochán and Rubén G. Barrera

Phys. Rev. Lett. **56**, 2221 (1986)

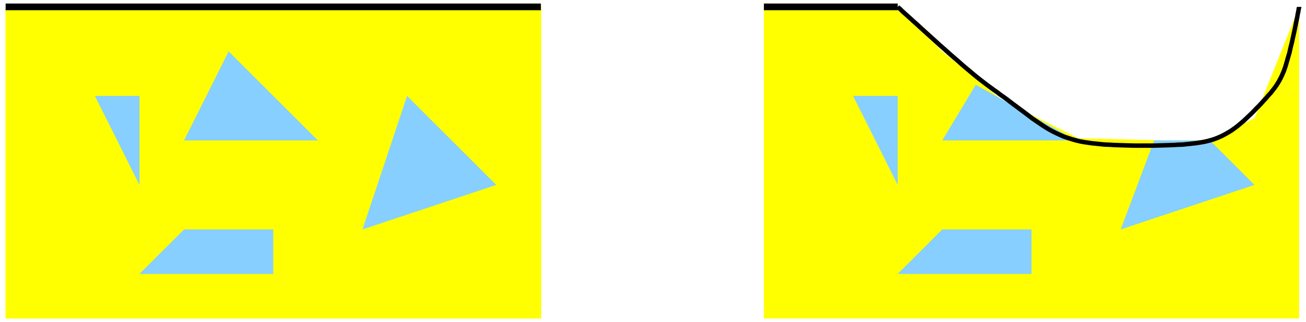
$Br_2/Ge(110)$





$\alpha_{\rm eff}/\alpha_0$

Depth resolution



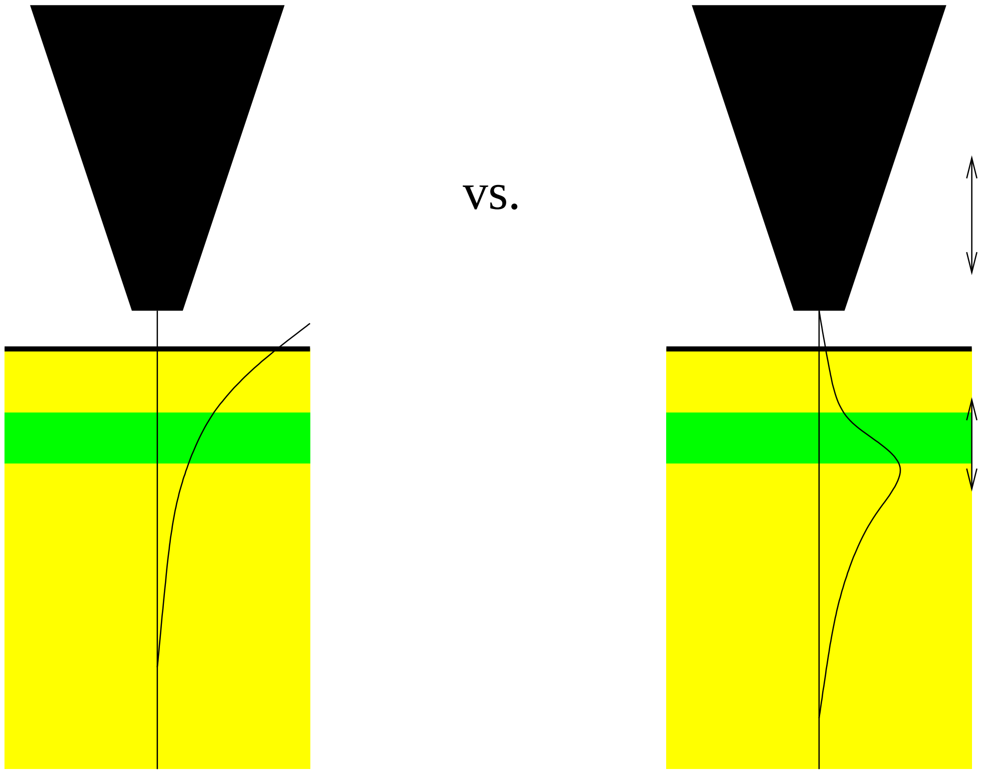
- To retrive depth information, it is brought to the surface destructively.
- Optical fields may probe the interior of matter. . .
- but penetration depth is too long. . .
- Evanescent fields have good lateral resolution. . .
- and a small penetration depth!

