Presented at the COMSOL Conference 2010 Boston

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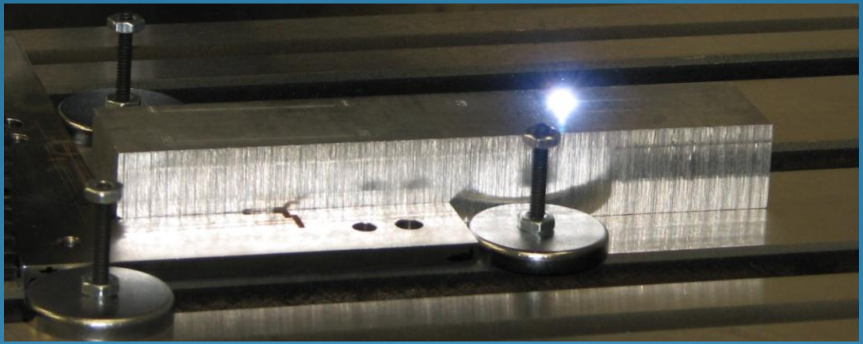
COMSOL Assisted Simulation of Laser Engraving



Presented by:
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Oct. 7, 2010

Creating and Building Sustainable Environments

Outline

- Background
- Objectives and Benefits
- Scope of Modeling
- Experiments
- COMSOL Modeling
- Simulation Results
- Future Directions

Background

- Applications of Laser engraving are growing rapidly, EDM alternative
- Material is removed by vaporization in a layer by layer fashion
- The quality of engraving is important process output
- Process inputs falling into two groups fixed and variable (controllable)
- Fixed inputs such as laser optics, wavelength, beam profile, ambient temperature, and workpiece material and dimension
- Variable inputs (laser parameters) such as laser power, pulse frequency, traverse speed
- Usually iteration is used to find the best thickness of the layer
- Setup time could be lengthy

Objectives and Benefits

- Computer simulation of laser engraving for a simple line
- Fundamental step towards complete 3D laser engraving
- If exists it can be used inversely for:
- ➢ Setting the laser parameters before and during laser engraving
- ➢ Adjusting the parameters in case of material or laser changes
- ➢ Tuning the parameters if scaling up/down of the artwork
- ➢ Microcracking study as a result of thermal stresses
- ➢ Reducing the time and cost of the process

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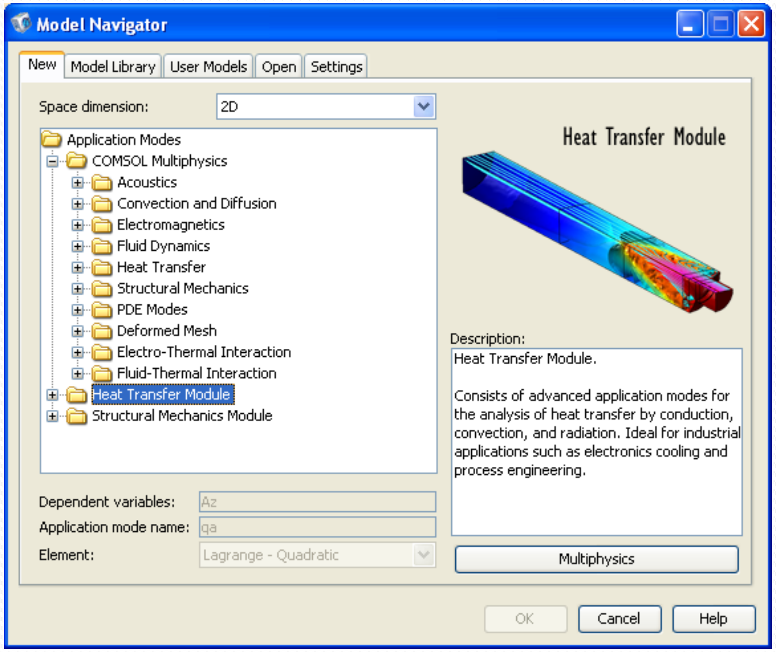
Scope of Modeling

- Using COMSOL software to simulate the laser as a moving heat source
- It uses FE method to solve PDEs such as heat equation
- Multiphysics nature for laser physics: optics, electromagnetic waves (RF), heat transfer, and electro-thermal interaction
- Not modeled: beam aperture size, bean expansion factor, q-switching, and spot overlap.



