# Interaction of the laser with the material - modelling of the microlenses creation

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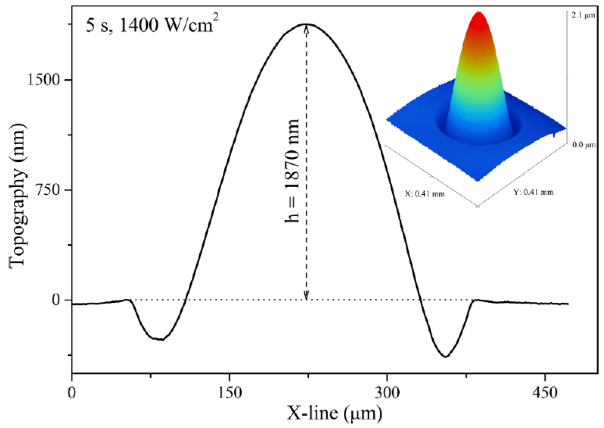
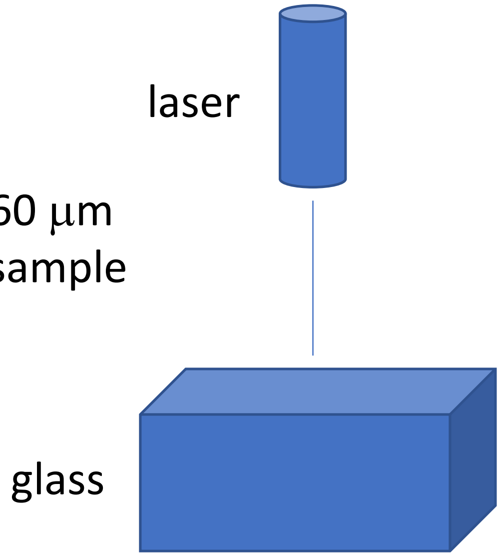
From Digital Holographic Microscope

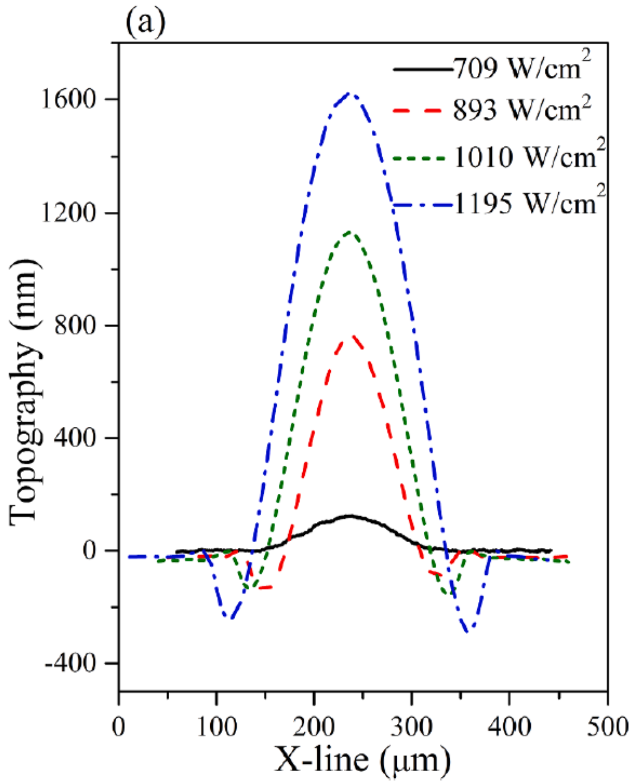
# Motivation




$\lambda$ = 447 nm
Spot diameter ~ 160 µm
Power density on sample up to 1800 W/cm²



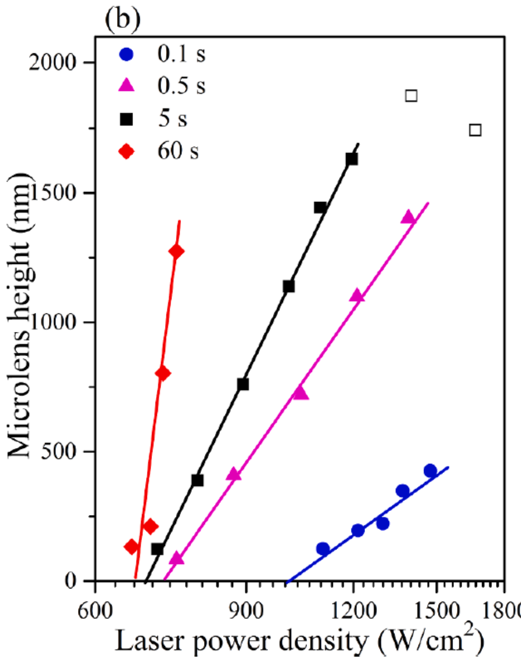

From Atomic Force Microscopy




We want to model the influence of:

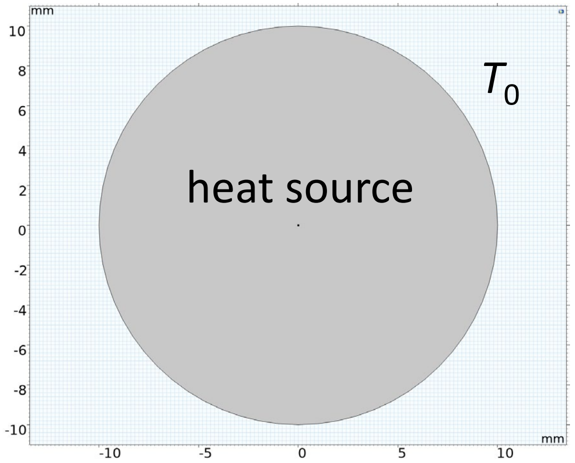
- Exposition time
- Intensity of the laser
- Material properties (especially penetration depth)
- Wavelength of the laser

$$h = \alpha_{eff}^{-1} \cdot \ln \frac{F}{F_{th}},$$



# Model

- https://www.comsol.com/blogs/modeling-laser-material-interactions-in-comsol-multiphysics/
- Application = localized heat source
- For opaque or nearly opaque material the laser can be treated as (localized) heat source




Stationary solution

Heat transfer

$$\nabla \cdot (-k\nabla T) = Q\delta$$

Dirac distribution

$$Q = {}^{P}/_{d_z}$$

volumetric heat source

Material parameters:
Heat capacity $C_p$ = 351 J/(kgK)
Thermal conductivity $k$ = 0.58 W/(mK)
Density $\rho$ = 7520 kg/m$^3$

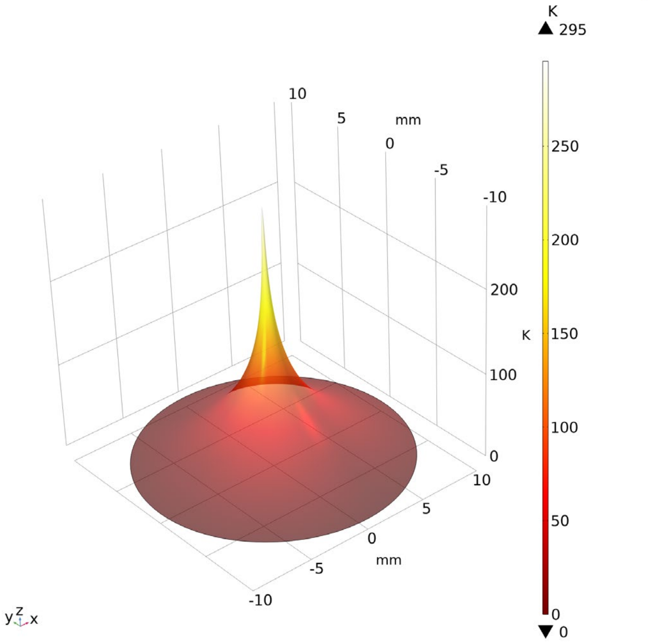
Parameters: diameter of the sample = 10 mm
Diameter of laser (heat source) = 0.2 mm
Surrounding temperature = $T_0$ = 300 K
Power of dissipiated heat = laser power
Out-of-plane thickness $d_z$ = 1 mm

