Design of Magnetoplasmonic Resonant Nanoantennas for Biosensing Applications

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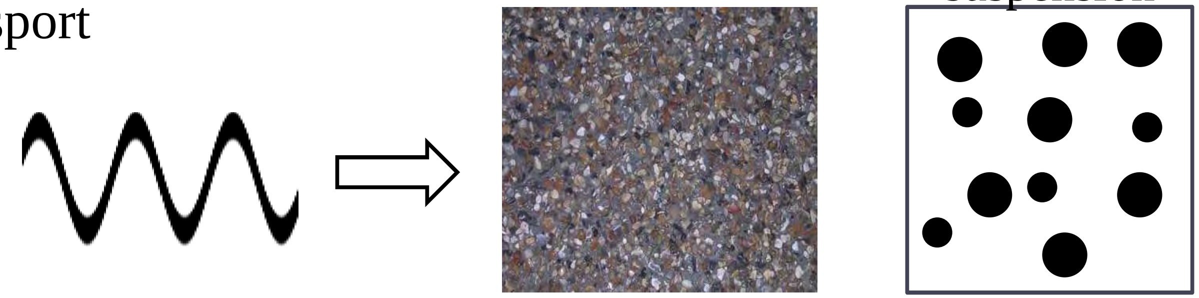
Introduction (1)

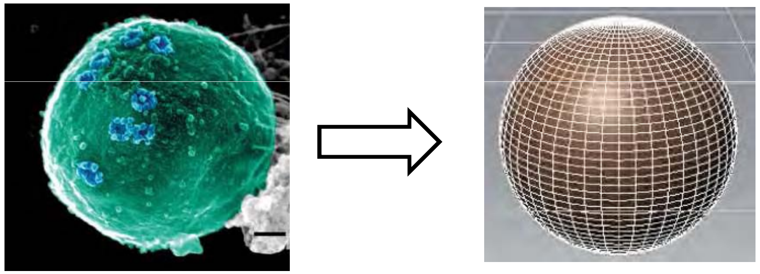
Brosseau's group activities

- Electromagnetic wave transport in composite materials

concrete

Colloidal suspension





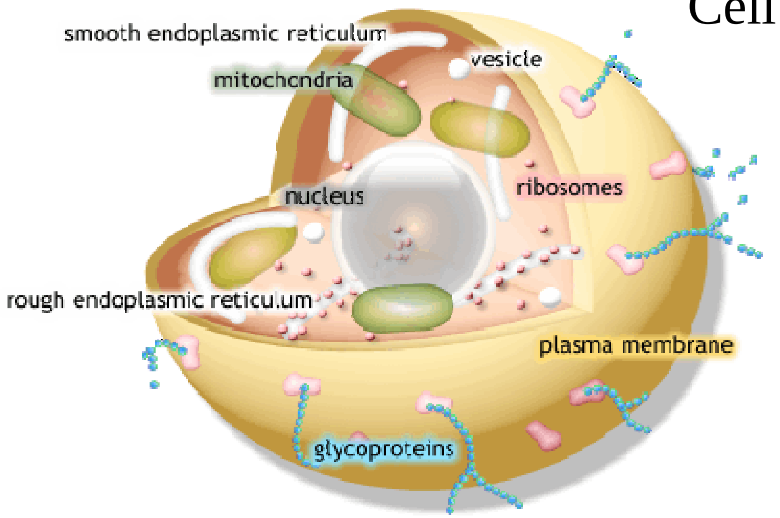
- Multiscale modeling of biological cells

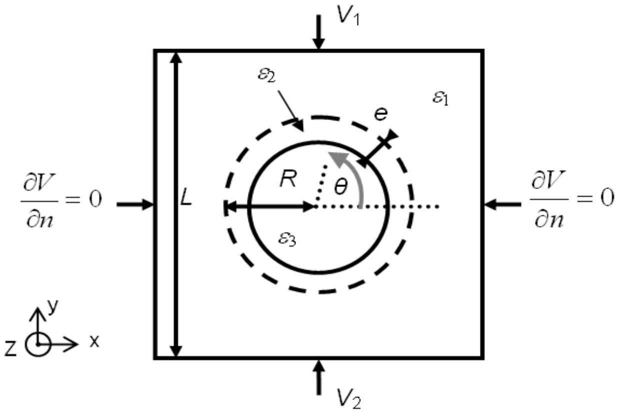
- Interface Physics-Biology (interaction electromagnetic wave - human body)

Introduction (2)

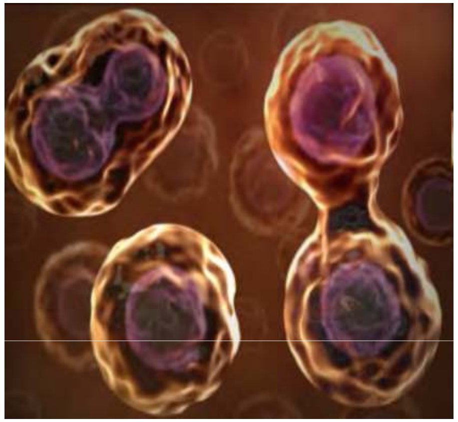
Earlier work [1-2]

