LASCAD Tutorial No. 3:
Modeling an Yb:YAG thin disk laser

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Note:
The project file `Tutorial_3.lcd` of the example generated with this tutorial can be found in the directory `Tutorials` on the CD-ROM or after installation of LASCAD in the subdirectory `Tutorials` of the LASCAD application directory. You can copy this file to a working directory and open it by double-click.

1 Starting LASCAD and Defining Pump Light Distribution

- Start LASCAD and open `Tutotial_3.lcd` in the directory `C:\Program Files\LASCAD\Tutorials`,
- Define a working directory,
- Stretch the mode plot, by the use of the "shrink-stretch" tool until you can see the yellow symbol for the thermal lensing disc. Since the disc is only is 0.12 mm thick, you must stretch a lot,
- Select the menu item **FEA→Parameter Input & Start of FEA code,** which opens the window **Crystal, Pump Beam, and Material Parameters**.

This window has six tabs. The tab **Models** shows pre-designed models provided with LASCAD, as shown in Fig. 1. In this tutorial, the model **Cylindrical rod with top hat...** is selected. That means that the absorbed pump power density is approximated by a top hat (= constant) distribution in the direction of the disc axis. Below the frame with the models you can see the dimensions of the disc.

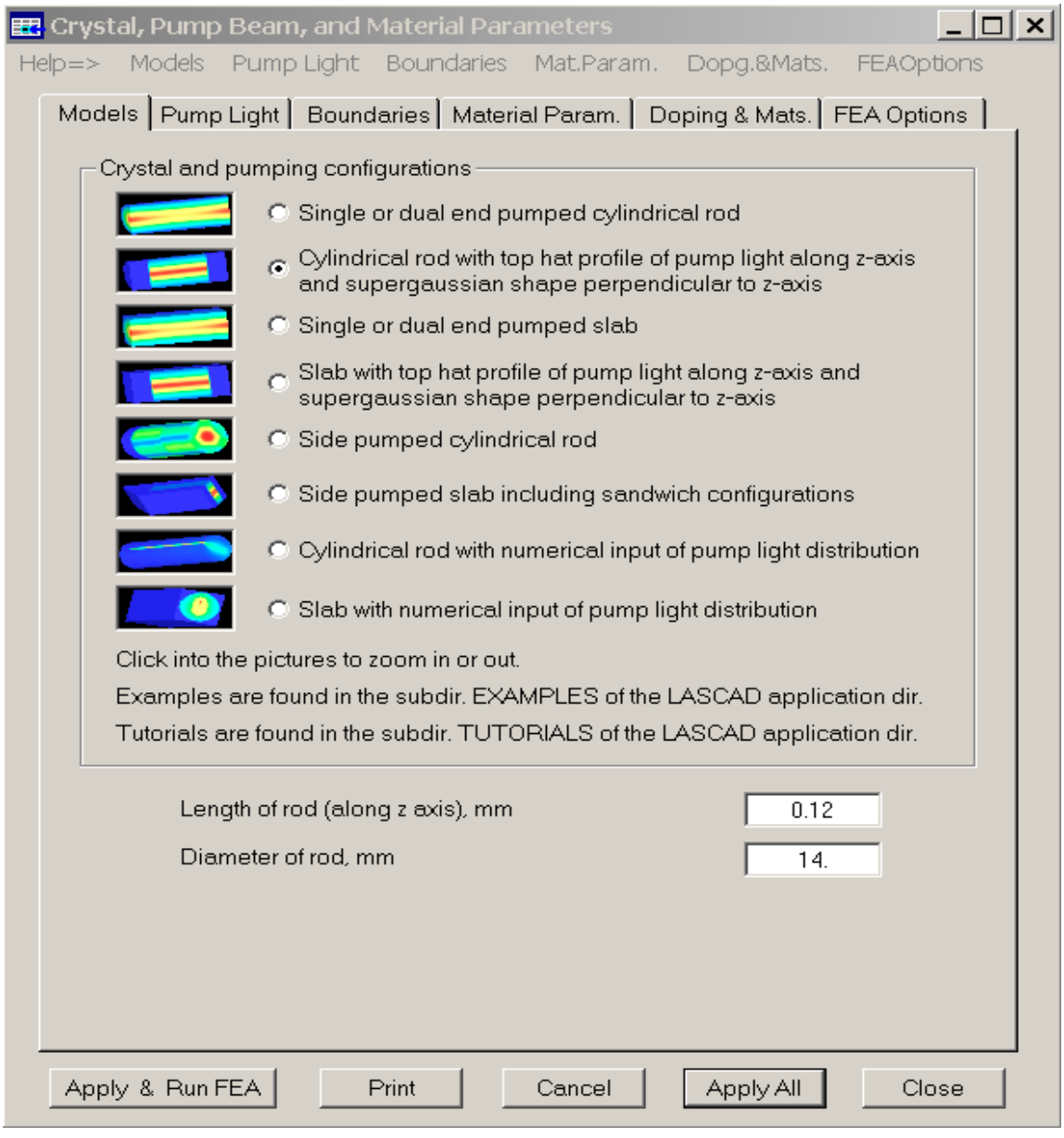

Fig. 1

Select the tab **Pump Light,** as shown in Fig. 2, to define the absorbed pump power density. With this model you must know in advance the totally absorbed pump power. It has been assumed that 500 W are absorbed in the disc. The pump profile perpendicular to the axis of the disc can be defined by the use of supergaussian functions, as explained in the **help=>** menu item **Pump Light→Top Hat Pump Light Distribution in Axis Direction,** or in the manual. The spot size is the radius of the distribution. If the super-gaussian exponent is increased to a large number, the profile approaches top hat. Click the button **Show Pump Profile** to see the profile. You can even subtract a negative contribution from the profile, based on a percentage scale, related to the absorbed pump power.

