# From apertureless near-field optical microscopy to infrared near-field night vision

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# From apertureless near-field optical microscopy to infrared near-field night vision

## Collaborators :

**Experimentation :**

F. Formanek
P-A. Lemoine

**Theory & Modelisation :**

J.-J. Greffet
R. Carminati

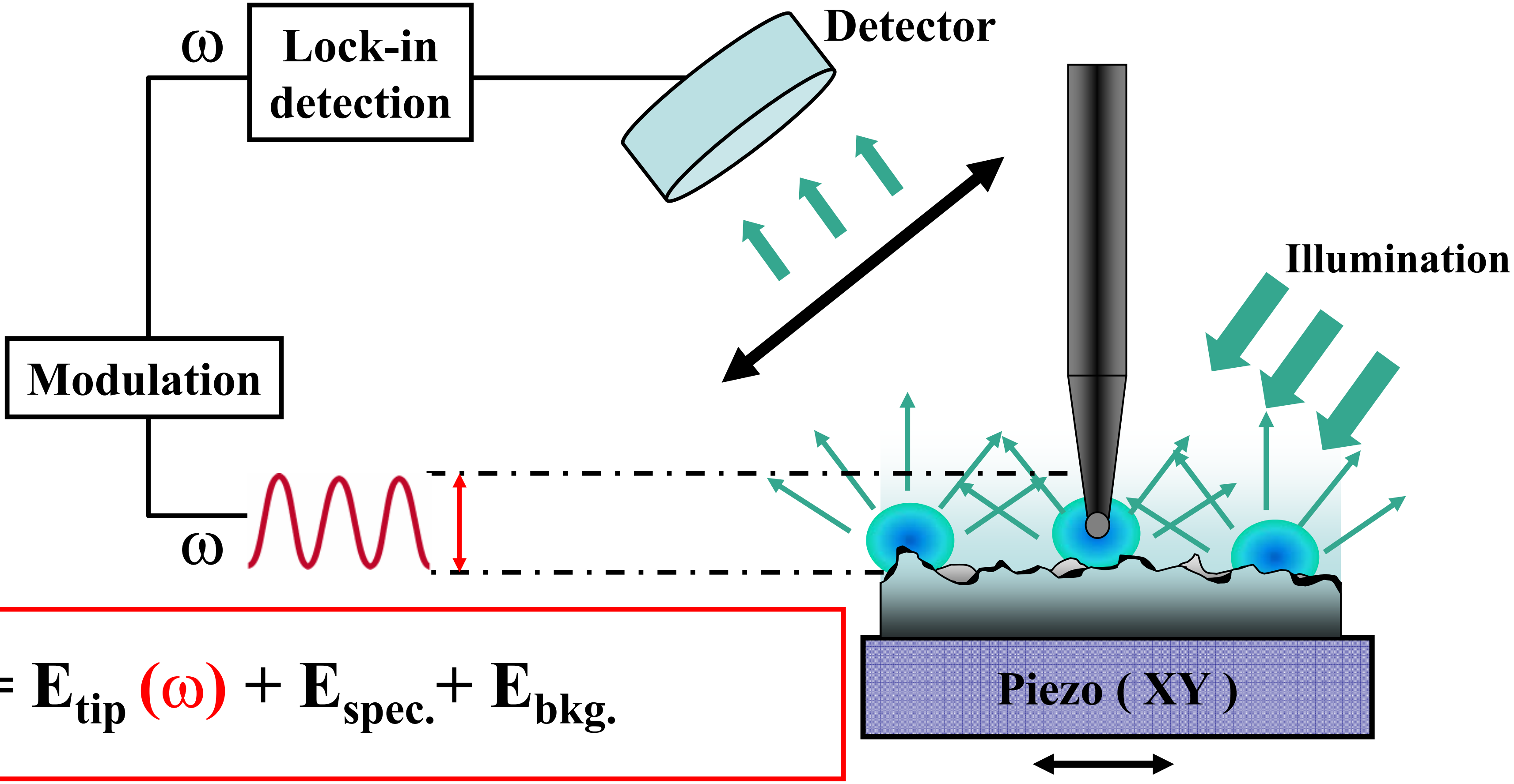
K. Joulain (ENSMA)
B. Gralak (I. Fresnel)

