Nanoparticle Acoustic Transducers

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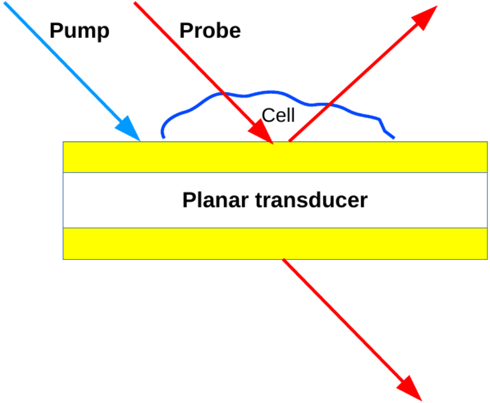
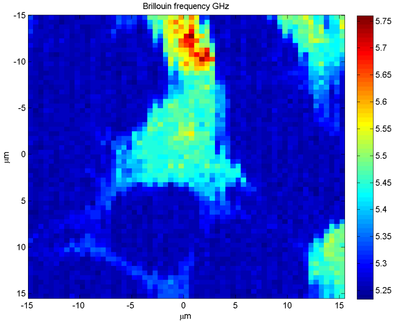
Outline

Motivation I

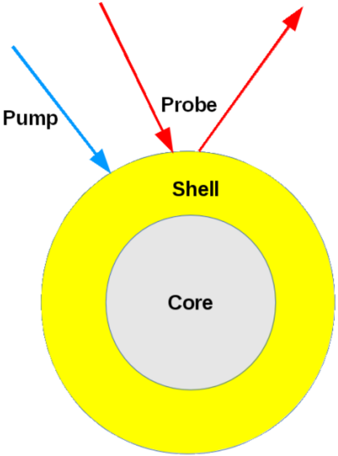




-R. Smith, F. Perez Cota, L. Marques, X. Chen, A. Arca, K. Webb, J. Aylott, M. Somekh, and M. Clark, "Optically excited nanoscale ultrasonic transducers", JASA.

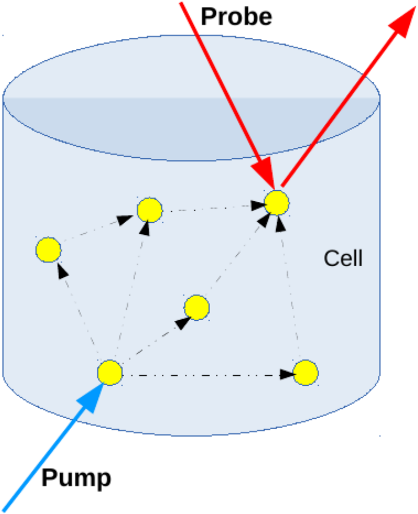
Motivation II

- Higher frequencies ⇒ Smaller size.
- But making the lateral dimensions of the transducers smaller than one micron is challenging.



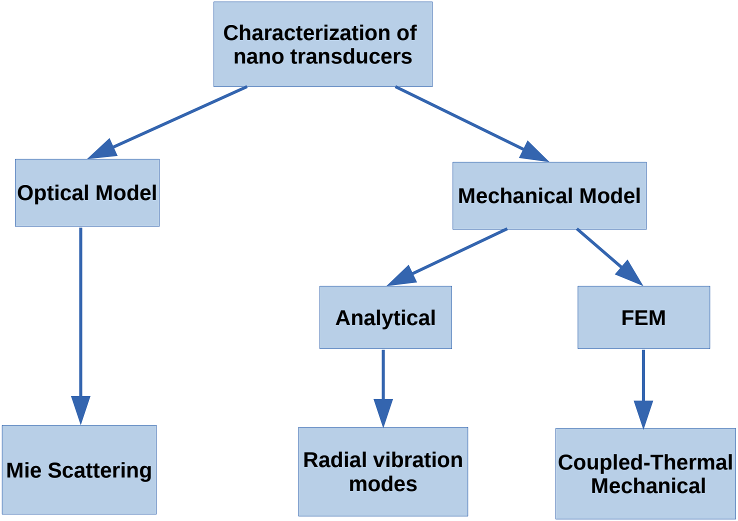
Motivation III

Our ambition



- Smaller size
- High frequencies
- Easy symmetry
- Be inside the sample
- Be made in large quantities
- Exploit plasmonics to enhance detection

