Tutorial 3:

How to compute thermal lensing and laser power output for an Yb:YAG thin disk laser?

Revised June 10, 2007

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The project file Tutorial_3.lcd of the example used 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.

1. Starting LASCAD and Defining Pump Light Distribution

- Start LASCAD by selecting Start/Programs/LASCAD/Lascad or double-click Tutorial_3.lcd in the directory ...\Programs\LASCAD\Tutorials.
- Define a working directory (Not necessary, if you double-click Tutorial_3.lcd),
- Click into the File->Open icon in the toolbar and open the file Tutorial_3.lcd.
- 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 only is 0.12 mm thick, you must stretch a lot.
- Click the menu item "FEA/Parameter Input & Start of FEA code" which opens the window "Crystal, Pump Beam, and Material Parameters".
- This window is showing six tabs.
- The tab "Models" is showing pre-designed models provided with LASCAD as shown in Fig. 1. 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.

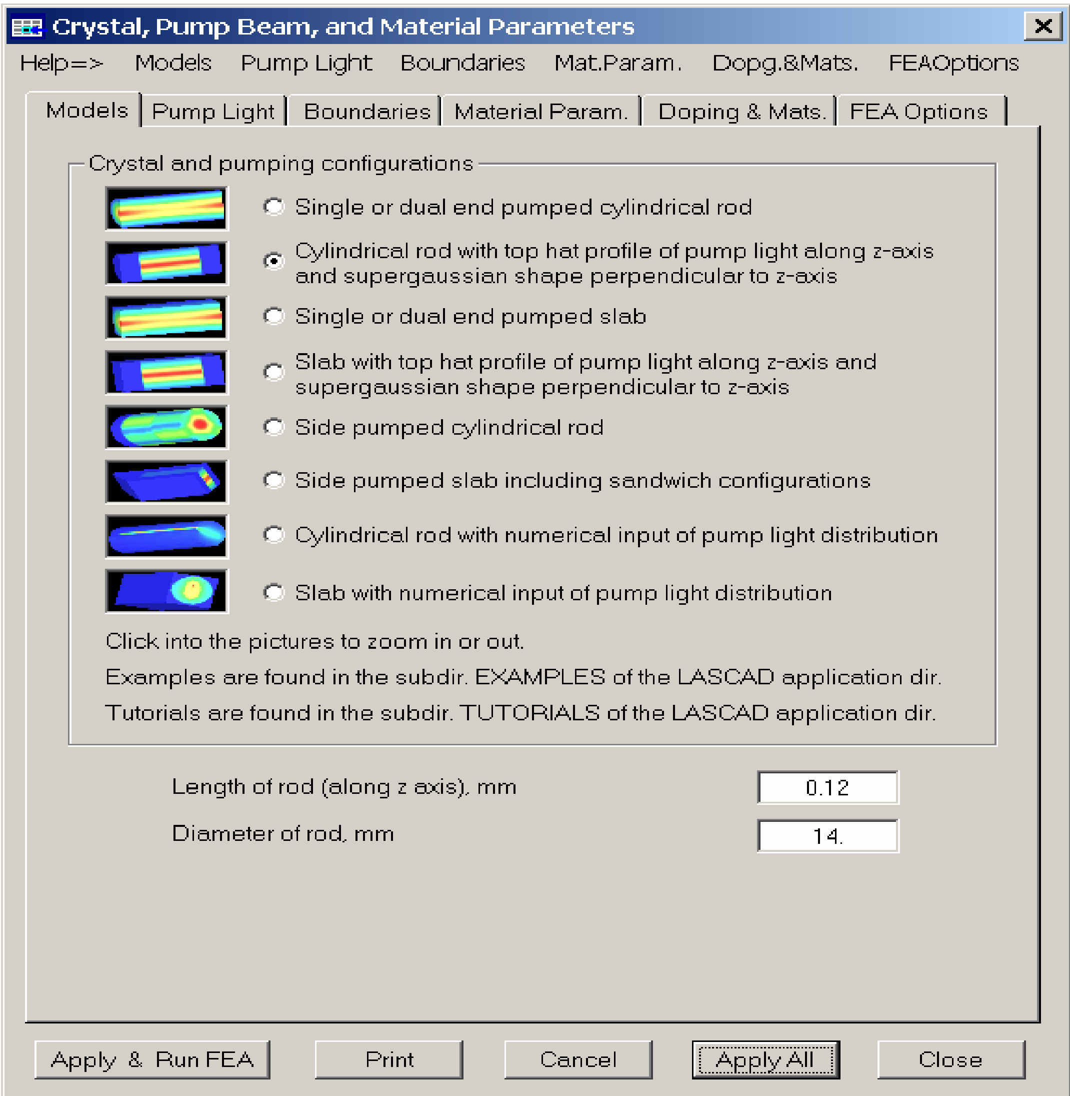

Fig. 1

Click into 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 supergaussian exponent is increased to a large number the profile approaches to a top hat profile. 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.