**Samples preparation :**

Y. Chen
(LPN-Marcoussis)

D. Courjon
C. Bainier
(LOPMD)

# Apertureless SNOM : Principle

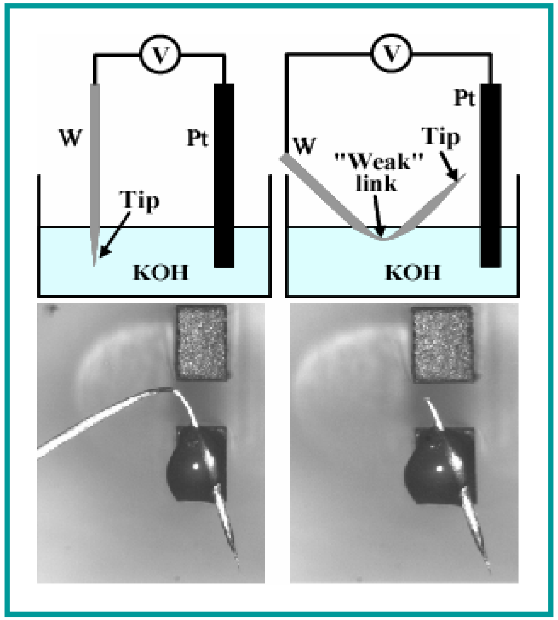


$$E_{det} = E_{tip}\,(\omega) + E_{spec.} + E_{bkg.}$$

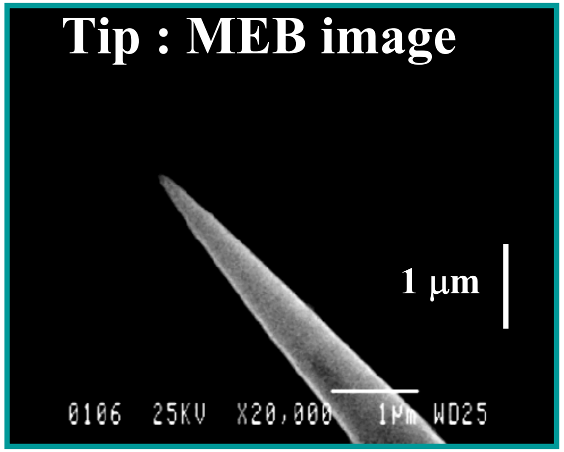
Vertical oscillation of the tip ⇒

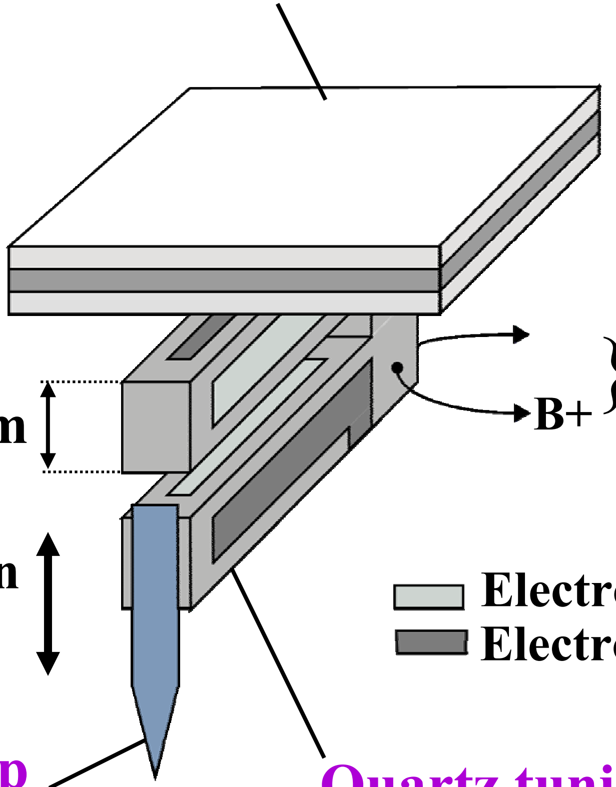
- To extract $E_{tip}(\omega)$ from the background
- Surface topography ( AFM, « tapping » mode )

# Apertureless SNOM based on a quartz tuning fork



Tip : MEB image





PZT plate (excitation)

0.4mm

Vertical oscillation "Tapping mode"

B+

Oscillation amplitude → z-feedback → Topography

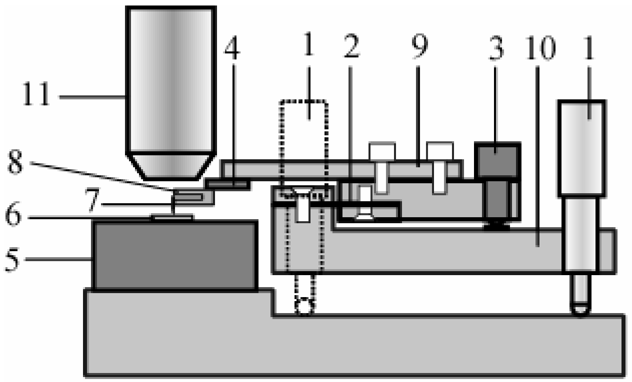
Electrode B

Electrode A

Tip (tungsten)