Models



Characterization of nano transducers
Optical Model
Mechanical Model
Analytical
FEM
Mie Scattering
Radial vibration modes
Coupled-Thermal Mechanical

Optical modelling I

- Yang[1] and Peña[2] improved and developed a recursive algorithm for light scattering by a multilayered sphere.

$$Q_{ext} = \frac{2}{x_L^2} \sum_{n=1}^{\infty} (2n+1) Re\{a_n + b_n\} \tag{1}$$

$$Q_{sca} = \frac{2}{x_L^2} \sum_{n=1}^{\infty} (2n+1)(|a_n|^2 + |b_n|^2) \tag{2}$$

$$Q_{bk} = \frac{1}{x_L^2} \left| \sum_{n=1}^{\infty} (2n+1)(-1)^n (a_n - b_n) \right|^2 \tag{3}$$

[1] Yang, W. "Improved recursive algorithm for light scattering by a multilayered sphere", Appl. Opt., vol. 42, no. 9, pp. 1710-1720, Mar. 2003.

[2] Peña, O. and U. Pal, "Scattering of electromagnetic radiation by a multilayered sphere", Computer Physics Communication, vol. 180, no. 11, pp. 2348-2354, Nov. 2009.

Optical modelling II

where a_n and b_n are:

$$a_n = \frac{m\psi_n(mx)\psi_n'(x) - \psi_n(x)\psi_n'(mx)}{m\psi_n(mx)\xi_n'(x) - \xi_n(x)\psi_n'(mx)} \tag{4}$$

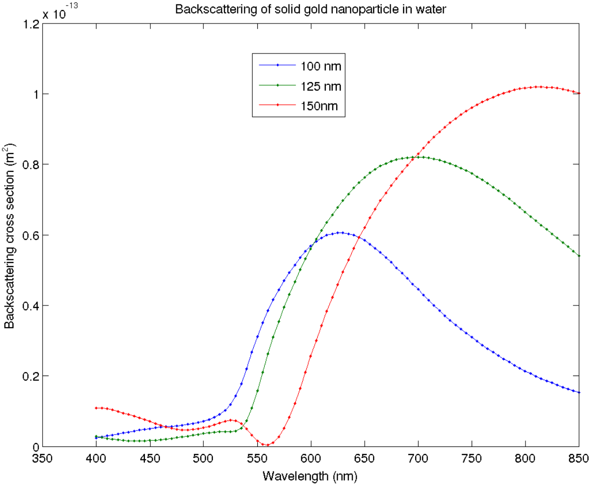
$$b_n = \frac{\psi_n(mx)\psi_n'(x) - m\psi_n(x)\psi_n'(mx)}{\psi_n(mx)\xi_n'(x) - m\xi_n(x)\psi_n'(mx)} \tag{5}$$

and the Ricatti-Bessel functions[3]

$$\psi_n(\rho) = \rho j_n(\rho), \qquad \xi_n(\rho) = \rho h_n^{(1)}(\rho) \tag{6}$$

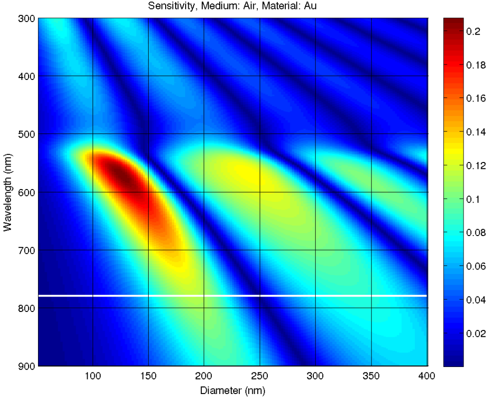
[3] Abramowitz, M. and I.A. Stegun, "Handbook of Mathematical Functions:with Formulas, Graphs, and Mathematical Tables", National Bureau of Standards Applied Mathematics Series 55, 1964.