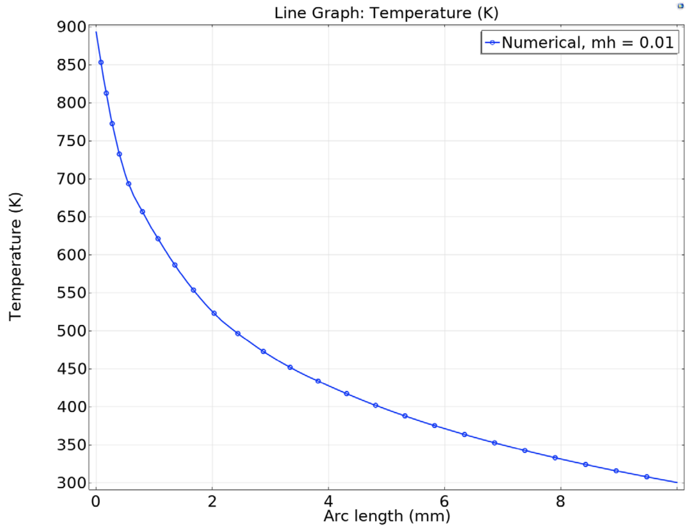
Introduce temperature dependence of material properties
-> Definition - interpolation

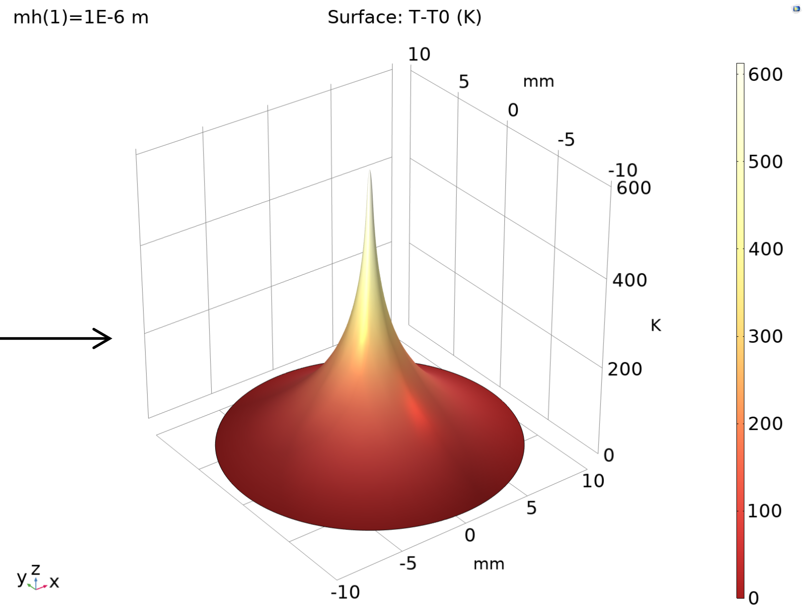
Laser power = power of heat source = 0.2 W

Laser power = power of heat source = 0.4 W

Glass transition temperature $T_g$ ~
Softening temperature $T_s$ is about 400 °C



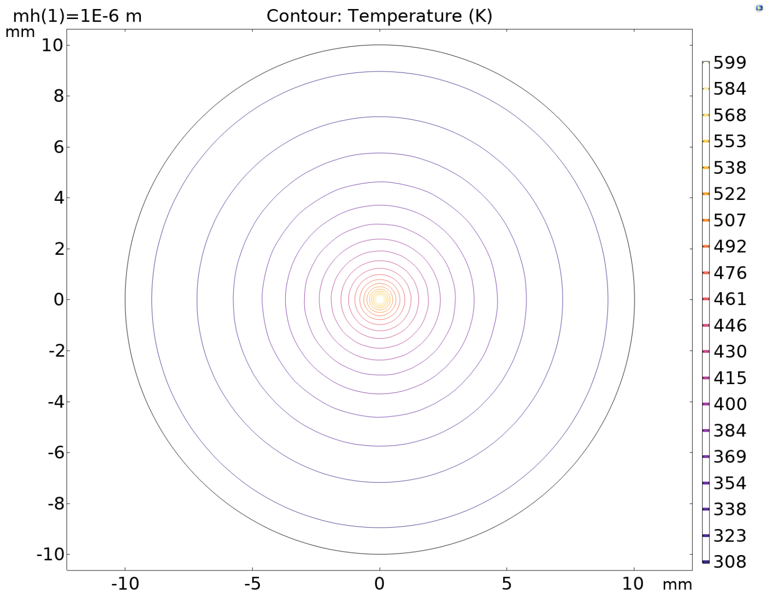



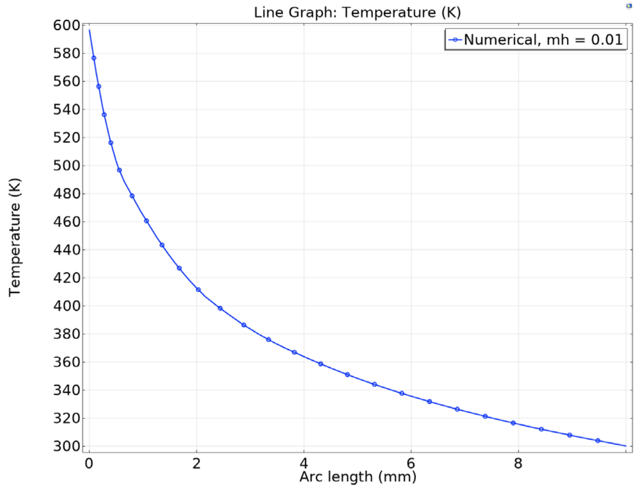



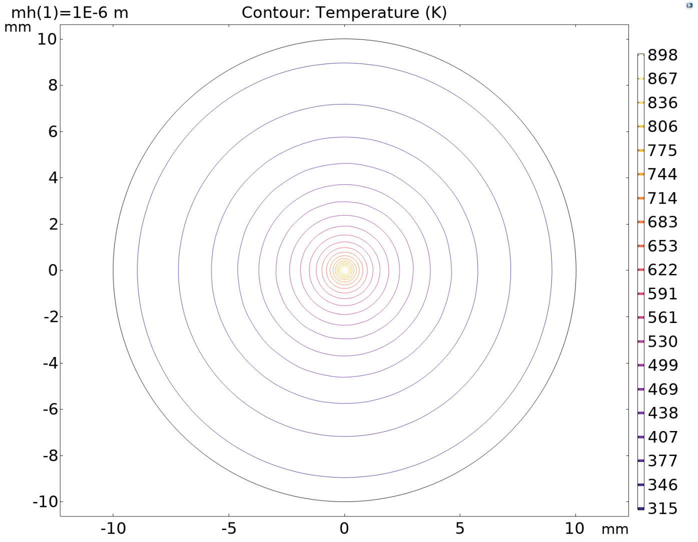

~ 300 K

Maximum temperature difference

~ 600 K



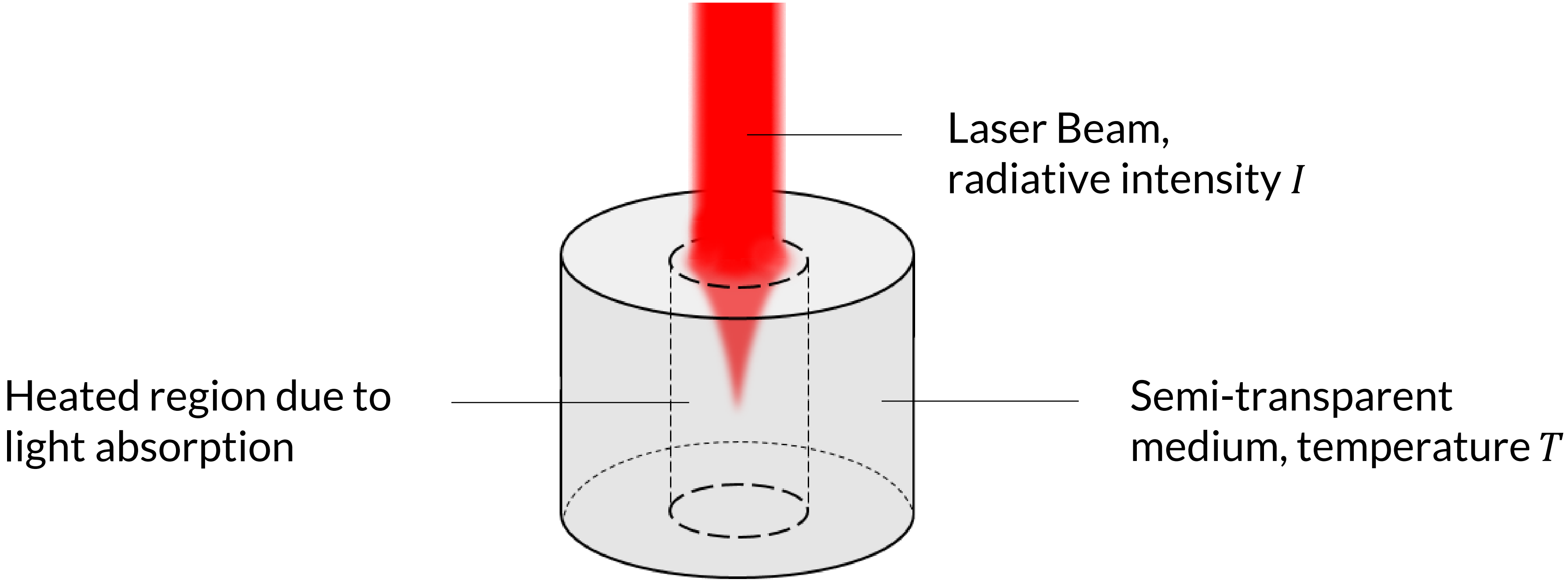
# Modeling Laser Beam Absorption in Silica Glass with Beer-Lambert Law

