COMSOL CONFERENCE BOSTON 2013

Finite Element Analysis of Photoacoustic Response From Gold Nanoparticle

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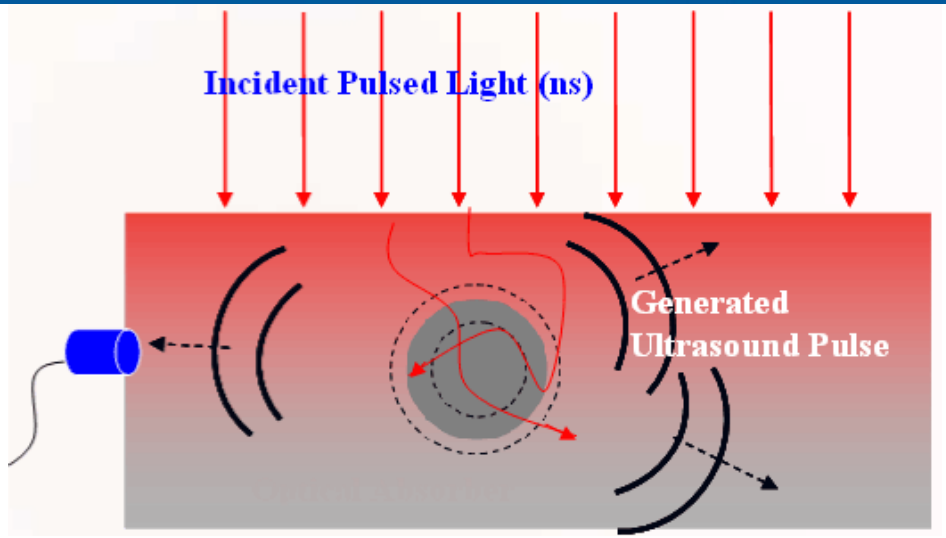
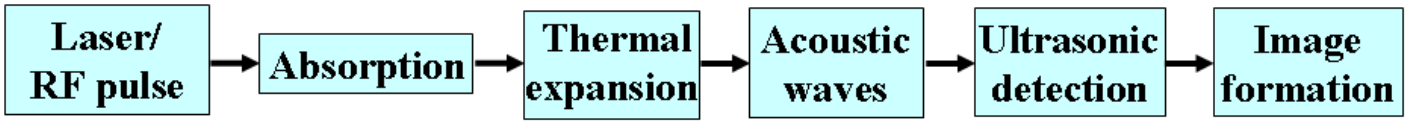
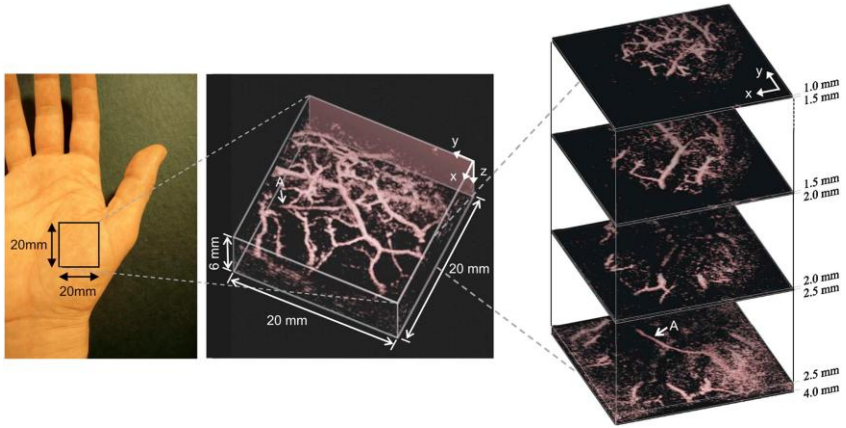
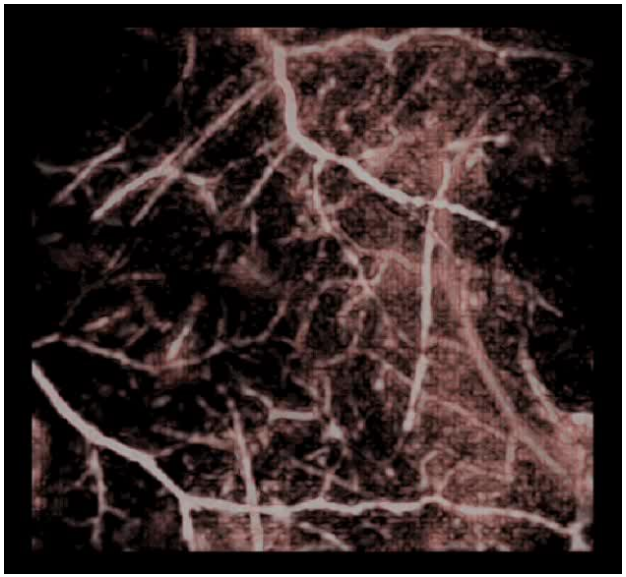
Photoacoustic Effect and Imaging