Can a near field optical microscope with depth resolution be developed?

Problem

Evanescent fields decay monotonously away from tip.

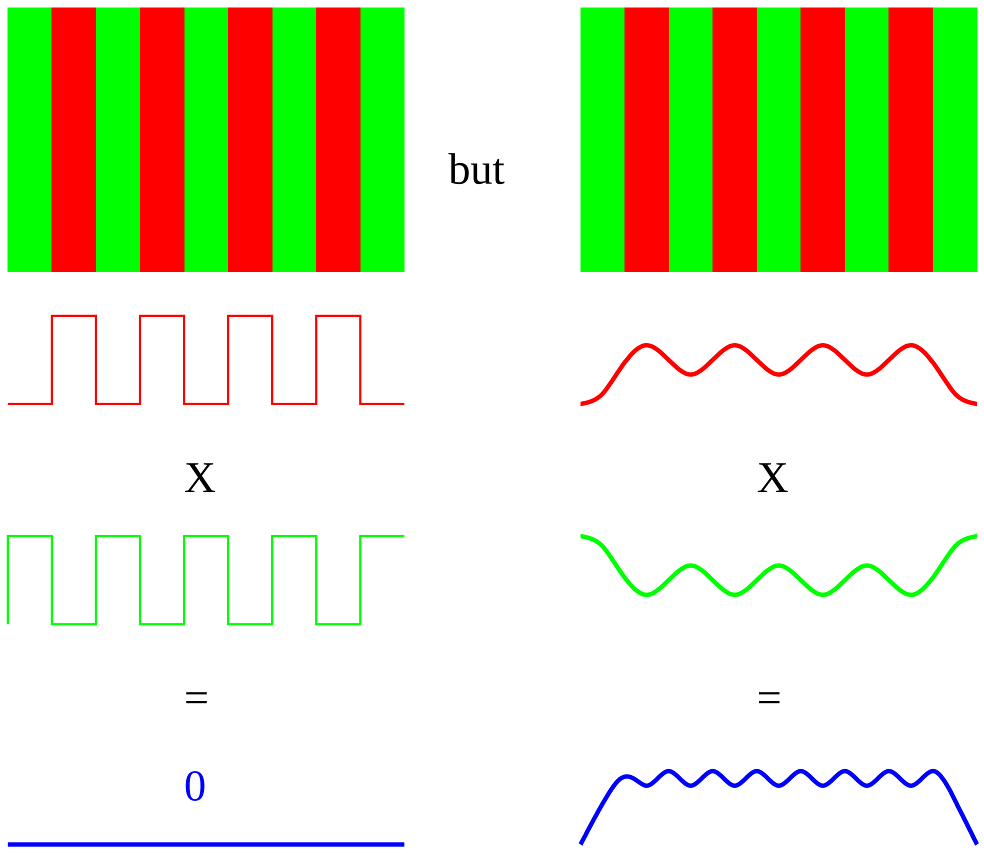
But nonlinear wave mixing could be null at tip, yielding maximum sensitivity some at a finite distance.



Example, SFG

$$P(\omega_3 = \omega_1 + \omega_2) \propto E(\omega_1)E(\omega_2)$$

Separate ω_1 and ω_2 spatially at tip using resonant superlattice.



Example SHG

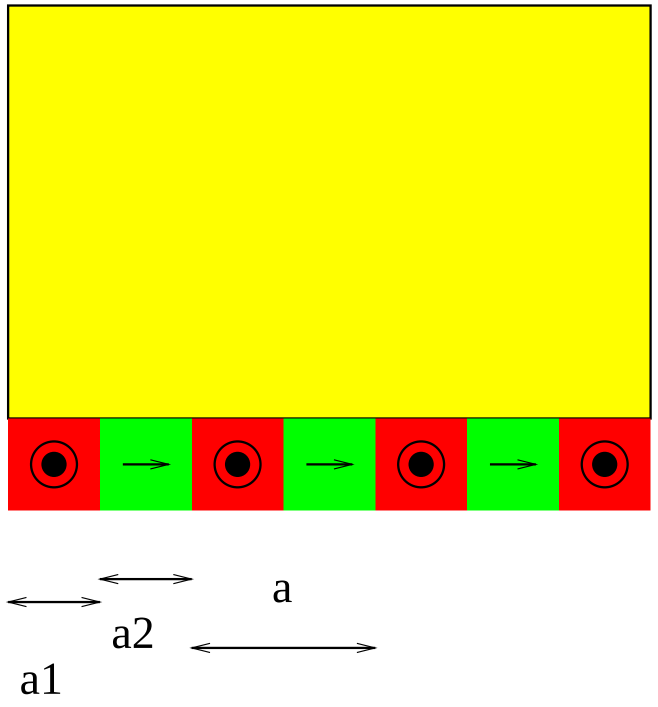
$$E_{sy} = \sum E_{sG} e^{iGx} e^{-|G|z}$$