Quartz tuning fork

# Apertureless SNOM based on a quartz tuning fork

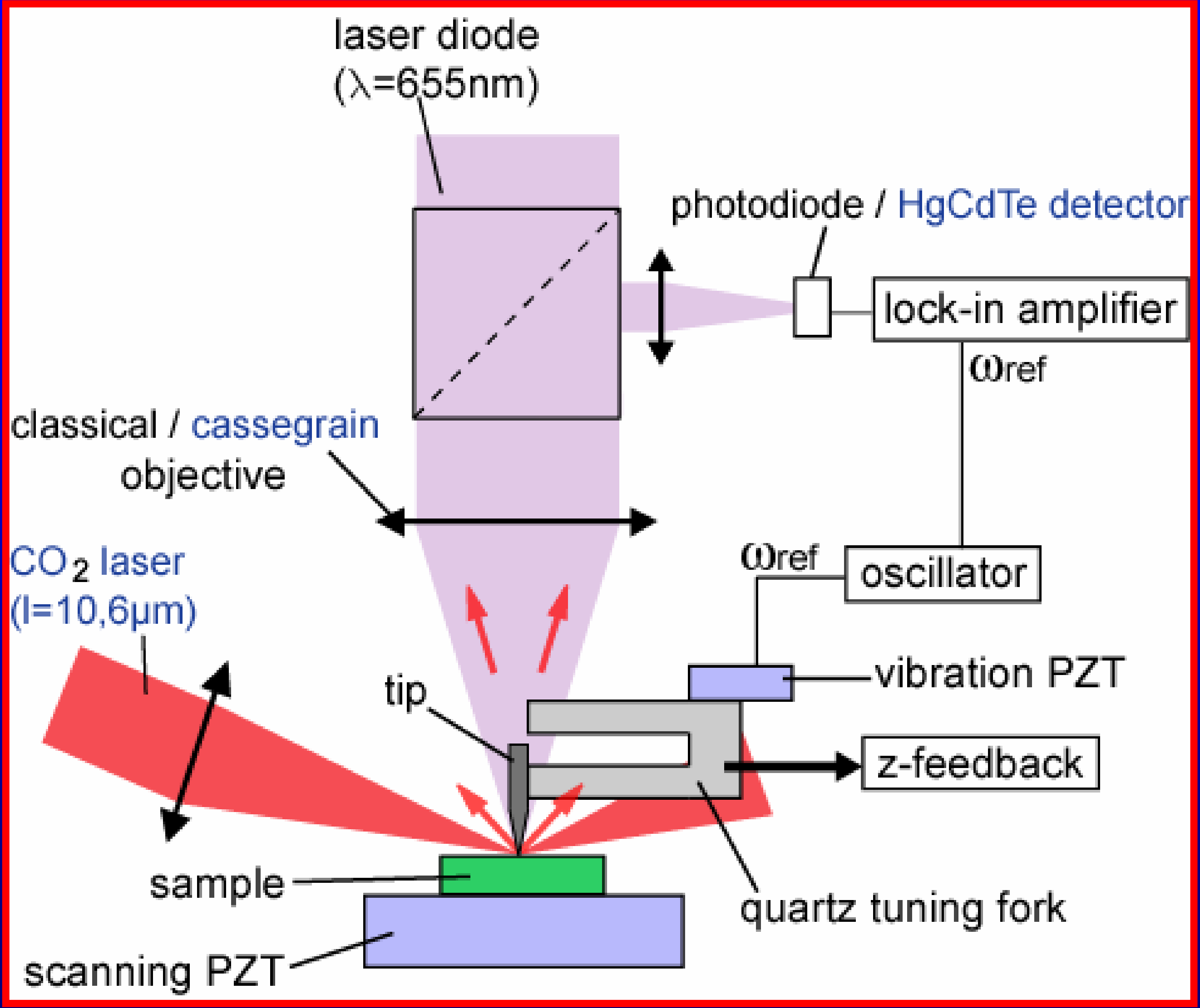


(1) micrometer screw
(2) leaf spring
(3) piezoelectric stack (z)
(4) piezoelectric disk
(5) piezoelectric plate (xy)
(6) sample
(7) tip
(8) tuning fork
(9) aluminum lever
(10) "triangular" plate
(11) objective

**Y. De Wilde, F. Formanek, L. Aigouy,**
**Rev. Sci. Instrum. 74, 3889 (2003)**

**Scan range (XY) : 34 µm x 34 µm**
**Vertical range (Z) : 17 µm**
**AFM resolution :**
  **- vertical ~ 1 nm**
  **- lateral ~ 20-50 nm**