$$p_0 \propto \Delta T \propto \mu_a F$$

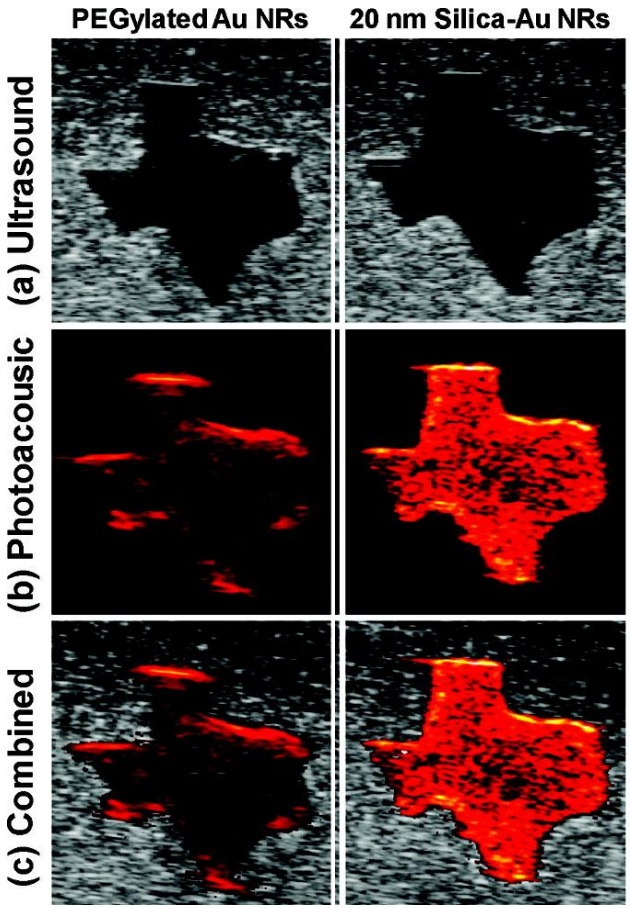




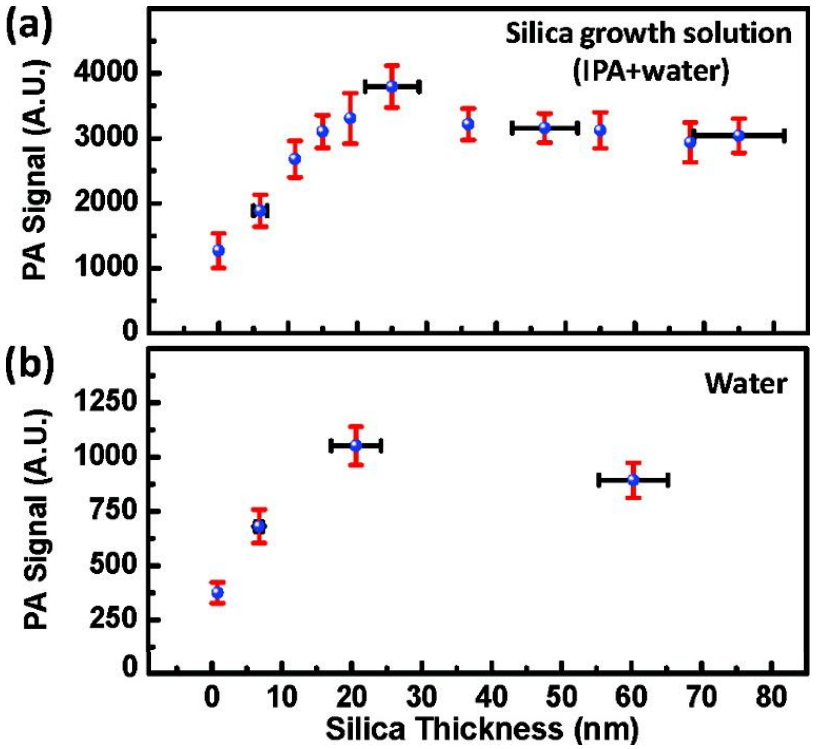


Zhang E. Z., *et. al.\Phys. Med. Biol.*, **2009**

Effect of Silica Thickness on Photoacoustic and Photothermal Properties of GNRs



(a) Ultrasound, (b) photoacoustic, and (c) combined ultrasound and photoacoustic images (top to bottom) of inclusions containing (I) PEGylated GNRs and silica coated GNRs with 20 nm shell thickness (left to right). Each image covers a 6 mm by 6 mm field of view.



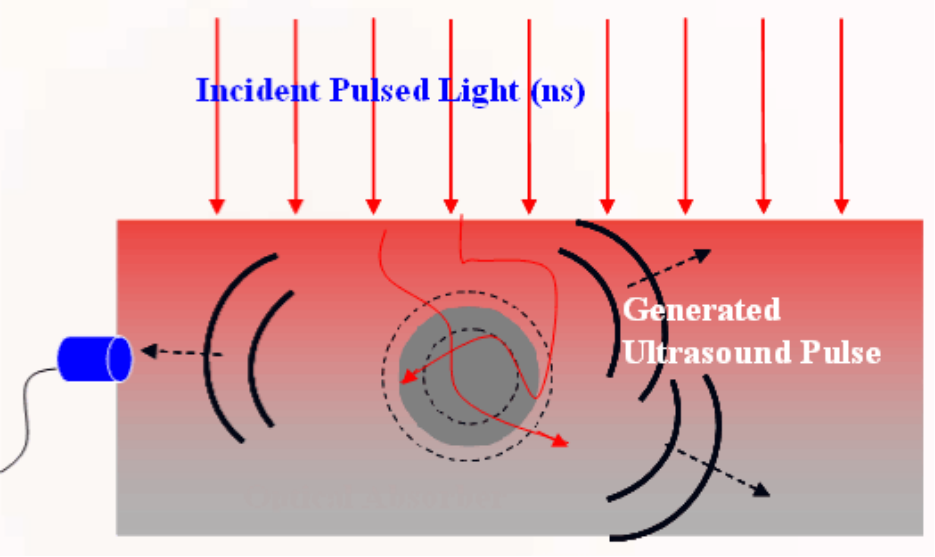
Photoacoustic signal amplitude of GNRs with varying thickness of the silica coating in (a) silica growth solution (IPA containing 26 vol % water). (b) water.

Chen Y.-S. *et. al.\Nano Lett.*, **2011**

Question

Is it possible to understand the physics behind PA signal enhancement and optimize nanoparticle design with the help of numerical analysis such as finite element method?

Theoretical Approach: Finite Element Modeling of Photoacoustic Phenomena



Laser/ RF pulse → Absorption → Thermal expansion → Acoustic waves → Ultrasonic detection → Image formation