$$E_{sG} = 2\frac{E_0}{Ga}\sin Ga_1/2$$

$$E_{px} = \sum E_{pG} e^{iGx} e^{-|G|z} e^{iGa/2}$$

$$E_{pG} = 2\frac{E_0}{Ga}\sin Ga_2/2$$

E_{pz} so that $\nabla \cdot \vec{E}_p = 0$



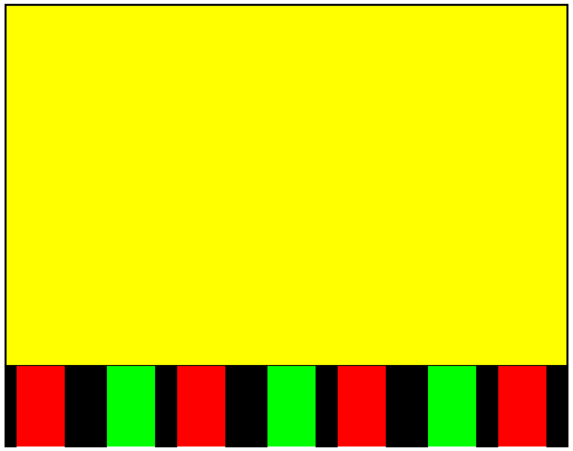
$$\vec{P}^{(2)} \propto \vec{E}_p \cdot \nabla \vec{E}_s$$

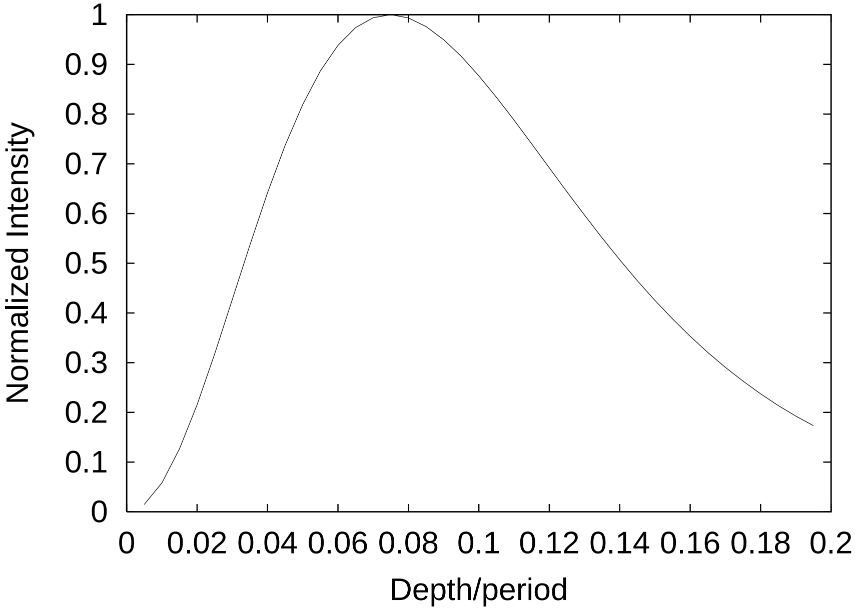
Averages to zero along surface!

Problem

System has $x \leftrightarrow -x$ symmetry.