Space dimension: 2D

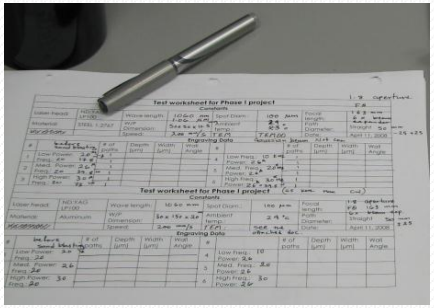
Description:
Heat Transfer Module.

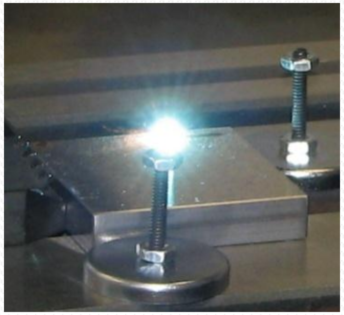
Consists of advanced application modes for the analysis of heat transfer by conduction, convection, and radiation. Ideal for industrial applications such as electronics cooling and process engineering.

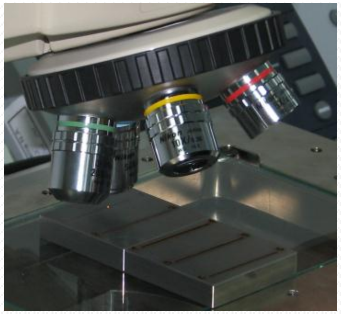
Dependent variables: Az
Application mode name: qa
Element: Lagrange - Quadratic

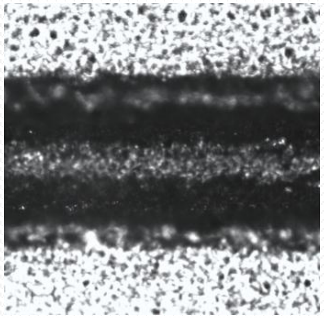
Experimentation

- Four materials are tested: Steel 1.2767 (DIN 45NiCrMo16), Aluminum, Copper, Brass
- LP100 Nd:YAG laser used to engrave a 40mm straight line at speed of 50mm/s
- 6 tests per material: low, medium, and high power at constant frequency and also 3 frequencies at constant power
- Depth and width of engraving measured using microscope at magnification of 50X
- Notice the non-flat bottom of the groove, more like a convex, this was observed for all four materials.









