Near-field Optical Microscopy

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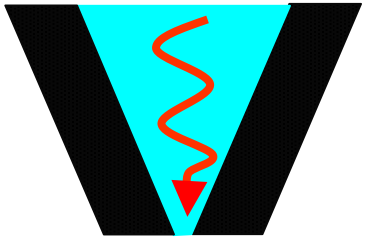


Conventional (*Far-Field*) Optical Microscopy

Optical Microscope

Robust and reliable

High throughput

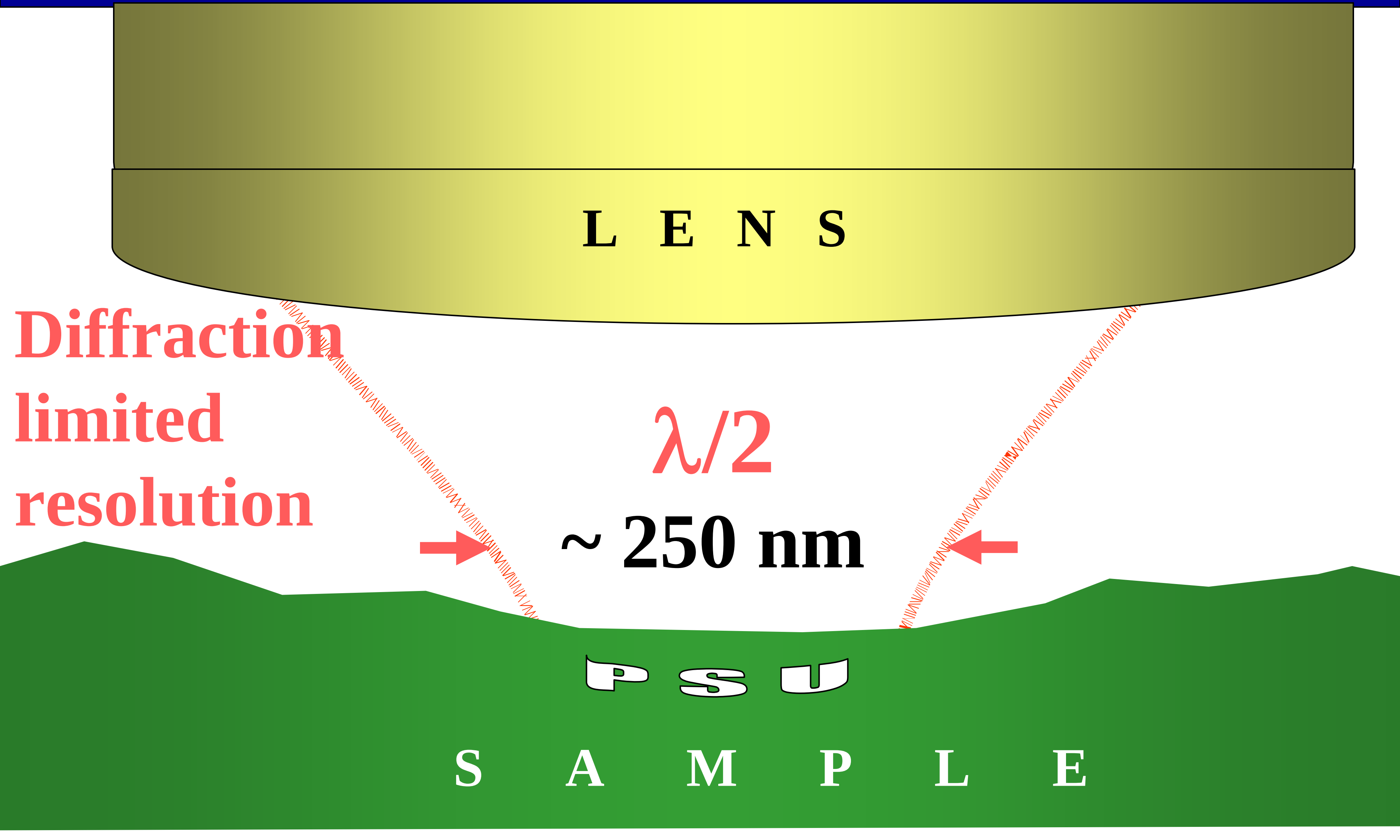
Non-invasive ✓

Low Cost

BUT

Limited Lateral Resolution

Conventional (*Far-Field*) Optical Microscopy



L E N S

Diffraction limited resolution

λ/2

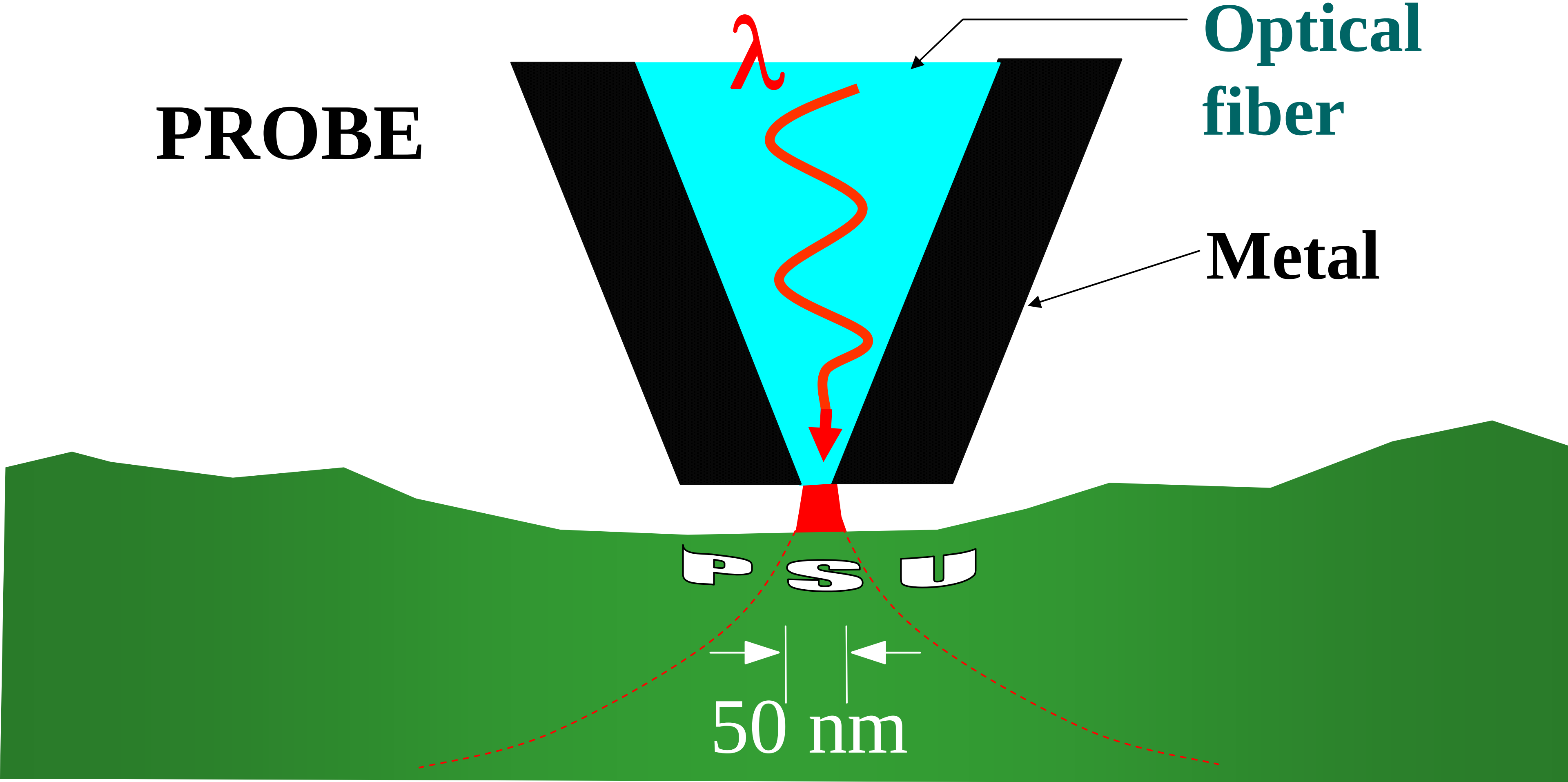
~ 250 nm

PSU

S A M P L E

