Analysis of PhotoThermal Ablation

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Outline

- Motivation
- Implementation
- Verification
- Application

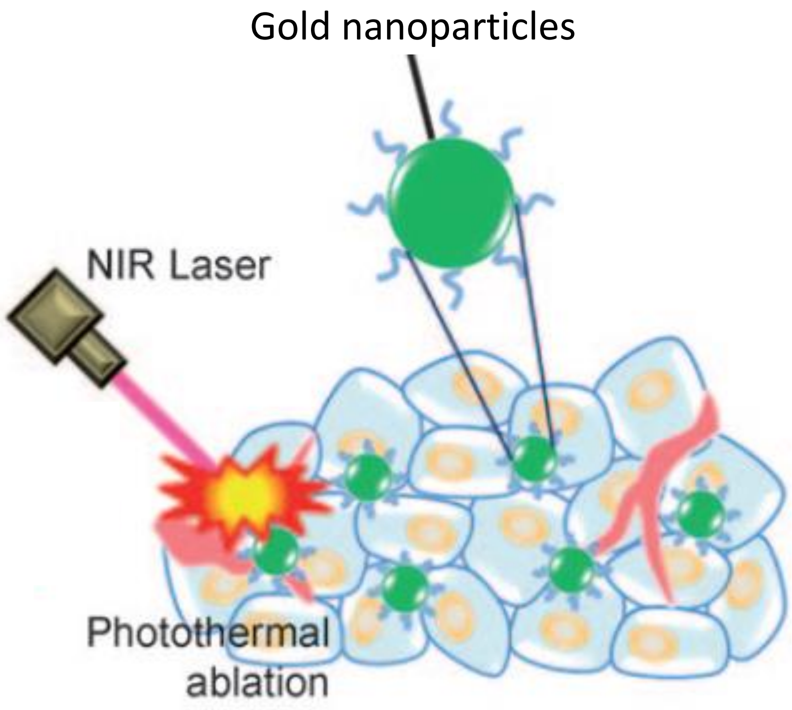
Tumor ablation

- Cancer tumors
- Tissue necrosis
  - Cancer cells irreversibly damaged at 42°C
  - Normal cells can survive up to 47°C
- Tumors have limited vascularity
  - Inability to disperse heat

- Minimally invasive ablation
  - Radiofrequency
  - Microwave
  - Laser

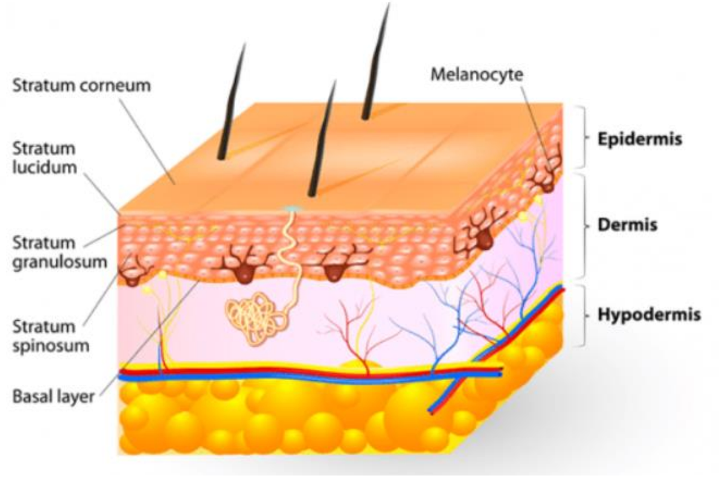
PhotoThermal Ablation

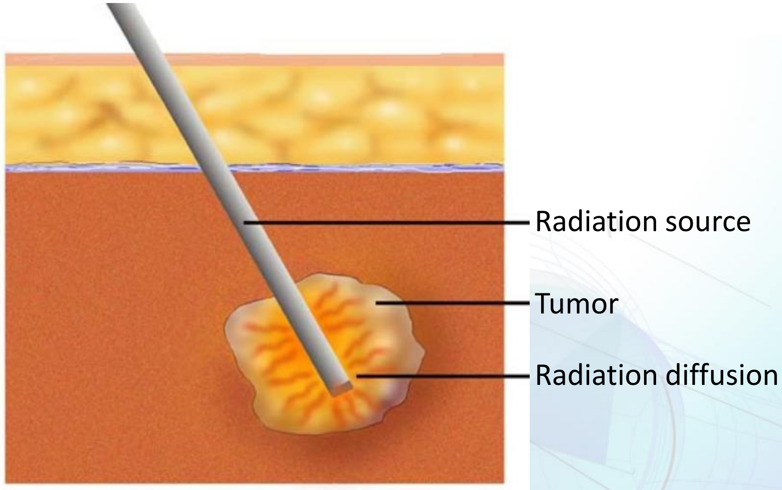
- Improved localization of treatment
- Laser interaction with photothermal sensitizers
- Gold nanoparticles
- Near IR laser radiation for tissue penetration
- Localized generation of heat