# Apertureless SNOM with visible or infrared laser illumination : experimental set-up



# Apertureless SNOM with visible or infrared laser illumination : experimental results

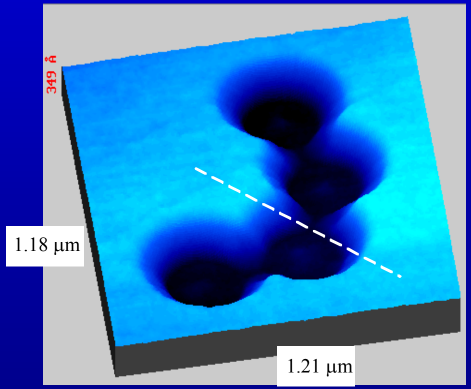
## SUBWAVELENGTH HOLES ($\phi$=200nm) : INFRARED imaging

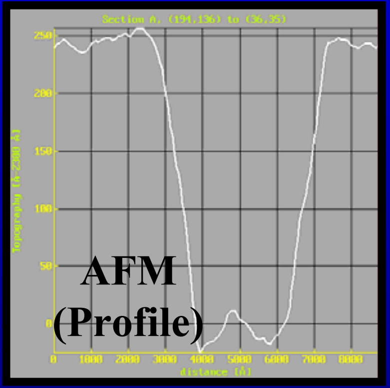
Microscopie électronique
(C. Bainier et D. Courjon)

**Formanek, De Wilde, Aigouy,**
**J. Appl. Phys. 93, 9548 (2003)**

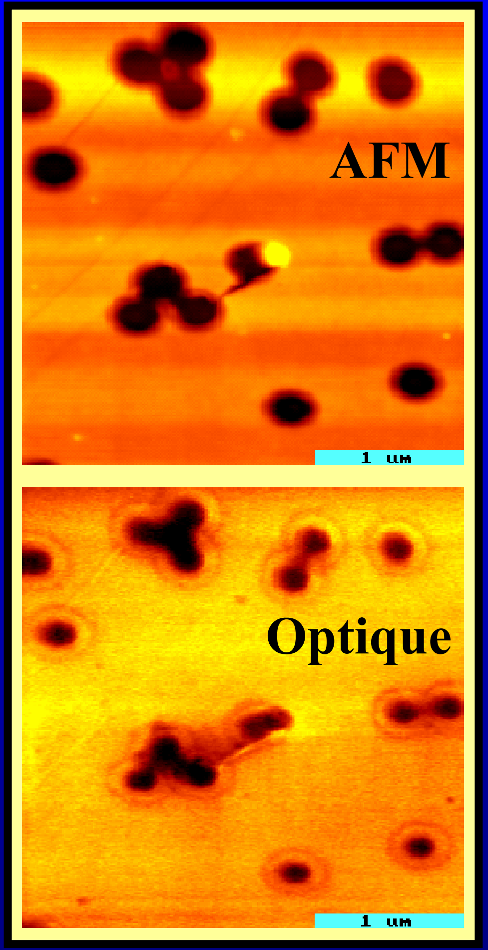
**GDR Optique de champ proche**
**Appl. Optics 42, 691 (2003)**

**AFM (topography)**





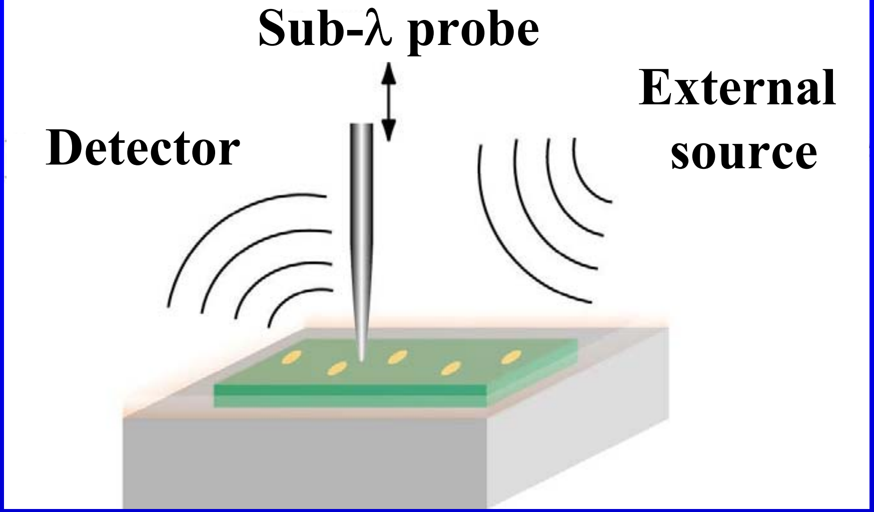
Optical resolution ~ 30 - 50 nm
~ $\lambda$/200



