Nanoparticle Acoustic Transducers

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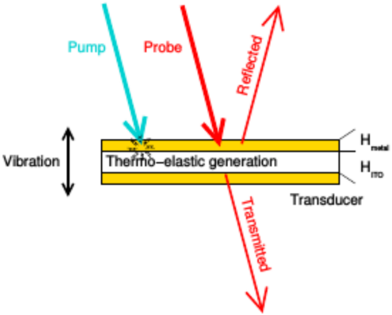
- Previously, planar transducers have been developed[1]



- Higher frequencies $\Longrightarrow$ Smaller size
- But making the lateral dimensions of the transducers smaller than one micron is challenging

[1] 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.

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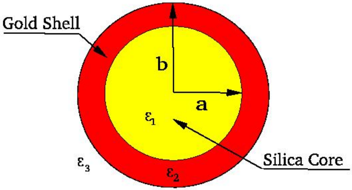

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$\Downarrow$

Use of Nanoparticles

(Solid Nanoparticles and Nanoshells)

Nanoparticle Acoustic Transducers

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

Optical modelling

- Optical model based on Mie Scattering developed by Gustav Mie in 1908[2]
- The expression of the scattered field is:

$$\mathbf{E}_s = \sum_{n=1}^{\infty} E_n \left(i a_n \mathbf{N}_{e1n}^{(3)} - b_n \mathbf{M}_{o1n}^{(3)} \right)$$
$$\mathbf{H}_s = \frac{k}{\omega\mu} \sum_{n=1}^{\infty} E_n \left(i b_n \mathbf{N}_{o1n}^{(3)} + a_n \mathbf{M}_{e1n}^{(3)} \right) \quad (1)$$

where the superscript (3) is specified by $h_n^{(1)}$ (Hankel function).

[2] Mie, G. "Contributions to the optics of turbid media, particularly of collodial metal solutions"

Optical modelling

where a_n and b_n are:

$$a_n = \frac{m\psi_n(mx)\psi_n'(x) - \psi_n(x)\psi_n'(mx)}{m\psi_n(mx)\xi_n'(x) - \xi_n(x)\psi_n'(mx)} \tag{2}$$

$$b_n = \frac{\psi_n(mx)\psi_n'(x) - m\psi_n(x)\psi_n'(mx)}{\psi_n(mx)\xi_n'(x) - m\xi_n(x)\psi_n'(mx)} \tag{3}$$

and the Ricatti-Bessel functions[3]

$$\psi_n(\rho) = \rho j_n(\rho), \qquad \xi_n(\rho) = \rho h_n^{(1)}(\rho) \tag{4}$$

[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.

Optical modelling

- Yang[4] and Peña[5] improved and developed a recursive algorithm for light scattering by a multilayered sphere.

$$Q_{ext} = \frac{2}{x_L^2} \sum_{n=1}^{\infty} (2n+1) Re\{a_n + b_n\} \tag{5}$$

$$Q_{sca} = \frac{2}{x_L^2} \sum_{n=1}^{\infty} (2n+1)(|a_n|^2 + |b_n|^2) \tag{6}$$

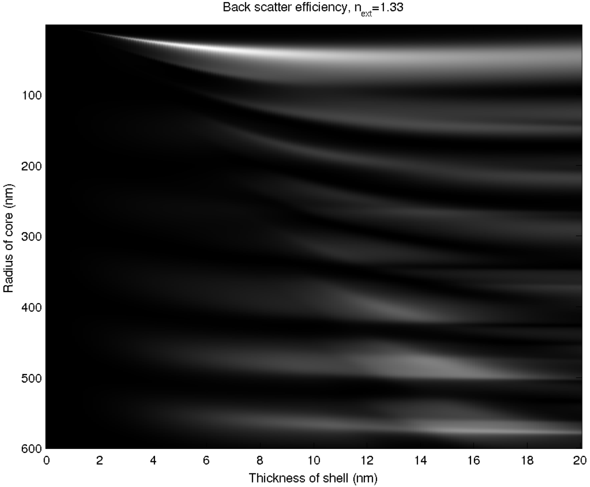
$$Q_{bk} = \frac{1}{x_L^2} \left| \sum_{n=1}^{\infty} (2n+1)(-1)^n (a_n - b_n) \right|^2 \tag{7}$$

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

[5] 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.