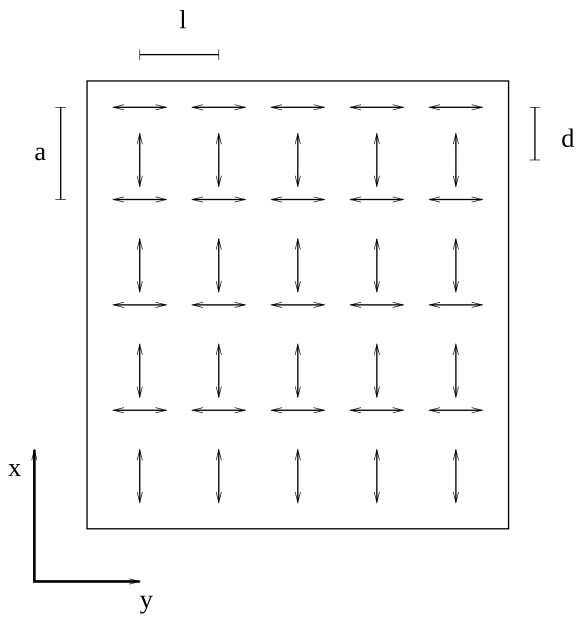
Solution: break symmetry with spacers.





$$a_1 = a_2 = .2,\ d = 0.65$$

Realization?



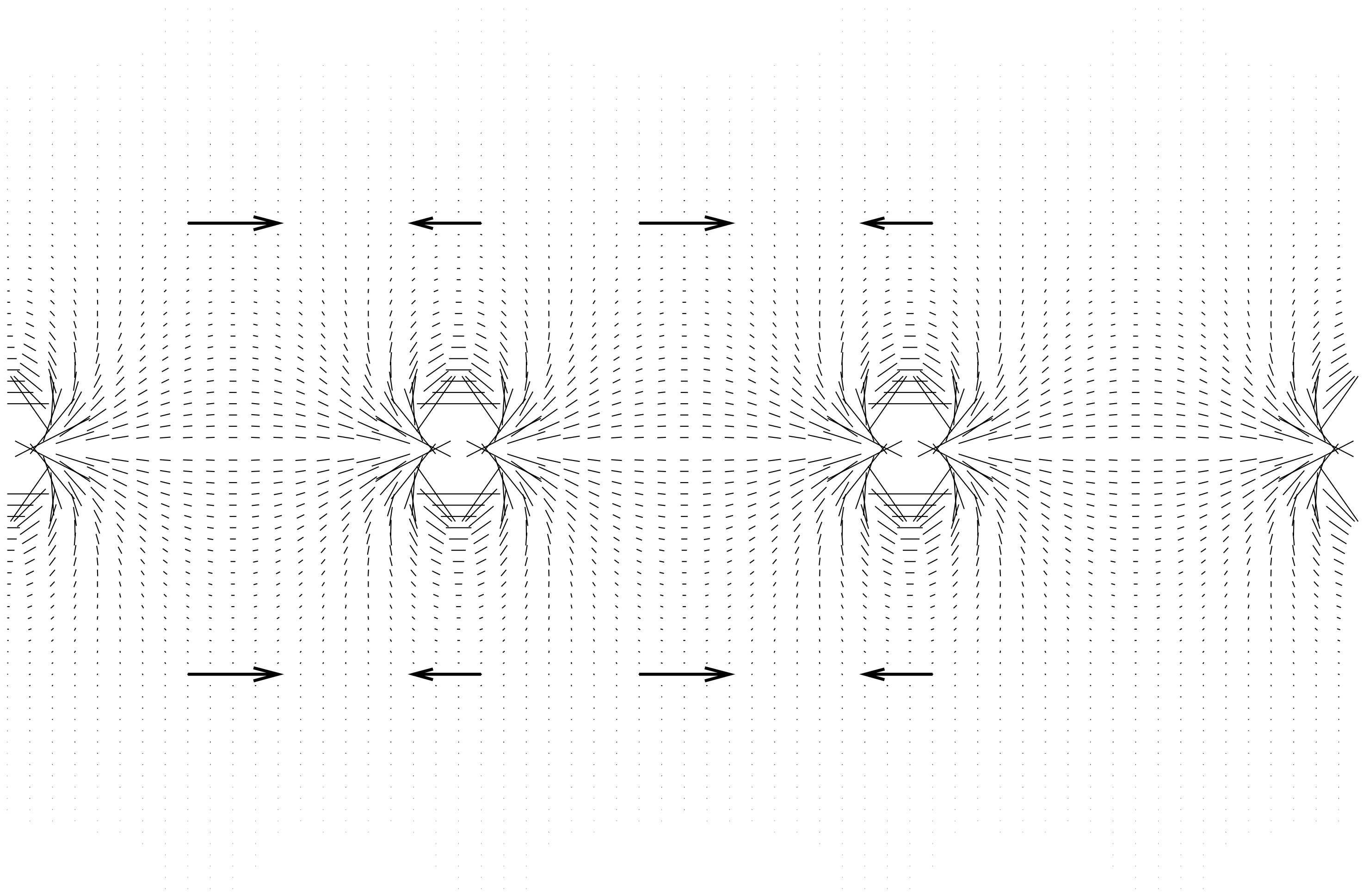
$$\vec{E}_p = -2\pi \frac{p_p}{la} \sum (|G|, 0, -iG) e^{iGx} e^{-|G|z}$$

$$\vec{B}_s = -2\pi i q \frac{p_s}{la} \sum (1, 0, i\mathrm{sgn}(G)) e^{iG(x-d)} e^{-|G|z}$$