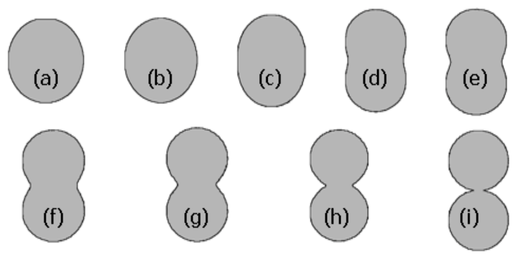
Cell



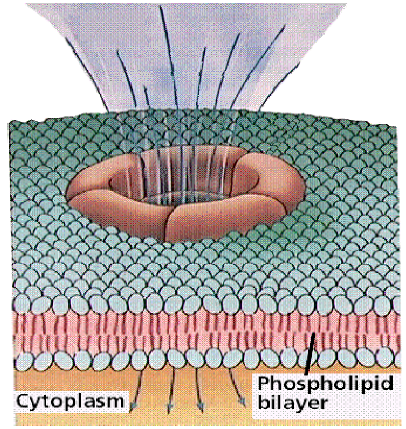


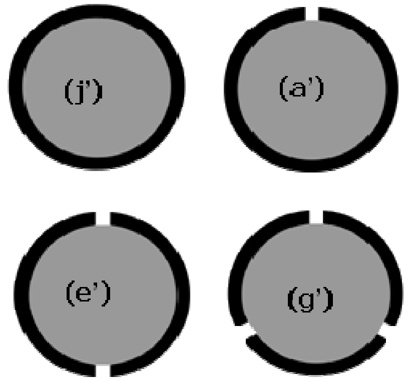
Cell division





Membrane disruption

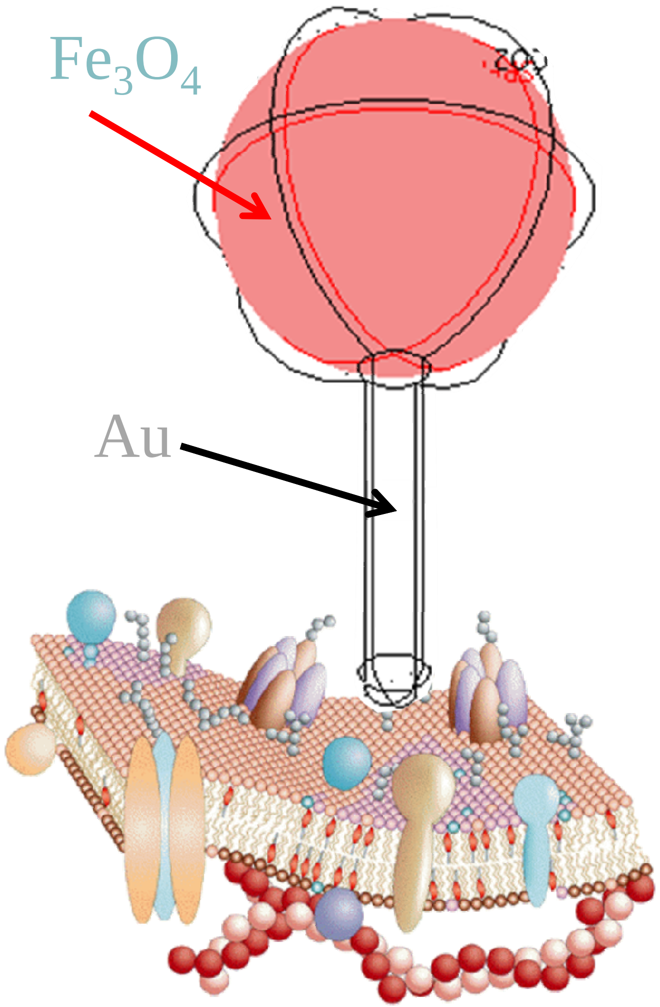




[1] P. Salou, A. Mejdoubi, and C. Brosseau, J.Appl. Phys.**105**, 114702 (2009)
[2] M. Essone Mezeme and C. Brosseau, J.Appl. Phys.**107**, 014701 (2010), ibidem **108**, 014701 (2010)

Introduction (3)

Design of new magneto-plasmonic core-shell nano-antennas



Au: ideal metal
Fe_3O_4 : ferromagnetic oxide
Au and Fe_3O_4 : biocompatible materials

Principles:

-Plasmonic resonance: surface plasmon excitation and energy confinement in very small length scale

-Gyromagnetic resonance: magnetic localization and microwave heating

Advantages:

-Controllable by **H**
-Separation of length scales (cell size ≈10µm and nano-antenna length ≈100nm)
-Confinement of electric field enhancement(≈ 40nm)

Outline

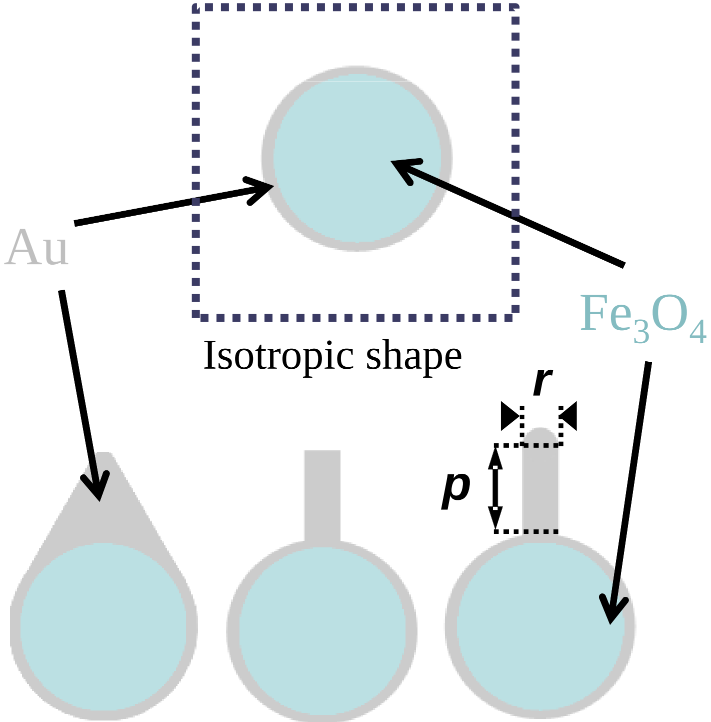
1- Numerical model and simulation

2- Results and discussion

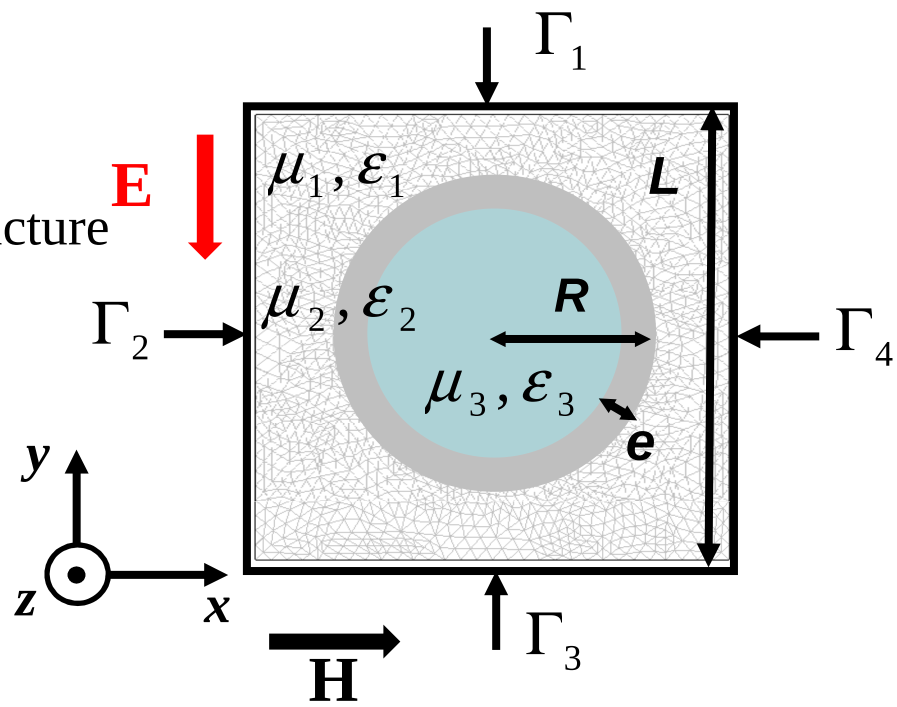
3- Concluding remarks

Numerical model and simulation (1)

- **- 3 phase system**
- **-Core-shell structure** embedded in a biological material
- -Cross-section of infinitely extended structure in the z direction (≈ 2D)
- -Finite structure (3D)