Using Radiative Beam in Absorbing Media Interface

(Heat Transfer Module)

COMSOL

# Laser Beam Absorption




Absorption coefficient $\kappa(T)$

$T \longrightarrow I$

$T \longleftarrow I$

Radiative heat source $Q(I)$

# Governing Equations

Heat Transfer equation

$$\rho C_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = Q_r$$

Beer–Lambert Law

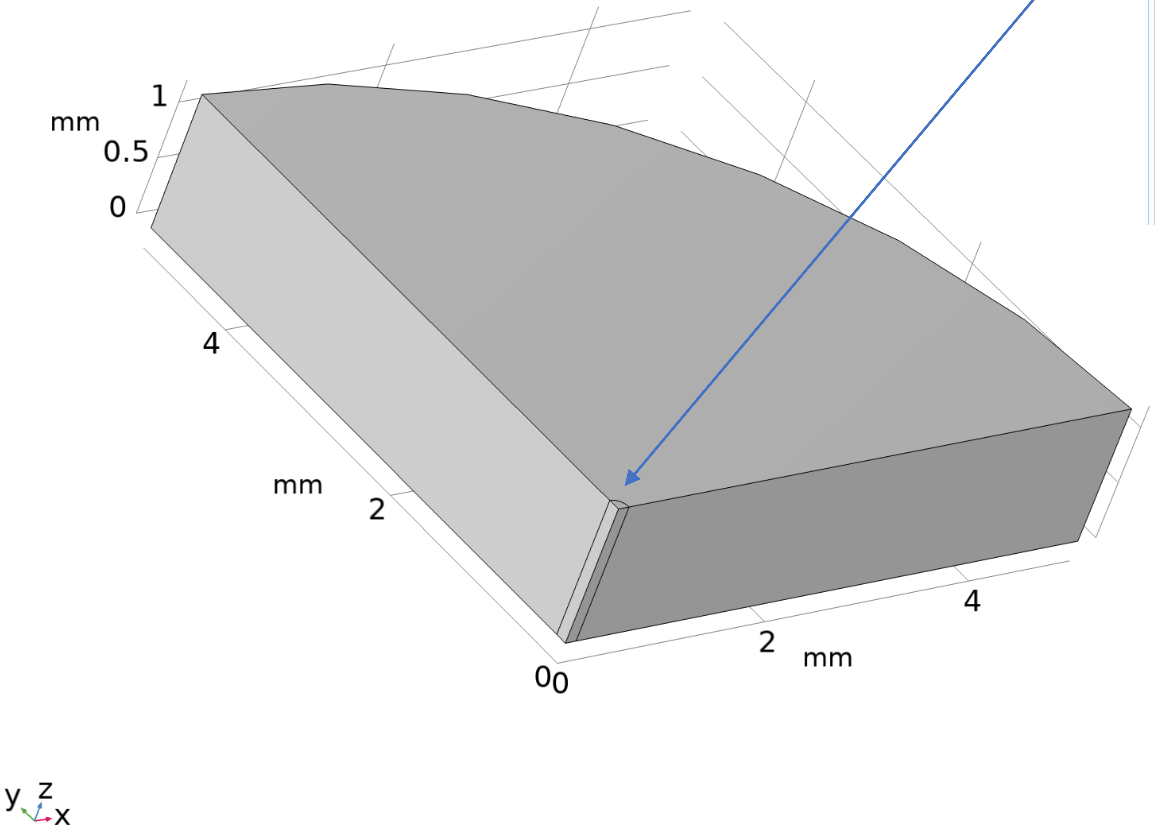
$$\frac{e}{\|e\|} \cdot \nabla I = -\kappa(T) I$$

