Finite Element Analysis of Photoacoustic Response From Gold Nanoparticle

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Photoacoustic Effect and Imaging

\[ p_0 \propto \Delta T \propto \mu_a F \]

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.

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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

MultiPhysics Problem

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
Validation of FE model against analytical solution and experimental data [Diebold (1991)]. (a) FE model, normalized pressure vs. $\tau$, where $\tau$ 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.

Theoretical Approach: Optical Properties

- Absorption
- Temperature
- Thermal expansion
- Acoustic waves

Optical properties

Heat transfer

Structural mechanics

Pressure

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

Bare GNR

Silica coated GNR

Absorption cross-section (nm²)

Wavelength (m)
Theoretical Approach: Heat Transfer

- Absorption
- Heat transfer
- Structural mechanics
- Acoustic waves

Optical properties
Temperature
Thermal expansion
Pressure

Graphs showing temperature variations at different conditions.
Theoretical Approach: Acoustics

Optical properties
Absorption

Heat transfer
Temperature

Structural mechanics
Thermal expansion

Acoustic waves
Pressure

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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