MultiPhysics Problem

Physics

EM: Electromagnetic Waves *(emw)*

HT: Heat Transfer in Fluids *(ht)*

SM - ACO: Acoustic-Solid Interaction, Transient *(astd)*

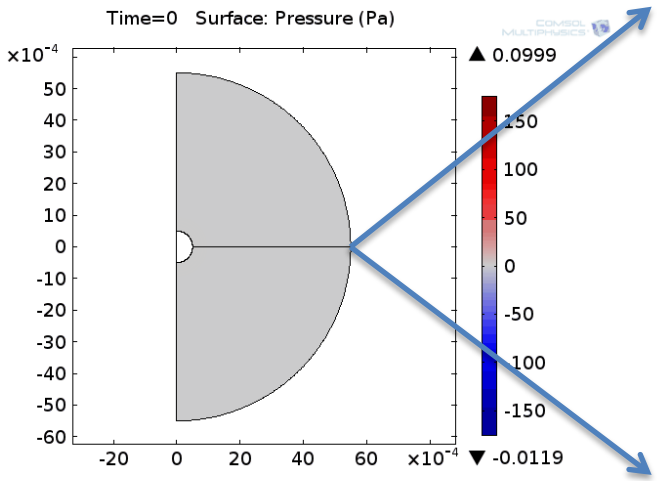
Optical properties → **Absorption**

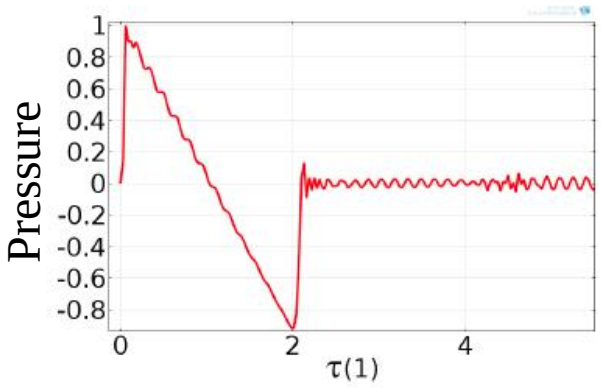
Heat transfer → **Temperature**

Structural mechanics → **Thermal expansion**

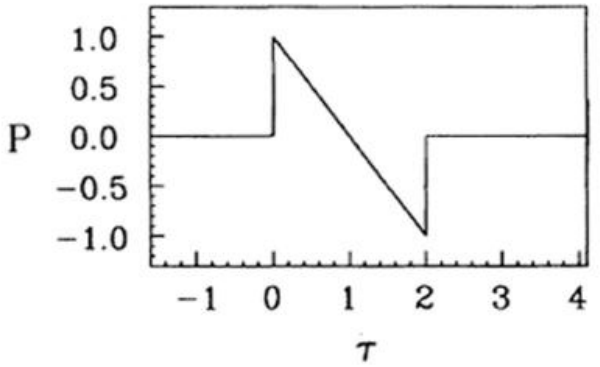
Acoustic waves → **Pressure**

PA Model vs. Diebold Model

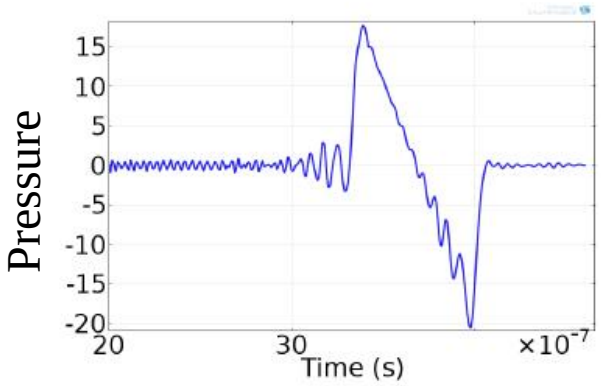




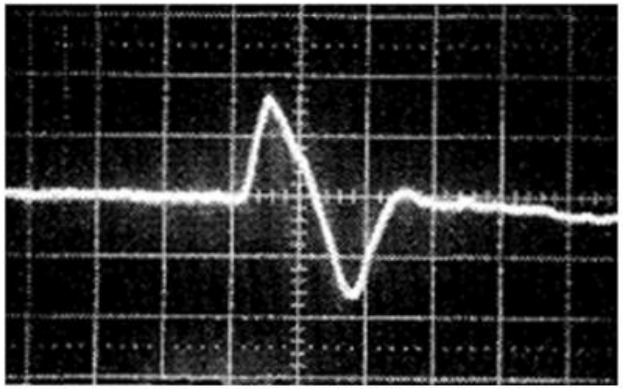
(a) FE model, dimensionless τ



(b) Analytical model (Diebold)



(c) FE model, time domain



(d) Experimental wave form, time domain

Validation of FE model against analytical solution and experimental data [Diebold (1991)]. (a) FE model, normalized pressure vs. **τ**, where **τ** is a dimensionless time. (b) An analytical solution. (c) Pressure measured at 1 mm away from the spherical particle, in time domain (FE model). (d) Experimental wave form obtained from [Diebold (1991)]. The time and voltage scales on the oscilloscope are 500 ns/div and 50 mV/div.