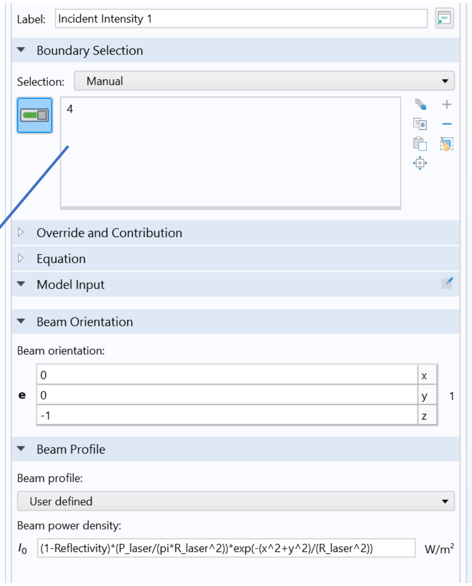
$$Q_r = \kappa(T) I$$

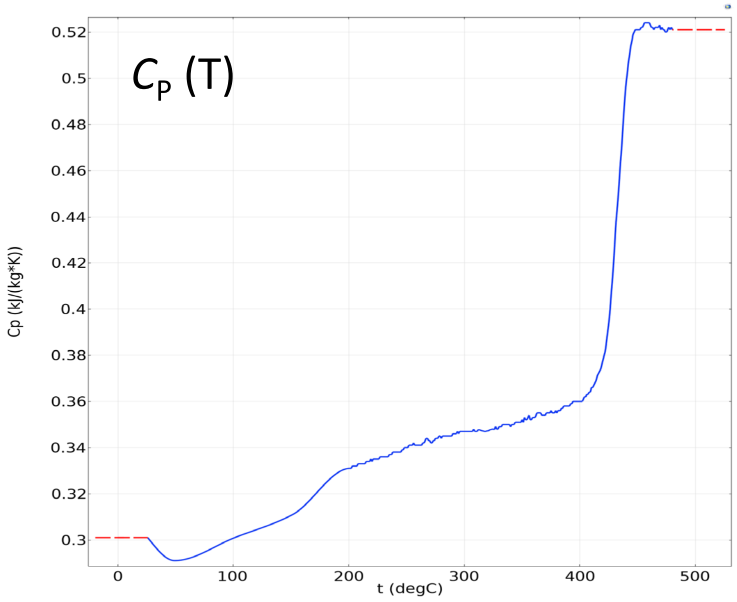
Absorption coefficient

# More advanced model

Gauss profile or top-hat profile of laser beam are available



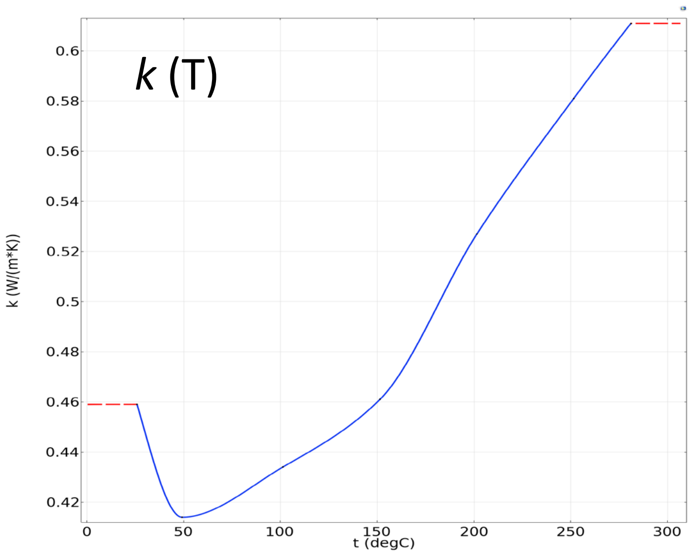




Absorption coefficient

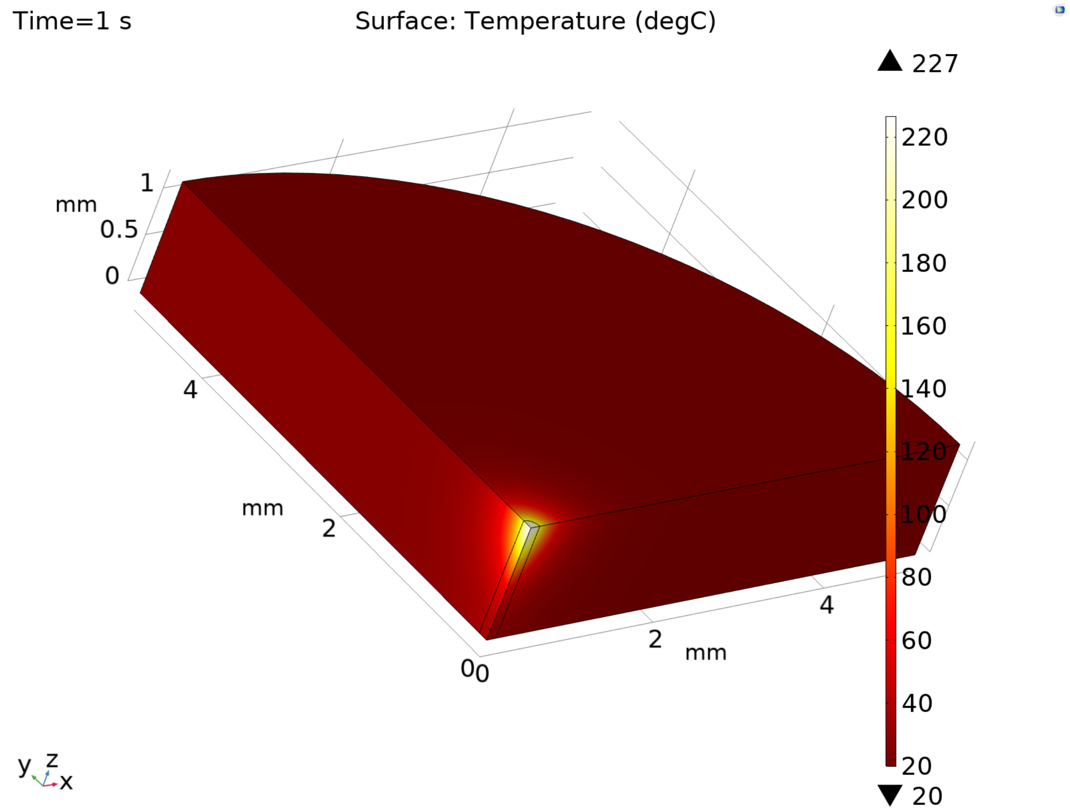
κ = 1 / penetration depth

Density $\rho$ = 7520 kg/m$^3$

==Multiphysics coupling==



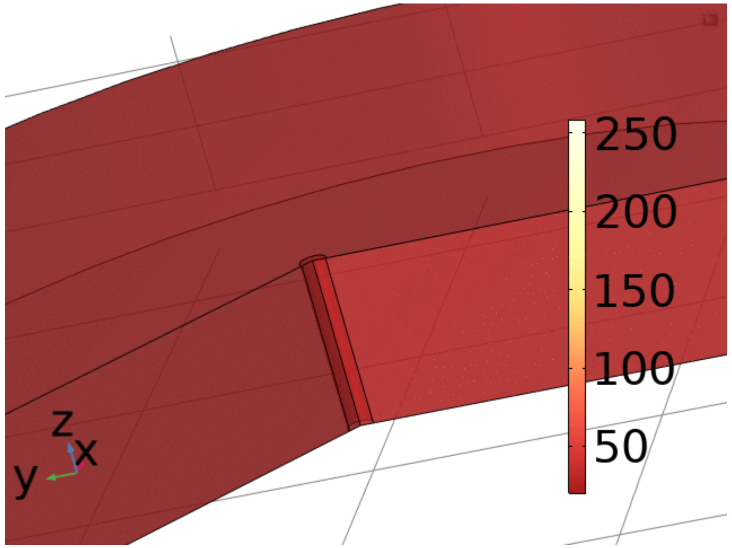

Constant temperature (300 K) on outer boundary

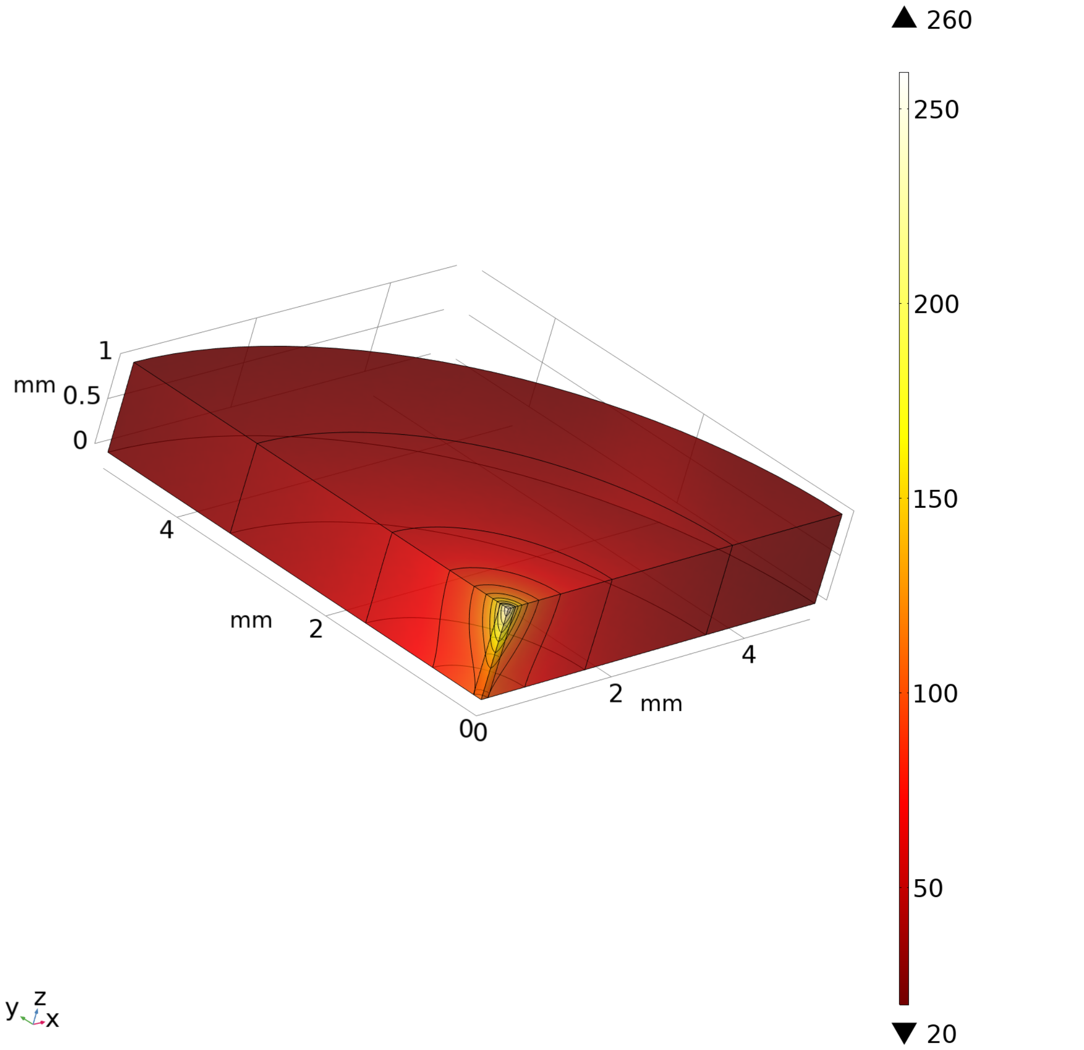



$P$ = 0.1 W

Penetration depth = 256 μm

Stationary solution



# Introducing thermal expansion

- The Microactuator Simplified

strain

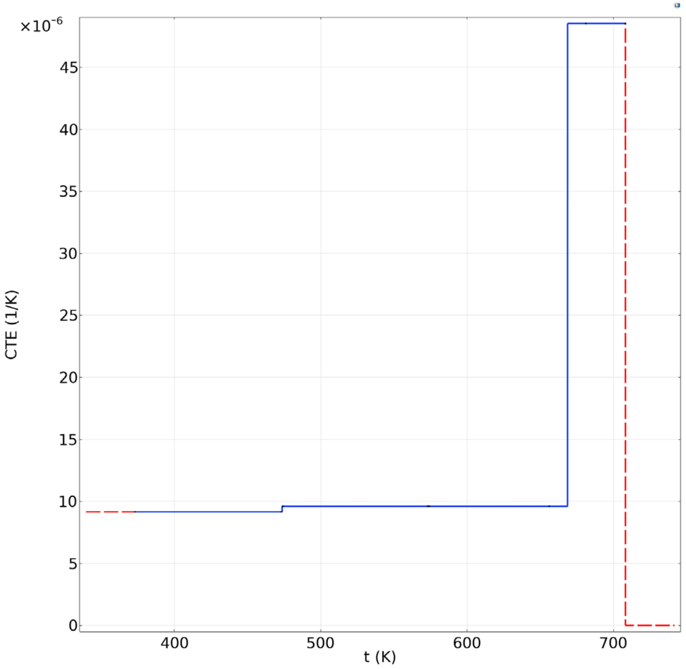
$$\varepsilon = CTE(T) \cdot dT = \vec{\nabla} \cdot \vec{u}$$

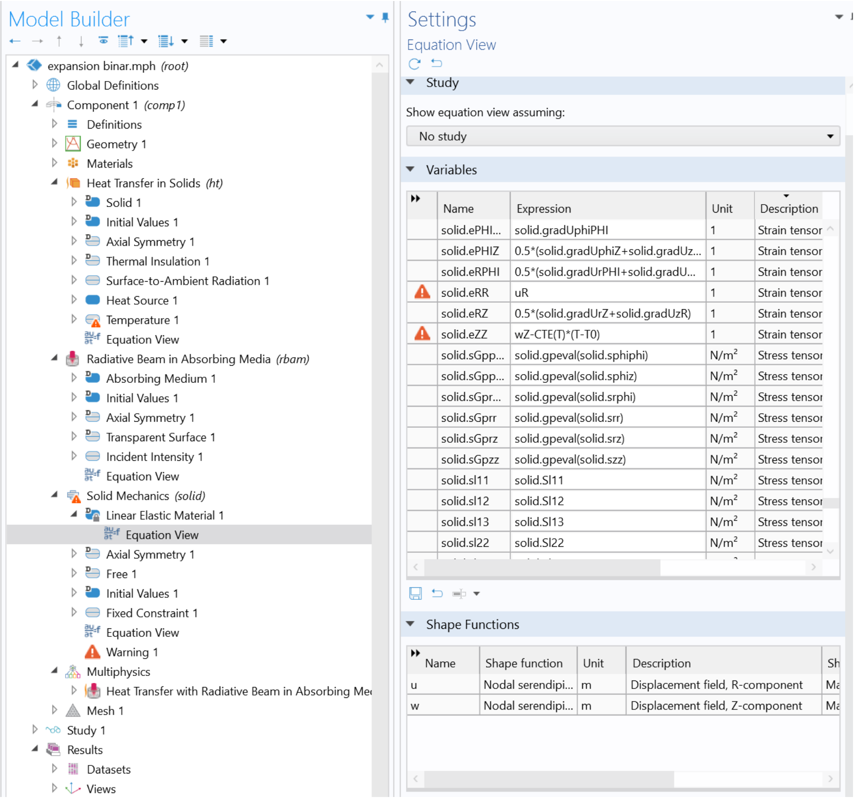
Local displacement vector

height

$$d\Delta z = CTE(T) \cdot dT \cdot \Delta z_0$$