COMSOL Multiphysics® model

- Light diffusion in tissue
  - Irradiance distribution
- Layered tissue structure
- Heat transfer due to absorption of light
- Heat dissipation
  - Perfusion
  - Convection from outer surface





Governing equations

- Time dependent diffusion:

$$\frac{1}{c}\frac{\partial}{\partial t}\Phi + \nabla \cdot -(D\nabla\Phi) = -\mu_a\Phi + S$$

Φ : photon fluence (number of photons per unit area per unit time),$[1/(m^2 \cdot s)]$
$D = 1/[3(\mu_a + \mu_s')]$: optical diffusion coefficient, $[m]$
μ_a: absorption coefficient$[1/m]$
μ_s': reduced scattering coefficient,$[1/m]$
c: speed of light in tissue, $[m/s]$
S: source, other than that due to absorption $[1/(m^3 \cdot s)]$

- Fluence flux:

$$\Gamma = -D\nabla\Phi,$$

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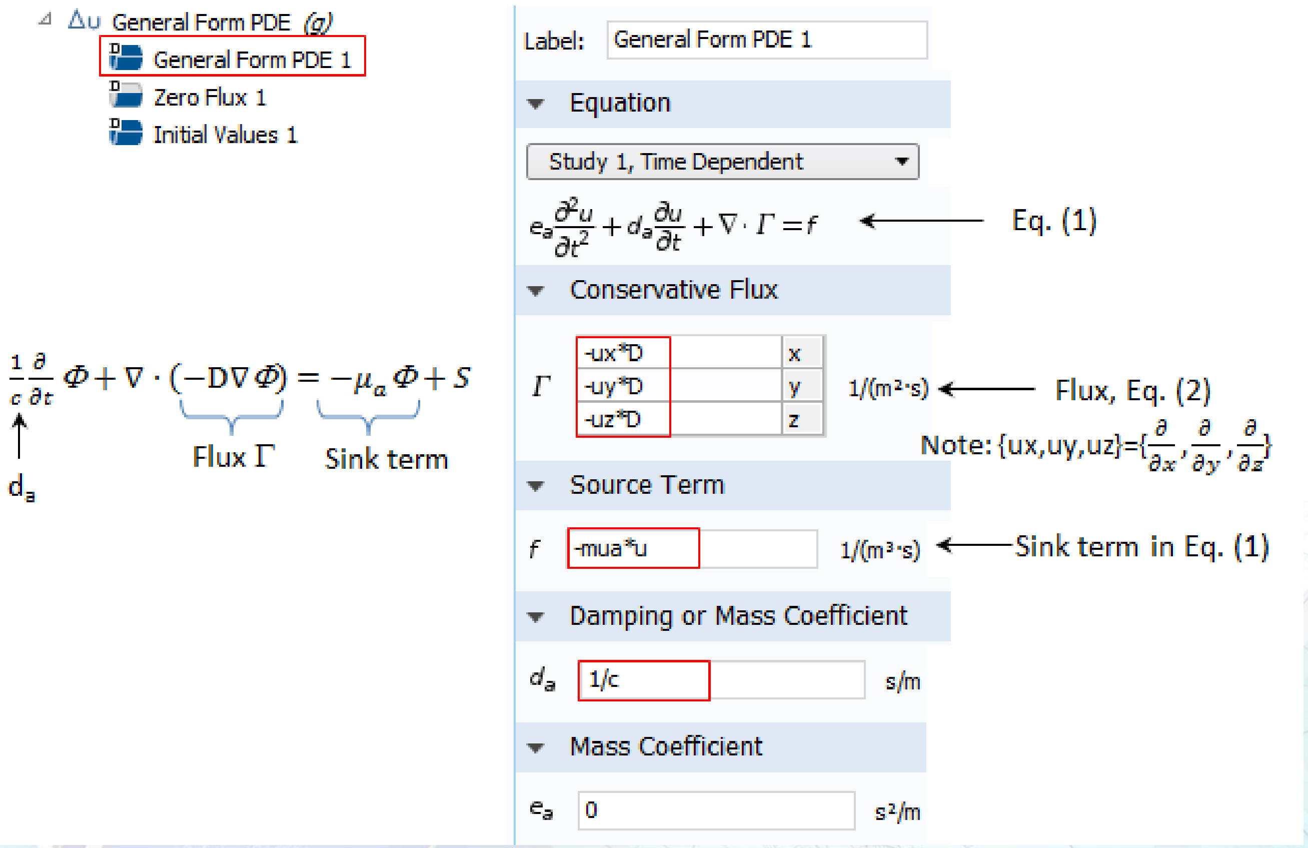
COMSOL Multiphysics® implementation