Diebold G.J. *et. al.\Phys. Rev. Lett.* **1991**

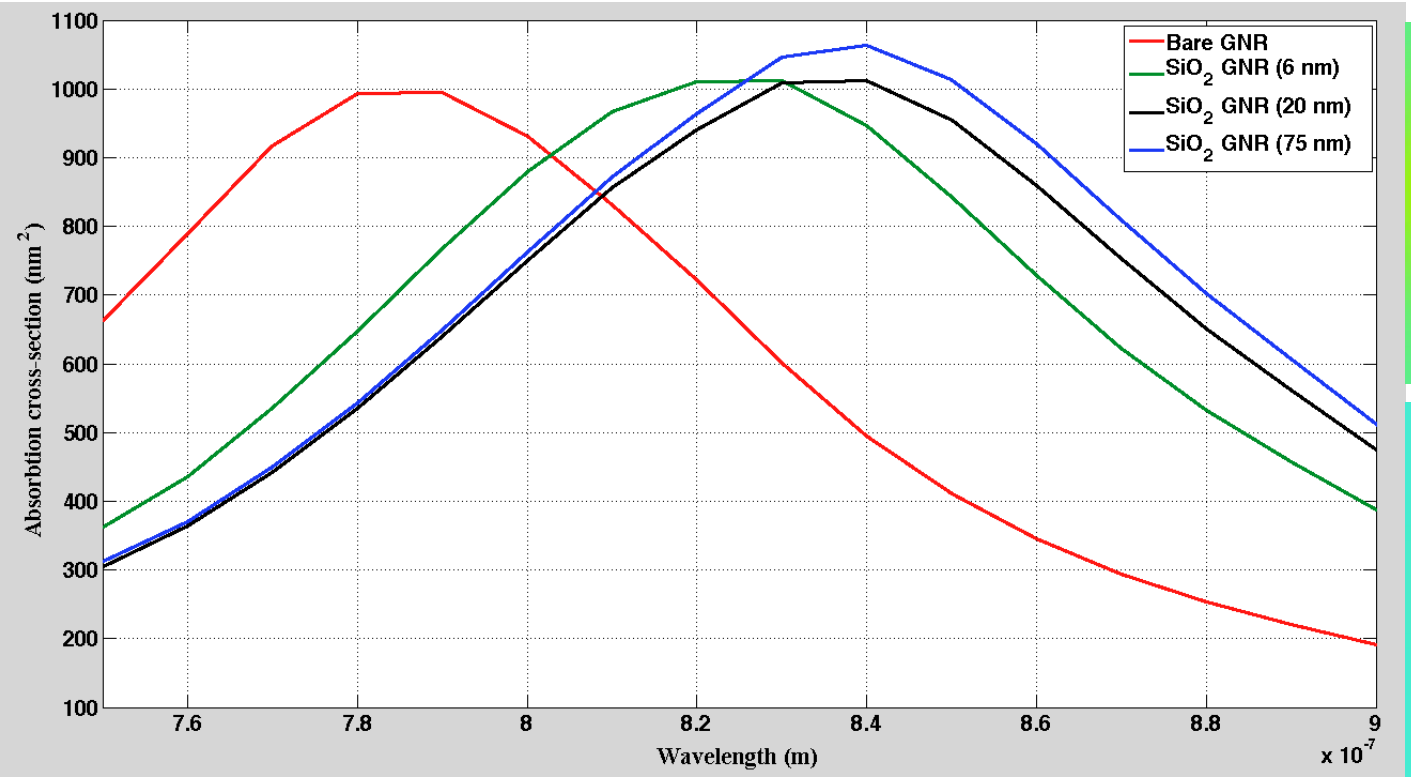
Theoretical Approach: Optical Properties

Optical properties → Absorption

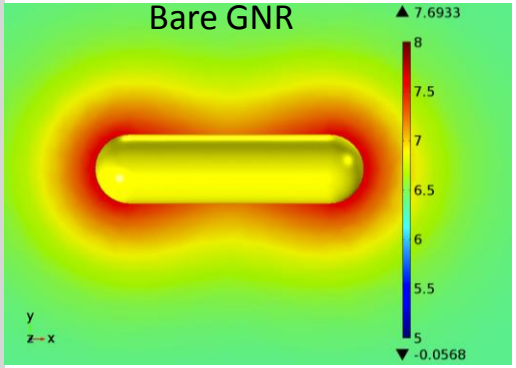
Heat transfer → Temperature

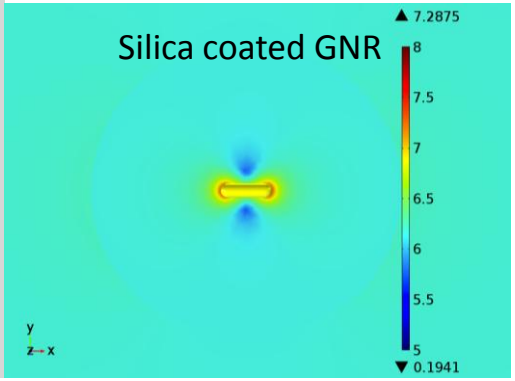
Structural mechanics → Thermal expansion