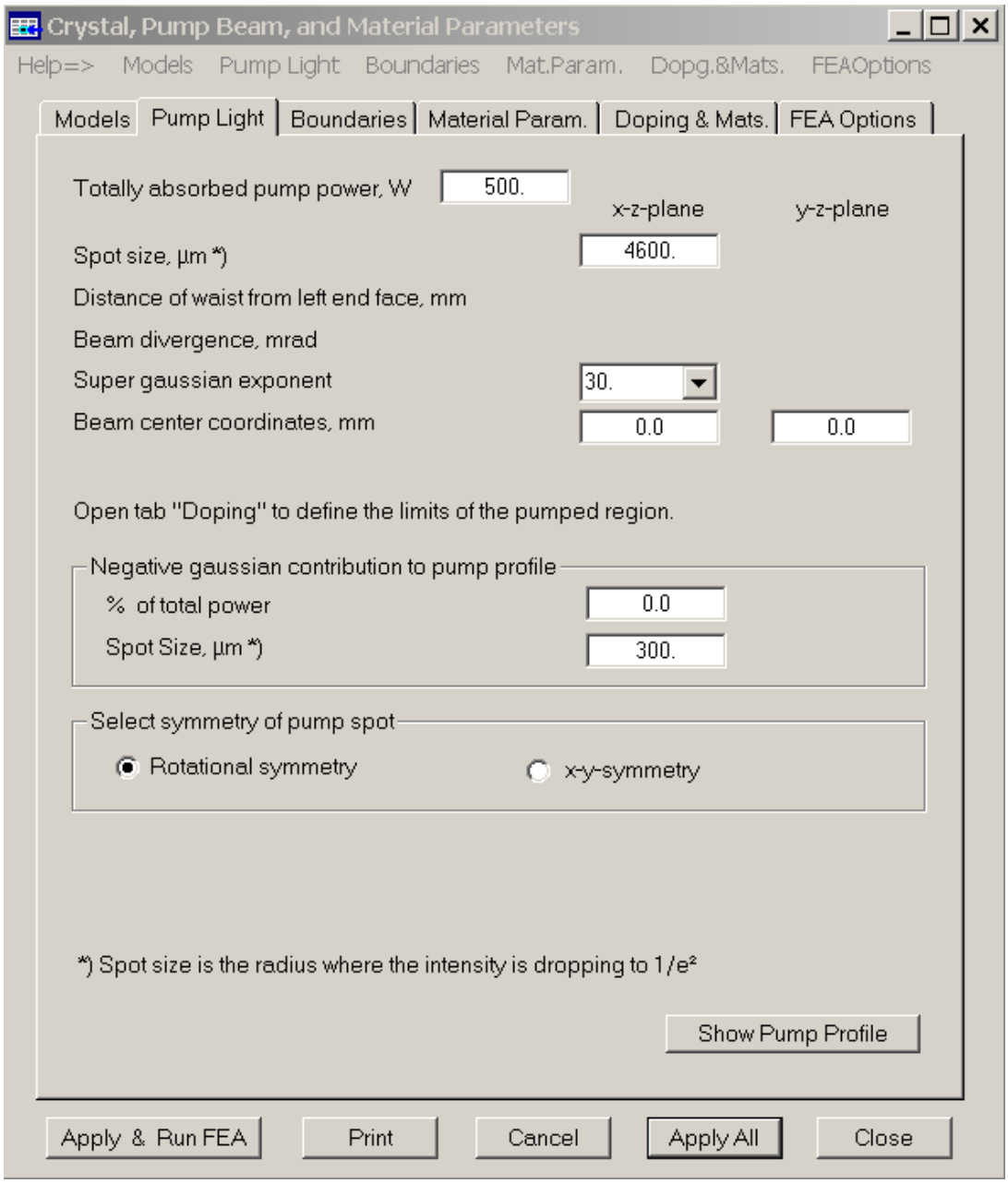

Fig. 2

2 Defining Boundary Conditions Used with FEA

Select the tab **Boundaries,** as shown in Fig. 3, to define the boundary conditions. It is assumed that the lower (z=0) surface of the crystal is in contact with a solid at constant temperature, but you also can check fluid cooling. The temperature of the solid is assumed to be 293 K. With 3-level-laser materials it is important to use the Kelvin scale. The reference temperature is used for the computation of the thermal deformation, and should have the same value as the temperature used for the solid contact.

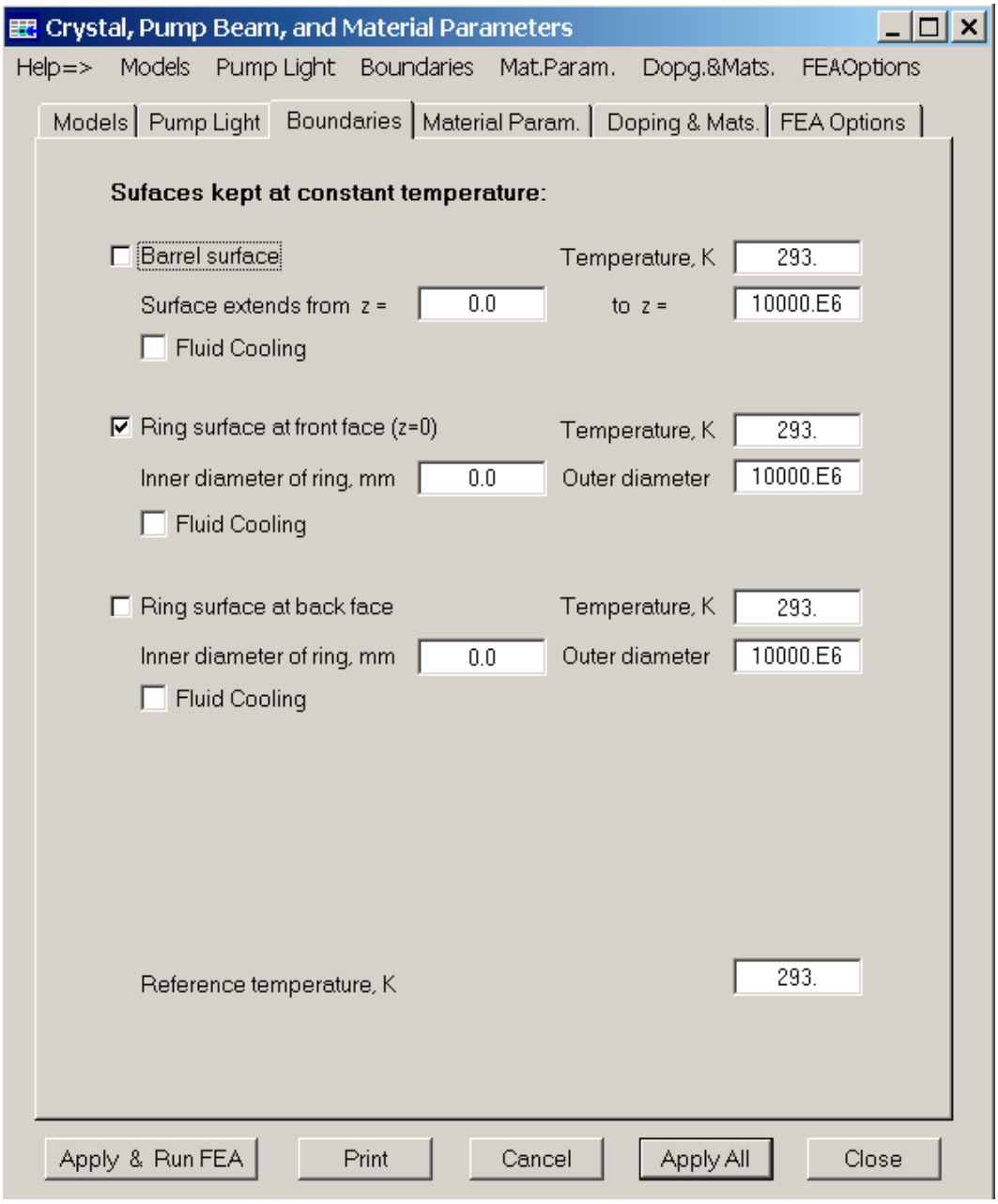

Fig. 3

The tab **Doping & Mats.** is not used with the present configuration

3 Defining Options to Control FEA

Select the tab **FEA Options**, as shown in Fig. 4, to define meshing parameters, convergence limits, and maximum number of iterations. Please refer to the help menu for more detailed information. You can leave the entries unchanged for now. For the current values of the mesh size, 700 MB RAM is recommended. To get more accurate results for the deformation, which is very small in the present case, you can reduce the mesh size along x and y to 0.06, but you need 1024 MB RAM minimum for this finer mesh.