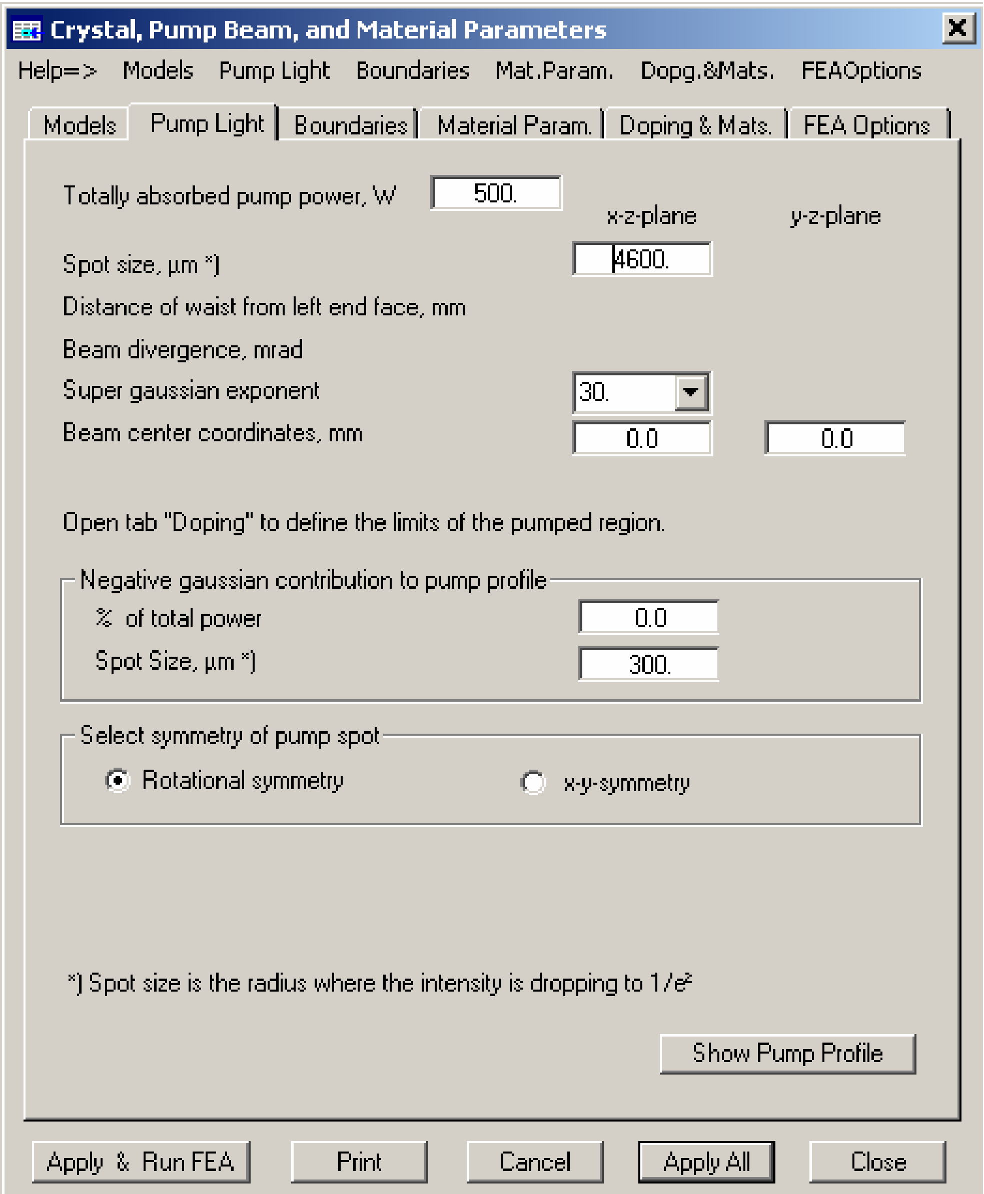

Fig. 2

2. Defining Boundary Conditions Used for FEA

Click into the tab "Boundaries" as shown in Fig. 3 to define the boundary conditions. It is assumed that the lower (z=0) surface 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.