Coefficient of thermal expansion CTE




*Linear Elastic Material 1*

1 Click the **Refresh Equations** button.

2 In the **Model Builder** window, expand the **Thermal Actuator (comp1)>** **Solid Mechanics (solid)>Linear Elastic Material 1** node, then click **Equation View**.

3 In the **Settings** window for **Equation View**, locate the **Variables** section.



4 In the table, enter the following settings:

| Name | Expression | Unit | Description | Selection | Details |
|---|---|---|---|---|---|
| solid.eXX | uX-alphaps*(T-T0) | 1 | Strain tensor, XX-component | Domain 1 | + operation |
| solid.eYY | vY-alphaps*(T-T0) | 1 | Strain tensor, YY-component | Domain 1 | + operation |
| solid.eZZ | wZ-alphaps*(T-T0) | 1 | Strain tensor, ZZ-component | Domain 1 | + operation |

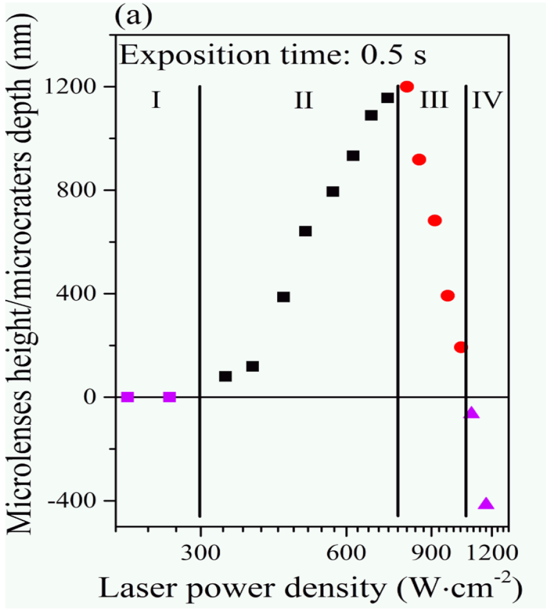
[Performing a Multiphysics Analysis of a Thermal Microactuator | COMSOL Blog]