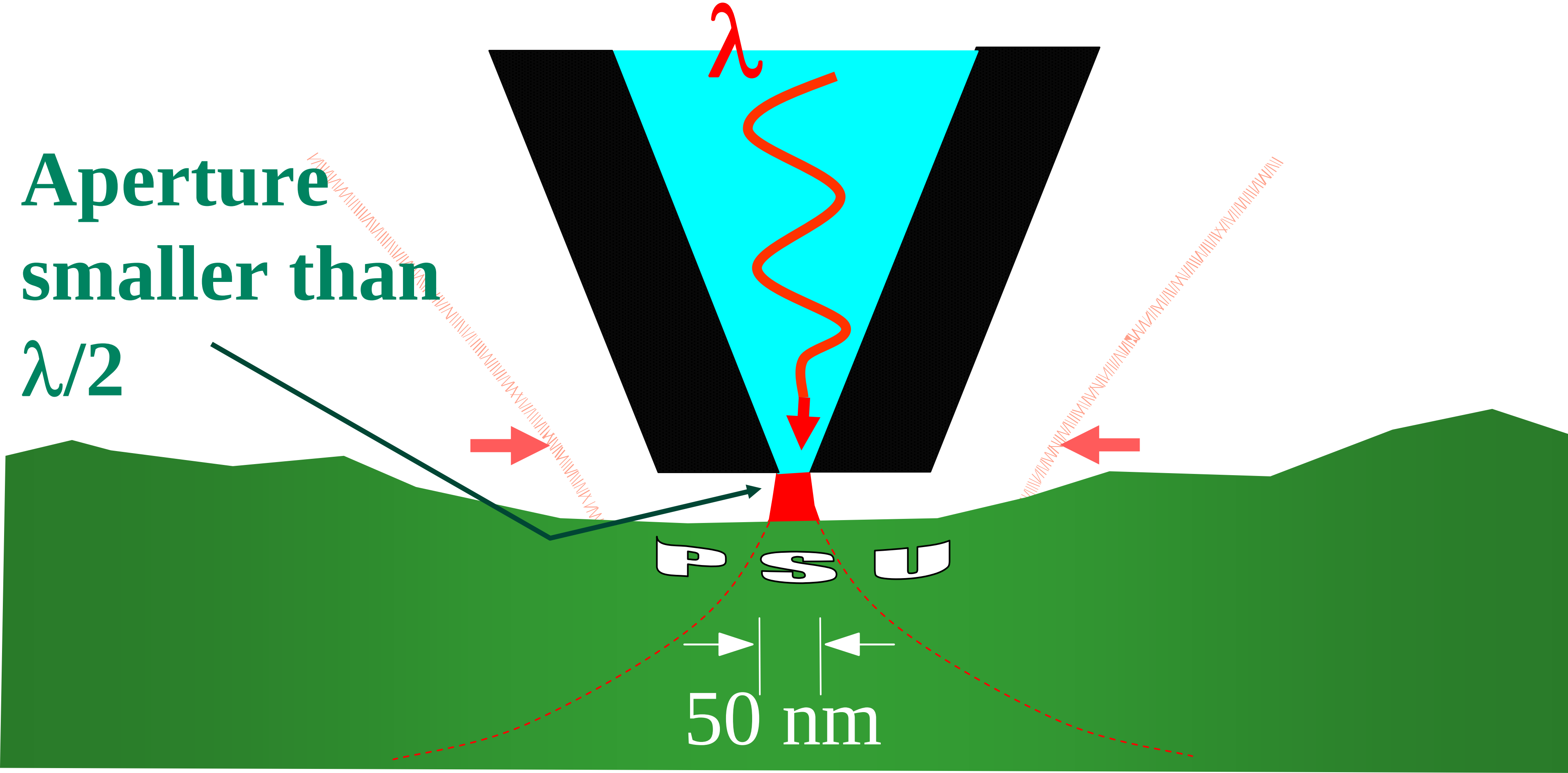
Near-Field Scanning Optical Microscopy (NSOM)

Surpassing the diffraction limited barrier



Near-Field Scanning Optical Microscopy (NSOM)

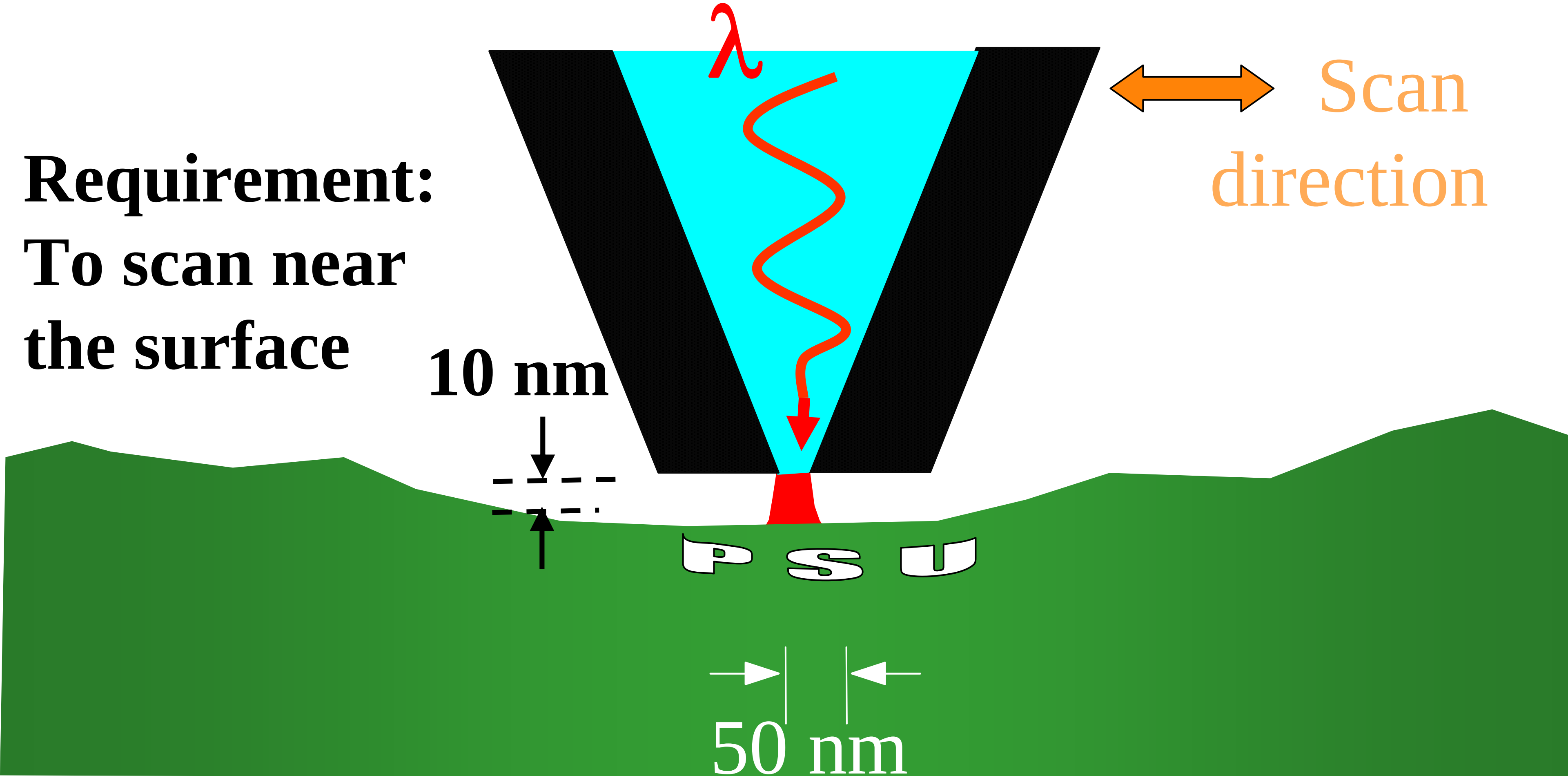
Surpassing the diffraction limited barrier



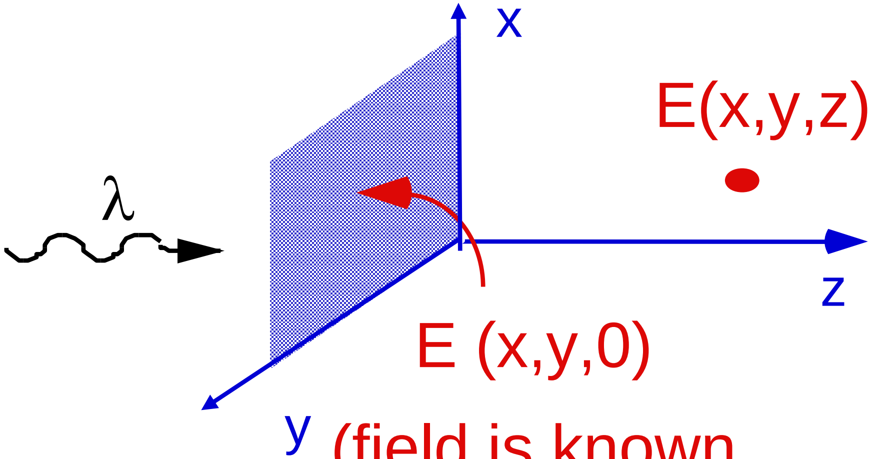
Near-Field Scanning Optical Microscopy (NSOM)

Surpassing the diffraction limited barrier

Requirement:
To scan near the surface



FOURIER OPTICS



E(x,y,z) = **?**

E (x,y,0)