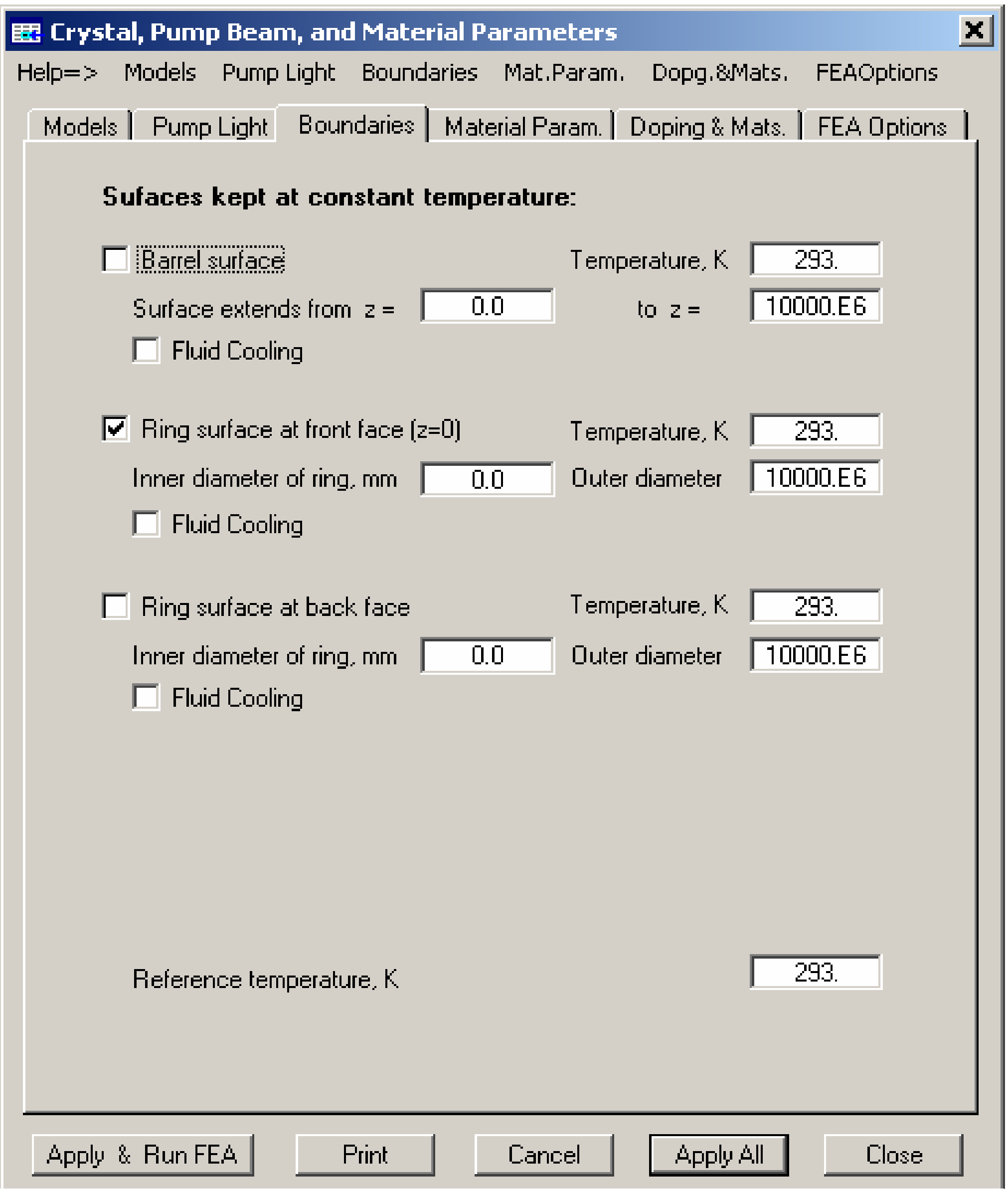

Fig. 3

The tab "Doping ..." is not used in the present configuration

3. Defining Options to Control FEA

Click into 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 are 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.