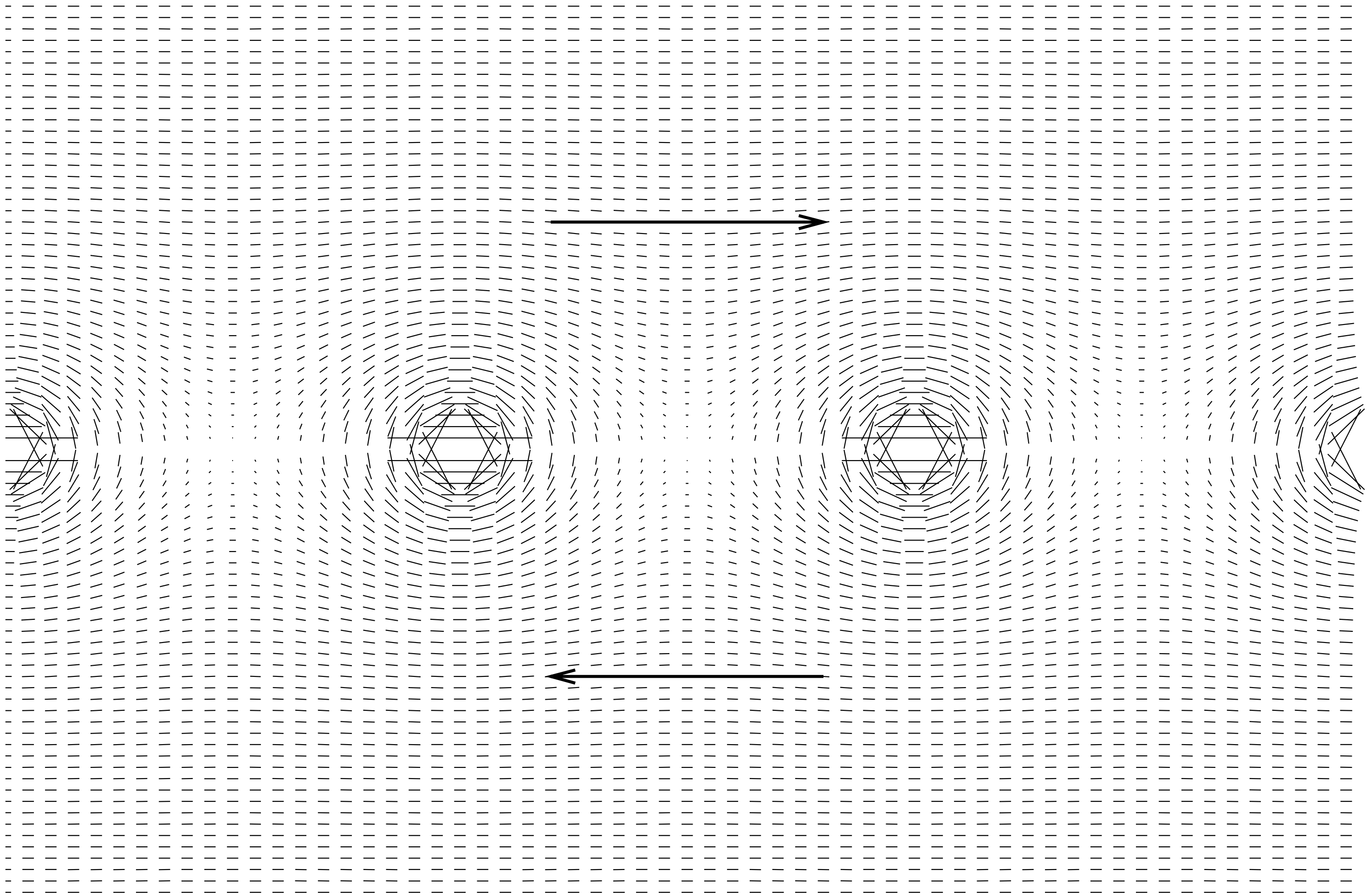
$$\nabla \times \vec{E}_s = iq\vec{B}_s$$