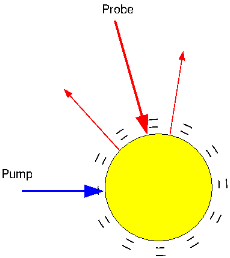
Backscattering of solid gold nanoparticle



Optical modelling IV: solid particle

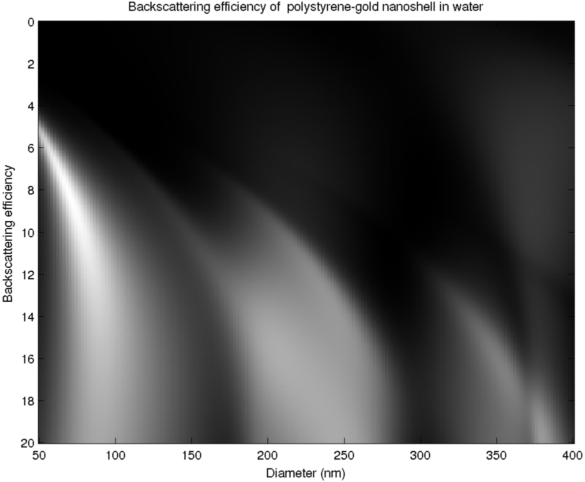
Sensitivity of solid gold nanoparticle





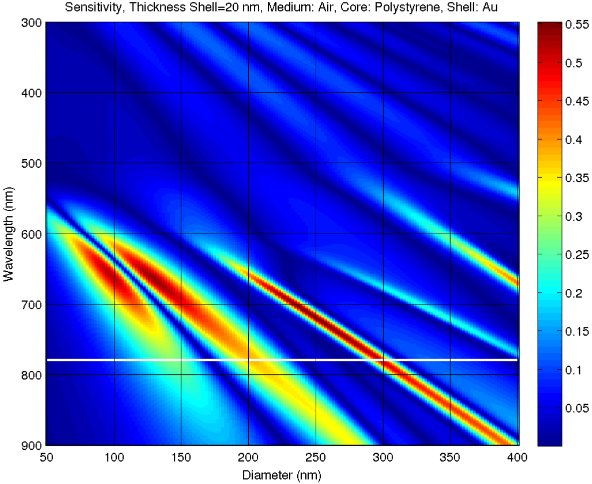
Optical modelling V: nano shell

Backscatter efficiency



Optical modelling VII: nano shell

Optical sensitivity for Au/PS nano transducer (ts = 20nm)



Mechanical modelling I: Solid particles

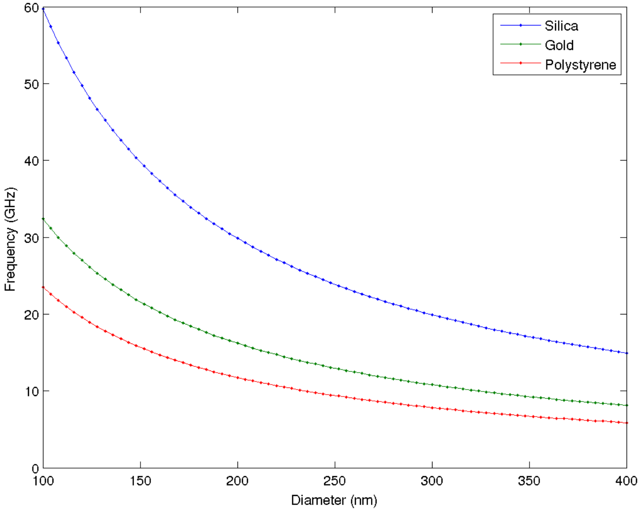
- Solid nanoparticles[4]
  - Vibration of a homogeneous elastic body
  - Assuming a weak coupling between sphere-medium

$$\omega = \pi \frac{c_L^{(s)}}{R} \tag{7}$$

[4] C. Voisin, D. Christofilos, N. Del Fatti, and F. Valle, "Environment effect on the acoustic vibration of metal nanoparticles", Physica B: Condensed Matter, vol. 316-317, pp. 89-94, May 2002.