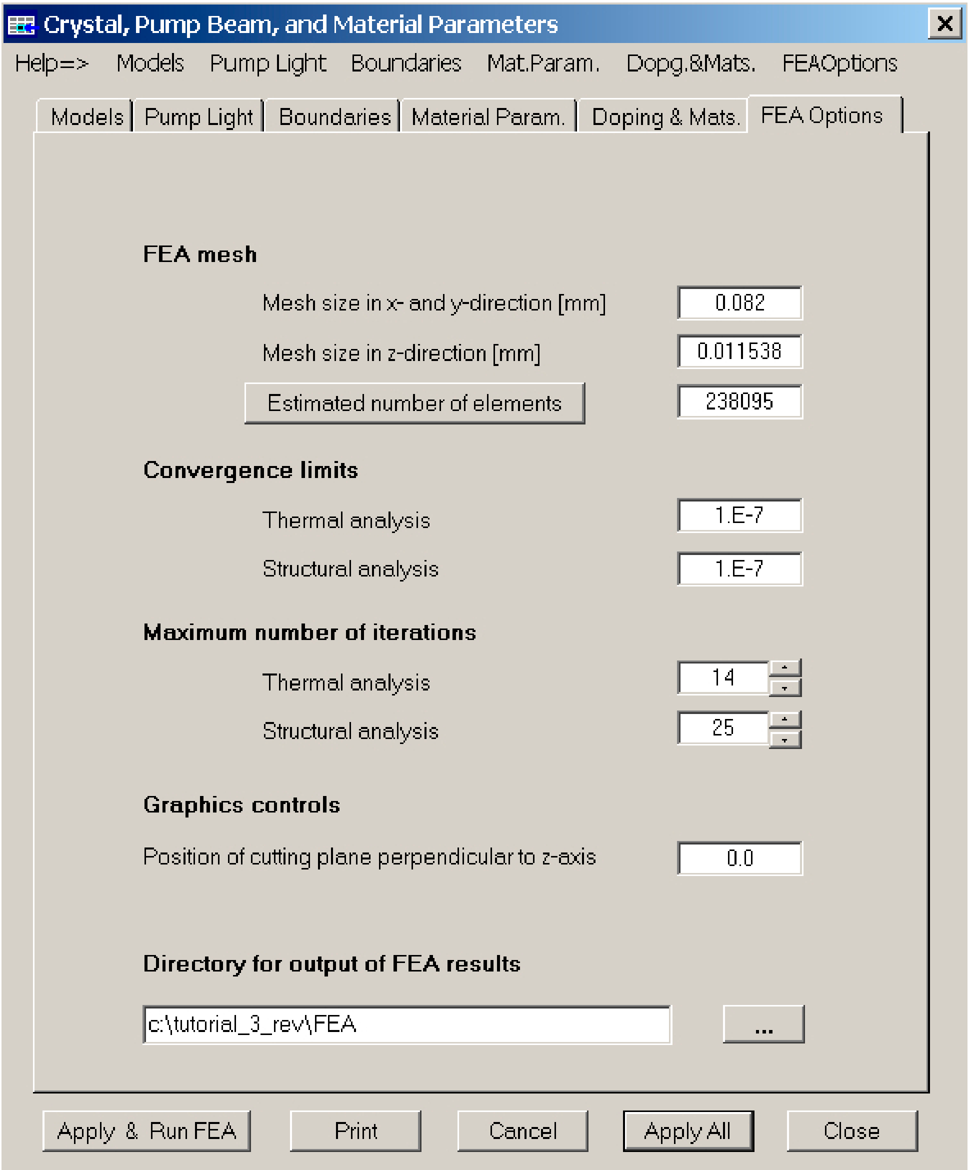

Fig. 4

Press the button **"Apply & Run FEA"** to start the FEA analysis. The window **"Finite Element Analysis"** is popping up showing the number of the currently running iteration. In addition, it is showing 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, press the button **"OK"** to close this dialog.

Please be aware that initialization of the FEA and generation of the mesh may take some time 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 is showing the temperature distribution at the side of the disc not being cooled.