Materials' absorptivity at 1064 nm

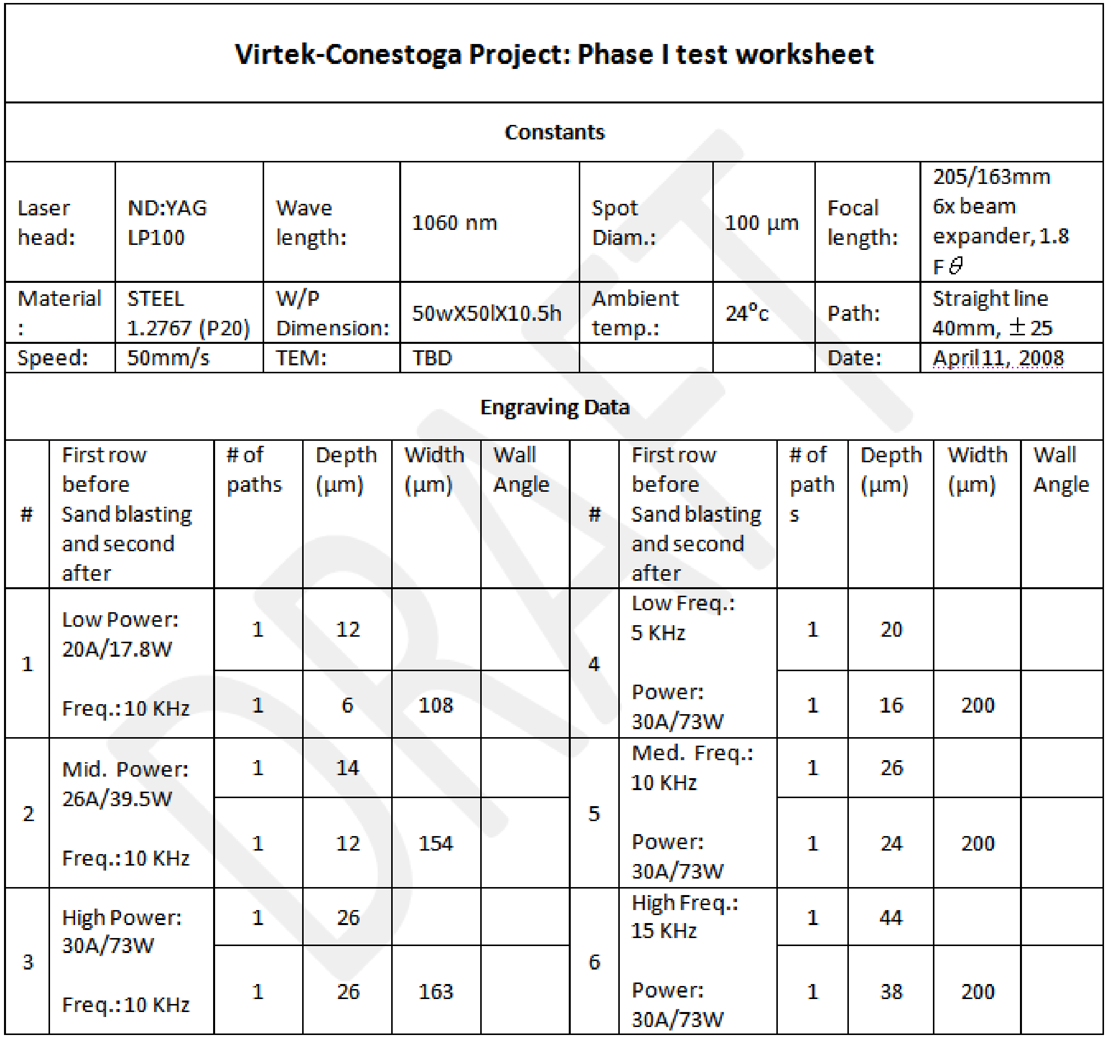
Material	rho (kg/m^3)	K (W/m*K)	C (J/K*kg)	Tm (K)	Tv (K)	Ab-Solid	Ab-Melting
Steel 1.2767	7850	28	460	1808	3003	0.36	0.9
Aluminum	2700	160	900	933	2333	0.2	0.8
Copper	8700	400	385	1356	2903	0.1	0.35

- For metals: reflectivity=1-absorptivity
- For transparent materials: reflectivity=1-(transmissivity+ absorptivity)
- Absorptivity is function of:
- ❖ Wavelength (roughly the shorter wavelength the higher absorptivity)
- ❖ Temperature (much higher absorptivity at melting state)***
- ❖ Surface oxidation thickness (acting as anti-reflection coating)
- ❖ Angle of incidence
- ❖ Material and surface roughness (roughness increases diffuse reflection)

Steel 1.2767-

depth and width of engraving

TABLE 1: LASER ENGRAVING RESULTS ON STEEL 1.2767



Virtek-Conestoga Project: Phase I test worksheet

Constants

Laser head:	ND:YAG LP100	Wave length:	1060 nm	Spot Diam.:	100 µm	Focal length:	205/163mm 6x beam expander, 1.8 F θ
Material :	STEEL 1.2767 (P20)	W/P Dimension:	50wX50lX10.5h	Ambient temp.:	24°c	Path:	Straight line 40mm, ± 25
Speed:	50mm/s	TEM:	TBD			Date:	April 11, 2008