Mechanical modelling II: Solid particles

Breathing frequency for different solid nanoparticles



Mechanical modelling III: Nano shells

- Core-shell decoupled[5]
  - Thin nano shell: $1 - R_1/R_2 \ll 1$

$$\omega = \frac{c_L^{(s)}}{R_2} 2\beta_s \sqrt{3 - 4\beta_s^2} \tag{8}$$

where $\beta_s = c_T^{(s)}/c_L^{(s)}$

- Core-shell coupled

$$\begin{aligned} \frac{\xi^2\kappa^2}{\xi\kappa\cot(\xi\kappa+\phi)-1} - \frac{\eta_c\xi^2\kappa^2}{(\xi\kappa/\alpha_c)\cot(\xi\kappa/\alpha_c)-1} + \chi_c = 0 \\ \frac{\xi^2}{\xi\cot(\xi+\phi)-1} + \frac{\eta_m\xi^2\kappa^2}{1+i\xi/\alpha_m} + \chi_m = 0 \end{aligned} \tag{9}$$

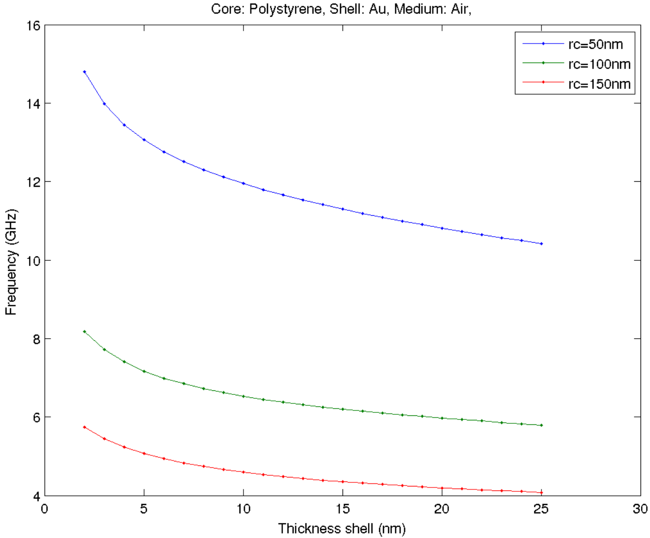
  - The breathing mode frequency

$$\omega = \xi\frac{c_L^{(s)}}{R_2} \tag{10}$$

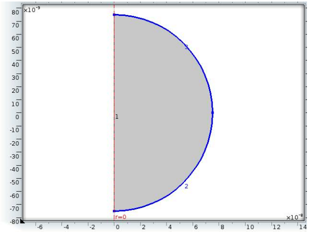
[5] Kirakosyan et al. Appl. Phys. B, vol. 84, no. 1-2, pp. 117-120, Apr. 2006.