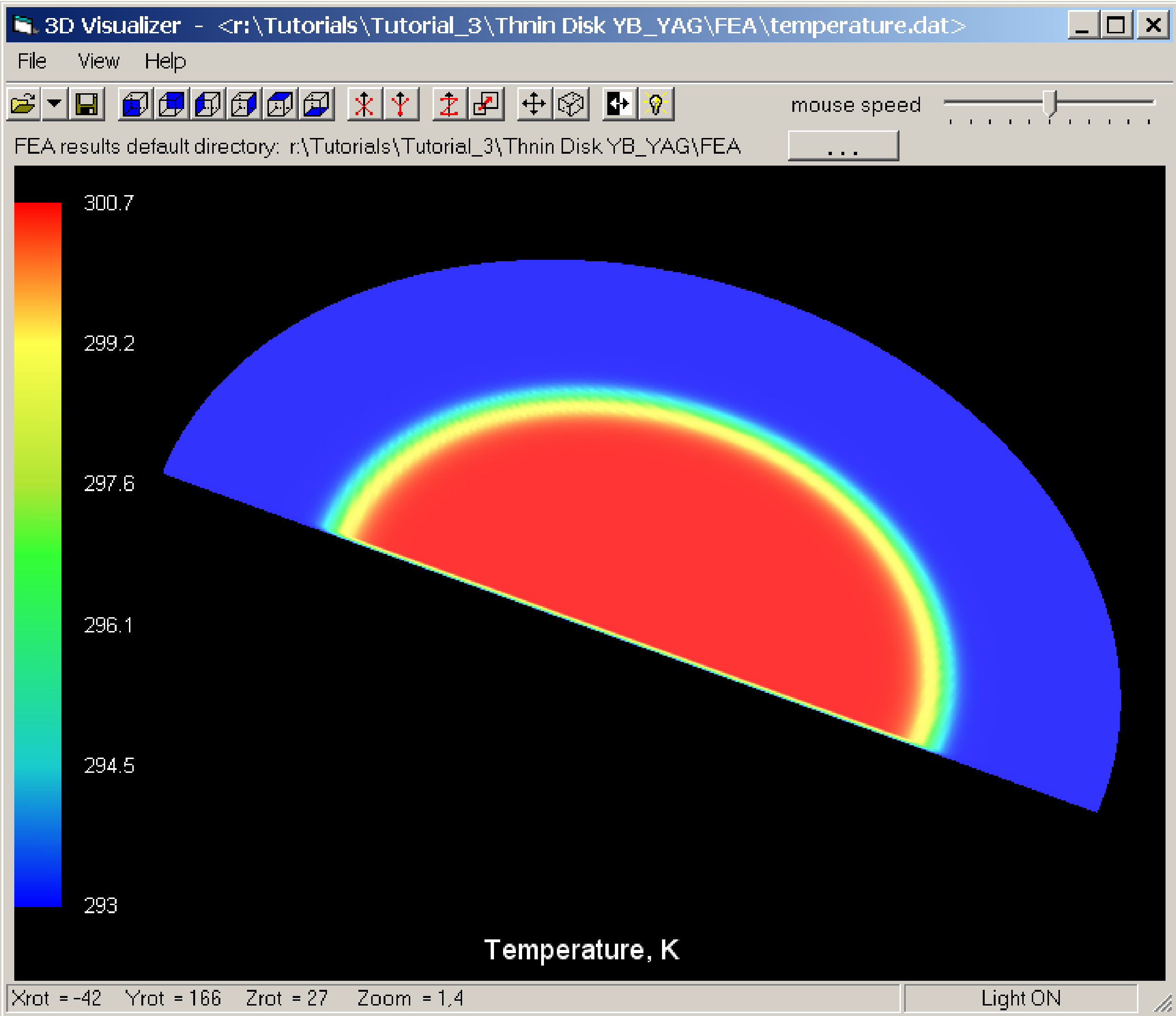

Fig. 5

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 which are corresponding to FEA discretization points. Use the mouse wheel to scroll along the z axis.

5. Creating a Parabolic Fit of the FEA Results

To carry through the parabolic fit the current thermal lens must be cleared advance in the mode plot window. Stretch the mode plot again, press the CTRL key and click into the yellow symbol.

Click the button "Refresh & Fit" to carry through a parabolic fit of the transverse refractive index distribution and the deformation. The fit is carried through for a series of sections along the z axis as being 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.