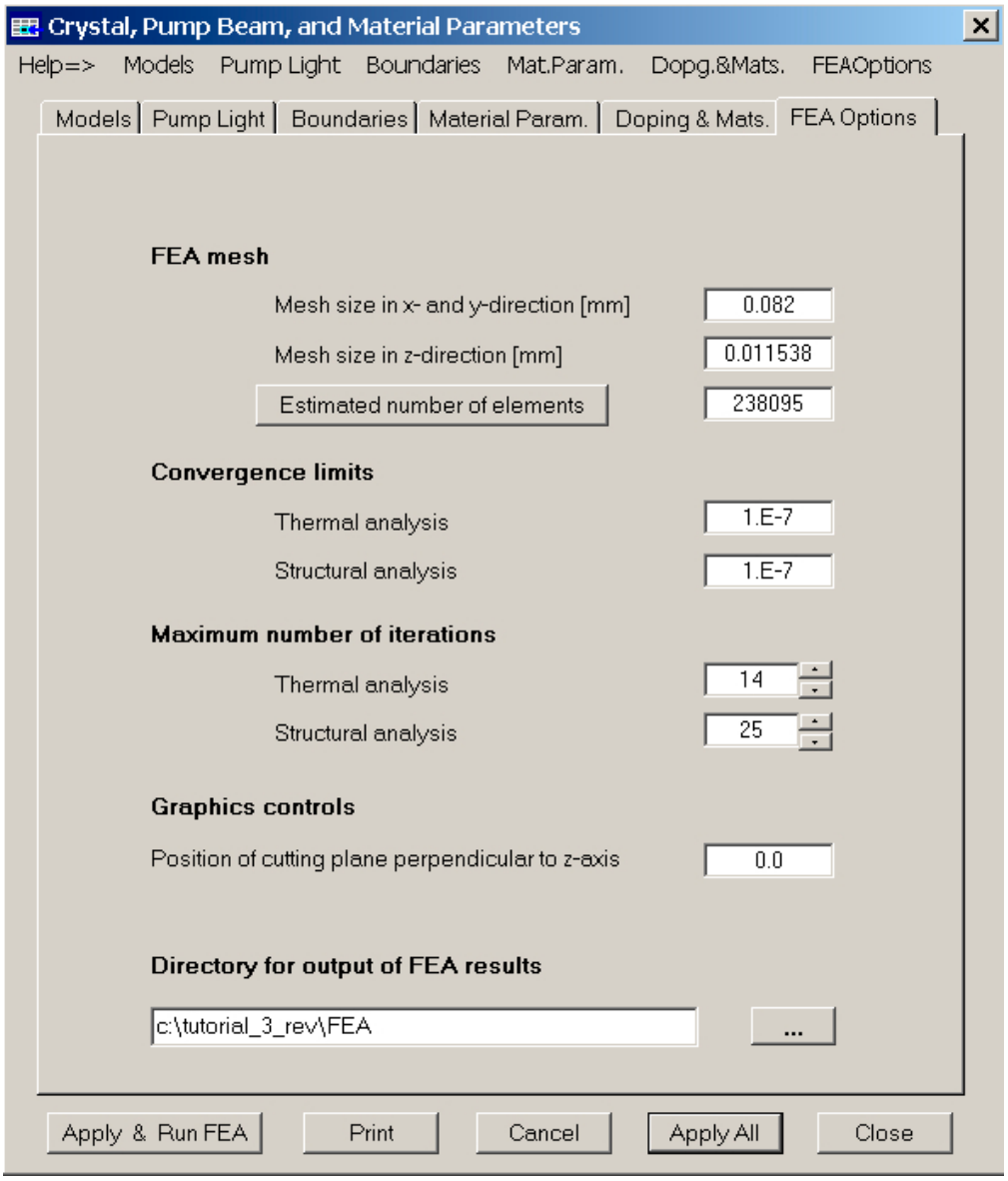

Fig. 4

Click **Apply & Run FEA** to start the FEA analysis. The window **Finite Element Analysis** pops up, up showing the number of the currently running iteration. In addition, it shows the maximum temperature during thermal analysis, and the absolute value of maximum nodal displacement during structural analysis. At the end of the computation, the message "FEA finished successfully" appears. Click **OK** to close this dialog.

Please be aware that initialization of the FEA and generation of the mesh may take a while for large element numbers.

4 Showing the FEA Results

When the FEA is finished, click **FEA→3D Visualizer**, in the main LASCAD menu, to show results for heat load distribution, temperature distribution, deformation and stress. Fig. 5 shows the temperature distribution at the side of the disc that is not being cooled.

