# OPTIMIZATION OF PHOTOTHERMAL LASER ABLATION USING AN EXPERIMENTAL-NUMERICAL APPROACH ON AGAROSE PHANTOM

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## Introduction

Cancer is one of the leading causes of death worldwide. Photothermal therapy (PTT) with laser energy is a minimally invasive cutting-edge technique for cancer removal. Gold nanoparticles (AuNPs) could be injected into the tumor region to enhance the treatment efficacy, preserving surrounding healthy tissue [1]. Fiber Bragg Grating (FBG) technology is an invasive thermometry technique, useful to map the material temperature distribution [2] accurately. *In vitro* verification and validation are required to assess the effectiveness of PTT [3]. The present work focuses on novel agarose-based phantoms and FBG configurations to quantify temperature profiles under PTT procedure. Concurrently, computational modeling was implemented to optimize the procedure and conduct predictive analysis in a combined experimental-numerical approach.

## Methods

The PTT experimental set-up of agarose phantom involves a 3D custom box in polylactic (PLA) to control the FBG arrangement and the reproducibility of the experiments. The NIR laser radiation (wavelength λ=1064 nm) was delivered via a quartz optical fiber and 4 FBG arrays were embedded in the phantom. The ablation procedure was performed with a laser power of 3 W for 2 minutes and a total amount of 20 acquisitions were collected. For each experiment, the ΔT (with $T_{\mathrm{ref}}$ = 20 °C) trends estimated by the 34 FBGs were analyzed and processed in MATLAB®. The computational model was implemented in COMSOL Multiphysics® considering two coupled models [4]: the Optical Diffusion Approximation (ODA) (Eq. 1) to replicate the laser light propagation and Pennes' bioheat equation (Eq. 2) to reconstruct the agarose temperature dynamics:

$$-D\frac{\partial^2\varphi(z)}{\partial z^2} + \mu_a\varphi(z) = s(z) \qquad (1)$$

$$\rho c\frac{\partial T}{\partial t} = \nabla\cdot[k\nabla T] + Q_p \qquad (2)$$

In Eq. 1, $\varphi(z)$ is the light fluence rate, $s(z)$ the light source, the tissue diffusion coefficient $D = 1/3(\mu_s' + \mu_a)$ strongly depends on optical properties: $\mu_a$, absorption coefficient and $\mu_s' = (1-g)\mu_s$, reduced scattering coefficient, $g$ is the tissue anisotropy factor and $\mu_s$ the scattering coefficient. The laser lateral spread was approximated by a bidimensional Gaussian distribution applied to the bottom laser applicator surface. In Eq. 2, $T$ is the agarose temperature, $\rho$, $c$ and $k$ are the density, specific heat and thermal conductivity of agarose, respectively. $Q_p = \mu_a\varphi(z)$ is the source term due to photon absorption. In the Eq. 2 an addition term $Q_{pNP}$ should be considered to model del PTT of an agarose-AuNPs phantom [3].

## Results

Temperature profiles over time of six FBGs closest to the laser applicator during laser ablation are displayed in Figure 1 (B). The measured ΔT strictly depends on the FBG placements. Temperature progressively decreases starting from the laser tip. A parametric study for material characterization allowed us to obtain well-approximated simulated profiles (dotted lines) with respect to the experimental data (solid lines). Nevertheless, the simulated temperature of A4, A6, C4, and D4 are underestimated. Figure 1 (A) highlights the laser beam shape and the relative positions of the FBGs considered.

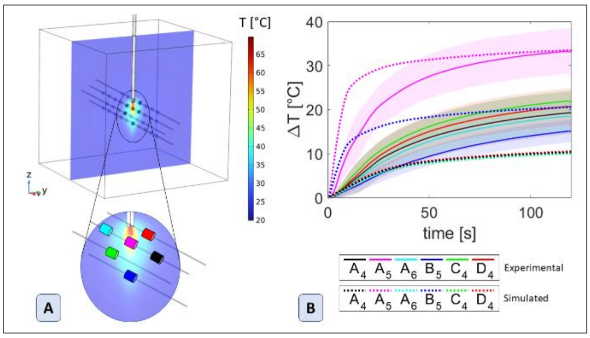

*Figure 1: (A) Central slice of temperature distribution in computational domain. Color cubes indicate the six FBGs. (B) ΔT evolution of six FBGs. Average temperature (solid line) and variability bands (shadowed bands). Dotted lines indicate the ΔT simulated profiles.*

## Discussion

Suitable modeling allows us to control the experimental set-up and predict the current temperature distribution. Experimental and simulated data could be combined to refine the computational model. Furthermore, a material experimental characterization could affect the preferential propagation direction of the laser beam. A follow-up study of agarose laser ablation mediated with AuNPs is proposed in parallel with a proper fine-tuned model, including the AuNPs contribution.

## References

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