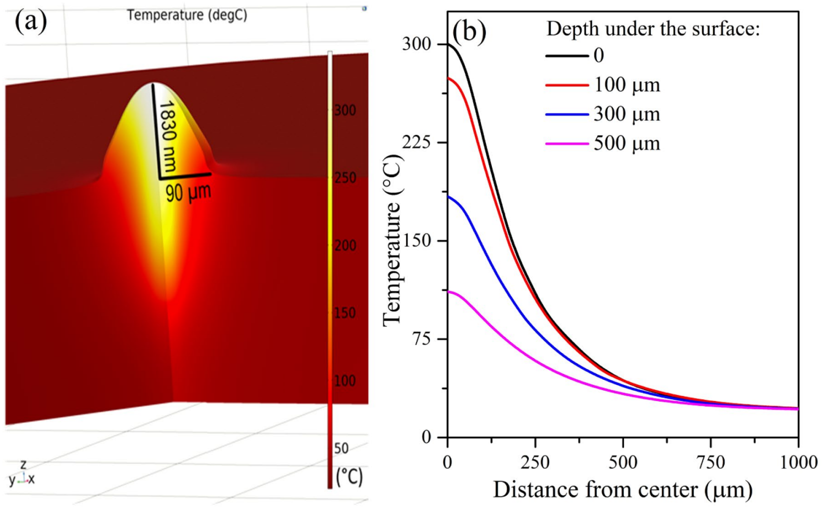
# $PbO$-$Bi_2O_3$-$Ga_2O_3$ glasses

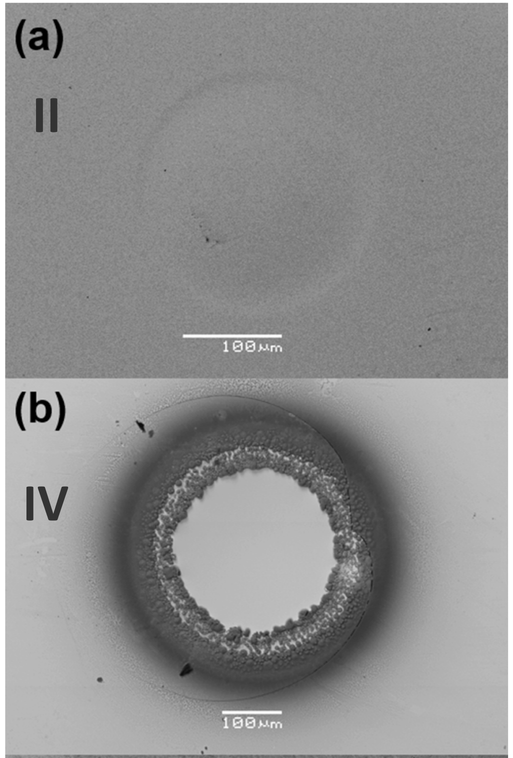
**Table 2**
The characterization of the prepared glasses: density (ρ), thermal properties obtained by TMA (bulk samples; $T_g$, $T_s$ and CTE) and by DTA (powder form of the samples was used; $T_c$, $T_m$), optical properties (optical band gap estimated as $E^{03}$ value, that is energy corresponding to absorption coefficient equal to $10^3$ $cm^{-1}$, and penetration depth of used laser ($d_p$)).

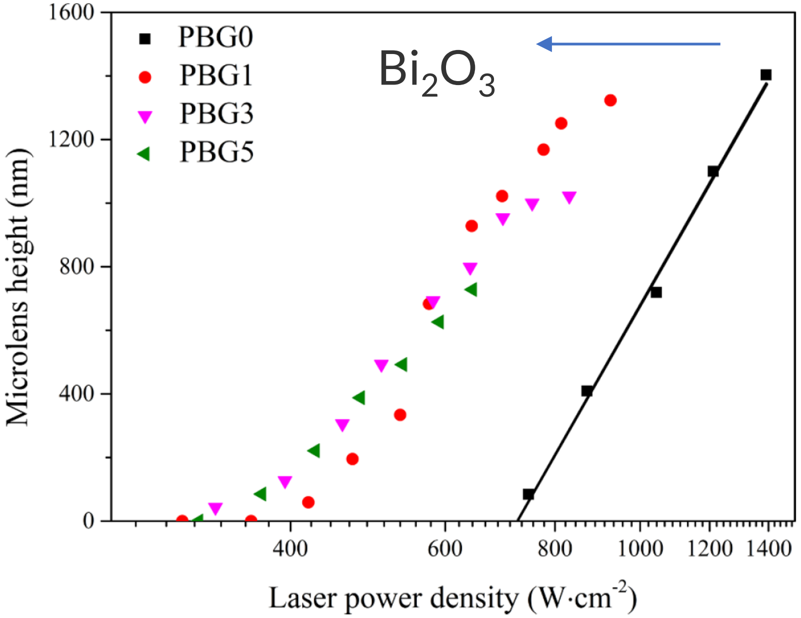
| Property\Abbreviation | PBG0 | PBG1 | PBG2 | PBG3 | PBG4 | PBG5 |
|---|---|---|---|---|---|---|
| Density ρ ($g \cdot cm^{-3}$) | 7.52 | 7.56 | 7.60 | 7.70 | 7.80 | 7.89 |
| Glass transition temperature $T_g$ (°C) | 408 | 394 | 383 | 377 | 372 | 370 |
| Softening temperature $T_s$ (°C) | 435 | 414 | 418 | 410 | 405 | 398 |
| Coefficient of thermal expansion CTE* ($ppm \cdot K^{-1}$) | 10.1 | 9.8 | 9.6 | 10.5 | 10.7 | 10.9 |
| Crystallization temperature $T_c$ (°C) | 499 | 521 | 496 | 480 | 492 | 501 |
| Melting point $T_m$ (°C) | 759 | 594 | 618 | 597 | 590 | 554 |
| Optical band gap $E^{03}$ (eV) | 3.100 | 3.075 | 3.054 | 3.055 | 3.057 | 3.048 |
| Optical penetration depth $d_p$ (μm) | 318 | 285 | 256 | 276 | 284 | 278 |