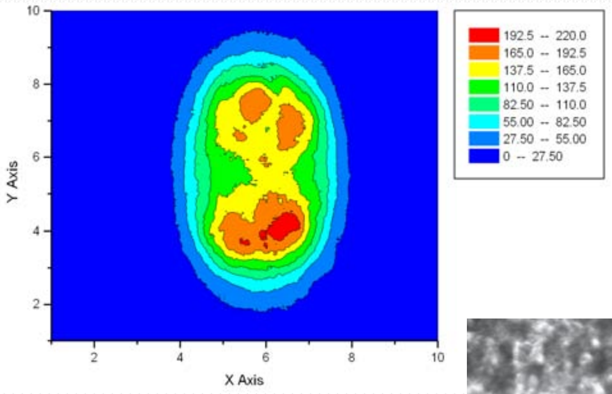
Engraving Data

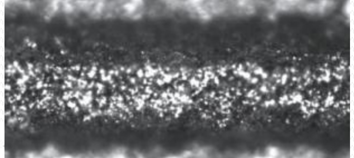
#	First row before Sand blasting and second after	# of paths	Depth (µm)	Width (µm)	Wall Angle	#	First row before Sand blasting and second after	# of paths	Depth (µm)	Width (µm)	Wall Angle
1	Low Power: 20A/17.8W Freq.:10 KHz	1	12			4	Low Freq.: 5 KHz Power: 30A/73W	1	20		
		1	6	108				1	16	200	
2	Mid. Power: 26A/39.5W Freq.:10 KHz	1	14			5	Med. Freq.: 10 KHz Power: 30A/73W	1	26		
		1	12	154				1	24	200	
3	High Power: 30A/73W Freq.:10 KHz	1	26			6	High Freq.: 15 KHz Power: 30A/73W	1	44		
		1	26	163				1	38	200	

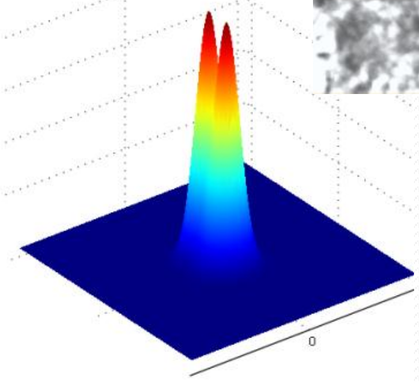
LP100 Beam Profile

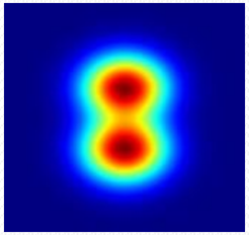
- Two separate tests indicate the beam profile is very similar to Hermite-Gaussian Mode, TEM01
- LP100 at 3KHz and the groove image of test 4 with Al
- 1st order mode of TEM01 is adopted for the modeling
- The ratio between min and max is 0.75
- The mathematical model for power intensity in 3D is:

$$Pxy = \frac{K\,P}{r_b^{\,2}\pi}\exp\left(\frac{-x^2}{\beta\, r_b^{\,2}}\right)\left(\frac{y^2}{\alpha^2+1}+4\alpha^2 r_b^{\,2}\right)\exp\left(\frac{-y^2}{4r_b^{\,2}(\alpha+1)}\right)$$