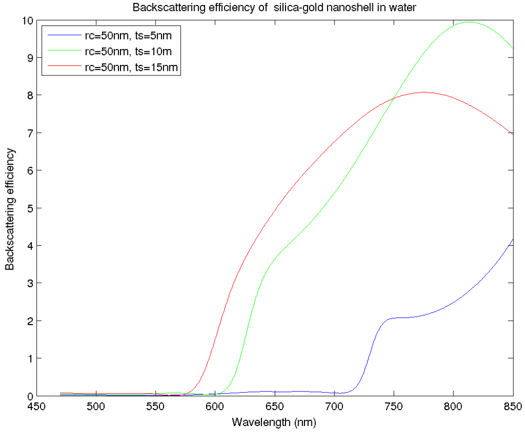
Optical modelling

Backscatter efficiency



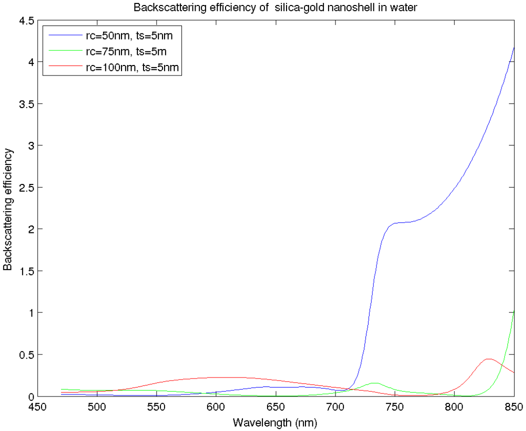
Optical modelling

Backscatter vs tickness shell



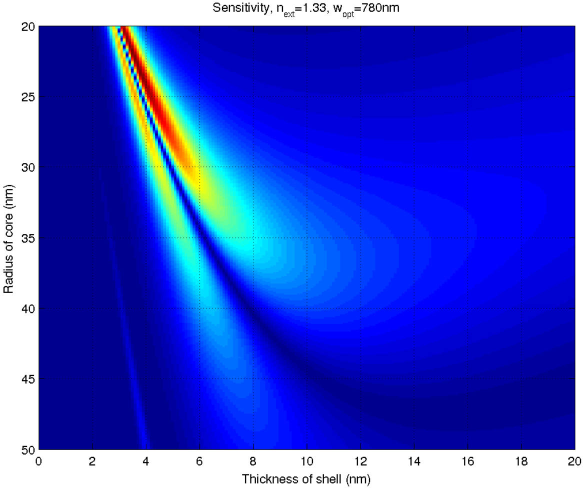
Optical modelling

Backscatter vs core radius



Optical modelling

Optical sensitivity



Mechanical modelling

- The nanoparticle vibrational modes can be described as the vibration eigenmodes of a homogeneous elastic sphere embedded in an infinite medium with different elasto-density properties[6].
- The complex frequency eigenvalues:

$$\tilde{\omega}(R) = \xi_{l,n} \nu_L^{(s)} / R \tag{8}$$

where $\nu_L^{(s)}$ is the longitudinal sound velocity in the sphere, $\xi_{l,n}$ the normalized eigenfrequency and R the radius of the particle.

[6] C. Voisin et al., "Environment effect on the acoustic vibration of metal nanoparticles", Physica B: Condensed Matter, vol. 316-317, pp. 89-94, May 2002

Mechanical modelling

- So the normalized frequency $\xi_{0,n} = \xi_n$ of the n-radial mode is solution of:

$$\xi_n cot(\xi_n) = 1 - \frac{\xi_n^2}{\eta} \frac{1 + i\xi_n/\alpha}{\xi_n^2 - 4\alpha^2\gamma^2(1 - 1/\eta\beta^2)(1 + i\xi_n/\alpha)} \quad (9)$$

and the different variables are defined as:

$$\alpha = \nu_L^{(m)}/\nu_L^{(s)}; \quad \beta = \nu_T^{(m)}/\nu_T^{(s)}$$

$$\gamma = \nu_T^{(m)}/\nu_L^{(m)}; \quad \eta = \rho^{(m)}/\rho^{(s)}$$

where $\rho^{(m)(s)}$ and $\nu_{L,T}^{(m)(s)}$ are the density and the longitudinal or transverse sound velocity of the matrix (m) and sphere (s) materials.