* for temperature interval 100–300 °C

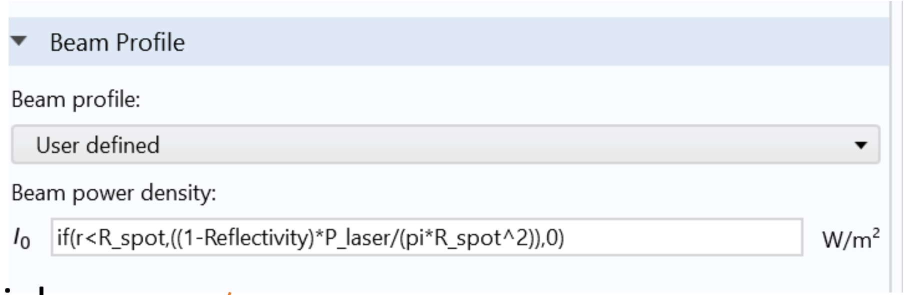


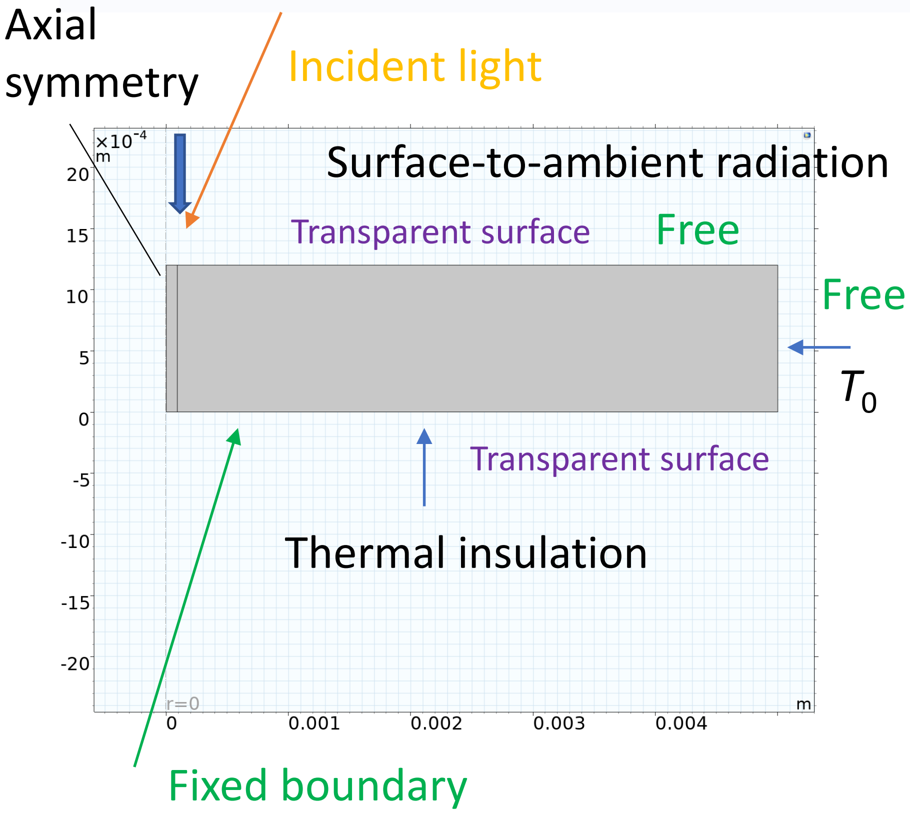



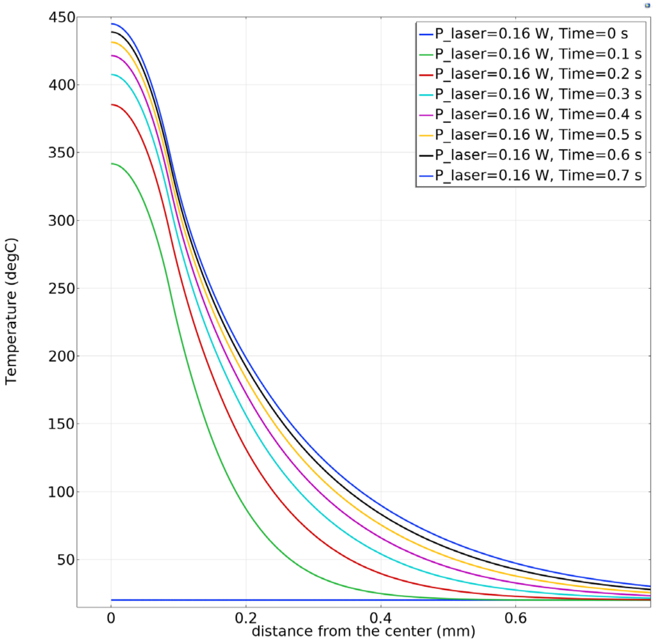



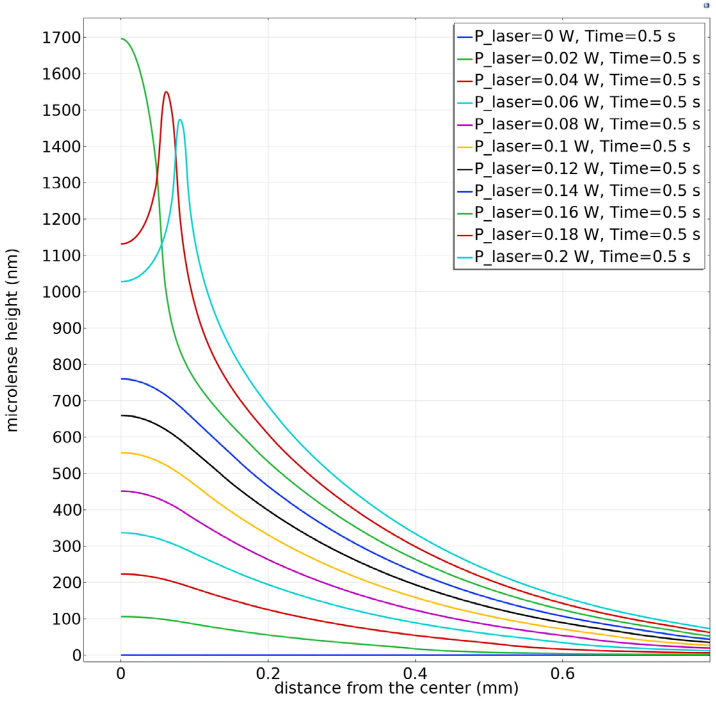



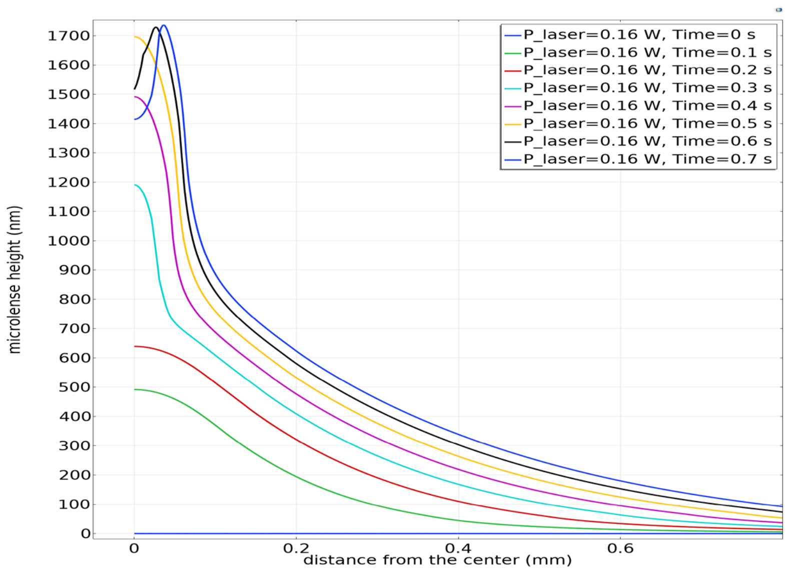
# Top-hat laser beam profile

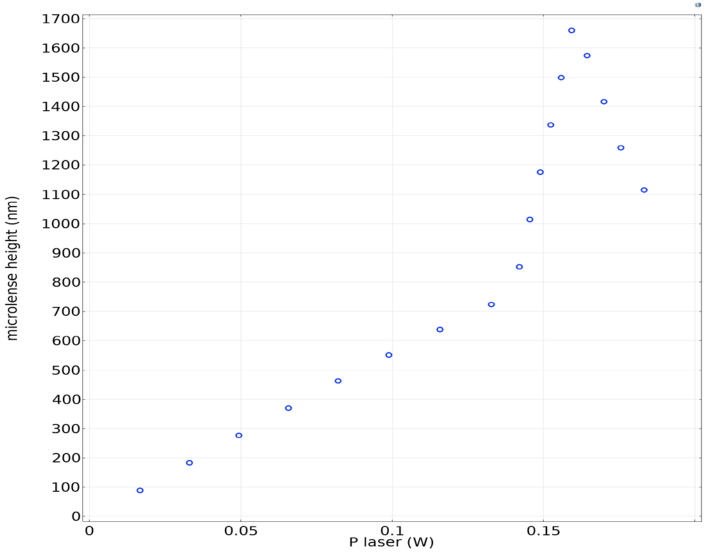


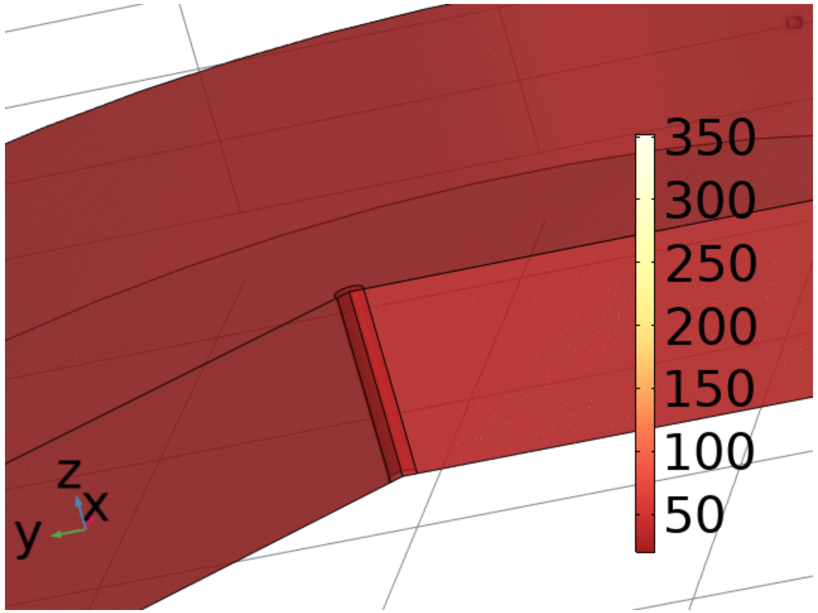



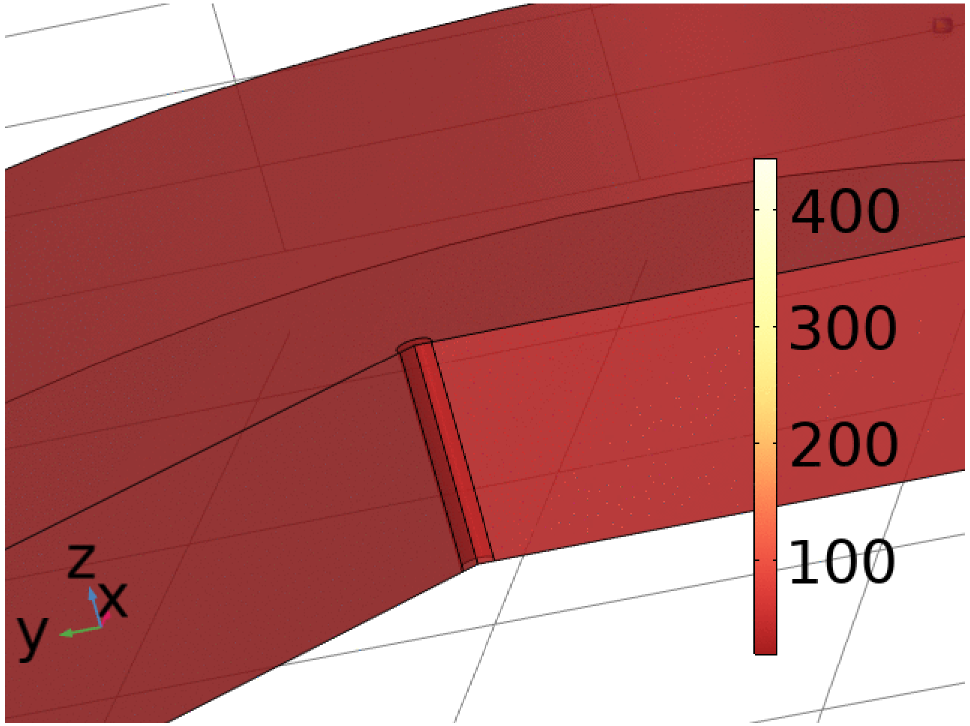



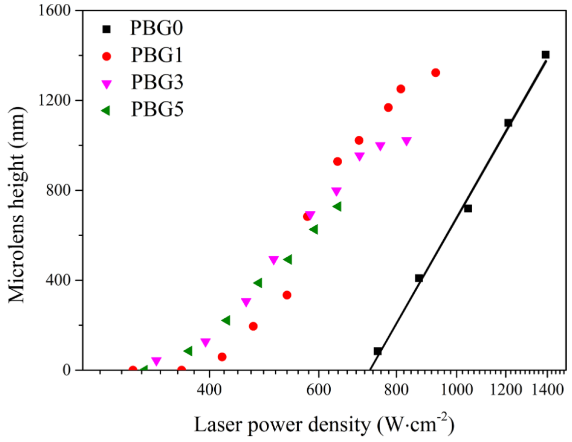
*P* = 0.12 W

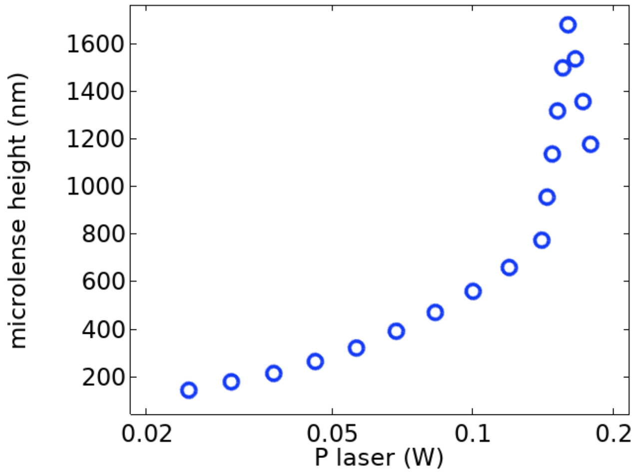


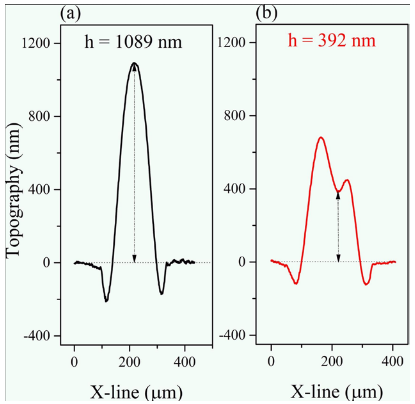

*P* = 0.16 W




experiment vs. model



# Conclusions

- Combination of heat transfer + radiative beam in absorbing media + solid mechanics is able to describe spatial distribution of temperature in the material after illumination of laser and also creation of microlens due to thermal expansion.
- Temperature dependences of material properties have significant influence on the results obtained from the model.