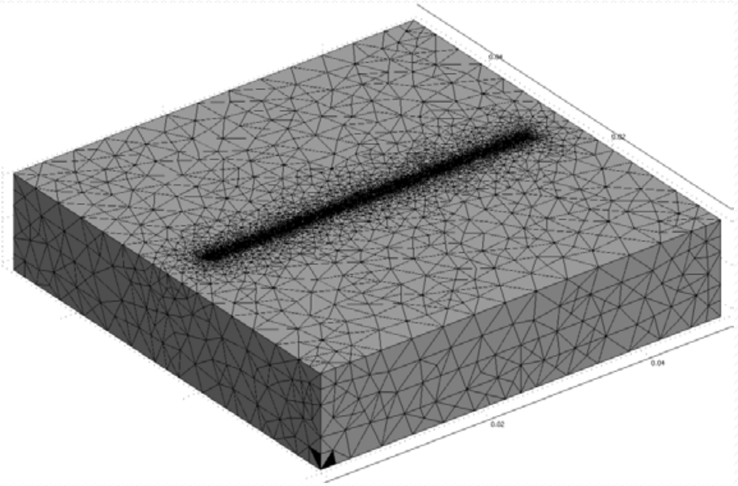






COMSOL Modeling

- Creating the block of 50X50X11mm made of Steel 1.2767
- Defining the laser path on the top surface
- Meshing the block with variable sizes
- The sizes are much smaller around the path of laser for greater accuracy (down to 5 micron)
- A finer mesh increases the total number of meshes and hence increase the computer simulation time
- For about 200,000 meshes it takes 30 min for solving 0.1sec of simulation



COMSOL Modeling- Physics

- Heat conduction equation

$$\rho C_p \frac{\partial T}{\partial t} + \nabla.(-k\nabla T) = Q$$

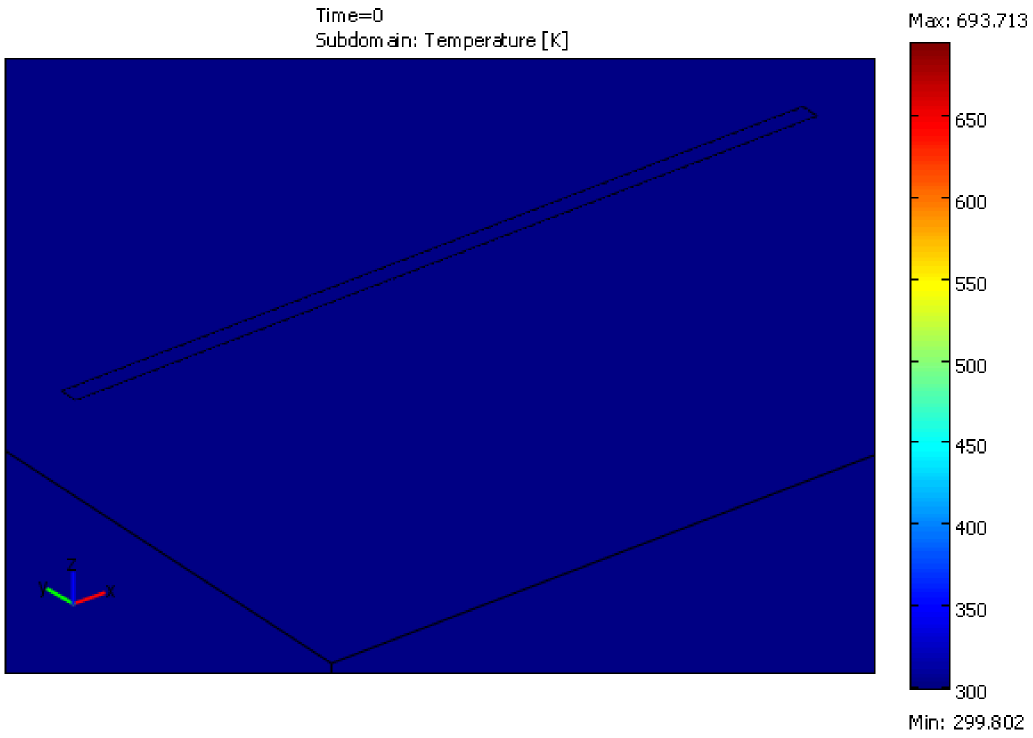
solved for its transient response under these conditions:

- Considered moving laser beam at 50 mm/s along a 40mm-long line
- 100-micron laser spot considered as a moving heat flux boundary condition with Q=0
- TEM01 considered for heat flux distribution over the laser spot
- Heat flux will be: $Pxy * Absorptivity$
- Absorptivity will be function of temperature and it switches to its new value as the material melts
- ALE mode is used to deform the meshes based on the local temperature
- Heat flux will switch ON and OFF at given frequency

