Effective modeling for hybrid nanoscale platforms: multi-modal photothermal and MRI applications

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Abstract

Recently, hybrid nanoplatforms combining iron oxide and gold materials have been developed for their simultaneous use in magnetic resonance imaging and plasmonic photothermal therapy. Submitted to a continuous-wave (CW) laser illumination, these hybrid nanoparticles absorb and convert some of the incident energy into heat. In this study, we investigate both the temperature gradients involved when a single nanoparticle is placed under CW laser illumination, as well as when a group of nanoparticles is subjected to the same illumination. These temperature gradients can have an impact on the transverse relaxation time in magnetic resonance imaging (MRI).

Structure

- Hybrid nanoplatforms → Nanoshell
  - 10 nm thickness (gold) 55 nm radius (magnetite)
  - Surrounding medium: water
  - Plasmonic resonance → $\lambda = 865$ nm

Theoretical model

- Analytical expression of the temperature profile (in the surrounding medium of the NP):
  
  \[ T_{\text{ext}}(r) = \frac{Q_{\text{core}} + Q_{\text{shell}}}{4\pi K_{\text{NP}}} + T_{\infty} \]

- The collective thermal model [1]:
  
  \[ T_{\text{collective}}(r) = \int_{4\pi} \left( \frac{q}{4\pi \varepsilon_0 \omega} \right) r'^3 dr' \]

- Experiment: solution of silica/gold nanoshells (140/20 nm) in physiological solution heated with a 810 nm laser (blank arrow). [2]

Temperature profile for a single nanoshell

- Nanoscale scale gradient with small temperature changes at therapeutic laser power.
- It does not explain the temperature rise in experimental results [2]!
- The effect on proton relaxation in MRI is negligible.
- Non-negligible gradient appears with high laser power.

- 0.33 W/cm² Therapeutic power
- 10000 W/cm² High power

Conclusion and outlook

- The temperature gradient at the single NP size is too weak to have an impact on the transverse relaxation time in magnetic resonance imaging, except with a very high laser power.
- The temperature gradient generated inside a solution of particles, by the beam itself can, however, have a significant impact.
- The impact of temperature gradients on the MRI contrast, due to changes in transverse relaxation time will be measured for three configurations:

  - Beam$_{\text{laser}}$ > Size MRI pixel
  - Beam$_{\text{laser}}$ < Size MRI pixel
  - Power$_{\text{laser}}$ > Power$_{\text{medical}}$

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