**SNOM (3µmx3µm)**

**Infrared illumination $\lambda$=10,6 µm**

# Near-field optics without external illumination



***A 'regular' SNOM requires 3 basic ingredients : Source-Probe-Detector***

- Screen with subwavelength hole

  Original idea

  **Synge, Phylos. Mag. 6, 356 (1928)**

- Aperture SNOM

  **Pohl, …, Appl. Phys. Lett 44, 651 (1984)**

- Scattering tip (apertureless) SNOM

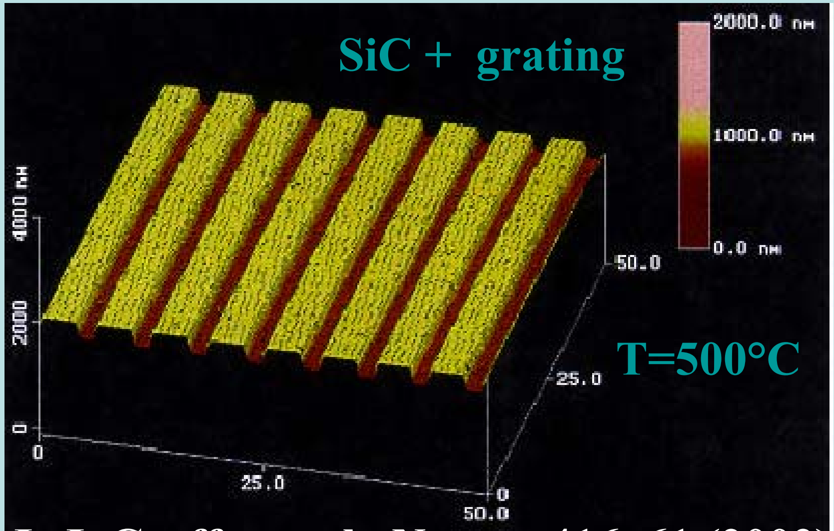
  **Zenhausern, Appl. Phys. Lett. 65, 1623 (1994)**