(field is known at z = 0)

$$\nabla^2 \begin{Bmatrix}\mathbf{E}\\ \mathbf{B}\end{Bmatrix} - \frac{n^2}{c^2}\frac{\partial^2}{\partial t^2}\begin{Bmatrix}\mathbf{E}\\ \mathbf{B}\end{Bmatrix} = \mathbf{0}$$

$$\mathbf{E}(\mathbf{r},t) = \mathbf{E}(\mathbf{r})e^{-\imath\omega t}$$

$$\mathbf{r} = (x,y,z) = (\mathbf{x},z)$$

$$E(\mathbf{x},0) = \iint [A_{\boldsymbol{f}}(0)]\, e^{i2\pi\, \boldsymbol{f}\cdot\boldsymbol{x}}\, df_x\, df_y \quad\Longrightarrow\quad E(x,z) = \iint [A_{\boldsymbol{f}}(z)]\, e^{i2\pi\, \boldsymbol{f}\cdot\boldsymbol{x}}\, df_x\, df_y\ ,$$

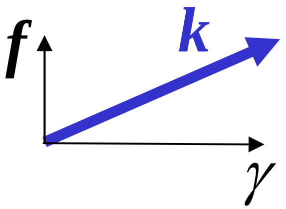
where $\boldsymbol{f} = (f_x, f_y)$

$$z \geq 0$$

$$\nabla^2 E + \left(\frac{2\pi n}{\lambda_0}\right)^2 E = 0$$

$$\frac{\partial^2}{\partial z^2}[A_{\boldsymbol{f}}] + (2\pi)^2\gamma^2 [A_{\boldsymbol{f}}] = 0\ , \qquad \text{where} \quad \gamma^2 = (n/\lambda)^2 - |\boldsymbol{f}|^2$$

$e^{i\mathbf{k}.\mathbf{r}}$



$$|\mathbf{k}|^2 = (2\pi n/\lambda_o)^2$$
$$= const$$

$$E(\mathbf{x},0) = \iint_{|\mathbf{f}|<R} [A_f(0)\, \overbrace{e^{i2\pi\gamma z}\ ]\ e^{i2\pi\,\mathbf{f}.\mathbf{x}}}\, df_x\, df_y$$

Propagating modes

$$+ \iint_{|\mathbf{f}|>R} [A_f(0)\, e^{-2\pi\gamma' z}\ ]\ e^{i2\pi\,\mathbf{f}.\mathbf{x}}\, df_x\, df_y$$

Evanescent modes

Where:

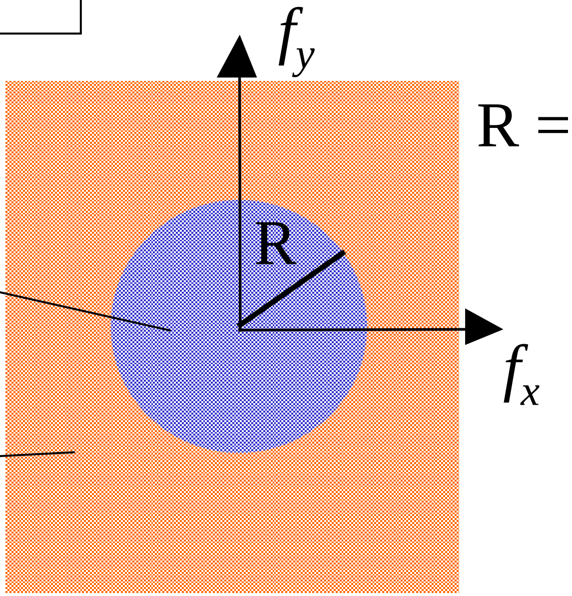
$$\gamma^2 = (n/\lambda_o)^2 - |\mathbf{f}|^2$$

and

$$\gamma'^2 = |\mathbf{f}|^2 - (n_o/\lambda)^2$$

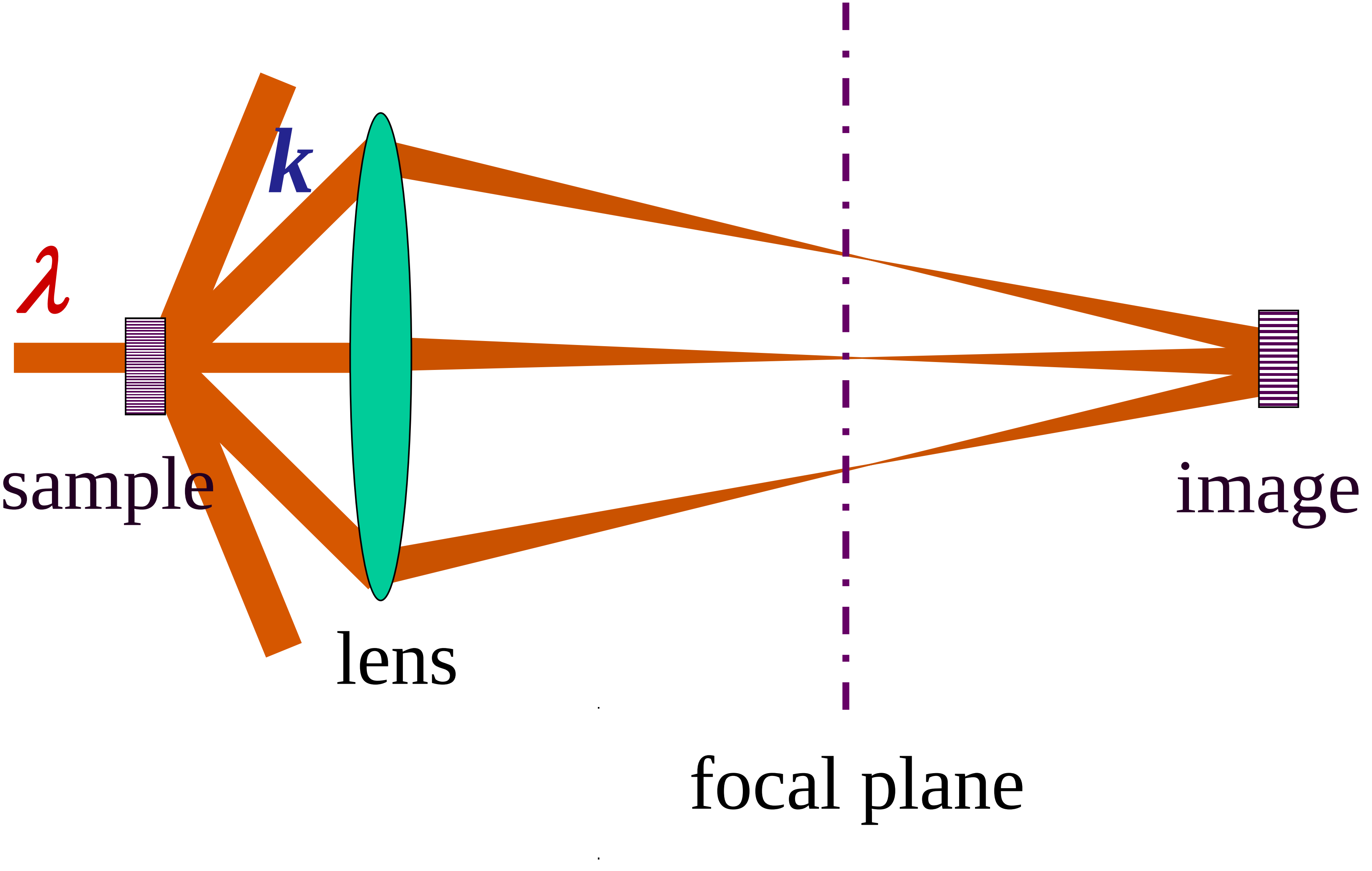
Propagating modes region $|\mathbf{f}| < R$

