Finite Element Analysis of Photoacoustic Response From Gold Nanoparticle

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Abstract

Over the last decade, Photoacoustic (PA) imaging has been applied to the biomedical research field and matured into a new clinical modality for tissue imaging and functional cancer cell research. PA imaging uses a pulsed laser to irradiate a region of interest and generate a thermally induced acoustic pressure wave that can be collected by an ultrasound transducer to form an image. The combination of ultrasound imaging and high optical contrast of the biological tissues is used in PA for in-vivo and in-vitro imaging of tissue and cells. The optical absorption/PA contrast of the region of interest can be enhanced by the use of plasmonic nanoparticles due to their high optical absorption. Optical properties of nanoparticles are governed by their plasmon resonance - a collective oscillation of free electrons confined by the surface of the nanoparticle. The nanoparticles can be tuned to resonate at the excitation wavelength by changing their size and shape. The PA wave from plasmonic nanoparticles depends on their local environment. Chen et. al. [1] experimentally observed an enhancement of the PA signal from silica-coated gold nanoparticles that depends on the silica thickness and the refractive index of the surrounding medium. The current work aims to develop a solid theoretical understanding of these observations, which can be used for optimization of the use of plasmonic nanoparticles during PA imaging.

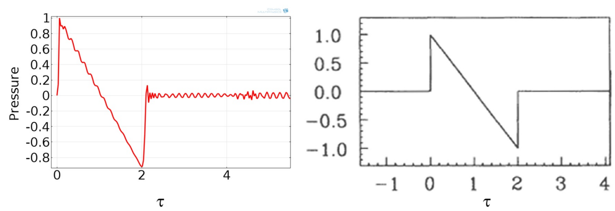
A theoretical understanding of the PA processes can be obtained through the use of computational modeling. The finite element analysis software COMSOL Multiphysics® is being used to model PA behavior of plasmon nanoparticles, including the effect of their local environment. The COMSOL Multiphysics model is being set up to couple the following physics modes into a single model: the electromagnetic (RF) wave equation (to obtain the optical properties of bare and silica-coated gold nanoparticles), transient heat transfer (HT) with a heat source that incorporates the characteristics of the laser pulse and the optical properties of the particle (coupling parameter to RF), and an acoustic pressure wave propagation that was generated by thermal expansion of the particle's surrounding (coupling to HT). The computational model has been validated against an analytical model produced by Diebold [2] (see Figure 1).

With the help of numerical methods such as finite element analysis, we will be able to understand the physics behind PA signal enhancement and provide optimized nanoparticle designs for use in PA imaging.

Reference

1. Y.-S. Chen, W. Frey, et al., “Silica-coated gold nanorods as photoacoustic signal nanoamplifiers,” Nano Letters, vol. 11, no. 2, pp. 348—354, 2011.
2. G. Diebold, T. Sun, and M. Khan, “Photoacoustic monopole radiation in one, two, and three dimensions,” Physical Review Letters, vol. 67, no. 24, pp. 3384—3387, 1991.

Figures used in the abstract



(a) (b)

Figure 1: A comparison of the FE model results (a) against an analytic solution (b)[2]. The plots show normalized pressure versus dimensionless retarded time, τ.