**New concept :**

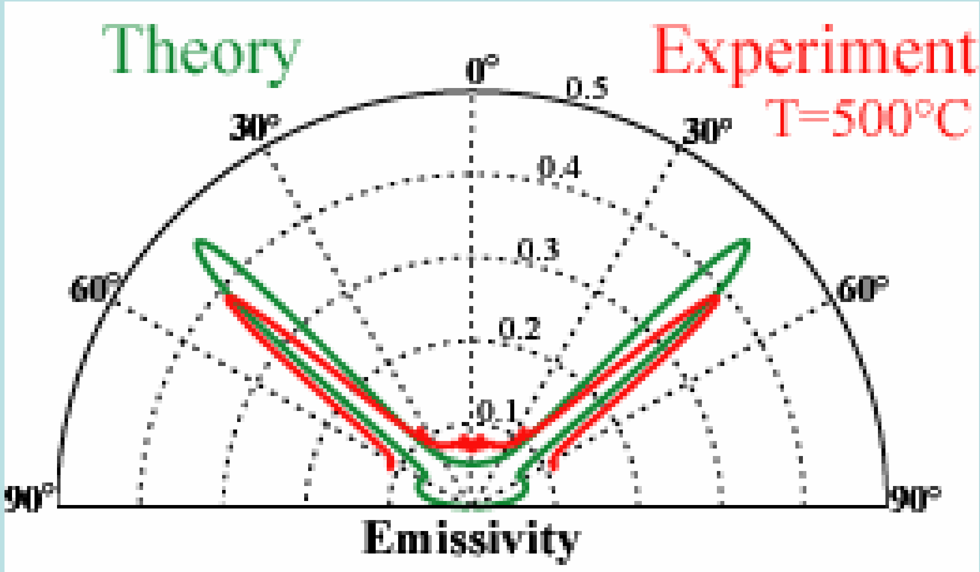
**SNOM <u>WITHOUT</u> EXTERNAL SOURCE**

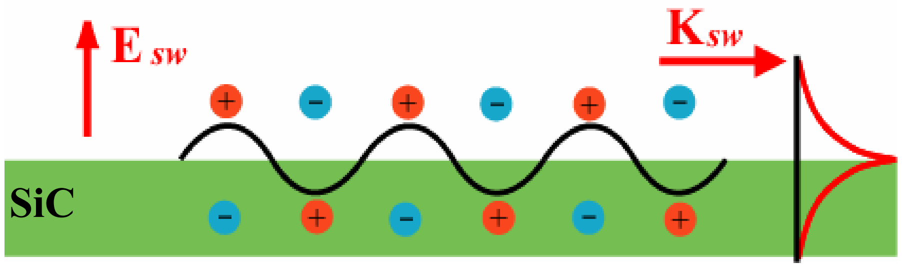
**SUBMITTED FOR PUBLICATION**

# Surface waves in silicon carbide (SiC)



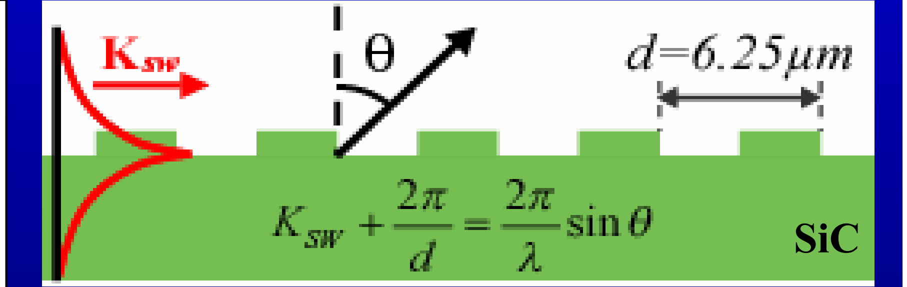
J.-J. Greffet et al., Nature 416, 61 (2002)





SiC = polar material which supports surface waves known as surface phonon-polaritons

=> Evanescent waves thermally stimulated



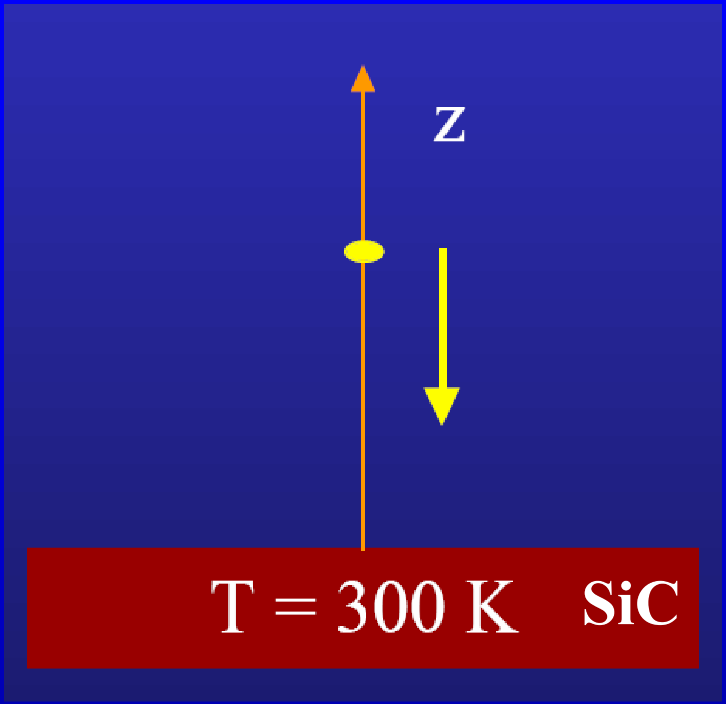
$$K_{sw} + \frac{2\pi}{d} = \frac{2\pi}{\lambda}\sin\theta$$