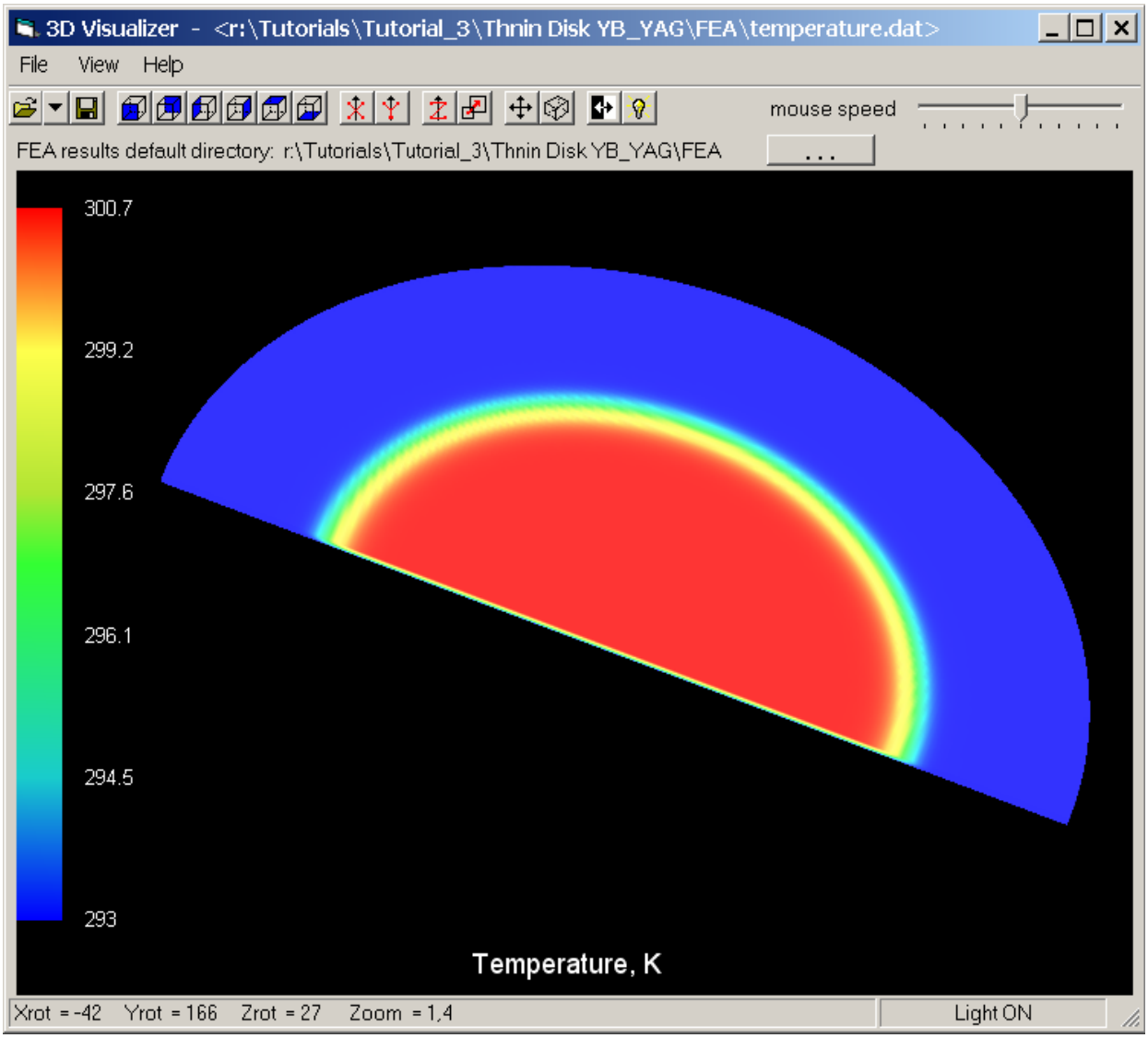

Fig. 5

Click **FEA→2D Data Profiles ...** in the LASCAD menu to open the window **2D Profiles & Parabolic Fit**, showing 2D plots of FEA results. By default, the temperature distribution is displayed. Use the drop-down box in the upper right corner of this window to show 2D plots at different positions along the z-axis of the crystal, which correspond to FEA discretization points. Use the mouse wheel to scroll along the z axis.

5 Creating a Parabolic Fit of the FEA Results

Click the button **Refresh & Fit**, in the window **2D Profiles & Parabolic Fit,** to carry through a parabolic fit of the transverse refractive index distribution and the deformation. The fit is computed for a series of sections along the z axis, as generated by the FEA discretization. For the current meshing parameters, about 10 subsections have been created. The fit for the refractive index distribution is shown in Fig. 6.

Note that the fit is shown at z = 0.06 mm.

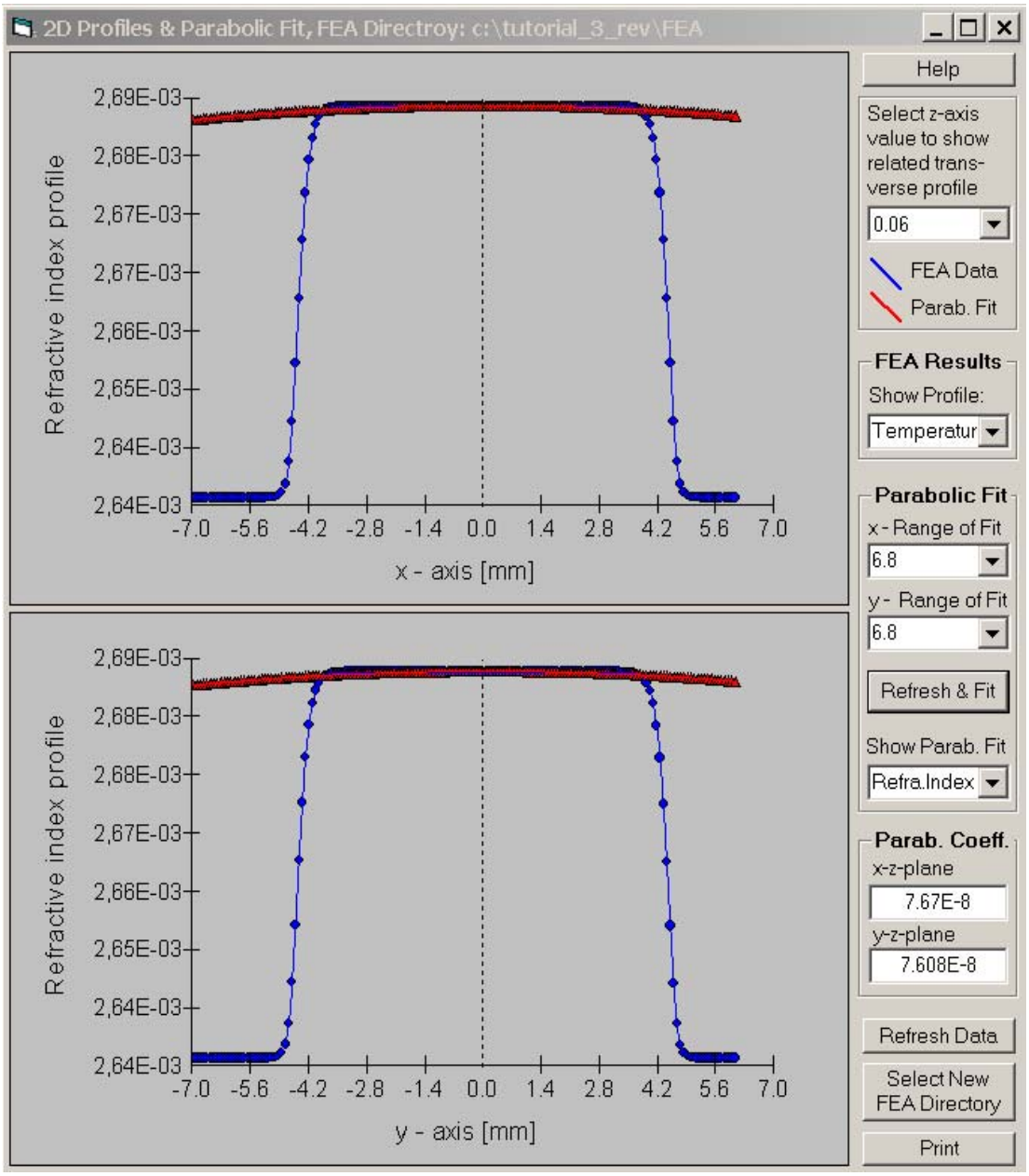

Fig. 6

Click the items **Left face** or **Right Face**, in the drop-down box **Show Parab. Fit**, to show the fit for the end faces. The results for the end faces are not accurate. Since the deformation is very small, you must use a finer mesh along x and y axis and run more iterations to get more accurate results. But this is not important for the present purpose, since the small deformation has almost no influence on the laser mode.

6 Inserting the Thermal Lens into the Mode Plot

Press the ALT key, and click in the mode plot between element 0 and 1. You may have to stretch in advance. The yellow symbol for the thermal lens should appear, but since the length of the plot is adjusted to the width of the picture box immediately after insertion, you must stretch the plot again to display the thermal lens as shown in Fig. 7.