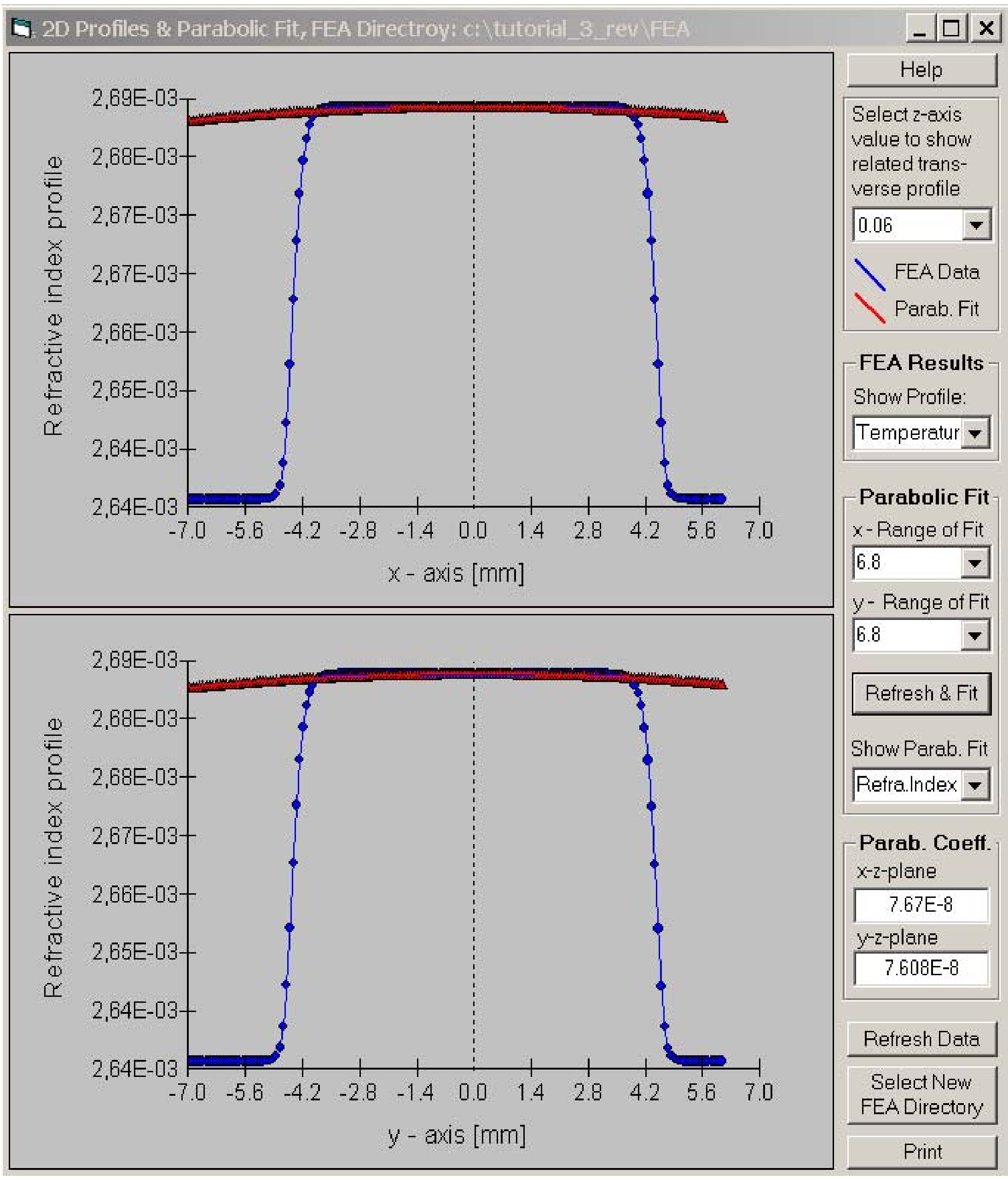

Fig. 6

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, perhaps you must stretch in advance. The yellow symbol for the thermal lens would 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.

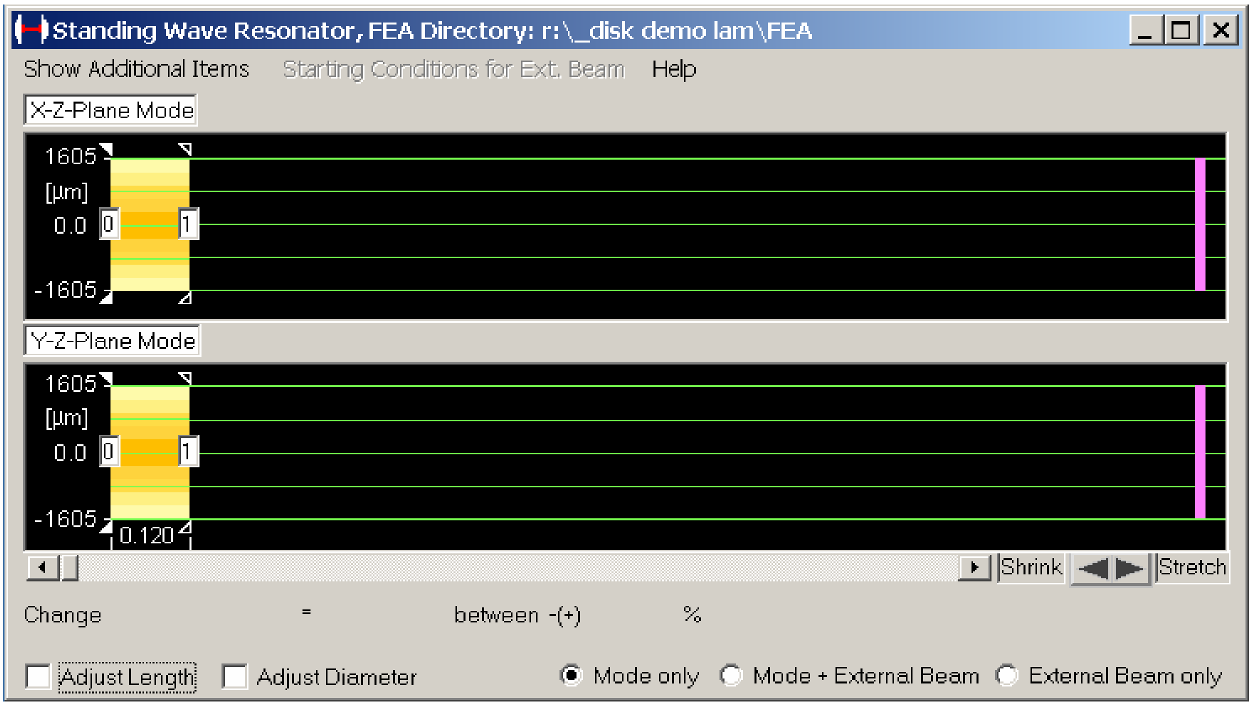

Fig. 7

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 often is utilized for thin disk lasers. It is a quasi-3-level material which means that the lower laser level is close to the ground level, and therefore, computation of the laser power output must 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 being checked in Fig. 9. To display parameters for 3-level-systems like energy levels and effective cross-section of reabsorption press the button "Show Material Parameters for 3-Level-Systems" as shown in Fig. 10.