- General form PDE interface
- Tissue properties defined in the Parameters node

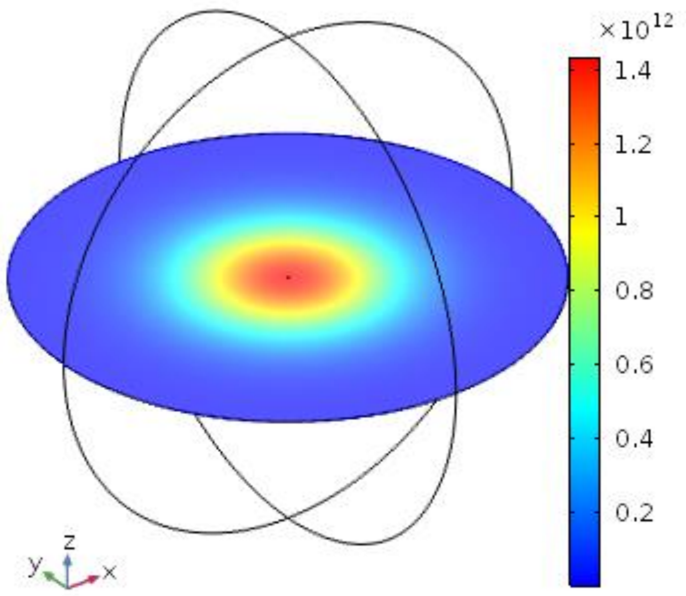


Model validation

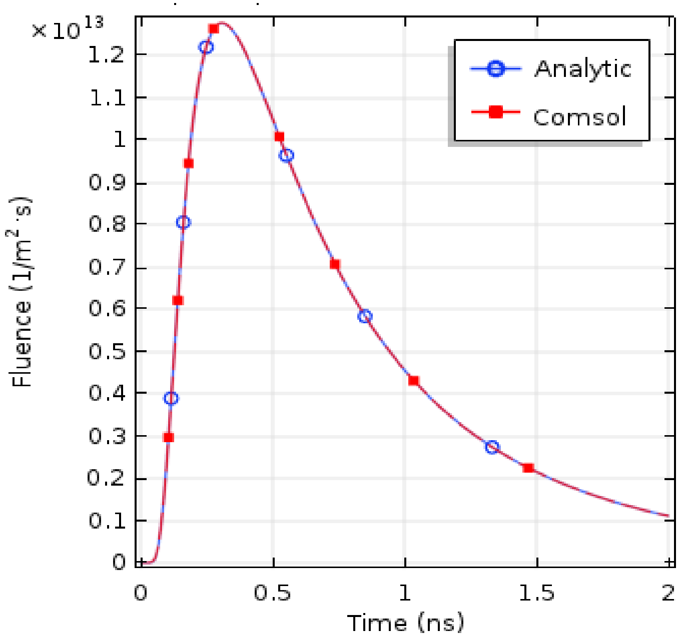
- Light pulse in an infinite homogeneous medium