Anisotropic shapes



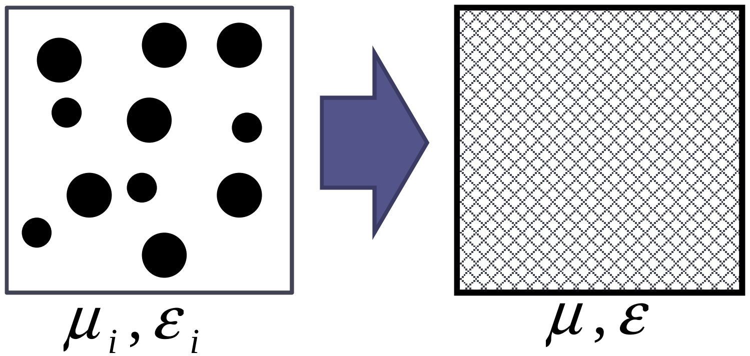
R≈50nm, e≈5nm, p≈50nm and r≈10nm

Boundary conditions:

Γ_1: V_2= 1V	Γ_1: J_2= 1Am^{-2}
Γ_2: $\partial V/\partial n$= 0	Γ_2: $H \times n$= 0
Γ_3: V_1= 0V	Γ_3: J_1= -1Am^{-2}
Γ_4: $\partial V/\partial n$= 0	Γ_4: $H \times n$= 0

Numerical model and simulation (2)

heterogeneous homogeneous



Assumptions:

-Long-wavelength physics λ >> **system size →no scattering.**

-Dielectric properties of biological material assimilated to water

-Continuum medium approach

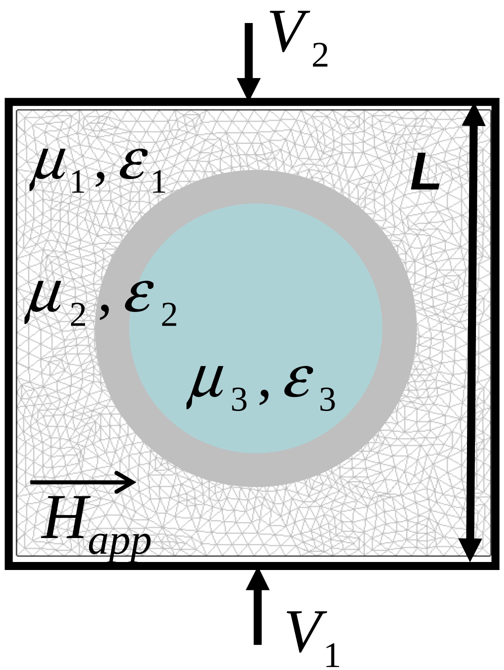
ε_1 : water

ε_2 and ε_3: Drude model

$\mu_1 = \mu_2 = 1$

μ_3: Landau-Lifshitz-Gilbert relaxation model

Water: Phase1 Au: Phase2 Fe_3O_4 : Phase3



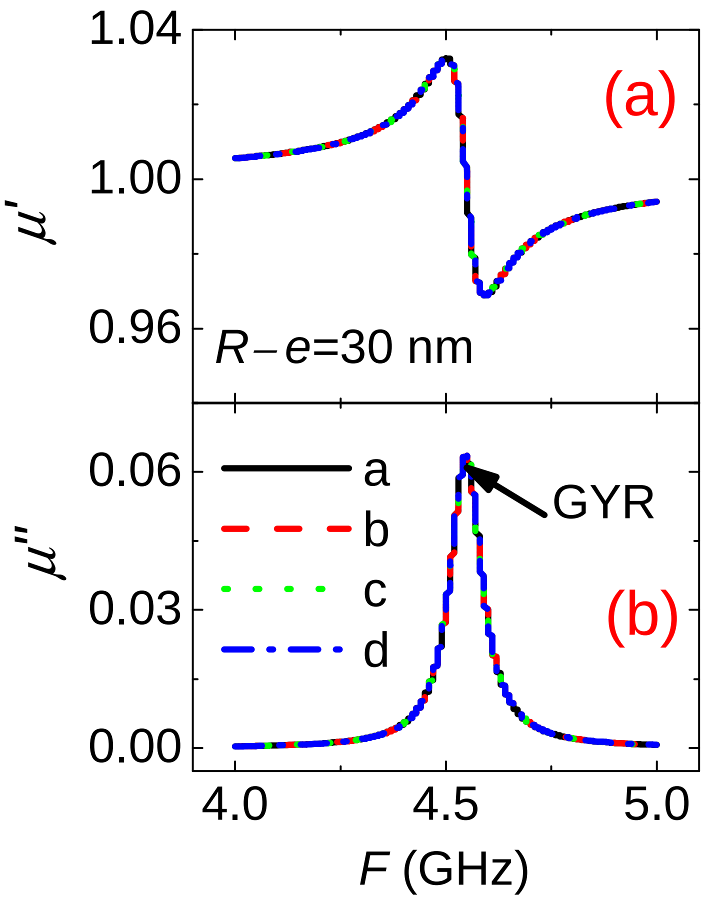
Effective permittivity:

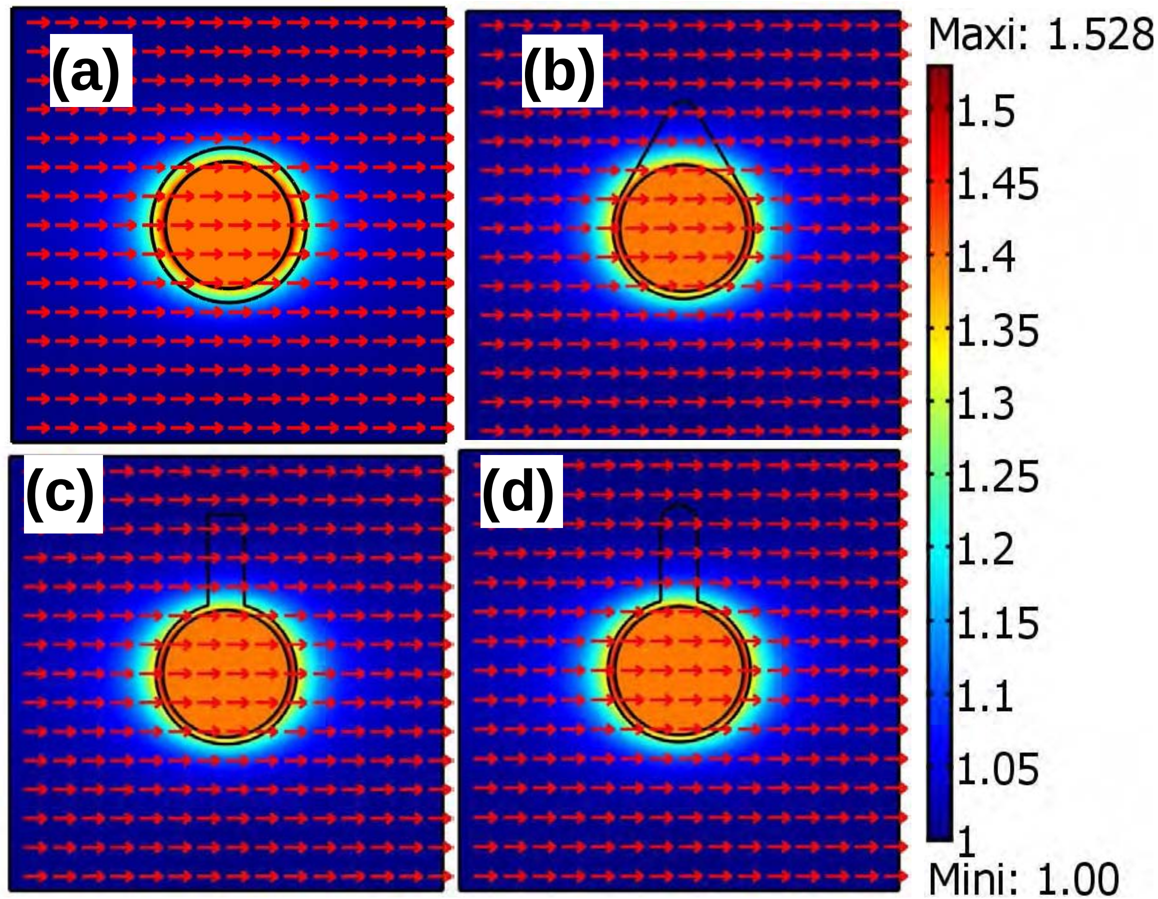
$$\varepsilon = \frac{1}{(V_2 - V_1)^2} \iint_S \varepsilon_k(x,y) \left(\left(\frac{\partial V}{\partial x} \right)^2 + \left(\frac{\partial V}{\partial y} \right)^2 \right) dxdy$$

Effective permeability:

$$\mu = \frac{1}{(H_{app} L)^2} \iint_S \mu_k(x,y) H^2(x,y)\, dxdy$$

Results and discussion (1)





GYR: Gyromagnetic resonance

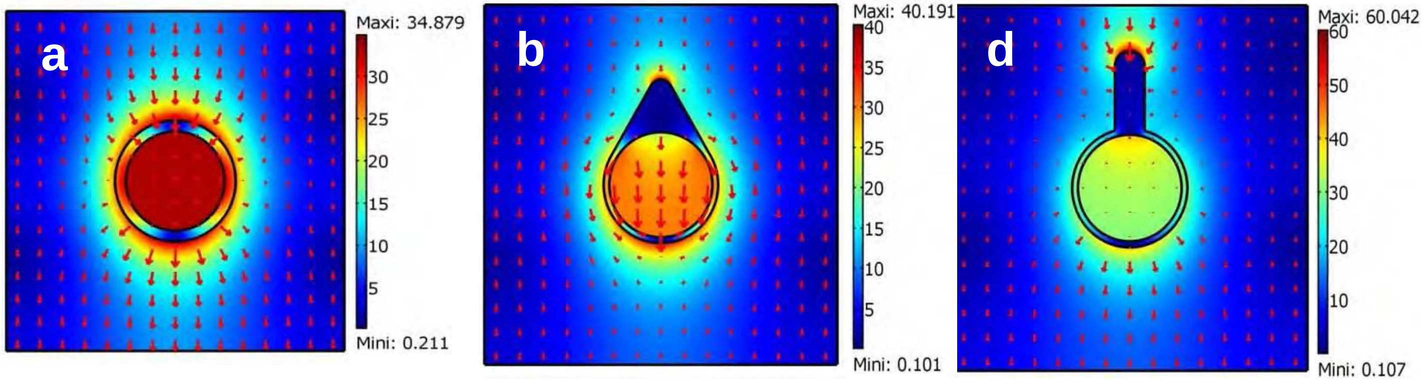
Magnetic Field Enhancement (MFE)