**Diffraction**

⬍

**Coherent thermal emission**

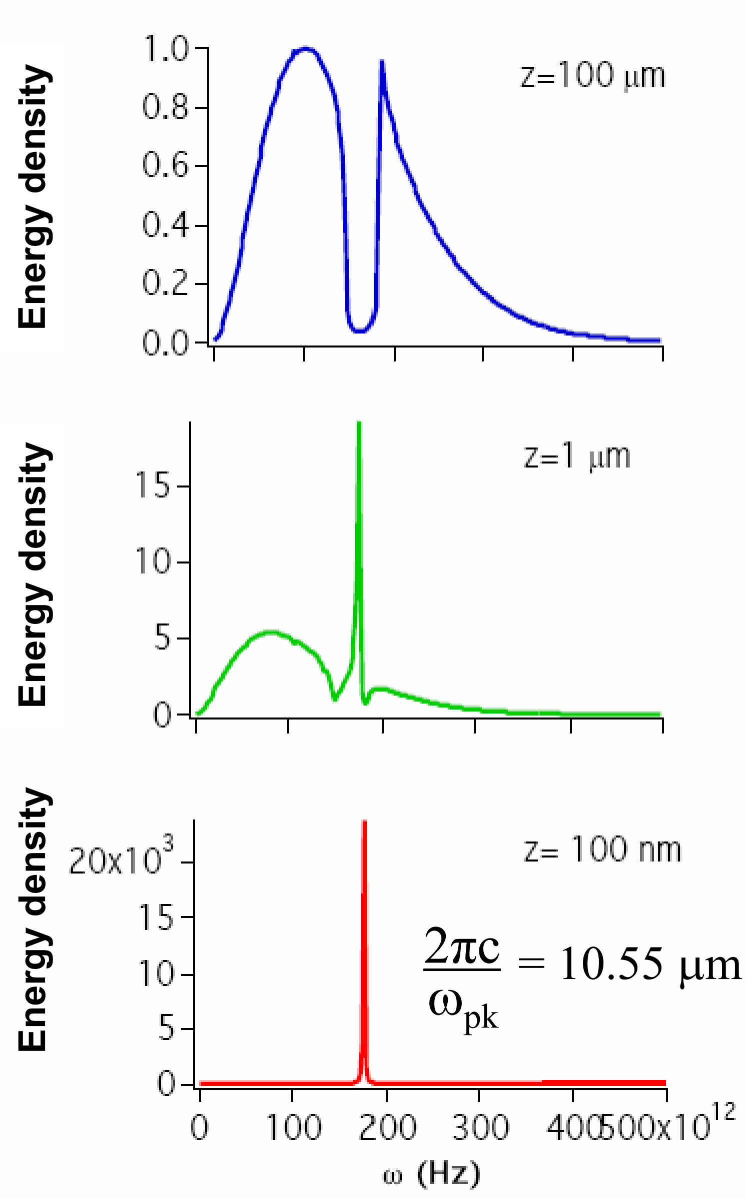
# Surface waves in silicon carbide (SiC)



**Enhanced electromagnetic energy density in near-field zone**

⬇

**Good first candidate !**



$$\frac{2\pi c}{\omega_{pk}} = 10.55\ \mu m$$

Shchegrov, Joulain, Carminati, Greffet, PRL. 85, 1548 (2000)

# Probing the local electromagnetic density of states (EM-LDOS)

- <u>**EM -LDOS**</u> **:**

**$\rho(\mathrm{r},\omega)$dr : Probability to find a photon ħω in r in a small volume dr.**

- **Local density of electromagnetic energy :**

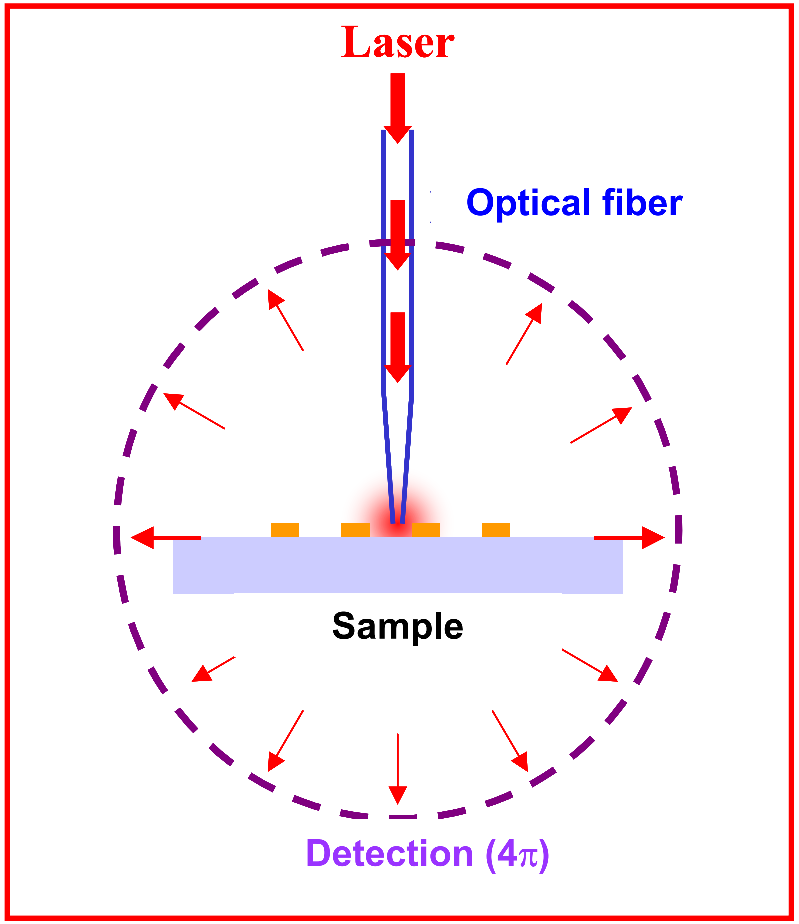
$$U(\mathrm{r},\omega)=\rho(\mathrm{r},\omega)\;\hbar\omega\,\frac{1}{\exp\left(\hbar\omega/kT\right)-1}$$