$$\Phi = c(4\pi Dct)^{-3/2} exp(-\mu_a ct) exp\left(\frac{-r^2}{4Dct}\right)$$

Fluence distribution



Analytical vs COMSOL



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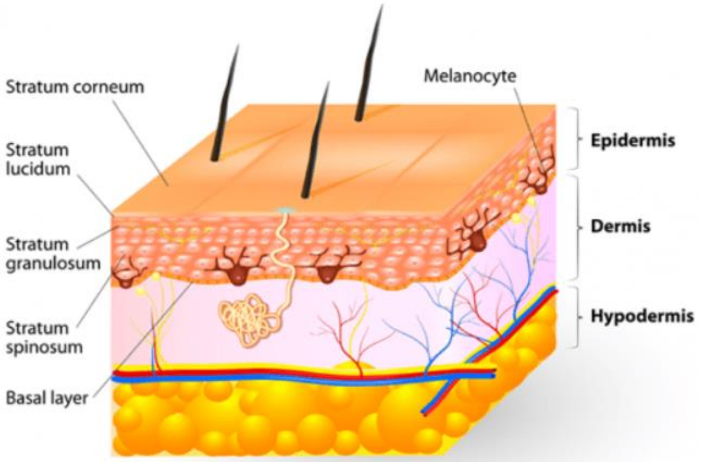
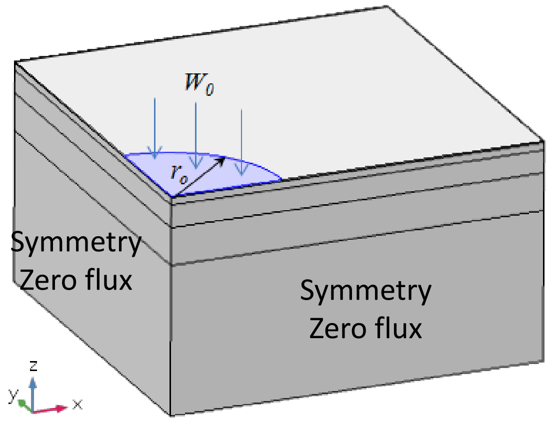
Light diffusion: Tissue

- Simplified layer structure



- Boundary conditions



Fluence continuity
Interior boundaries

Heat transfer: Tissue

- Time dependent tissue temperature due to photon absorption

$$\rho C_p \frac{\partial}{\partial t} T + \nabla \cdot (-k\nabla T) = Q_{light} + Q_{bio}$$