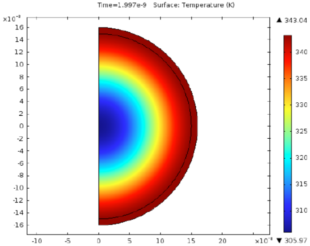
Mechanical modelling IV

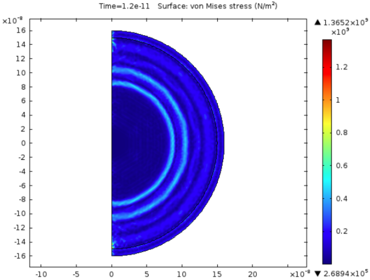
Breathing mode for Au@PS Nanoshells

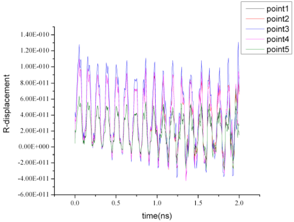


Finite Element Model I

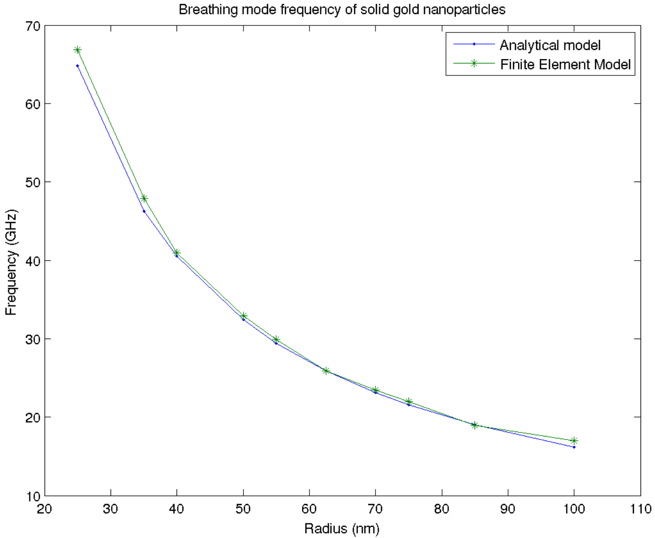




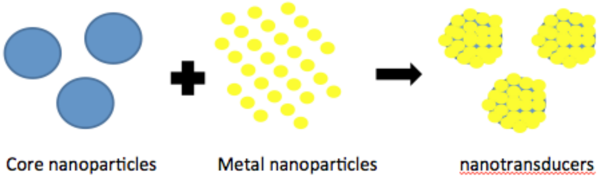




Finite Element Model II



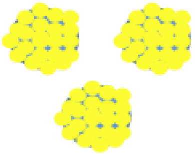
Fabrication I

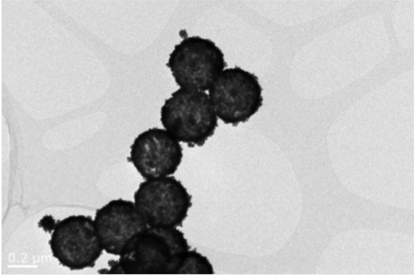


The process consist in self-assembly of metal nanoparticles to a core particle to generate the nanotranducers[6]. The surface of the core nanoparticles is modified chemically with reactive groups (e.g SH) to allow the metal nanoparticles to assembled onto it.

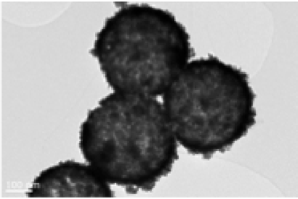
[6]Leon R. H Irsch et all, "Metal Nanoshells, Annals of Biomedical Engineering", Vol. 34, No. 1, January 2006 pp. 15-22

Fabrication II





Once the assembly process is finished, the metal layer can be further increase for its size. An extra chemical plating reduction using the metal salt as precursor can be applied in solution.

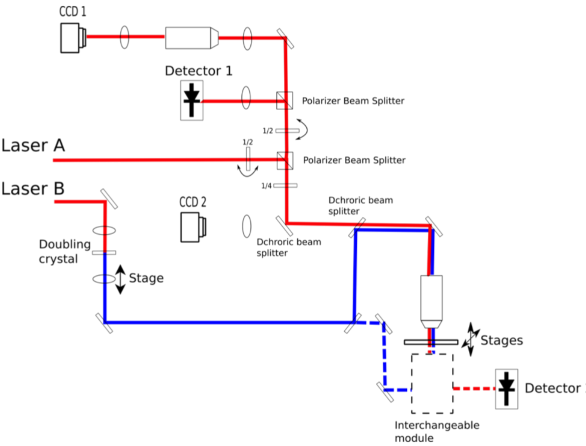


- Our aim is to get a nanoparticle acoustic transducer with high optical sensitivity and frequency for a specific wavelength

Solid particles or Nano Shells?