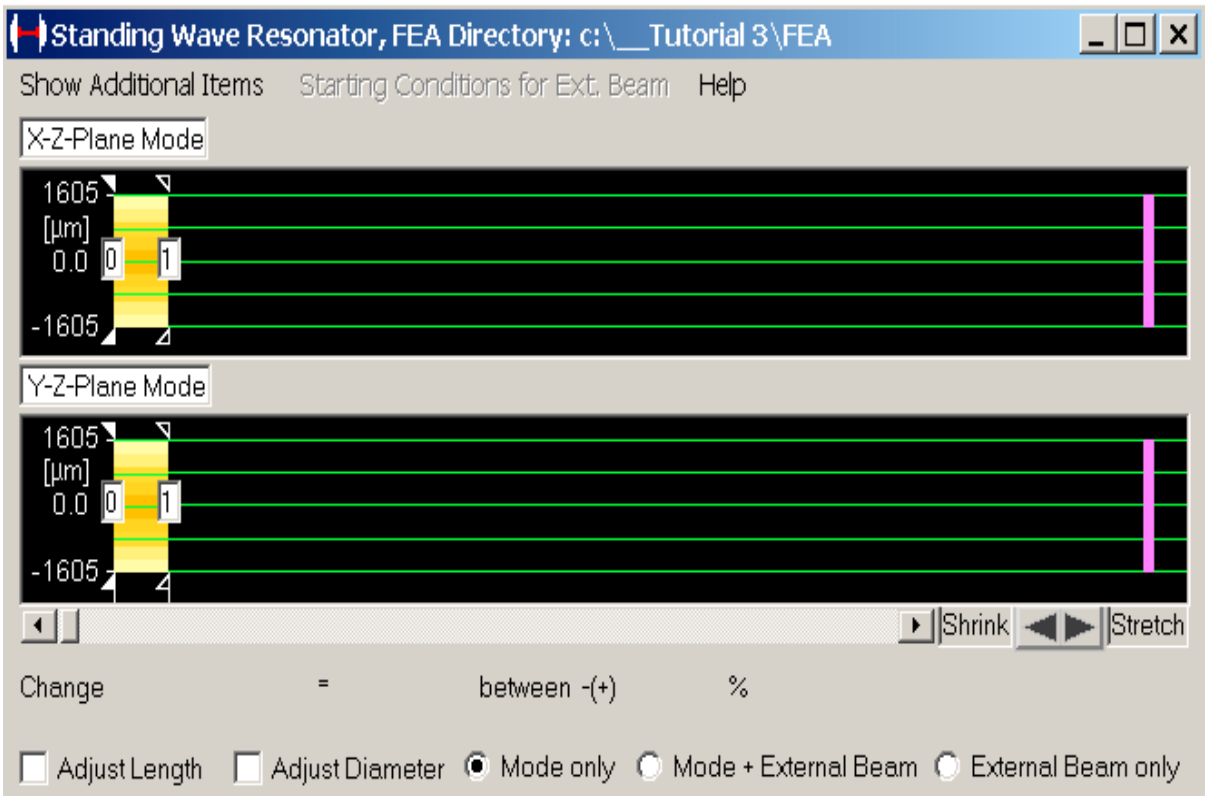

Fig. 7

7 Computing Laser Power Output

Click the menu item **Laser Power** to open the window **Laser Power Output**, as shown in Fig. 8.

In this example Yb:YAG is used as laser material, which is common for thin disk lasers. It is a quasi-3-level material, which means that the lower laser level is close to the ground level. Computation of the laser power output must, therefore, take into account reabsorption of the laser radiation in the lower level.

Open the tab **Material Parameters,** in the window **Crystal, Pump Beam, and Material Parameters,** to display the material parameters for Yb:YAG, as shown in Fig. 9. You can see that the box **3-Level-Laser-System** is checked in Fig. 9. To display parameters for 3-level-systems like energy levels and effective cross-section of reabsorption, click the button **Show Material Parameters for 3-Level-Systems,** as shown in Fig. 10.

The theory and mathematical method to compute the laser power output are described in the technical document `Laser Power.pdf`, which can be downloaded from https://www.las-cad.com/lascad_download.php, or found on the CD-ROM. Due to the temperature dependent population of the lower laser level, it is important to take into account the local temperature distribution, as obtained by FEA in the computation. LASCAD 3.5 is the first commercial program which is taking into account the full 3D temperature distribution to compute laser power output for 3-level-laser systems.

Since thin disk lasers usually operate in multimode operation, the box **Multimode Operation** is checked in Fig. 8.

To confine the radius of the mode structure, the box **Account for Apertures** is checked. The apertures are defined in the tab **Apertures** of the window **Parameter Field**, and are approximately equal to the radius of the pump spot.

Select the option **Plot single point**, and click **Apply & plot,** to compute laser power output for 500 W absorbed pump power.

Alternatively, you can select the option **Plot curve with … grid points**, and use the predefined number of 20 grid points. This computation will take somewhat longer. For the latter case, minimum and maximum of the absorbed pump power have been set to 300 and 500 W in the frame **Define X- and Y-Scale**, respectively. This computation delivers threshold and slope efficiency, as shown in Fig. 8.

Please select **Help→GUI** in the window **Laser Power Output**, or refer to LASCAD Tutorial No. 2, or to the manual for additional information.