Acoustic waves → Pressure



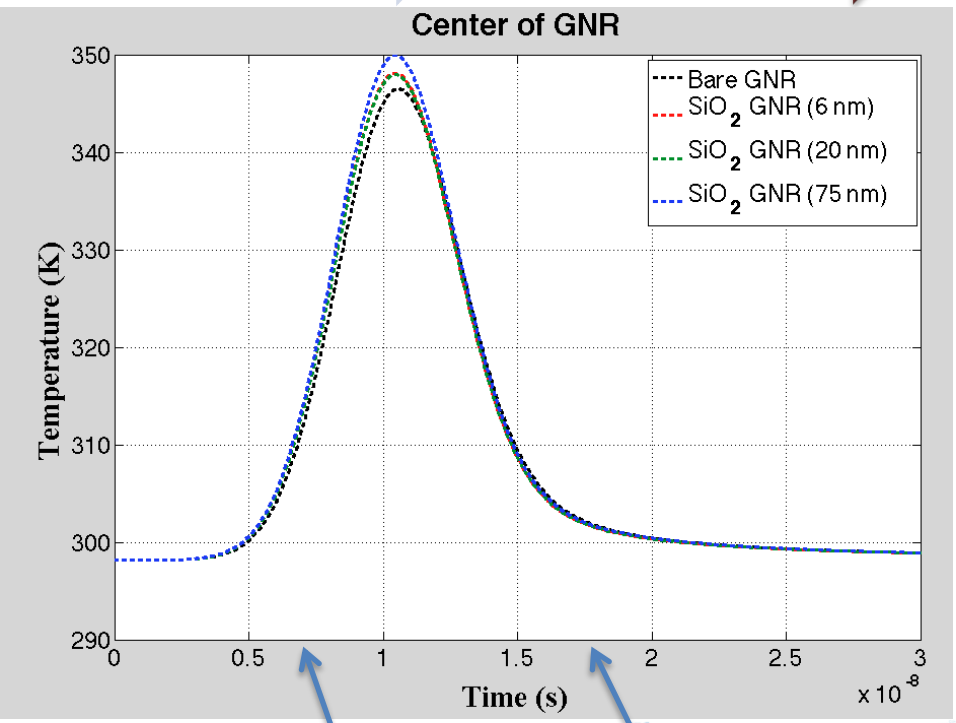
$\log_{10}(\text{normE})$

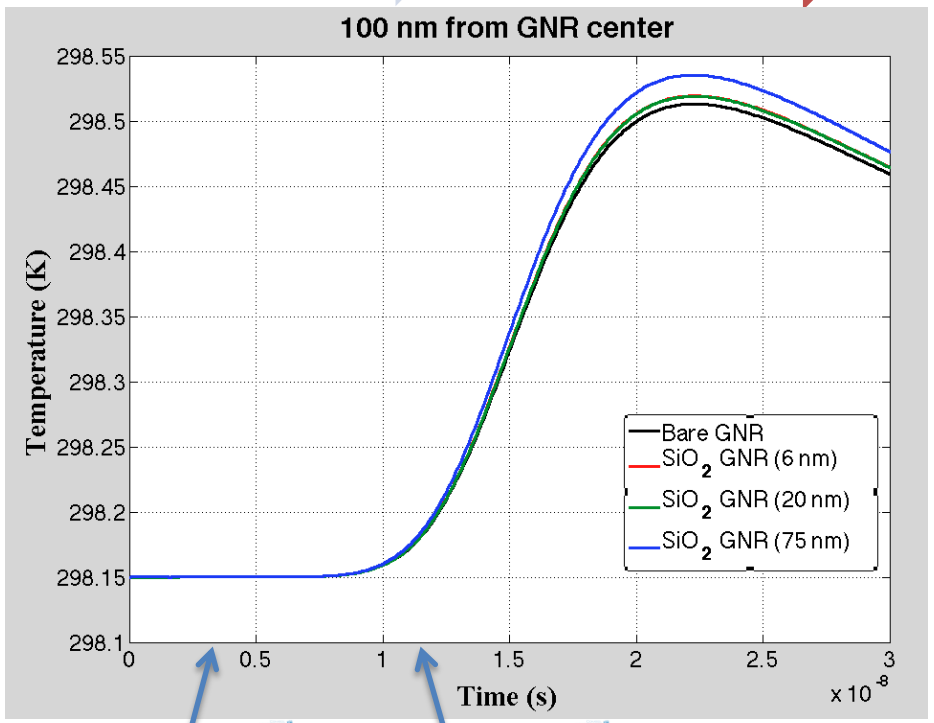


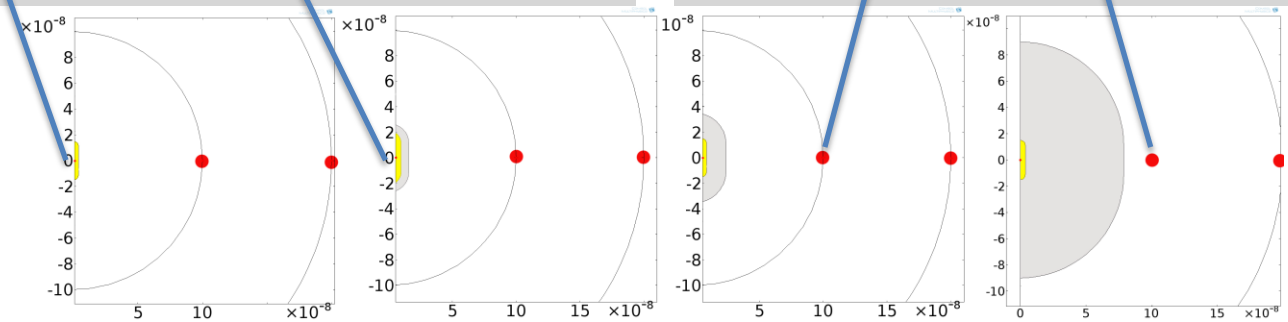


Theoretical Approach: Heat Transfer

Optical properties → Absorption → Heat transfer → Temperature → Structural mechanics → Thermal expansion → Acoustic waves → Pressure