$$\vec{P}^{(2)} \propto \vec{E}_p \times (\nabla \times \vec{E}_s)$$

P polarized 'longitudinal' $\vec{E}$

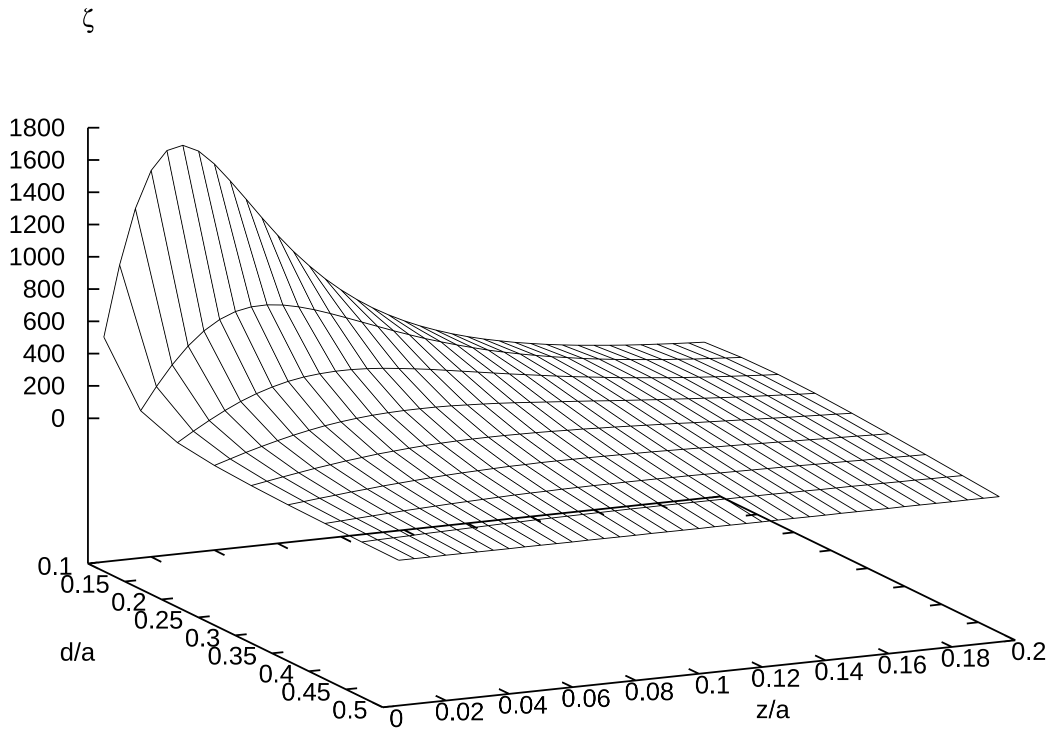


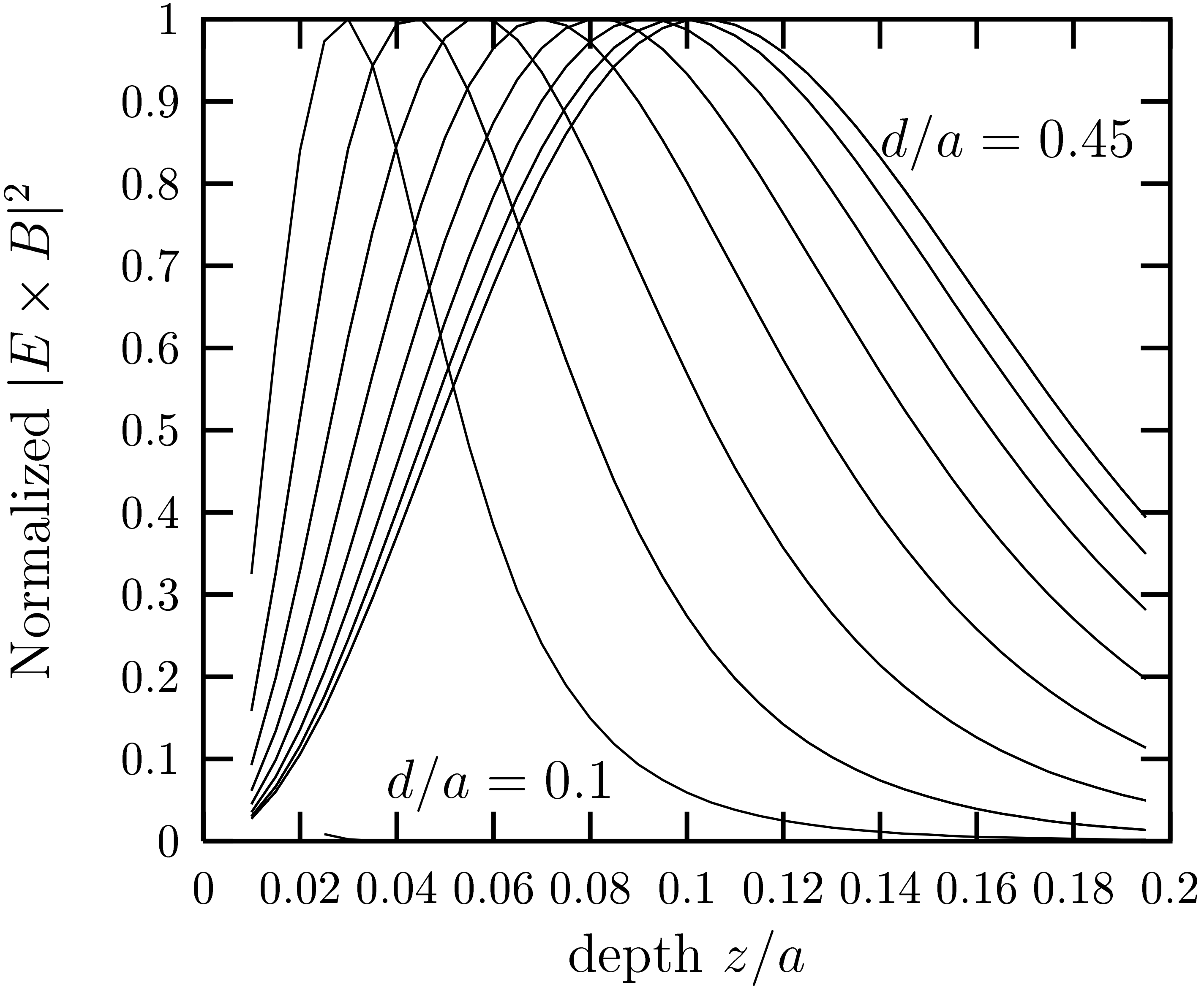
S polarized 'transverse' $\nabla \times \vec{E}$



Non linear source

$$E \times (\nabla \times \vec{E}) = \zeta (ql)^2 (l/a)^2 P^2 / a$$





Normalized $|E \times B|^2$
depth z/a
$d/a = 0.45$
$d/a = 0.1$
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2

Size of signal

- A single dipole radiates a field $E^{(2)} \sim p^{(2)}/\lambda^2 r$.

- A polarized region of width w and depth ℓ radiates a field $E^{(2)} \sim P^{(2)} \ell w^2/\lambda^2 r$.

- Constructive interference requires $r^2 + w^2 \sim (r+\lambda)^2$, $w^2 \sim r\lambda$.

- Then, $E^{(2)} \sim q\ell P^{(2)}$.
- For the *nanoscope*, $P^{(2)} \sim \frac{a_B^3}{e} \vec{E} \times (\nabla \times \vec{E}) \sim \zeta \frac{a_B^3}{e} (ql)^2 (l/a)^2 P^2/a$, $\ell \approx 0.1a$, $l \sim a_B$, $a \sim 10a_B$, $P = \chi E$.
- For surface SHG, $P^{(2)} \sim \frac{a_B^2}{e} E^2$ and $\ell \sim a_B$.
- Thus $E_{\text{nano}}/E_{\text{surf}} \sim 10^{-3}(qa_B)^2 \chi^2 \zeta$.

Conclusions

- Three wave mixing may be employed to construct a surface probe with depth resolution in the nanometer scale by spatially modulating, with a small period the fundamental beams at the *tip*, and separating them.
- Separated s-p fields may be generated by alternating linear chains of oriented anisotropic molecules.
- The arrangements must be non-centrosymmetric along the surface.
- The source of SHG peaks a distance $\sim$ period/10 from the tip, and it can be depth-scanned.
- The signal is expected to be similar to that of ordinary surface SHG.