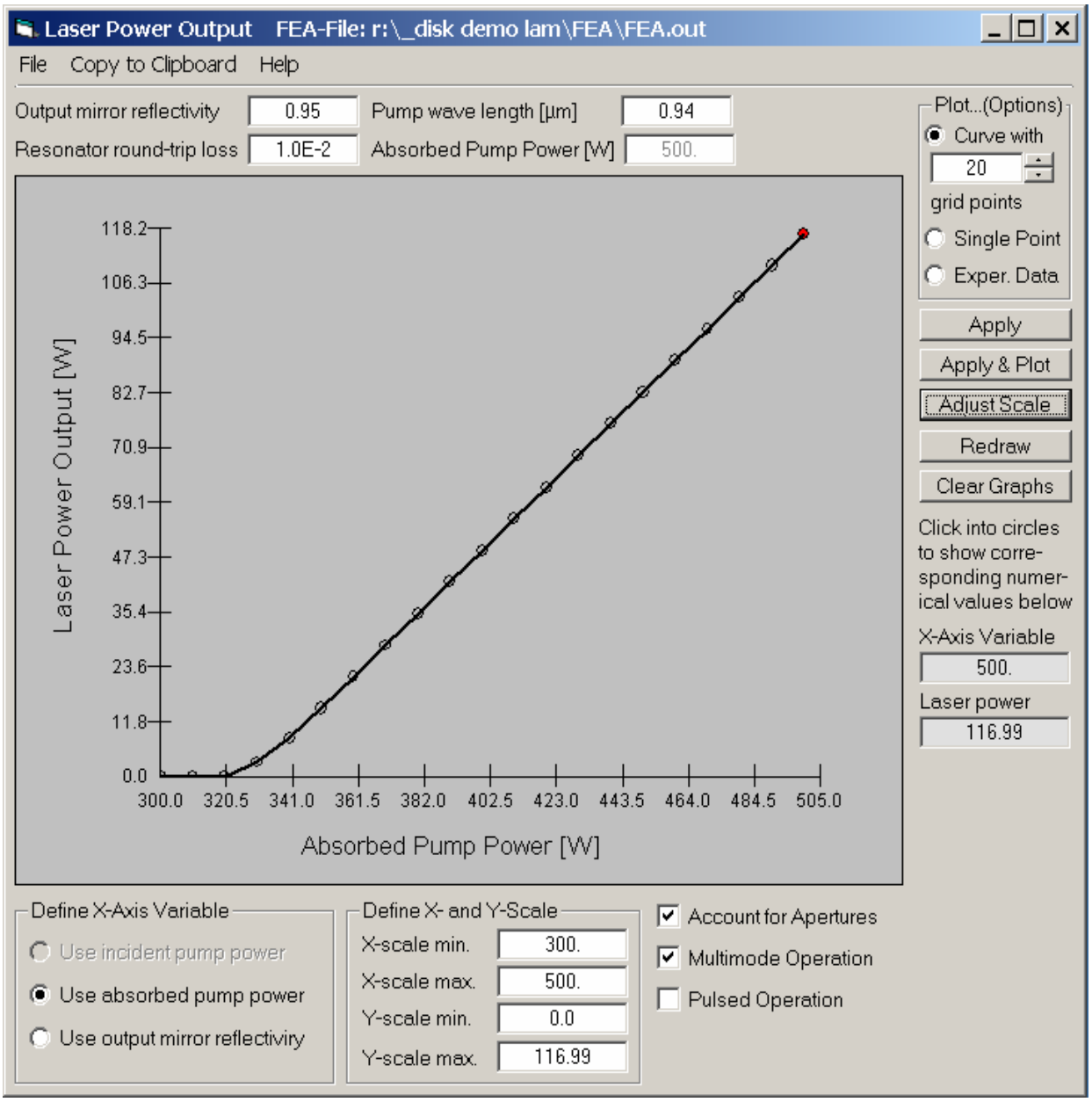

Fig. 8

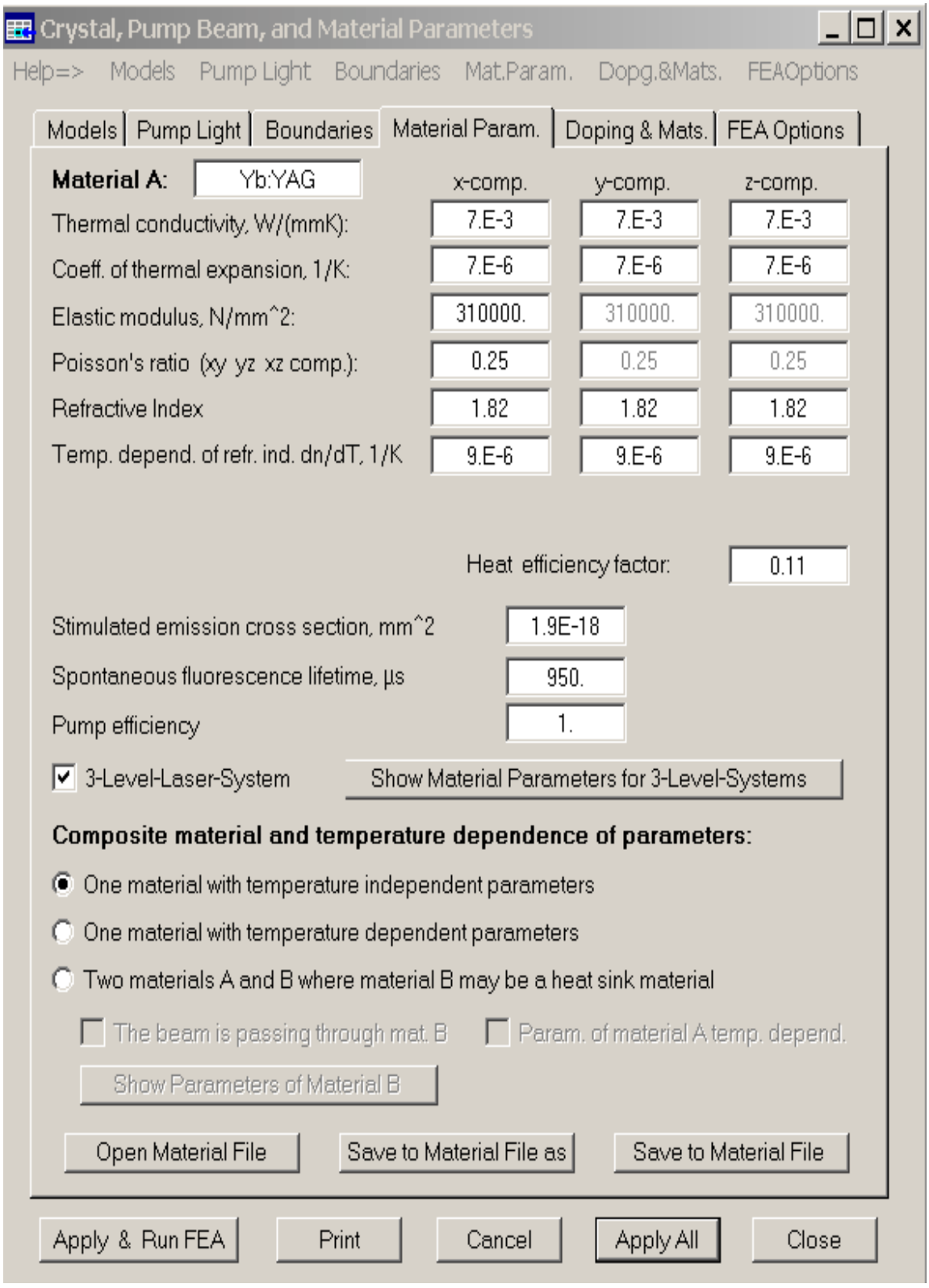
Crystal, Pump Beam, and Material Parameters
Help=> Models Pump Light Boundaries Mat.Param. Dopg.&Mats. FEAOptions
Models
Pump Light
Boundaries
Material Param.
Doping & Mats.
FEA Options
Material A:
Yb:YAG
x-comp.
y-comp.
z-comp.
Thermal conductivity, W/(mmK):
7.E-3
7.E-3
7.E-3
Coeff. of thermal expansion, 1/K:
7.E-6
7.E-6
7.E-6
Elastic modulus, N/mm^2:
310000.
310000.
310000.
Poisson's ratio (xy yz xz comp.):
0.25
0.25
0.25
Refractive Index
1.82
1.82
1.82
Temp. depend. of refr. ind. dn/dT, 1/K
9.E-6
9.E-6
9.E-6
Heat efficiency factor:
0.11
Stimulated emission cross section, mm^2
1.9E-18
Spontaneous fluorescence lifetime, µs
950.
Pump efficiency
1.
3-Level-Laser-System
Show Material Parameters for 3-Level-Systems
Composite material and temperature dependence of parameters:
One material with temperature independent parameters
One material with temperature dependent parameters
Two materials A and B where material B may be a heat sink material
The beam is passing through mat. B
Param. of material A temp. depend.
Show Parameters of Material B
Open Material File
Save to Material File as
Save to Material File
Apply & Run FEA
Print
Cancel
Apply All
Close