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 3.3.4 is the first commercial program which is taking into account the full 3-D temperature distribution to compute laser power output for 3-level-laser systems.

Since thin disk lasers usually are working in multimode operation, the box "Multimode Operation" is being checked in Fig. 8.

To confine the radius of the mode, the box "Account for Apertures" is checked additionally. 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 press "Apply & plot" to compute laser power output for 500 W absorbed pump power.

Alternatively, you can select the option **"Plot curve with ... grid points"**, 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 is delivering threshold and slope efficiency as shown in Fig. 8.

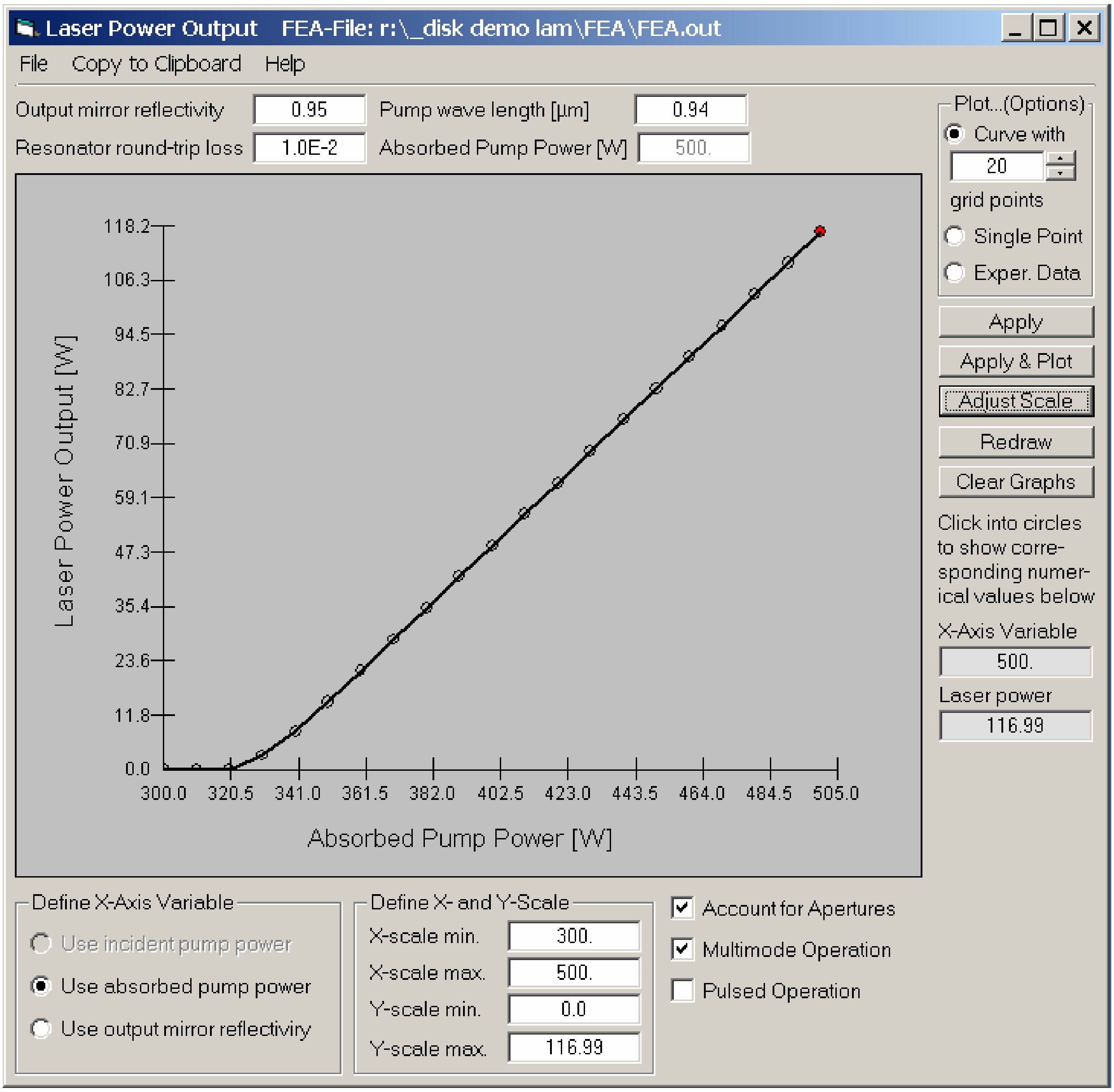

Fig. 8

Please Click "Help/GUI", or refer to Tutorial_2, or to the manual for additional information.