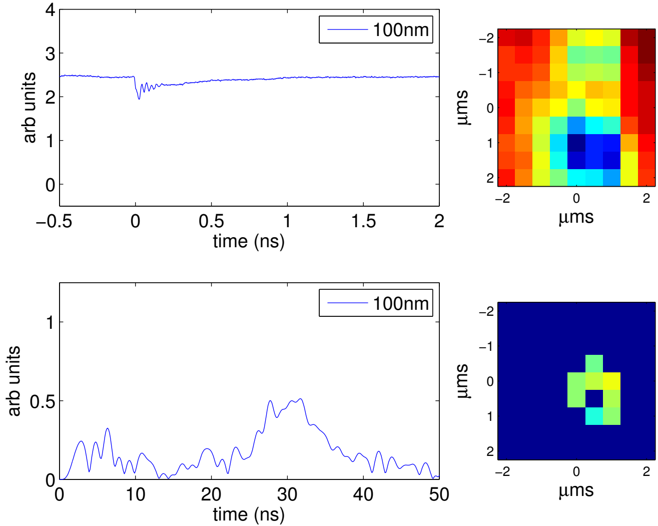
Experimental setup

- Two fs lasers in ASOPS configuration.
- 780nm probe, doubled pump.
- Simple photodiode detector in reflection or transmission.
- Pump incident either from top or bottom of sample.
- Data acquisition by oscilloscope.