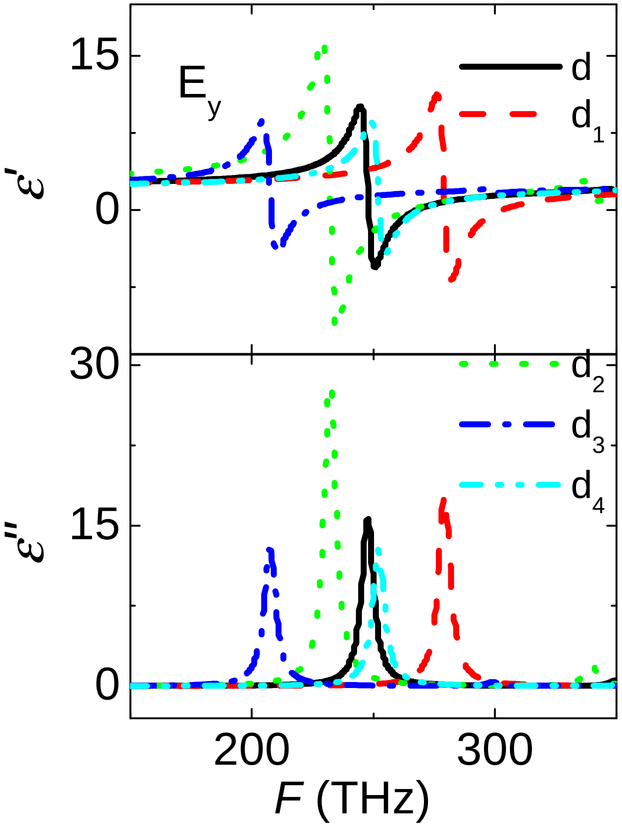
MFE=| H |/|H_{app} |

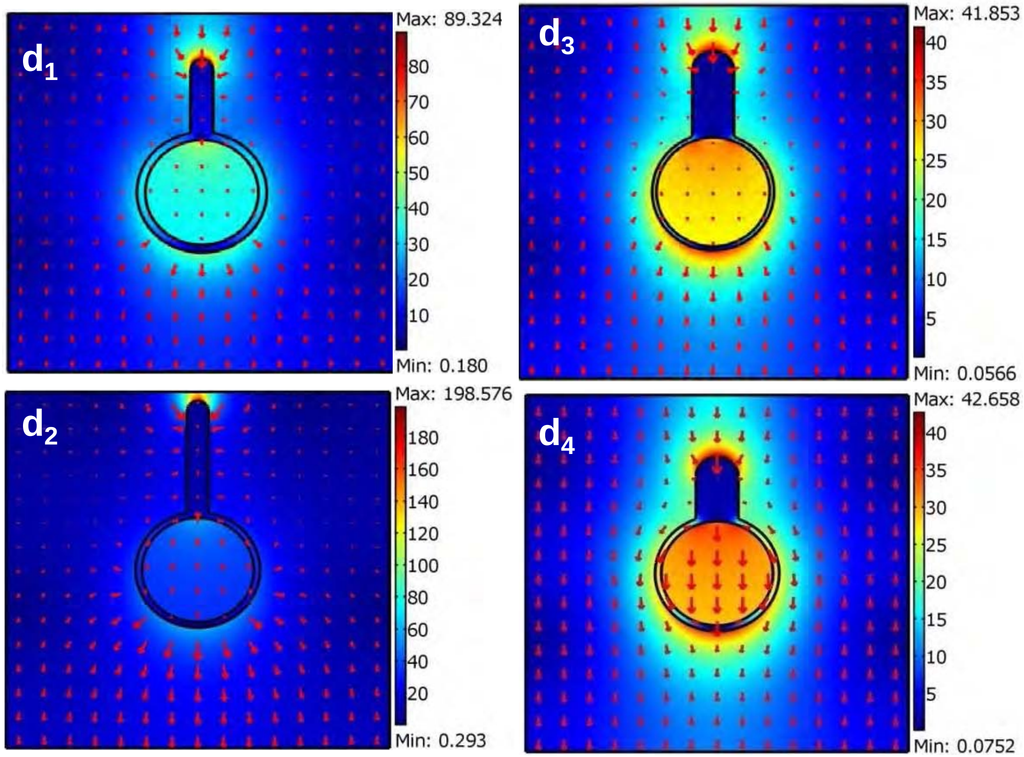
Results and discussion (2)