Fig. 9

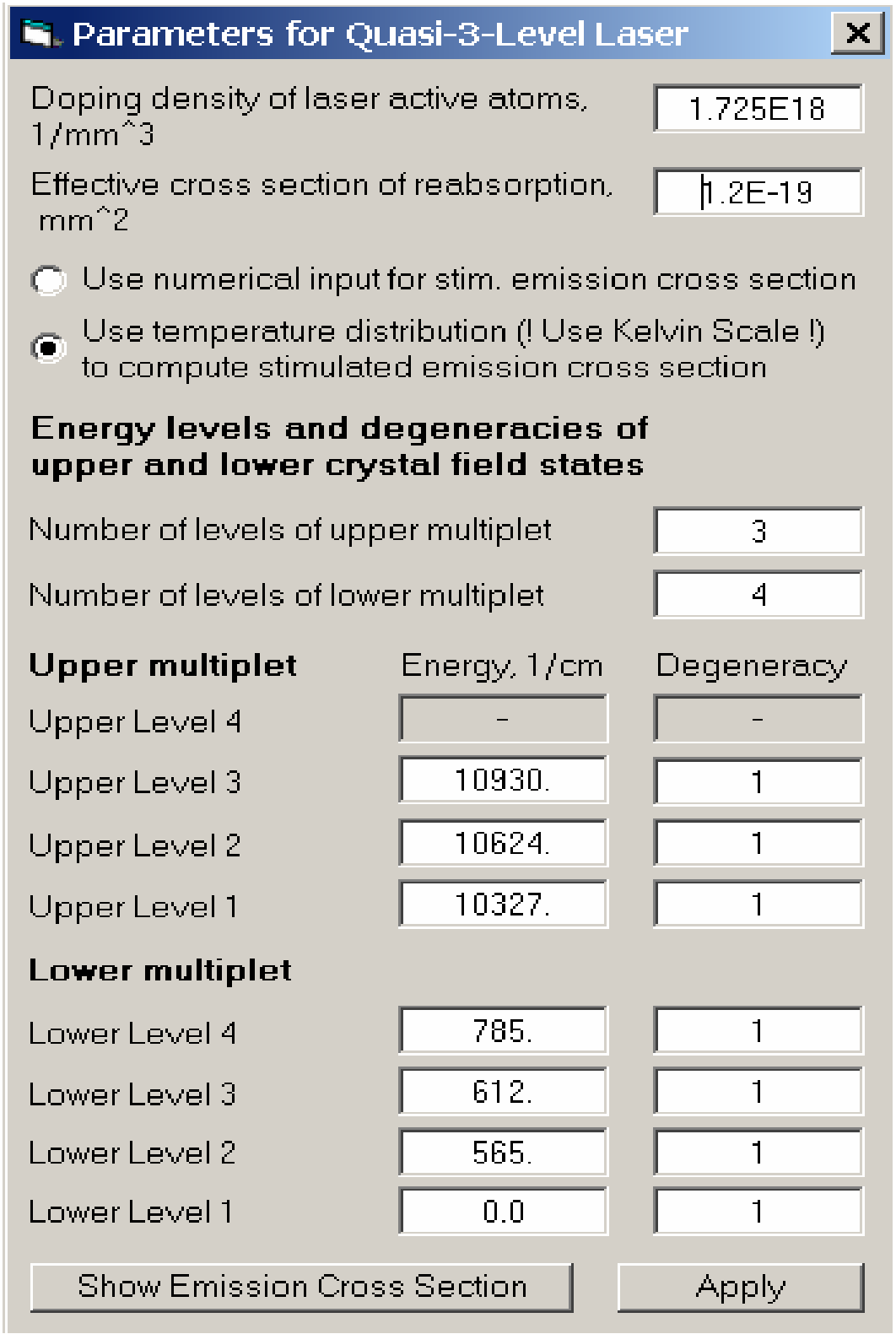
Parameters for Quasi-3-Level Laser
Doping density of laser active atoms, 1/mm^3
1.725E18
Effective cross section of reabsorption, mm^2
1.2E-19
Use numerical input for stim. emission cross section
Use temperature distribution (! Use Kelvin Scale !) to compute stimulated emission cross section
Energy levels and degeneracies of upper and lower crystal field states
Number of levels of upper multiplet
3
Number of levels of lower multiplet
4
Upper multiplet
Energy, 1/cm
Degeneracy
Upper Level 4
-
-
Upper Level 3
10930.
1
Upper Level 2
10624.
1
Upper Level 1
10327.
1
Lower multiplet
Lower Level 4
785.
1
Lower Level 3
612.
1
Lower Level 2
565.
1
Lower Level 1
0.0
1
Show Emission Cross Section
Apply

Fig. 10

8 The Beam Propagation Code (BPM)

LASCAD also provides a physical optics beam propagation code. This provides full 3D simulation of the interaction of a propagating wave front with the hot, thermally deformed crystal, without using parabolic approximation. Here only a short instruction is given on starting the BPM code. For details please refer to the manual.

To start the BPM code, select **BPM→Run BPM**, in the menu bar of the main LASCAD window to open the window shown in Fig. 11.

To compute the multimode structure, use the entries shown in Fig. 11. Uncheck the boxes in the frame **Use results of gaussian analysis …** . Check the option, "**The full computational window is used as aperture",** in the frame **Use of Apertures** in Fig. 11. Then select, as initial beam profile, "**Gaussian with spot size defined in the box below"**. With the full version you can alternatively use the option, "**Circular top hat".** An example for a multimode profile is shown in Fig. 12.