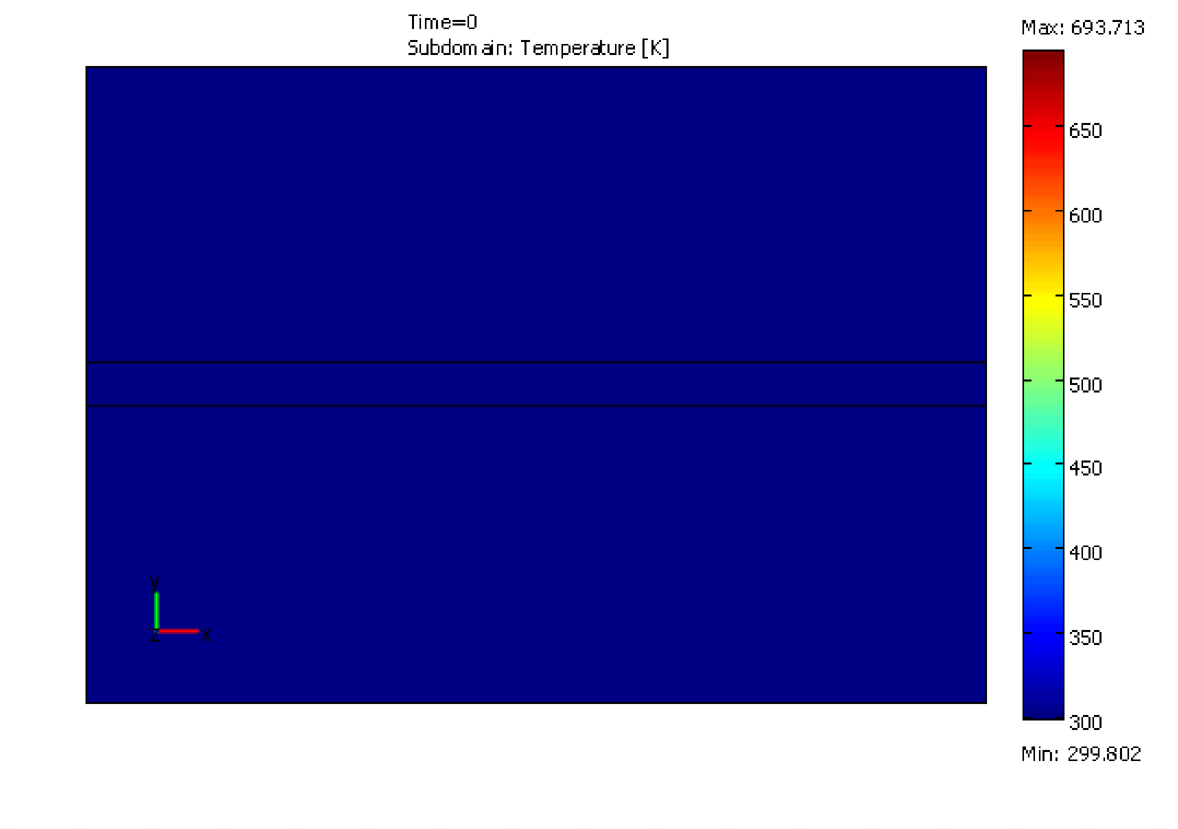
COMSOL Modeling: inputs -outputs

- Inputs:
  - Material properties (absorptivity at solid and melting states, melting and vaporizing temperatures, heat conductivity, density, specific heat capacity…)
  - Material geometry and dimensions
  - Ambient temperature
  - Beam properties (spot size, profile, power, speed, frequency, …)
  - Yet to be modeled: the effects of optic system on spot size and peak power, q-switching, surface roughness, oxidation thickness, …
- Outputs:
  - The geometry of the groove: depth, width wall angle,…
  - Heat penetration
  - Temperature distribution
  - Animation of laser engraving