Evanescent modes region $|\mathbf{f}| > R$



$R = n / \lambda_0$

Resolution and Finite Entrance Pupil

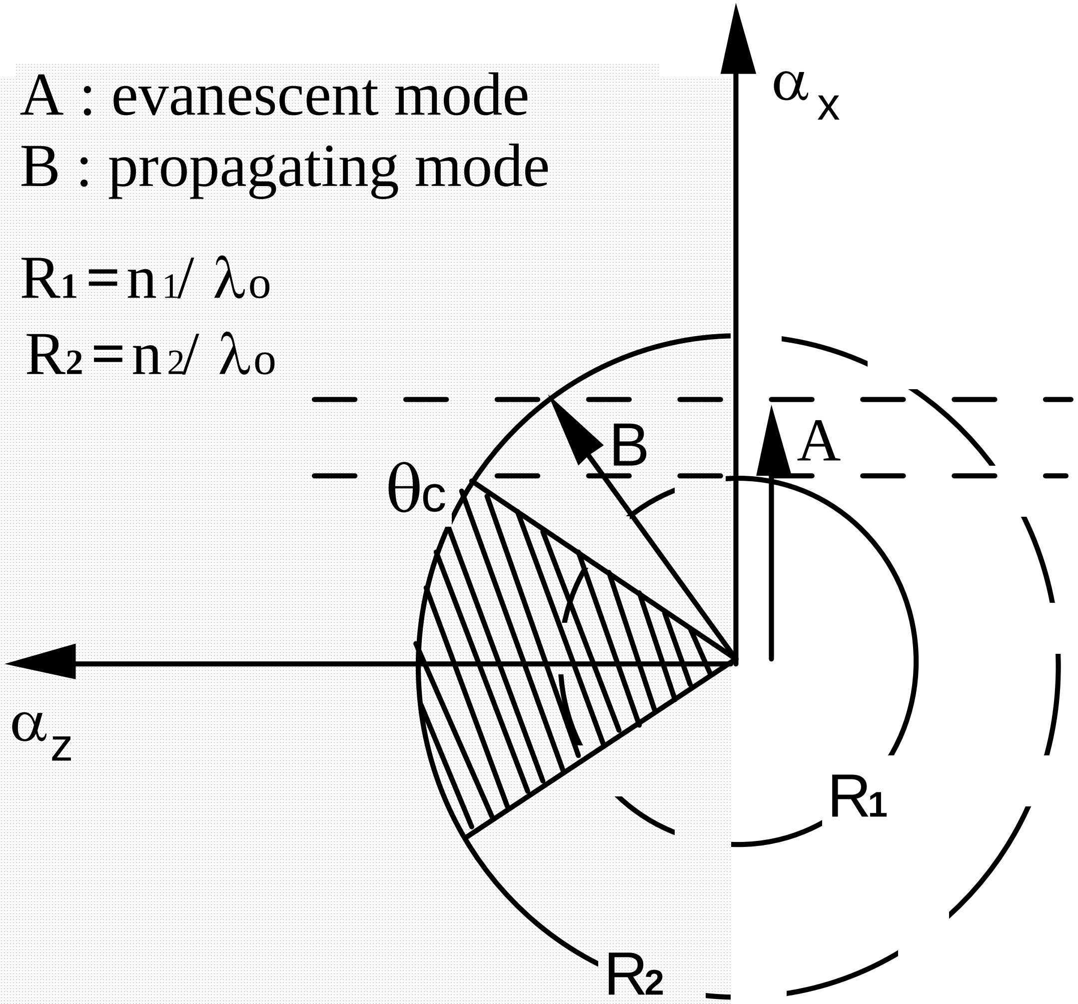


A : evanescent mode

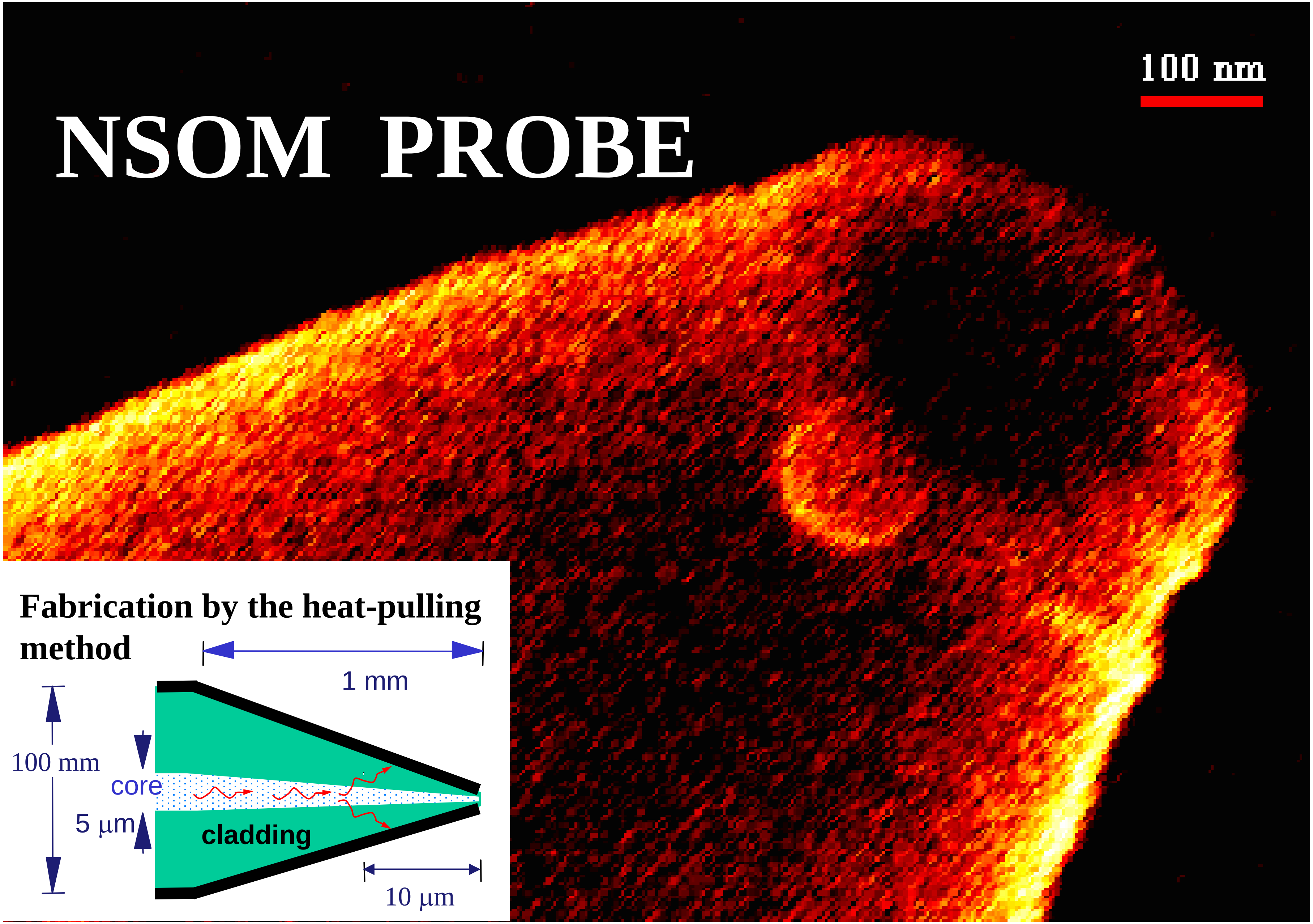
B : propagating mode

$R_1 = n_1 / \lambda_o$

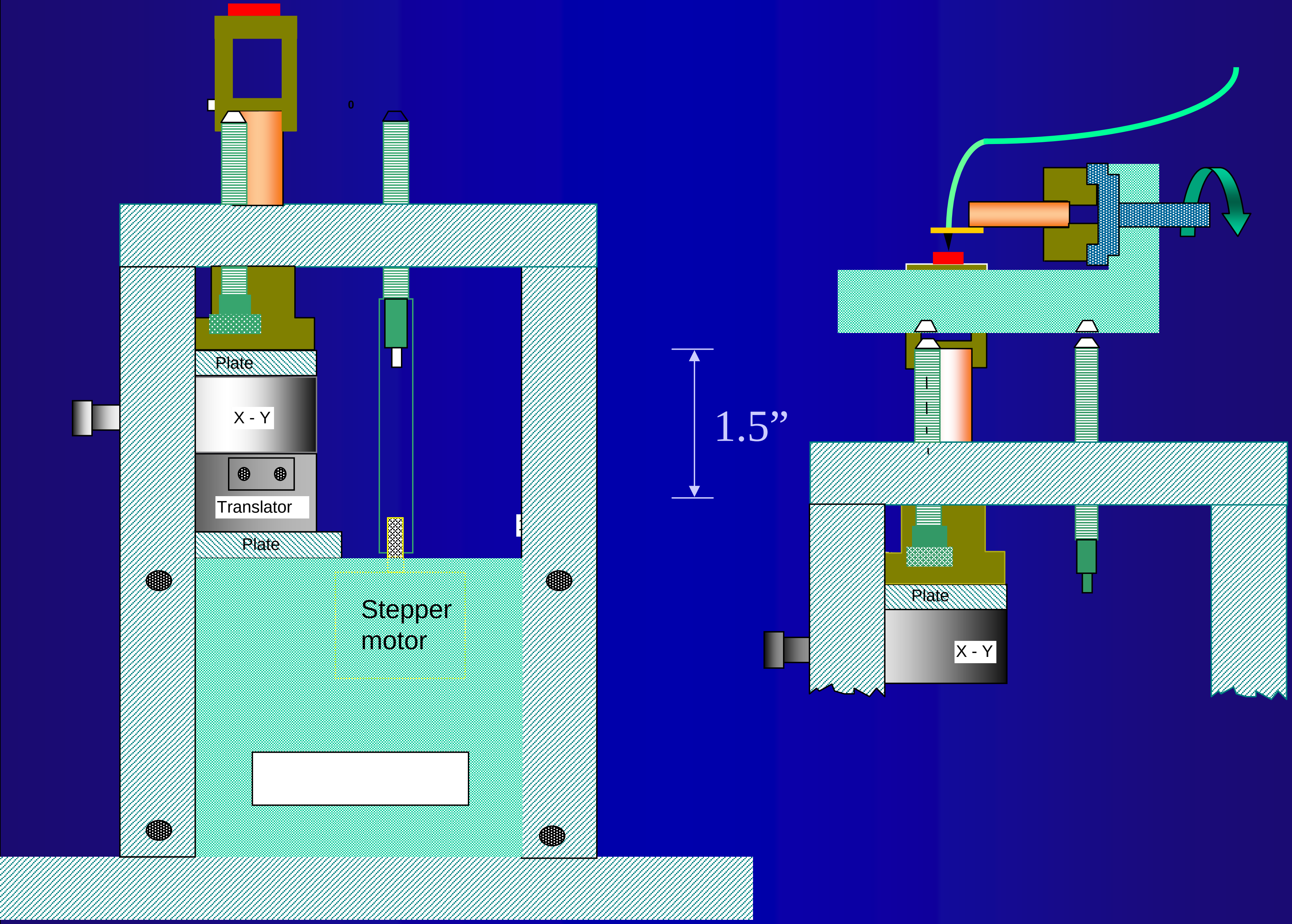
$R_2 = n_2 / \lambda_o$



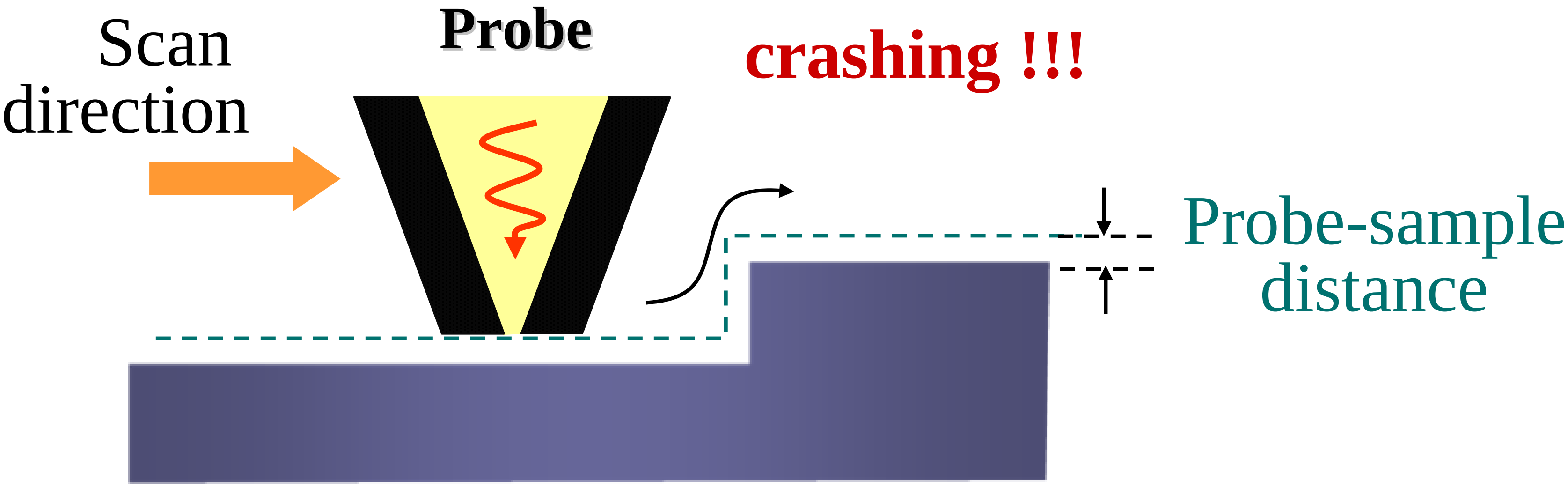
NSOM PROBE



Fabrication by the heat-pulling method


0
Plate
X - Y
Translator
Plate
Stepper motor
1.5”
Plate
X - Y

Need of probe-sample distance regulation