Mechanical modelling

Assuming weak coupling between the sphere and matrix, $Im(\xi_n) \ll Re(\xi_n)$, the radial mode frequencies, $\omega_{0,n} = \omega_n$ can be related to the real part of ξ_n:

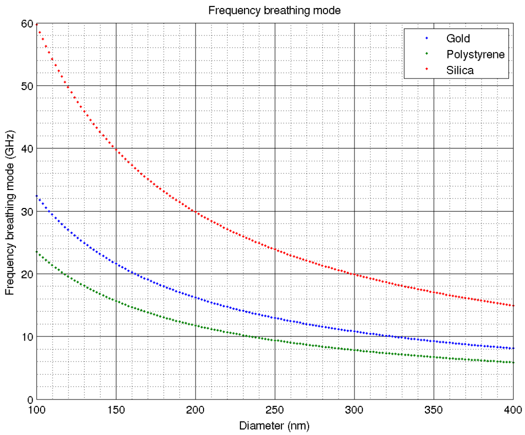
$$\omega_n = Re(\xi_n)\frac{\nu_L^{(s)}}{R} \approx (n+1)\pi\frac{\nu_L^{(s)}}{R} \tag{10}$$

Material	Sound velocity (m/s)	f_0, Frequency (GHz)
Gold	3240	16.02
Silver	3650	18.25
Silica	5968	29.84
Polystyrene	2350	11.75

Table : Breathing mode frequency for different solid nanoparticles (R=100nm)

Mechanical modelling

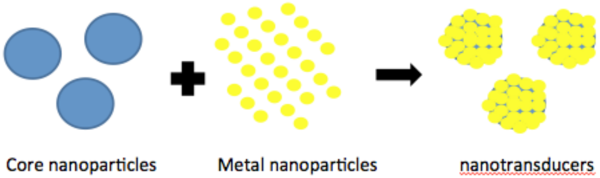
Breathing mode frequency



FEM

- Finite element model in Comsol software.
- Planar transducer model developed.
- Work in the spherical model.

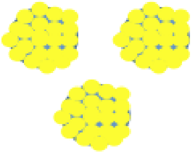
Fabrication

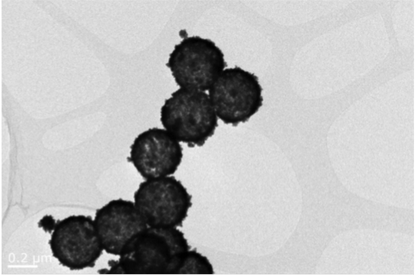


The process consist in self-assembly of metal nanoparticles to a core particle to generate the nanotranducers[7]. The surface of the core nanoparticles is modified chemically with reactive groups (e.g SH) to allow the metal nanoparticles to assembled onto it.

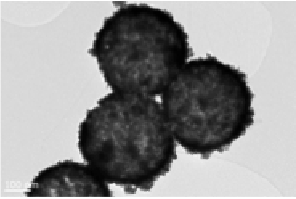
[7] Leon R. H Irsch et all, "Metal Nanoshells, Annals of Biomedical Engineering", Vol. 34, No. 1, January 2006 pp. 15-22

Fabrication



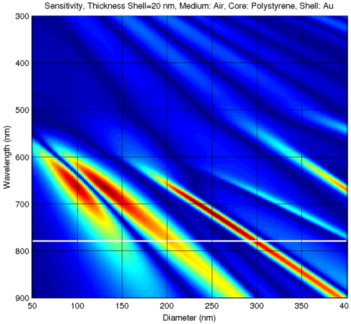


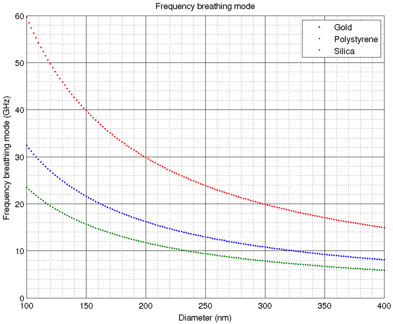
Once the assembly process is finished, the metal layer can be further increase for its size. An extra chemical plating reduction using the metal salt as precursor can be applied in solution.



Experiments

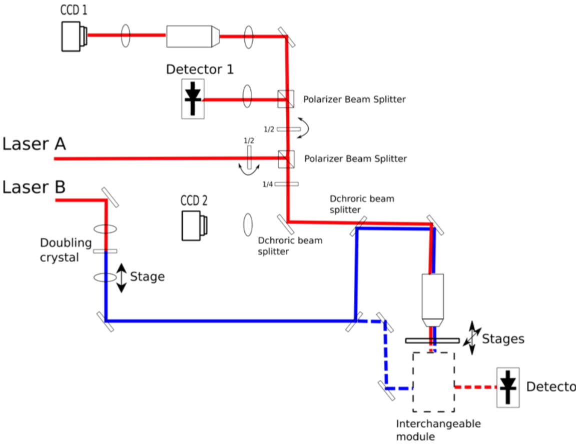
- Our aim is to get a nanoparticle acoustic transducer with high optical sensitivity and frequency for a specific wavelength