Results of Simulation – only for demonstration



Zoomed Simulation- only for demonstration



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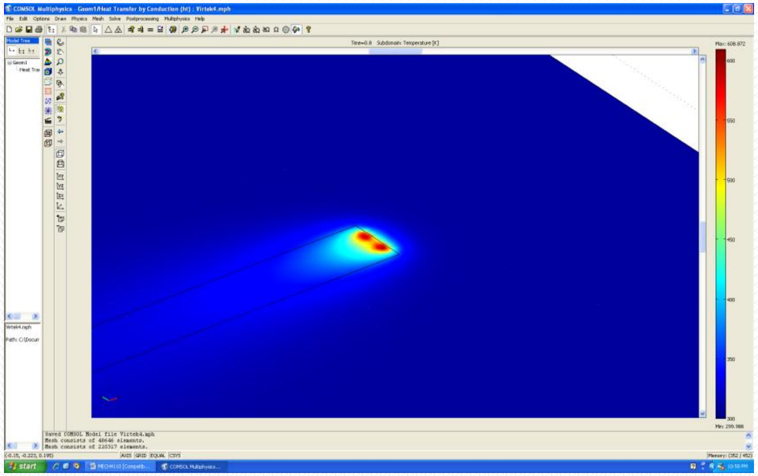
Results of Simulation- Vertical and horizontal



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Saved COMSOL Model file Virtek4.mph
Mesh consists of 48646 elements.
Mesh consists of 210317 elements.
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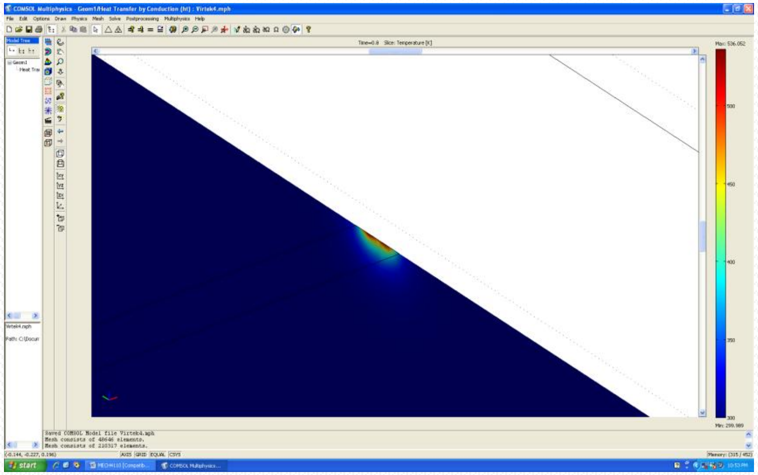