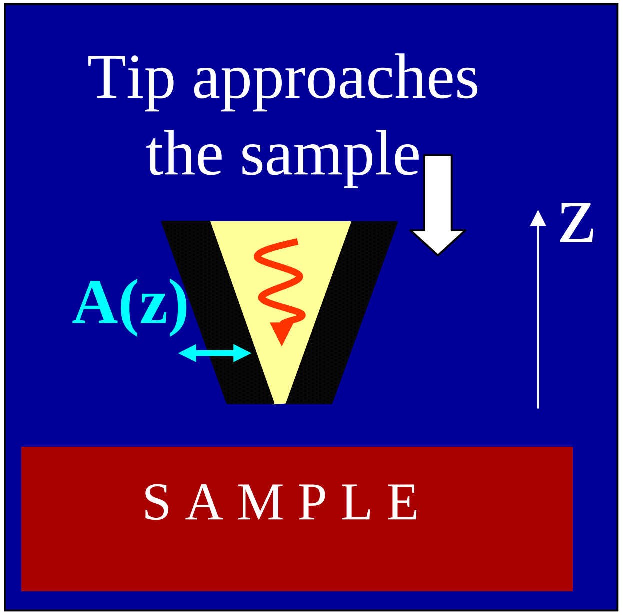


How to avoid crashing !!!

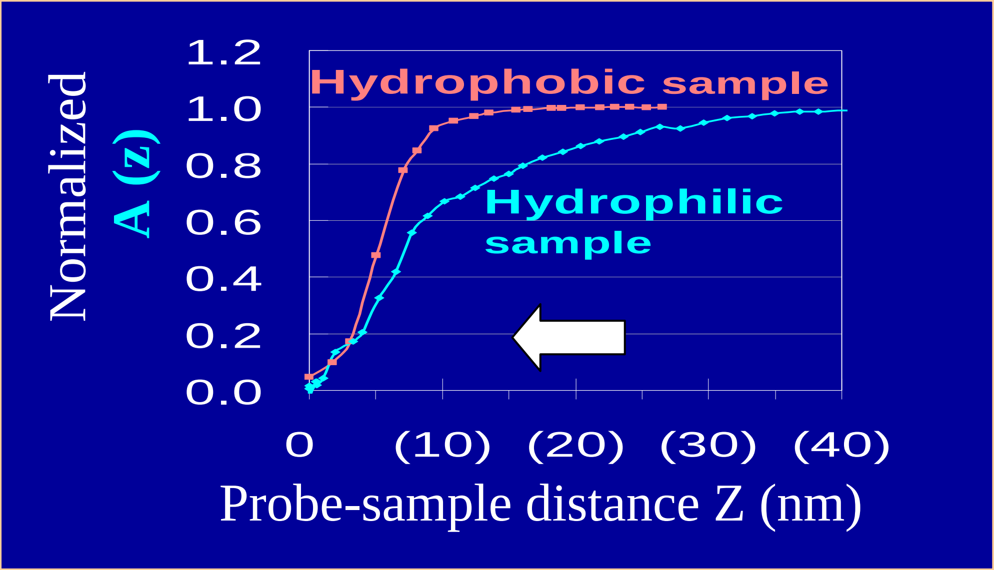
How to automatically control the probe’s vertical position?

STRATEGY

- **Probe is set to perform lateral oscillation (by an external device.)**
- **It is observed that the amplitude “A” of the lateral oscillations are damped when the probe’s tip is in the proximity (~20 nm) to the sample’s surface.**

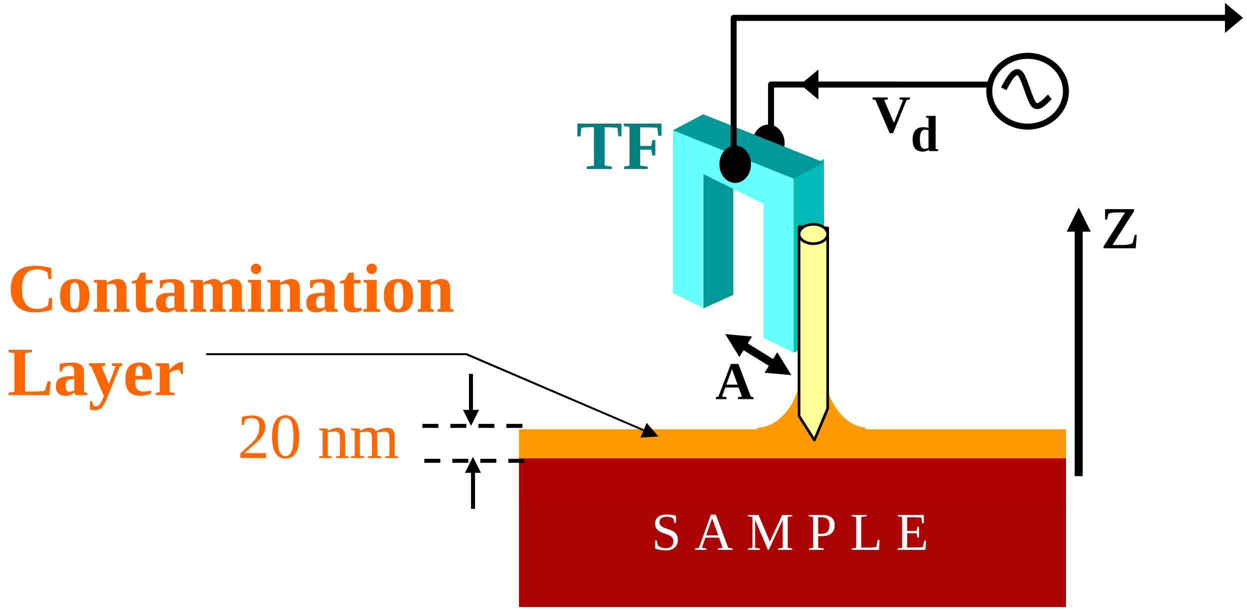


Approach Curves



Amplitude of lateral oscillations “A” decreases with distance “z”

