

■ *External heat source term*

- The heat source equation used in simulation as follows:

[Calculating the heat input]

$$Q(x, y, z)_{external} = Q_0(1 - R_c) \cdot \frac{A_c}{\pi\sigma_x\sigma_y} e^{-\left[\frac{(x-x_0)^2}{2\sigma_x^2} + \frac{(y-y_0)^2}{2\sigma_y^2}\right]} \cdot e^{-A_c z}$$

- Q_{in} : incident laser power at the skin surface [W/m²]
 - R: surface reflectivity [1/m]
 - A: absorptivity [1/m]
- The incident laser power is distributed in time and space with a Gaussian shape according to the following expression:

[Calculating the incident laser power]

$$Q_{in} = Q_0 \left(\frac{1}{\pi\sigma_x\sigma_y} \right) \cdot \exp \left[-\left[\frac{(x-x_0)^2}{2\sigma_x^2} + \frac{(y-y_0)^2}{2\sigma_y^2} \right] \right]$$

■ Variables for external heat source term in modeling

- The incident laser power was used as follows:

The screenshot displays the COMSOL Multiphysics software interface. The top ribbon includes tabs for File, Home, Definitions, Geometry, Physics, Mesh, Study, and Results. The main workspace is divided into three panes: Model Builder, Variables, and Graphics.

Model Builder: Shows a tree view of the model structure, including Global Definitions, Parameters, Variables, Functions, Geometry Subsequences, Load and Constraint Groups, Component 1 (comp1), and Study 1.

Variables: A table lists the variables defined in the model:

Name	Expression	Unit	Description
Q_skin	$Q_0 * \mu_{\text{skin}} * (1 - 0.05) * (1 / (\pi * \sigma_x * \sigma_y)) * \text{an1}(x, x_0, s, \dots)$	W/m ²	Power input
Q_fat	$Q_0 * \mu_{\text{fat}} * (1 - 0.55) * (1 / (\pi * \sigma_x * \sigma_y)) * \text{an1}(x, x_0, s, \dots)$	W/m ²	
Q_muscle	$Q_0 * \mu_{\text{muscle}} * (1 - 0.6) * (1 / (\pi * \sigma_x * \sigma_y)) * \text{an1}(x, x_0, s, \dots)$	W/m ²	

Below the table, the 'Expression' field for the variable 'Q_skin' is highlighted with a red box and contains the following formula:

$$Q_0 * \mu_{\text{skin}} * (1 - 0.05) * (1 / (\pi * \sigma_x * \sigma_y)) * \text{an1}(x, x_0, \sigma_x, y, y_0, \sigma_y) * \exp(-\mu_{\text{skin}} * \text{abs}(z)) * \text{an2}(t)$$

The 'Description' field for 'Q_skin' is 'Power input'.

Graphics: Shows a 3D visualization of a rectangular domain with a coordinate system (x, y, z). The z-axis ranges from 0 to 6, and the x-axis ranges from 0 to 20. A laser beam is shown incident on the top surface of the domain.

Analytic for Gaussian shape of the external heat source term in modeling

File Home Definitions Geometry Physics Mesh Study Results

Component 1 Add Component Parameters Variables Functions Build All Import LiveLink Browse Materials New Material Add Material Bioheat Transfer Add Physics Build Mesh Mesh 1 Compute Study 1 Add Study Temperature (ht) Add Plot Group Model Libraries More Windows Layout

Model Builder

- [7, 3D multilayered tissue, Pulse]
 - Global Definitions
 - Parameters
 - Variables
 - Functions
 - Analytic 1 (an1)
 - Triangle 1 (tri1)
 - Analytic 2 (an2)
 - Gaussian Pulse 1 (gp1)
 - Analytic 3 (an3)
 - Geometry Subsequences
 - Load and Constraint Group
 - Component 1 (comp1)
 - Definitions
 - Geometry 1
 - Materials
 - Bioheat Transfer (ht)
 - Mesh 1
 - Study 1
 - Results

Analytic

Plot Create Plot

Function Name

Function name: an1

Definition

Expression: $\exp(-((a-a0)^2/(2*sigma^2))-((b-b0)^2/(2*sigb^2)))$

Arguments: a, a0, sigma, b, b0, sigb

Derivatives: Automatic

Periodic Extension

Units

Arguments: mm,mm,mm,mm,mm,mm

Function:

Advanced

Plot Parameters

Argument	Lower limit	Upper limit
a	0	1
a0	0	1
sigma	0	1
b	0	1

Graphics

Progress Log

■ Triangle for pulsed heat source term in modeling

The screenshot displays the COMSOL Multiphysics software interface. The top ribbon includes tabs for File, Home, Definitions, Geometry, Physics, Mesh, Study, and Results. The ribbon contains various tool icons for model building, material selection, physics addition, meshing, and study execution.

The **Model Builder** pane on the left shows a tree view of the model structure. Under **Global Definitions**, the **f(x) Functions** folder is expanded, and **Triangle 1 (tri1)** is selected.

The **Triangle** configuration pane in the center shows the following settings:

- Function Name:** tri1
- Parameters:**
 - Lower limit: pulse_width/2
 - Upper limit: pulse_width/2 + pulse_width
- Smoothing:** (Expanded)

The **Graphics** pane on the right shows a 3D model of a rectangular domain with a coordinate system (x, y, z). The z-axis ranges from 0 to 6, and the x-axis ranges from 0 to 20. A blue pulse is visible on the top surface of the domain.

An inset window titled **Graphics** shows a 2D plot of the triangle function. The x-axis represents time, ranging from 0 to 0.0025, and the y-axis represents the function value, ranging from 0 to 0.9. The plot shows a triangular pulse that starts at approximately 0.0006, reaches a peak of 0.9 at approximately 0.0014, and ends at approximately 0.0022.

The **Progress** and **Log** panes at the bottom right show the simulation progress and log output.

Analytic for pulsed heat source term in modeling

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Model Builder

- [7, 3D multilayered tissue, Pulse]
 - Global Definitions
 - Parameters
 - Variables
 - Functions
 - Analytic 1 (an1)
 - Triangle 1 (tri1)
 - Analytic 2 (an2)**
 - Gaussian Pulse 1 (gp1)
 - Analytic 3 (an3)
 - Geometry Subsequences
 - Load and Constraint Group
 - Component 1 (comp1)
 - Definitions
 - Geometry 1
 - Materials
 - Bioheat Transfer (ht)
 - Mesh 1
 - Study 1
 - Results

Analytic

Plot Create Plot

Function Name

Function name: an2

Definition

Expression: tri1(x)

Arguments: x

Derivatives: Automatic

Periodic Extension

Units

Arguments: s

Function:

Advanced

Plot Parameters

Argument	Lower limit	Upper limit
x	0	1

Graphics

COMSOL MULTIPHYSICS

Progress Log

- I want to adjust the spectral width of laser like this.
Please give me any comments about that. Thank you so much.