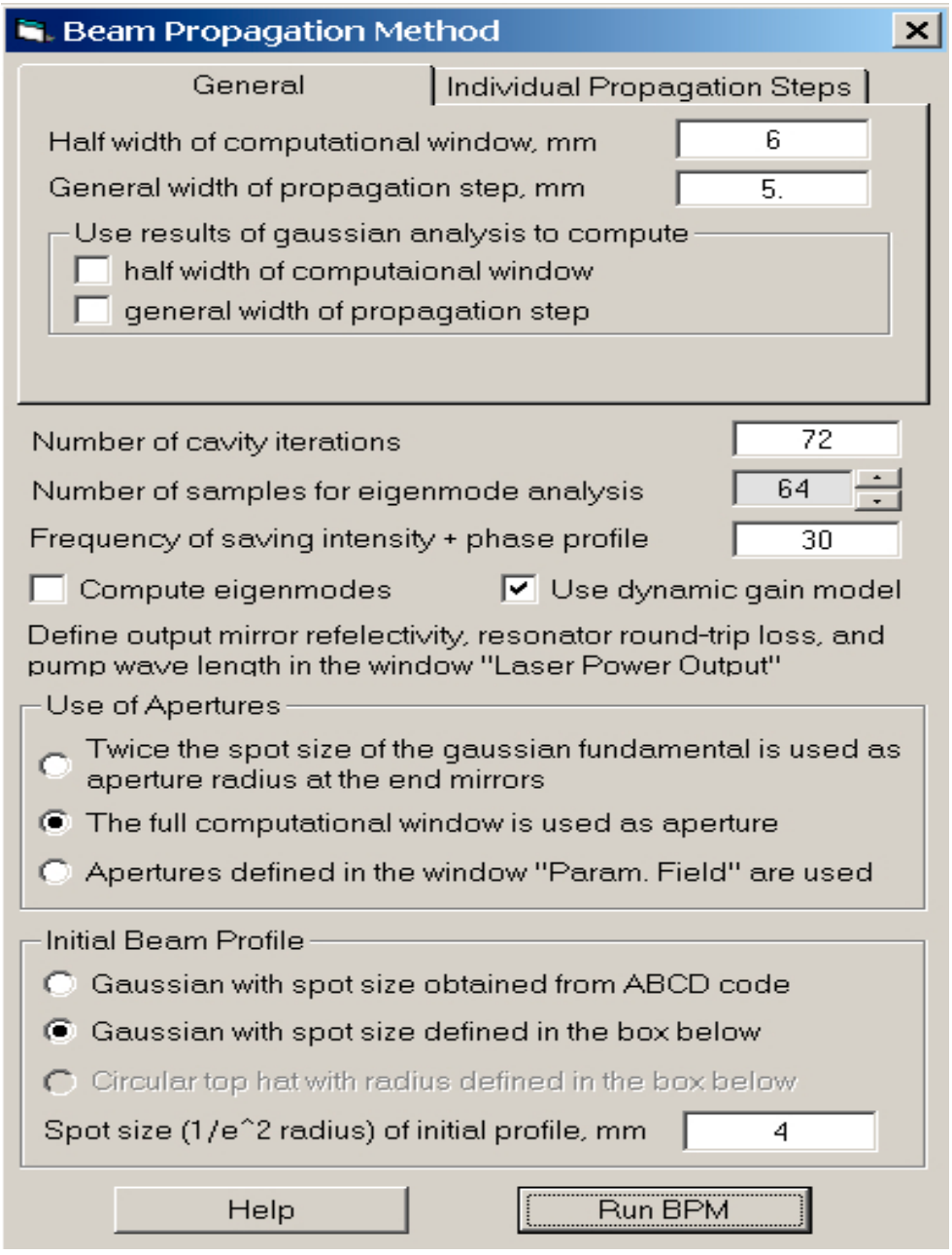

Fig. 11

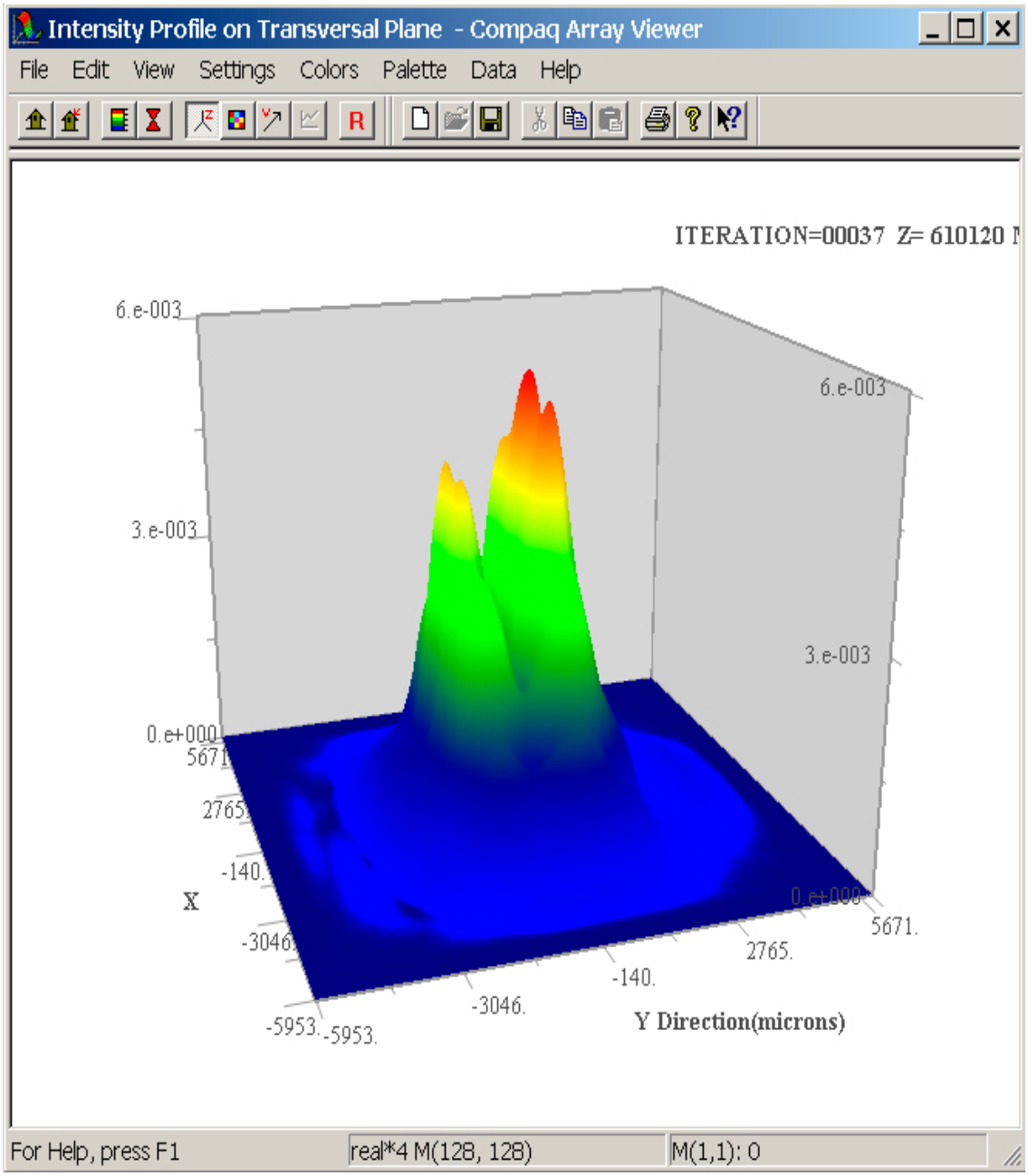

Fig. 12

A detailed listing of numerical results created by the BPM code, such as laser power output, beam quality etc. can be found in the file `lyra.txt` in the subdirectory `BPM` of the LASCAD working directory. A user guide for the BPM code can be found in the file `BPM user_guide.chm`, in the subdirectory `Documentation` of the LASCAD application directory.