Electric Field Enhancement (EFE)
$EFE = |E|/|E_{app}|$

Influence of shape



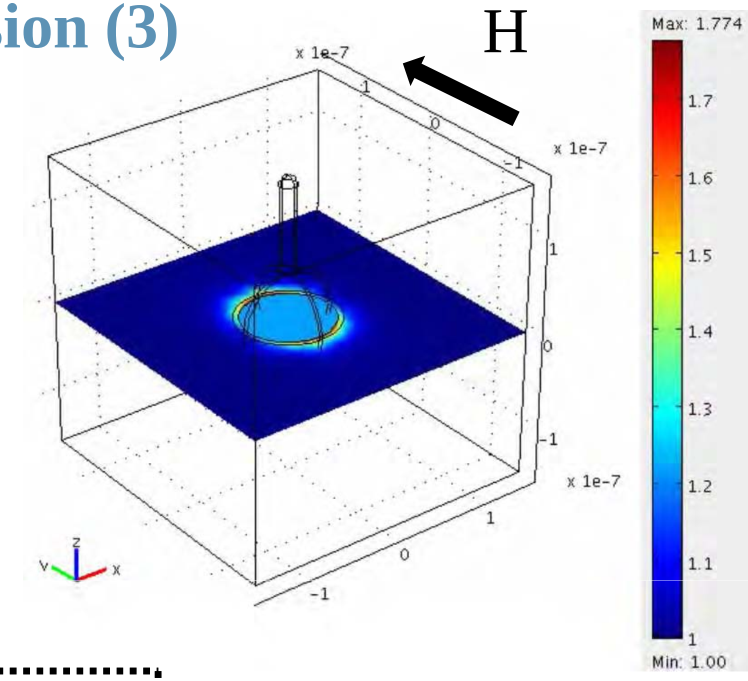




Results and discussion (3)

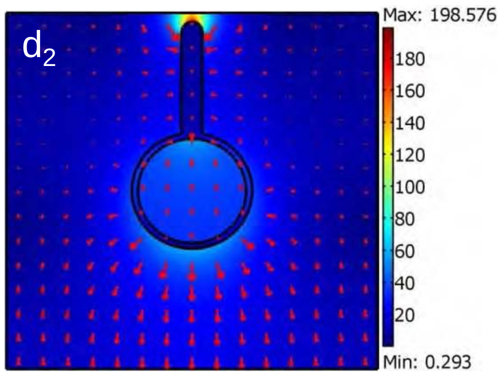
Parameters	**2-dimensional**	**3-dimensional**
F_{GYR}	4.5 GHz	4.5 GHz
F_{PLR}	250 THz	100THz
MFE	1.5	1.8
EFE	199	773
Confinement length	20nm	40nm
Au concentration	3.5%	0.6%
Fe_3O_4 concentration	7.0%	1.4%