Mechanical measurements

- Two fs lasers in ASOPS configuration.
- Signal 10GHz limite
- 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

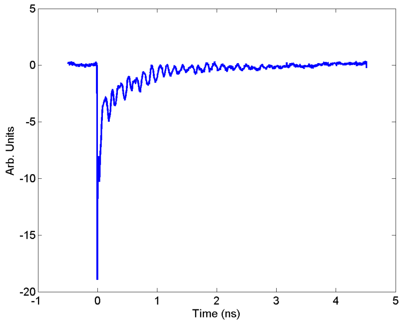


Figure : Example raw trace for a particle (polystyrene-gold nanotransducer rc=150nm)

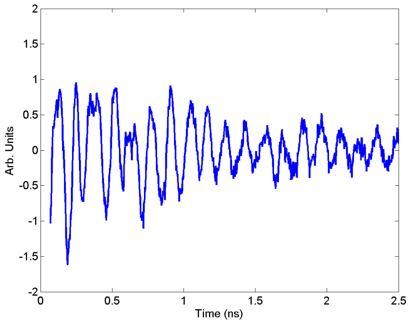


Figure : Raw trace processed. The co incidence lasers peak removed.

Results

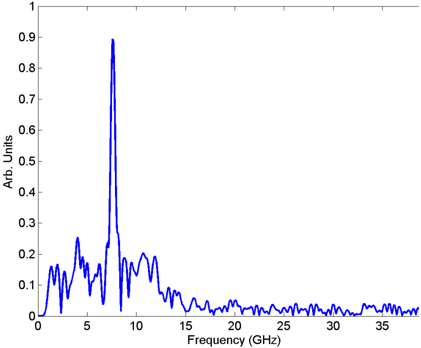


Figure : FFT (Frequency peak at 7.5GHz)

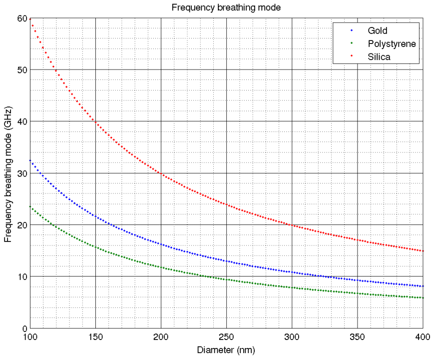


Figure : Breathing mode frequency for solid nanoparticles

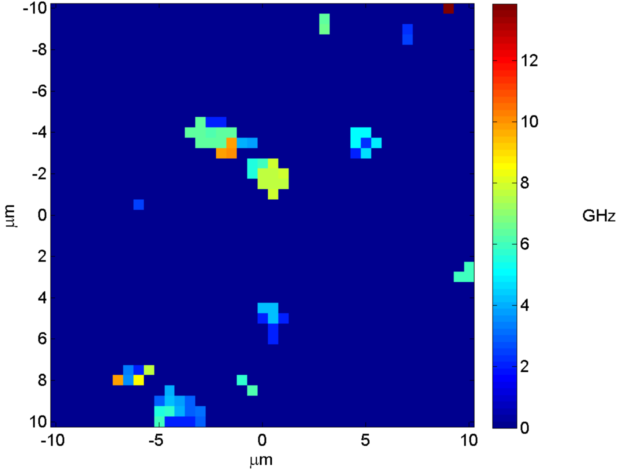
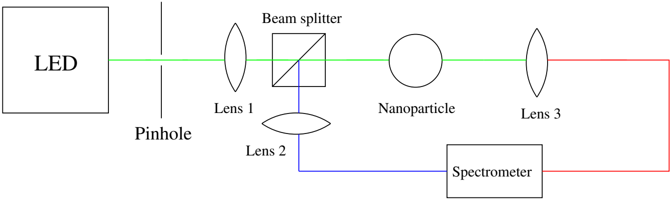


Figure : Frequency of the nanotransducer

Future work

- Create a Finite Element Model.
- Build spectroscopy system.
- Improve mechanical measurements (ASOPs system).
- Using different resonances to get smaller particles
- Imaging cells[8]



[8] J. W. Aylott, "Optical nanosensors - an enabling technology for intracellular measurements", Analyst, vol. 128, no. 4, pp. 309-312, Apr. 2003.

Thank you for your attention!

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