**EM-LDOS** **Energy of 1 photon** **N. Photons / state**

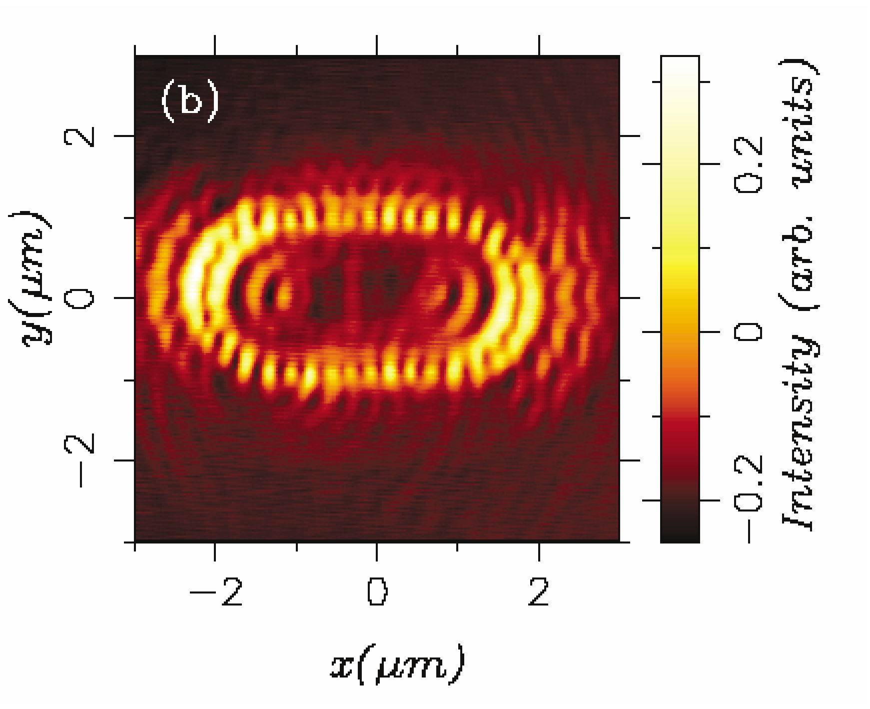
**<u>Vacuum</u> : $\rho(\mathrm{r},\omega)=\dfrac{\omega^2}{\pi^2 c^3}$** **Homogeneous, isotropic**

**<u>But</u> : Spatial variations of ρ(r,ω) are expected near an interface (evanescent modes, plasmons, phonon-polaritons, …) or in photonic structures.**

# Probing the local electromagnetic density of states (EM-LDOS)

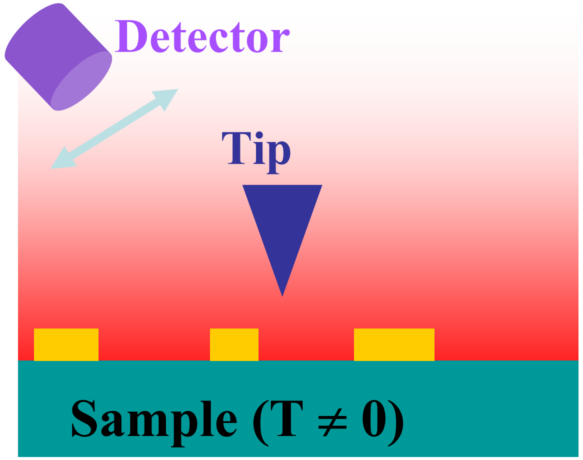


Corral structure



C. Chicanne, T. David, R. Quidant, J. C. Weeber, Y. Lacroute, E. Bourillot, A. Dereux, G. Colas des Francs and C. Girard, Phys. Rev. Lett. 88, 097402 (2002)

# Probing the local electromagnetic density of states (EM-LDOS)



At T≠0, all available states are occupied, according to Bose-Einstein statistics

↓

A point-like SNOM probes the EM-LDOS

Joulain, Carminati, Mulet, Greffet, PRB 68,245405 (2003)

# Conclusions :

- SNOM which operates with visible or infrared laser illumination

- SNOM without laser :
  - Detects the infrared near-field thermal radiation
    « Near-field infrared night-vision camera »
  - Observation of near-field coherence effects on gold patterns on SiC
  - Probes the EM-LDOS
    => Behaves as an « infrared STM » (IRSTM)