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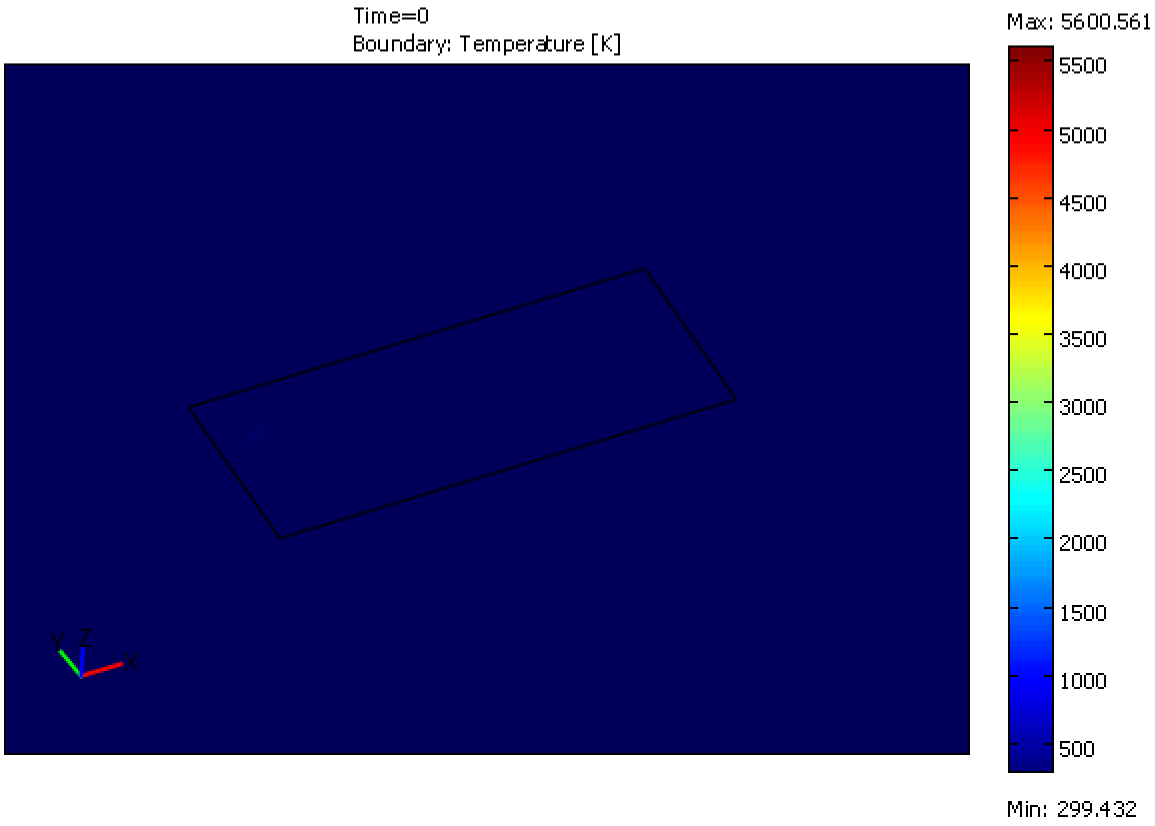
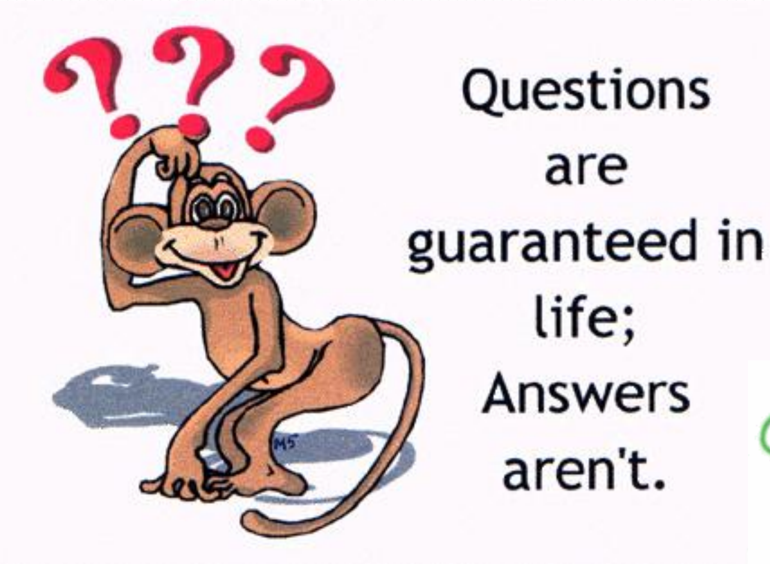
Laser Engraving in 3D



Future Directions

- Extending the simulation for 3D flat and curved surfaces (layer)
- Simulation of 3D laser engraving by importing of CAD files
- Using a beam power detector for inputting power intensity
- Including the effects of laser optics, polarization, angle of incident, surface roughness, and oxidation thickness in absorptivity rate
- Letting user to choose their lasers such as UV lasers (this is totally different modeling as the process is not thermal anymore)
- Inverse modeling: input geometry, laser, and material and output the laser settings
- Developing a data base consists of material-laser settings information



Questions are guaranteed in life; Answers aren't.