Damping contamination layer (hypothesis)



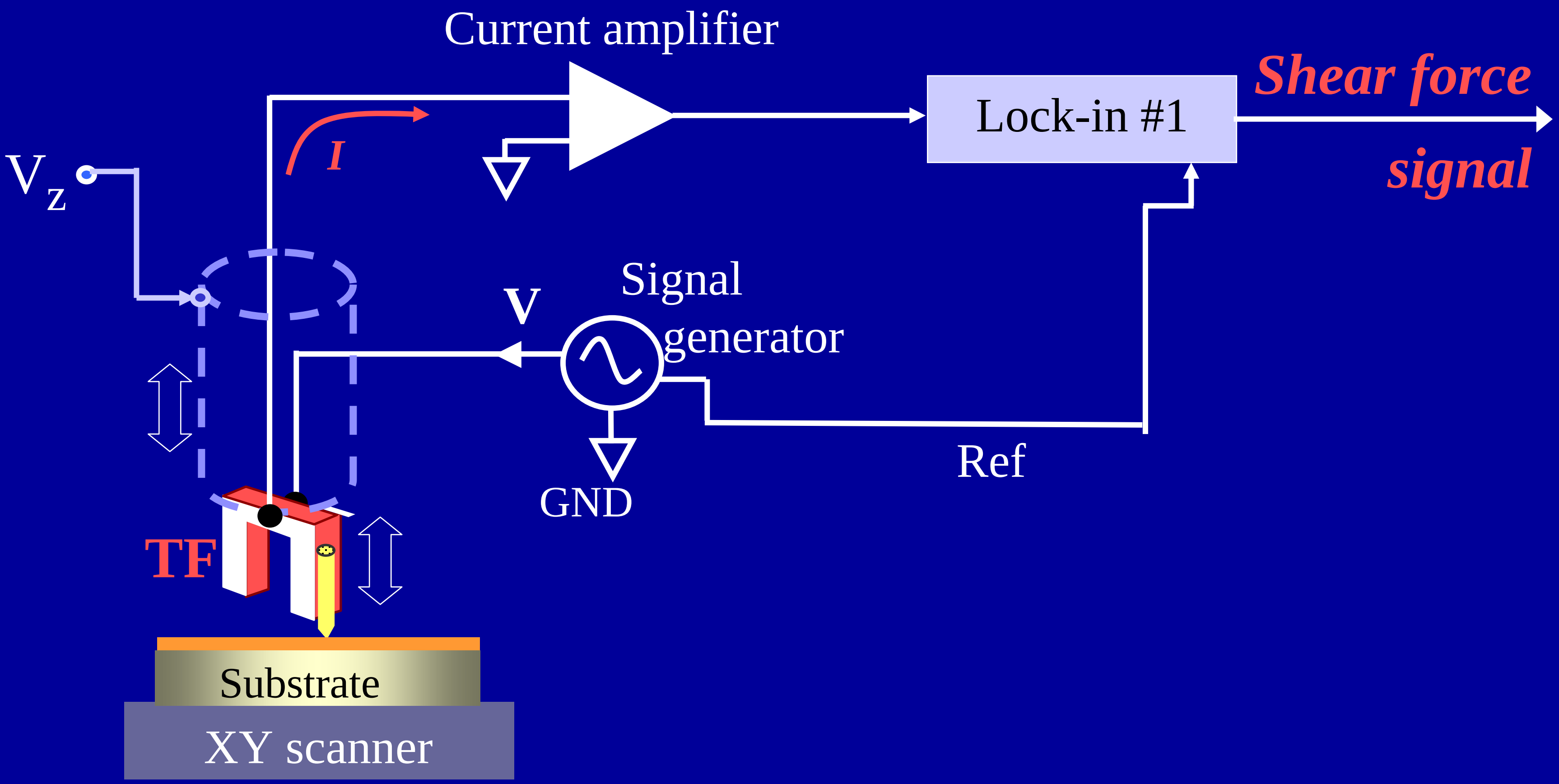
Shear-force mechanism

Hypothesis: The damping effect of the contamination layer should produce a distance dependence on the probe's amplitude of oscillations.

That is: A = A(z)