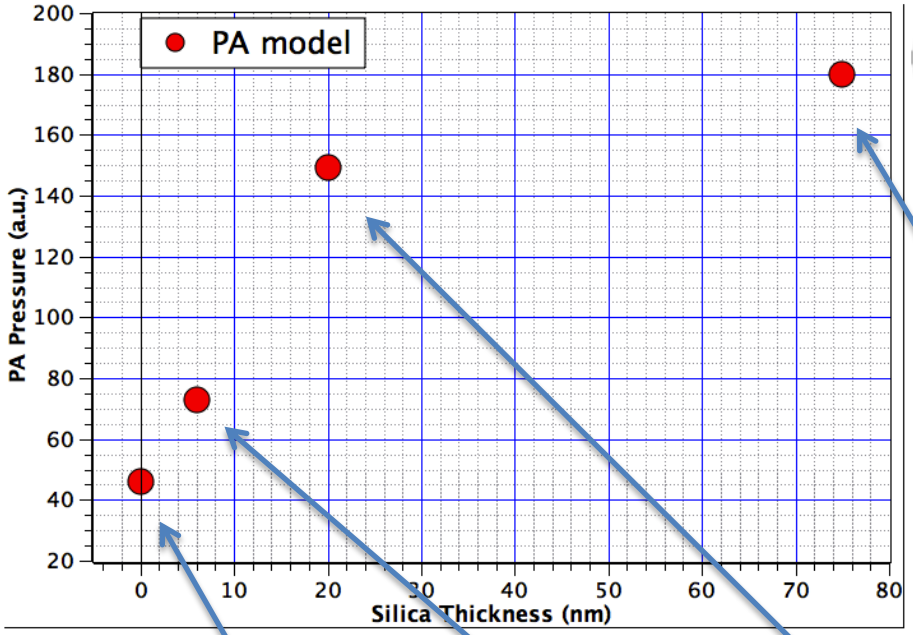


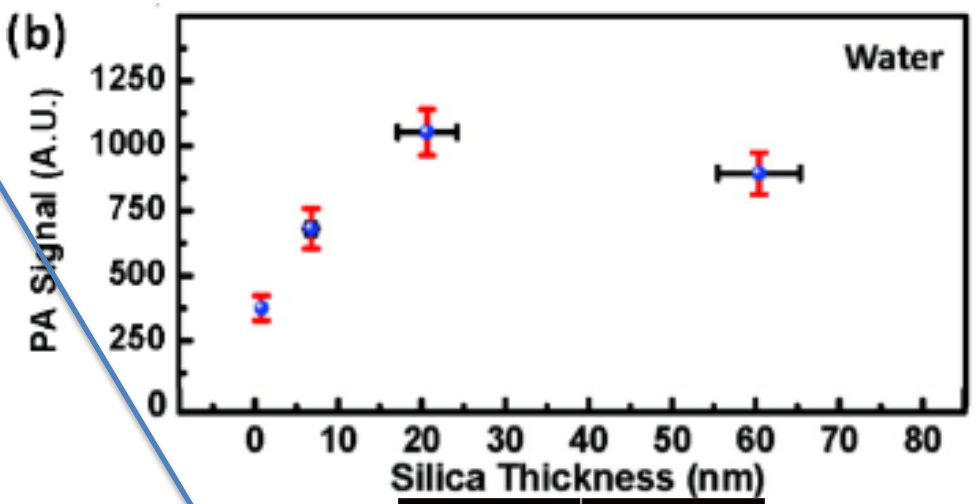


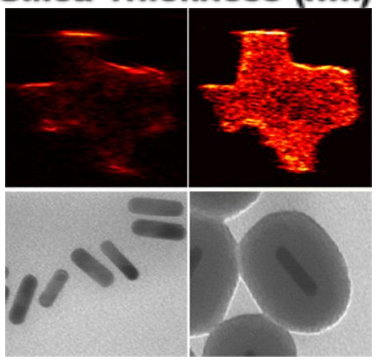


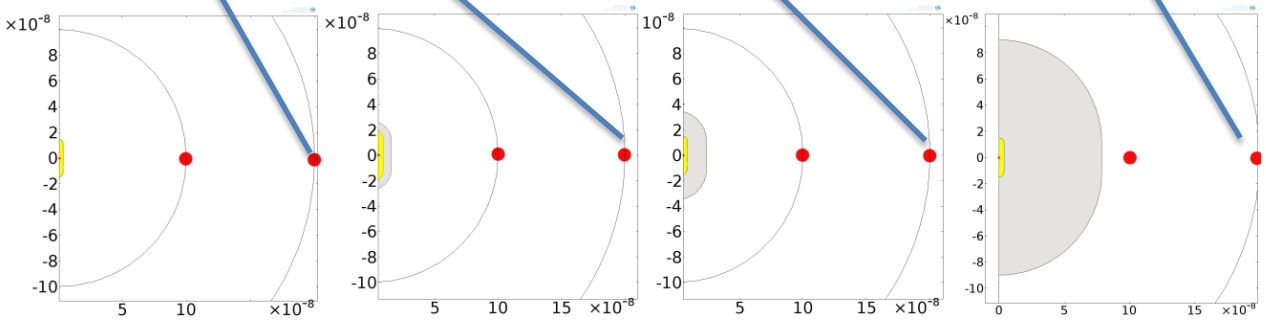
Theoretical Approach: Acoustics

Optical properties → **Absorption** → **Heat transfer** → **Temperature** → **Structural mechanics** → **Thermal expansion** → **Acoustic waves** → **Pressure**









Chen Y.-S. *et. al.\Nano Lett.*, **2011**

Summary

- Finite element model of PA signal generation from bare and silica coated GNR provides similar results of experimentally observed phenomena
- Heat Transfer and Acoustic modeling results need further analysis to evaluate if interfacial thermal resistance plays a role in PA signal enhancement
- This study can help to understand and optimize the use of gold nanoparticles during pulsed laser light irradiation for the purpose of diagnostic imaging and early cancer detection with PA imaging

Acknowledgements

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CRSNG

People. Discovery. Innovation.