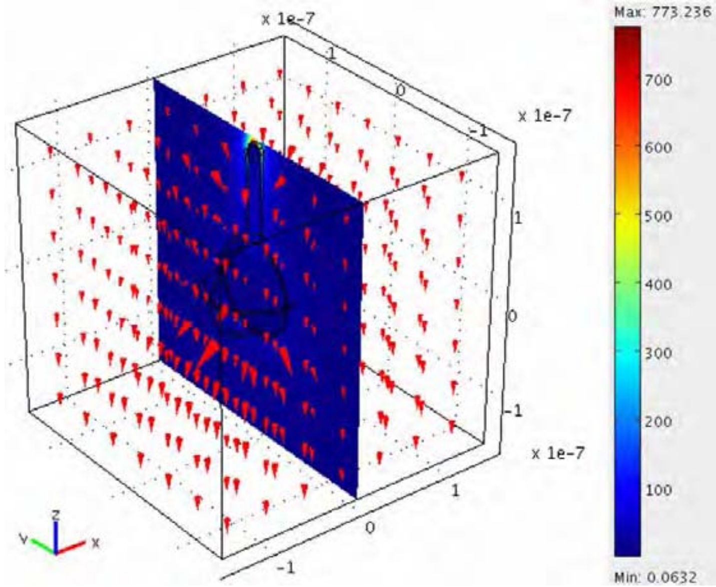
H

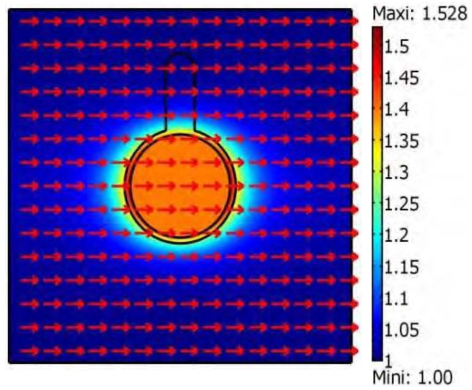


MFE at GYR

EFE at PLR







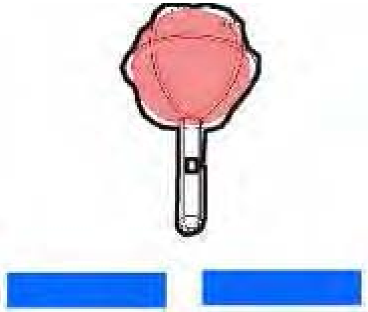
Concluding remarks (1)

Magneto-plasmonic core-shell nano-antennas are based on:

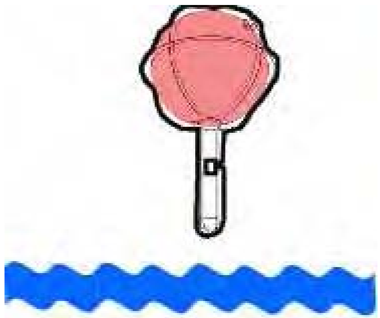
Magnetic core: -Controllable by **H**
-Useful for local microwave heating (hyperthermia)

Plasmonic shell: -Induces a localized enhancement of **E** on 40nm
-Optically detectable

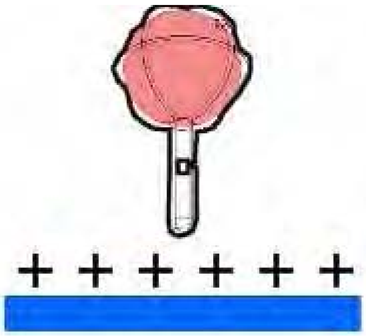
Perspectives



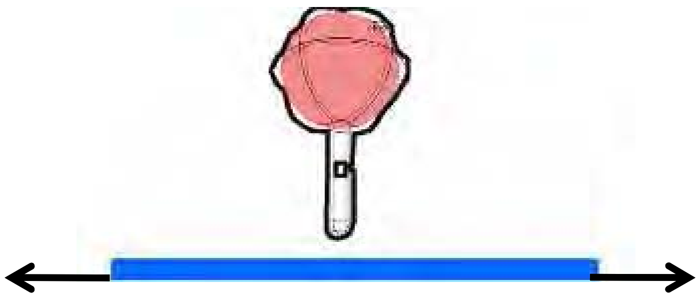
Membrane disruption



Curvature fluctuation



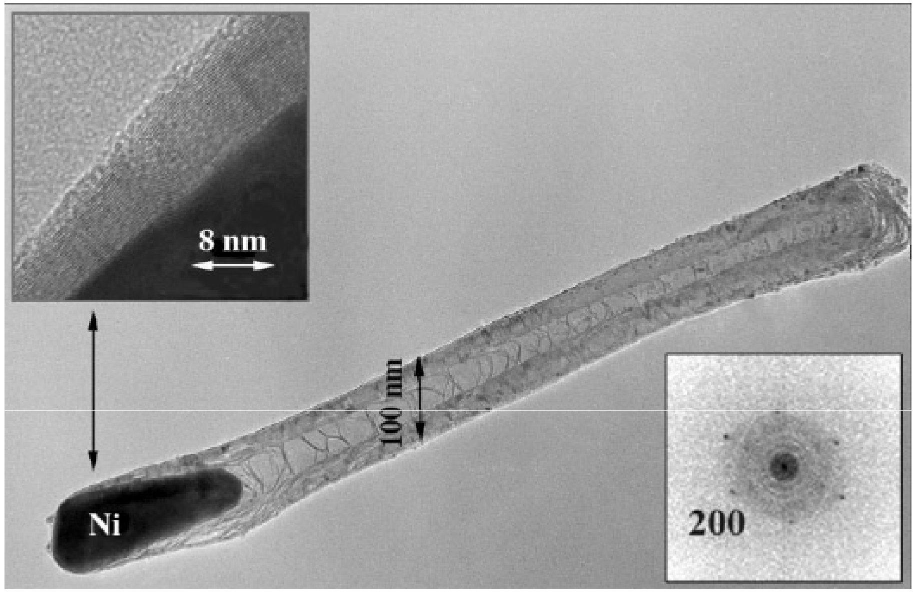
Surface charges



Mechanical stress

Concluding remarks (2)

Possible experimental realization of optical antennas using stuffed carbon nanotube :



K. Kempa *et al*. Adv. Mater. **19**, 421-426 (2007)

Acknowledgement:

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