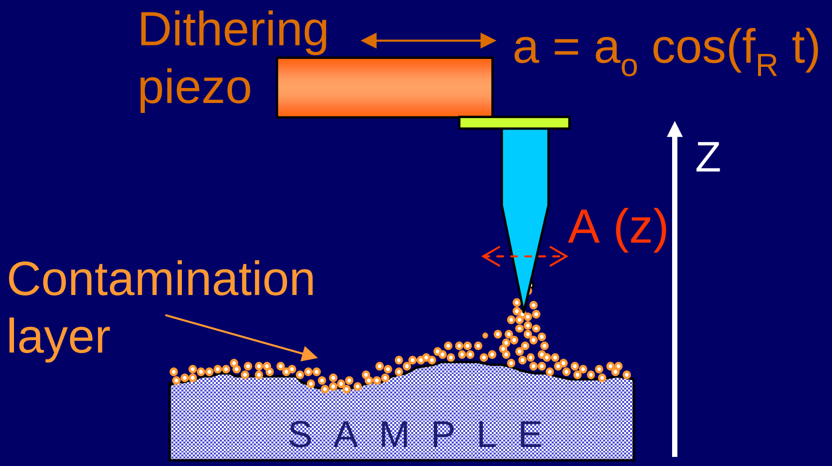
Shear-force detection

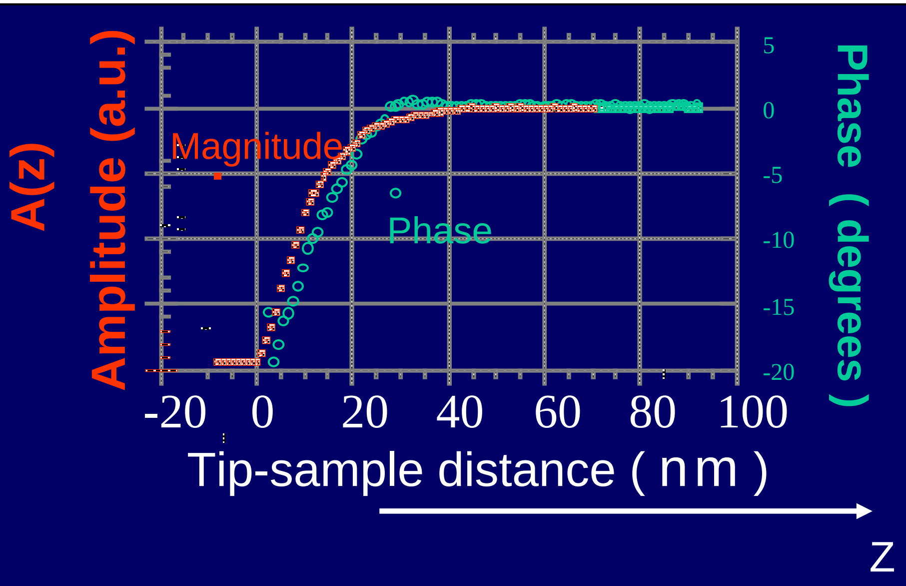
Electrical implementation



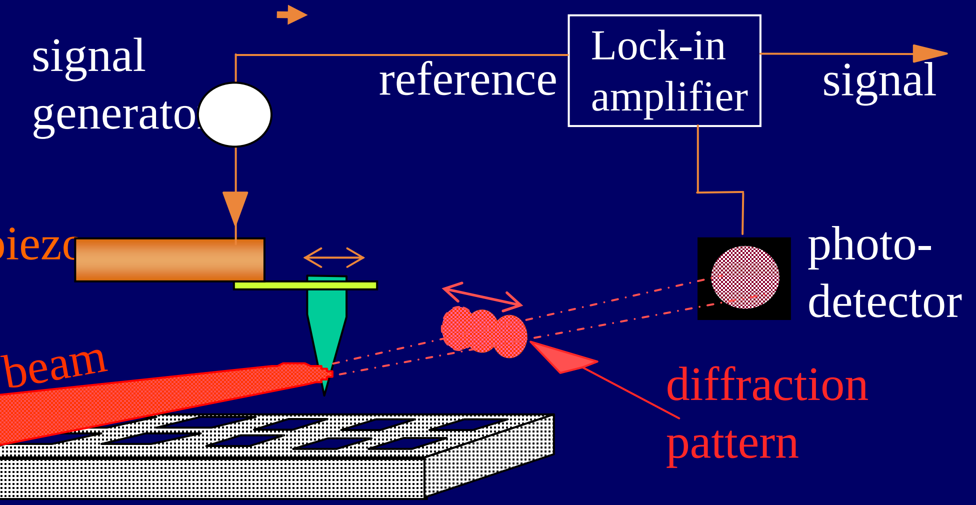
Shear-force detection

Optical implementation

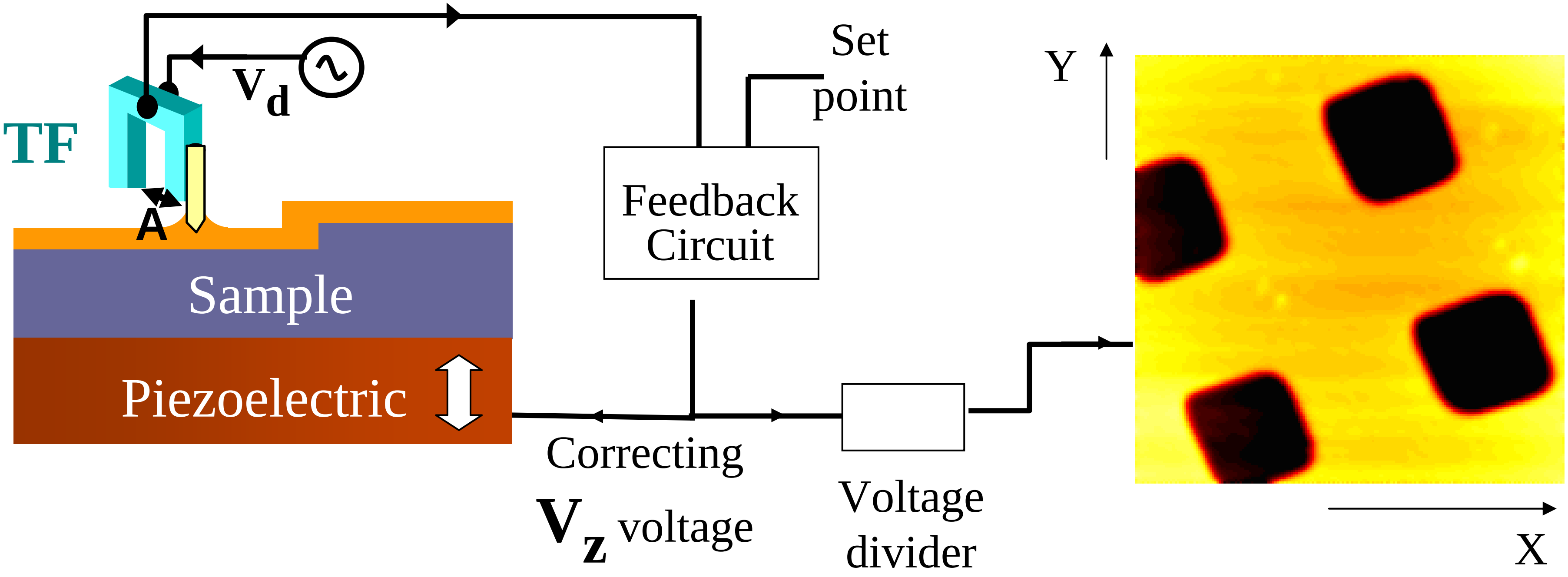




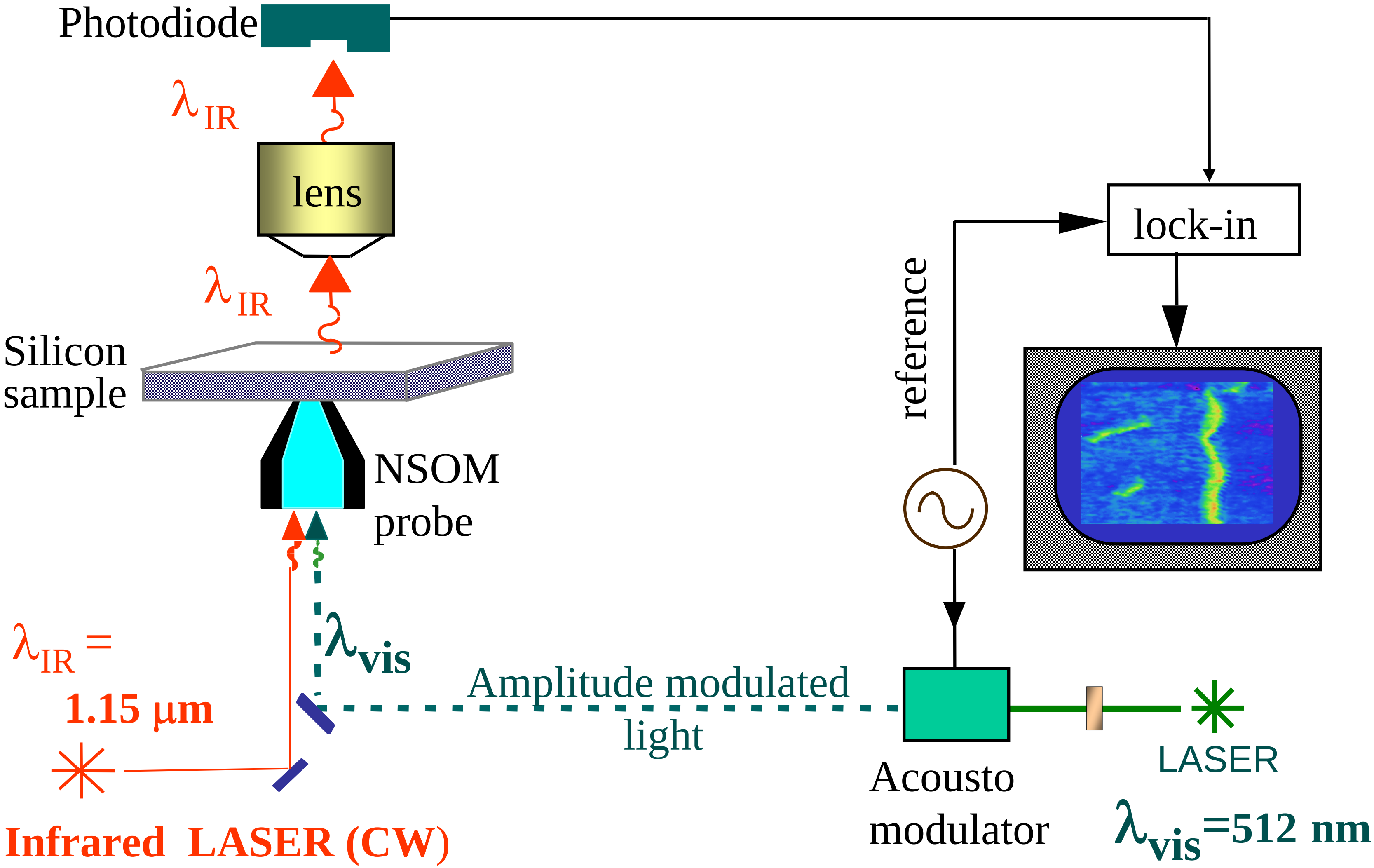
Amplitude of
oscillations
A = a Q

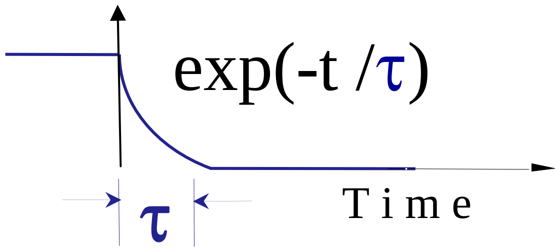


Implementing probe-sample distance regulation in NSOM

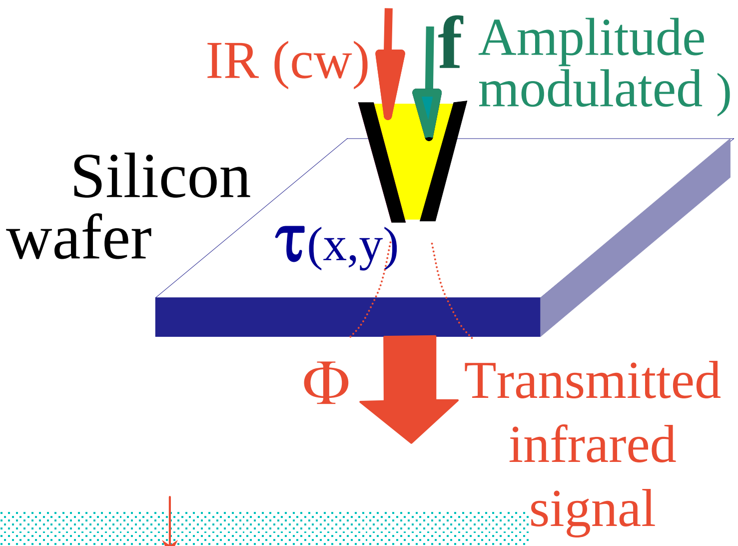


Experimental setup: Freq Resolved Contrast





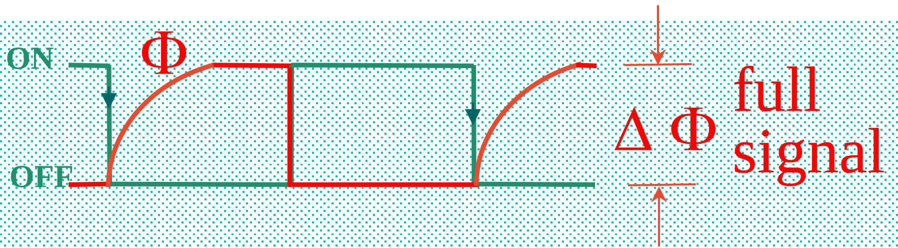
τ: carrier lifetime



Φ AS A FUNCTION OF TIME

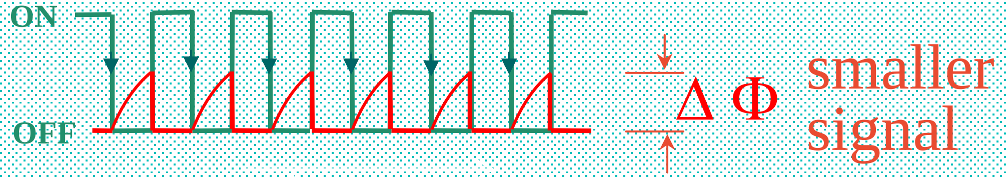
At low frequencies:

f < (1 / 2π τ)