- Estimated maximal height of the microlens is higher than experiment for $PbO$-$Bi_2O_3$-$Ga_2O_3$ glass.

# Next plans

- Modelling of the flow of viscous glass when temperature is higher than softening temperature.
- Modelling of ablation leading to creation of micro-craters.

# Open question

Sample thickness ~ 1.2 mm

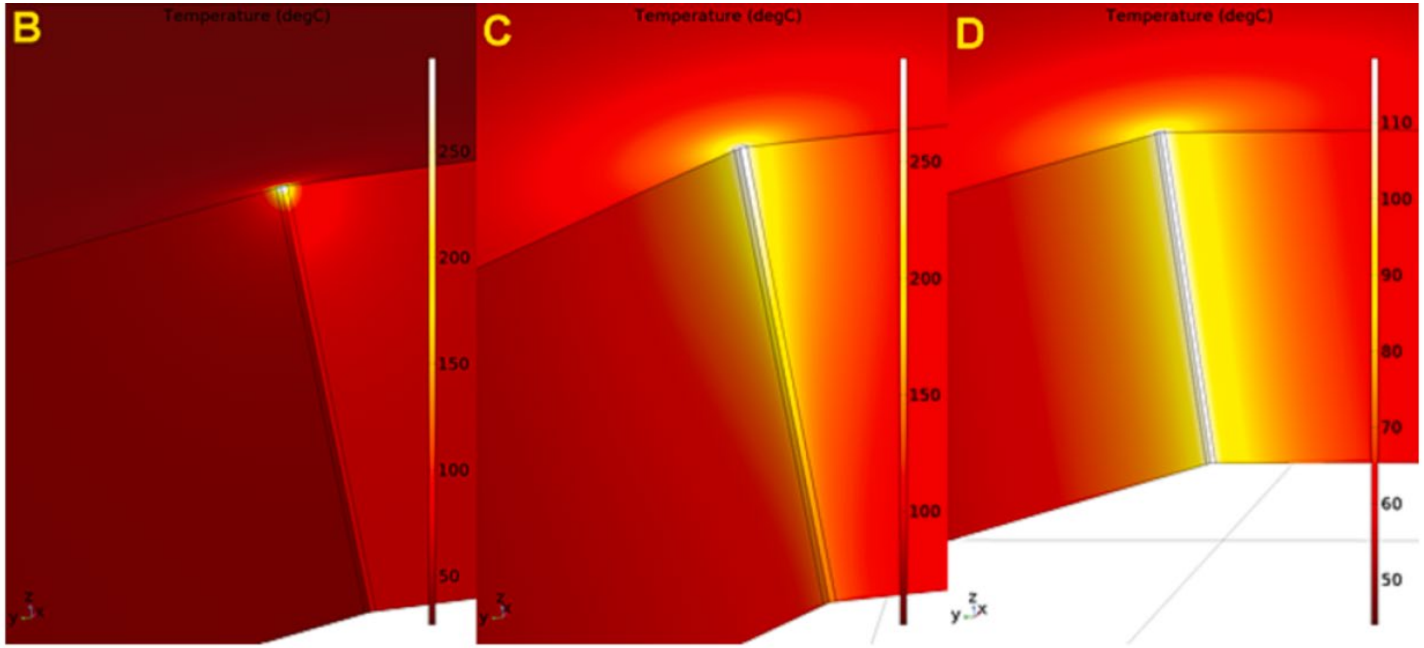
time of enlightenment ~ 10 min

- Modelling of the case when the penetration depth is higher than the sample thickness

Strong influence of boundary conditions (cooling of the sample)

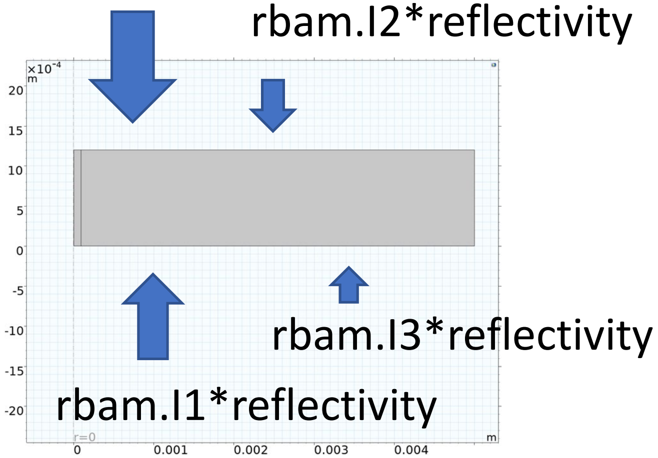
Penetration depth

20 μm　　750 μm　　50 000 μm




https://www.comsol.com/blogs/modeling-the-pulsed-laser-heating-of-semitransparent-materials

Incident light

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# References


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