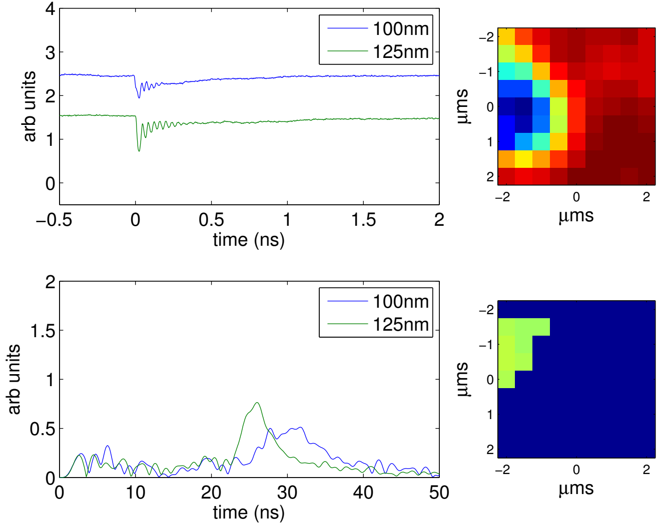
Results: Gold NPs I

100nm, $f_{model} = 32.40\ GHz$



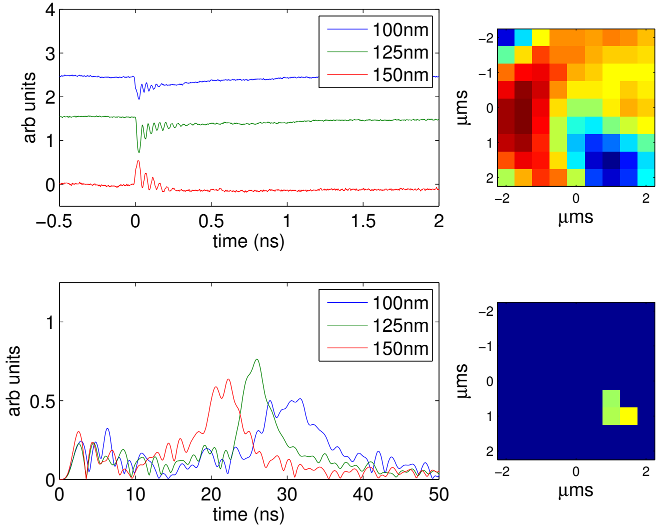
Results: Gold NPs III

125nm, $f_{model} = 25.92\ GHz$

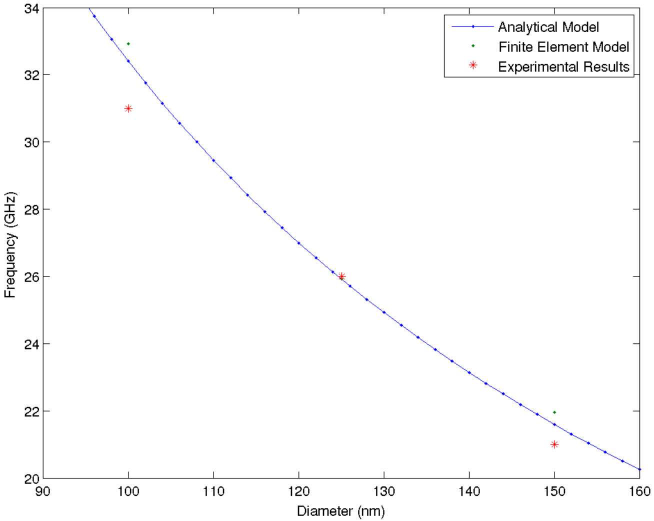


Results: Gold NPs V

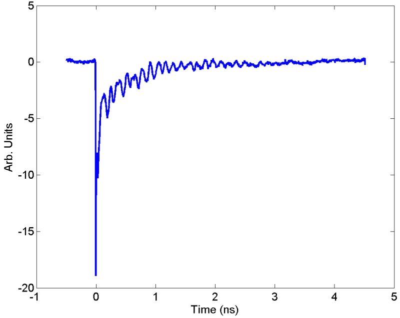
150nm, $f_{model} = 21.60\ GHz$



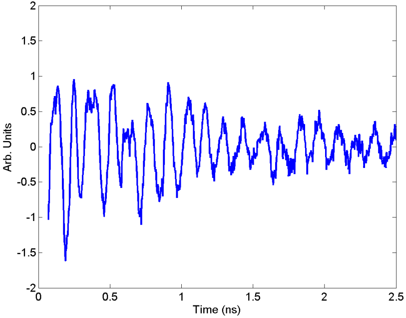
Results: Gold NPs VII



Results: Shells I



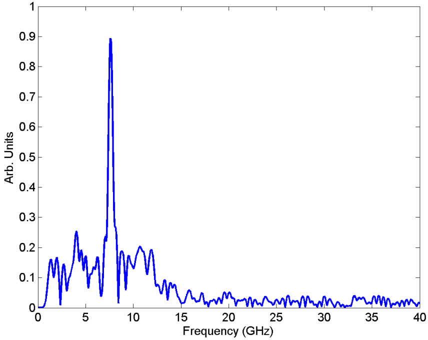
Example raw trace for a particle (Au@PS nanotransducer, rc=150nm)



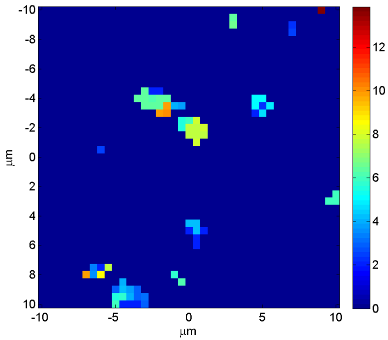
Raw trace processed. The co incidence lasers peak removed.

Results: Shells II

FFT

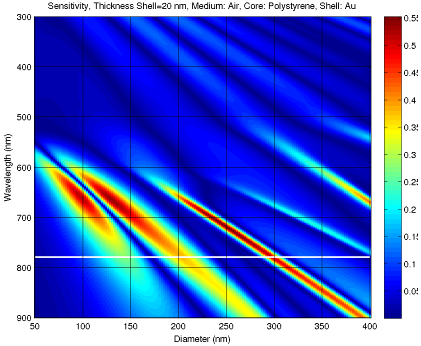


Frequency nano transducer

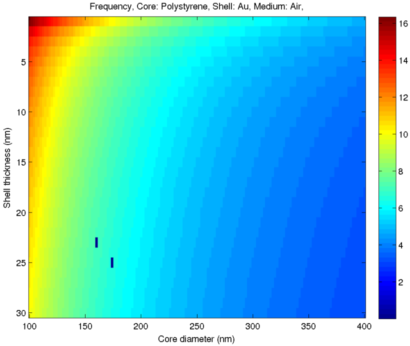


Results: Shells III

Optical model



Mechanical model



Conclusions/Future work

- Conclusions
  - An optical model for solid and shells nanoparticles
  - Analytical model, FEM and results of solid gold nanoparticles.
  - Two different mechanical models from a nano shell.
- Future work
  - More results of nano shells.
  - Discuss when the core-shell are either coupled or decoupled.
  - Cell imaging

Thank you for your attention!

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Any question?

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