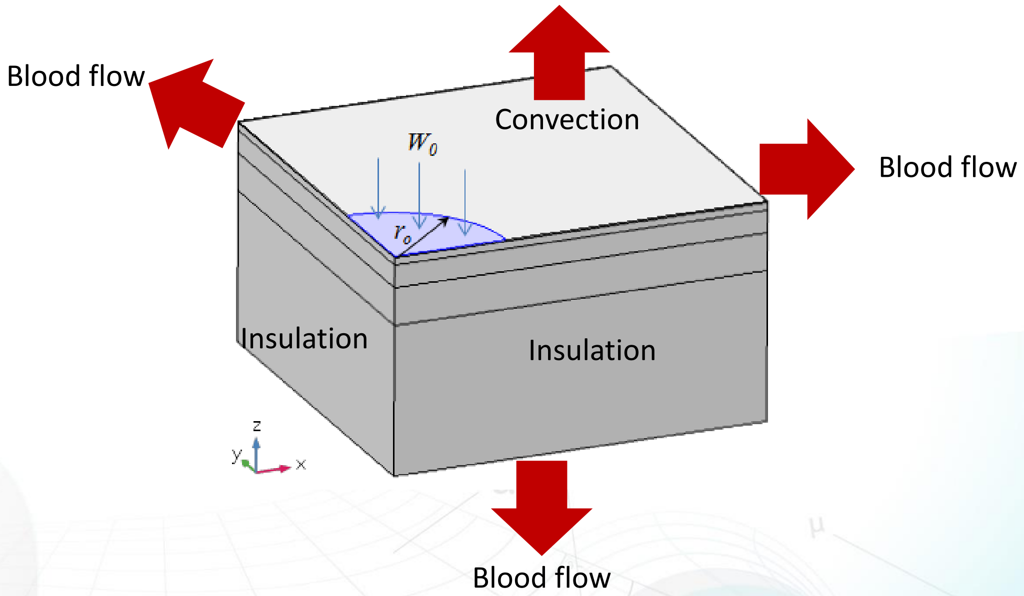
- Heat source due to light

$$Q_{light} = \mu_a \Phi \cdot h(\nu)$$

- Heat transfer due to perfusion

$$Q_{bio} = \rho_b C_{p,b} \omega_b (T - T_b)$$

- Boundary conditions



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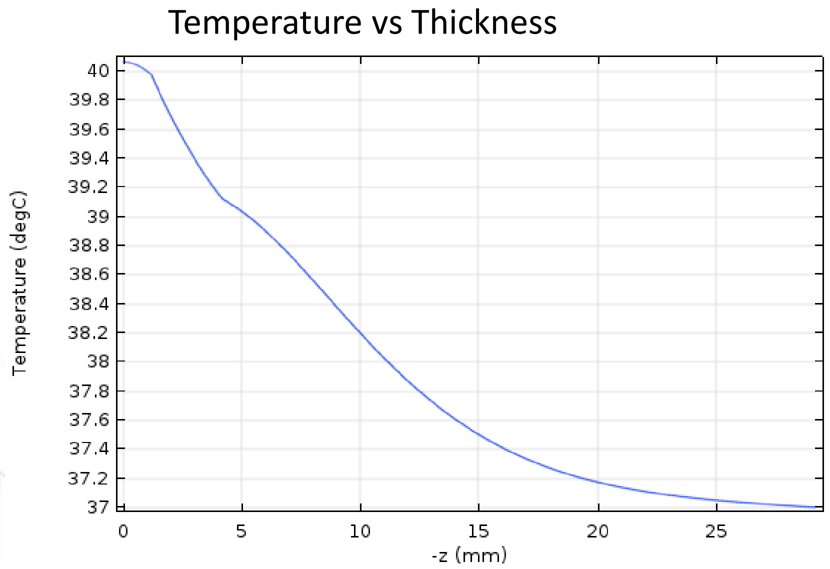
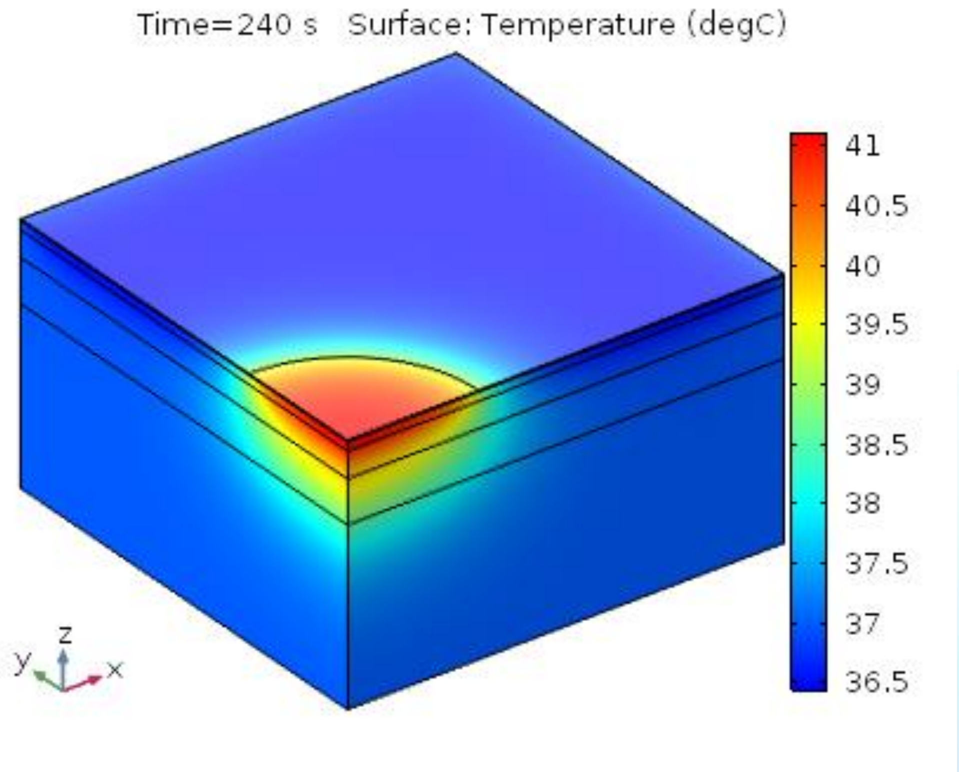
Tissue heating

- Transient and steady state temperature distribution as a function of laser light parameters





Summary

- Model developed to predict transient temperature response of human tissue when subject to laser radiation
- Thermal history:
  - Laser power
  - Thermal dissipation due to human body
- Optimization of therapeutic patient treatment profiles