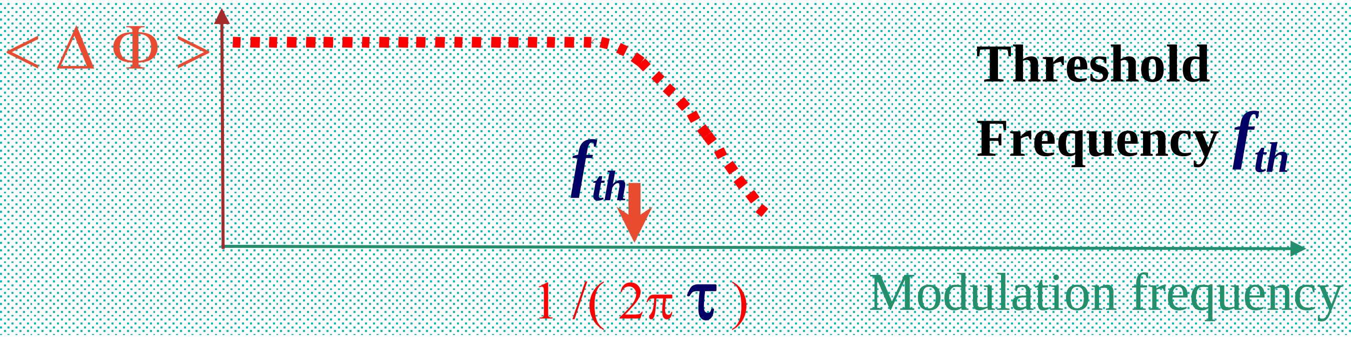


At high frequencies:

f > (1 / 2π τ)

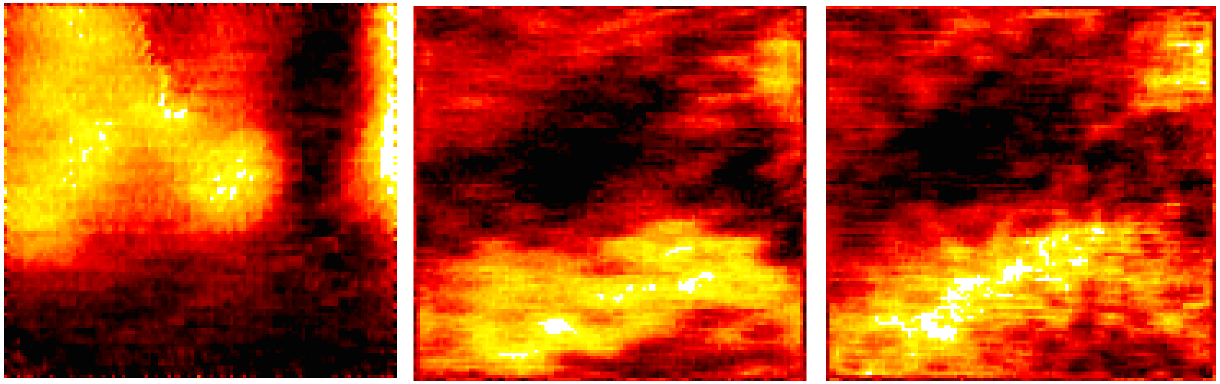


< Δ Φ > AS A FUNCTION OF FREQUENCY



Frequency Resolved Contrast

Charge Carrier Dynamics in Silicon



100 Hz *1 KHz* *20 KHz*

Optical excitation frequency

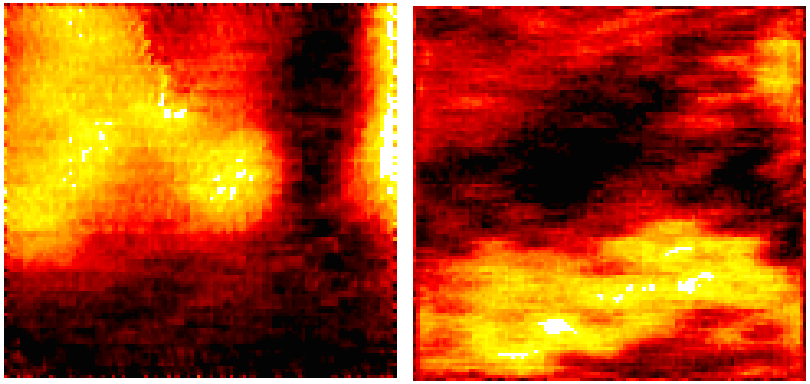
Near-Field images taken over the same region (7.5 μm^2)

To be compared with standard (far field) techniques: Resolution > 1 mm

Carrier Dynamics in Silicon

Near-field measurement

τ-NSOM



100 Hz *1 KHz*

Optical excitation frequency

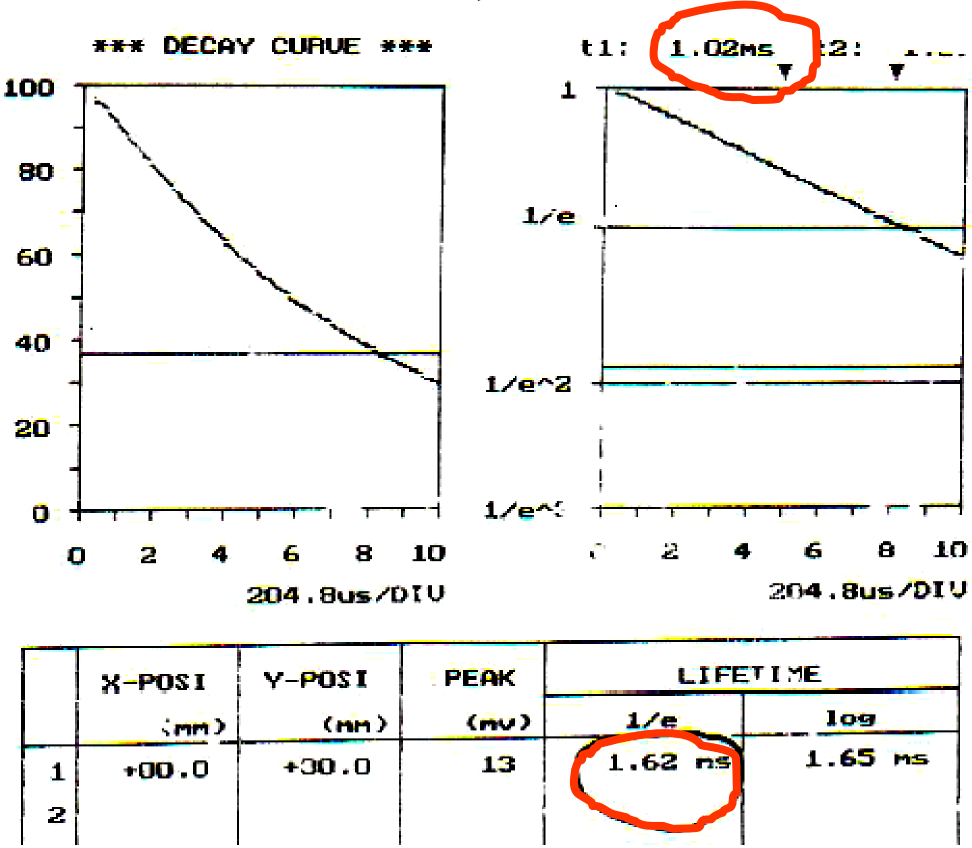
For a threshold frequency of

f_{th} ~ 100 Hz:

$\tau = 1 / 2\pi f_{th}$) ~ 1.5 ms !

Far-field measurement

Laser/Microwave
Lifettech-88, Semitex Co.



	X-POSI (mm)	Y-POSI (mm)	PEAK (mv)	LIFETIME 1/e	LIFETIME log
1	+00.0	+30.0	13	1.62 ms	1.65 ms
2					