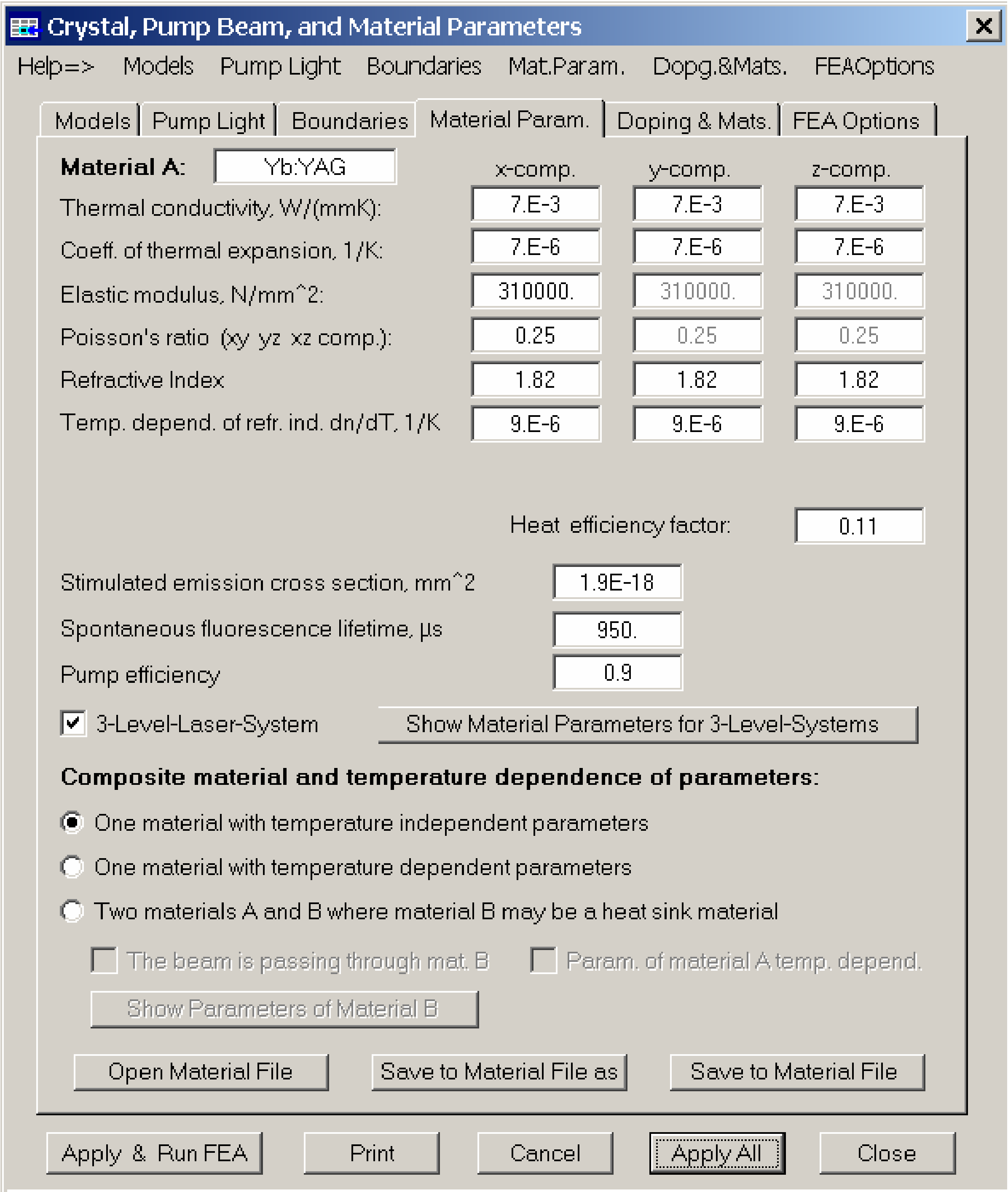
Crystal, Pump Beam, and Material Parameters
Help=> Models Pump Light Boundaries Mat.Param. Dopg.&Mats. FEAOptions
Models Pump Light Boundaries Material Param. Doping & Mats. FEA Options
Material A: Yb:YAG
x-comp. y-comp. z-comp.
Thermal conductivity, W/(mmK): 7.E-3 7.E-3 7.E-3
Coeff. of thermal expansion, 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 0.9
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

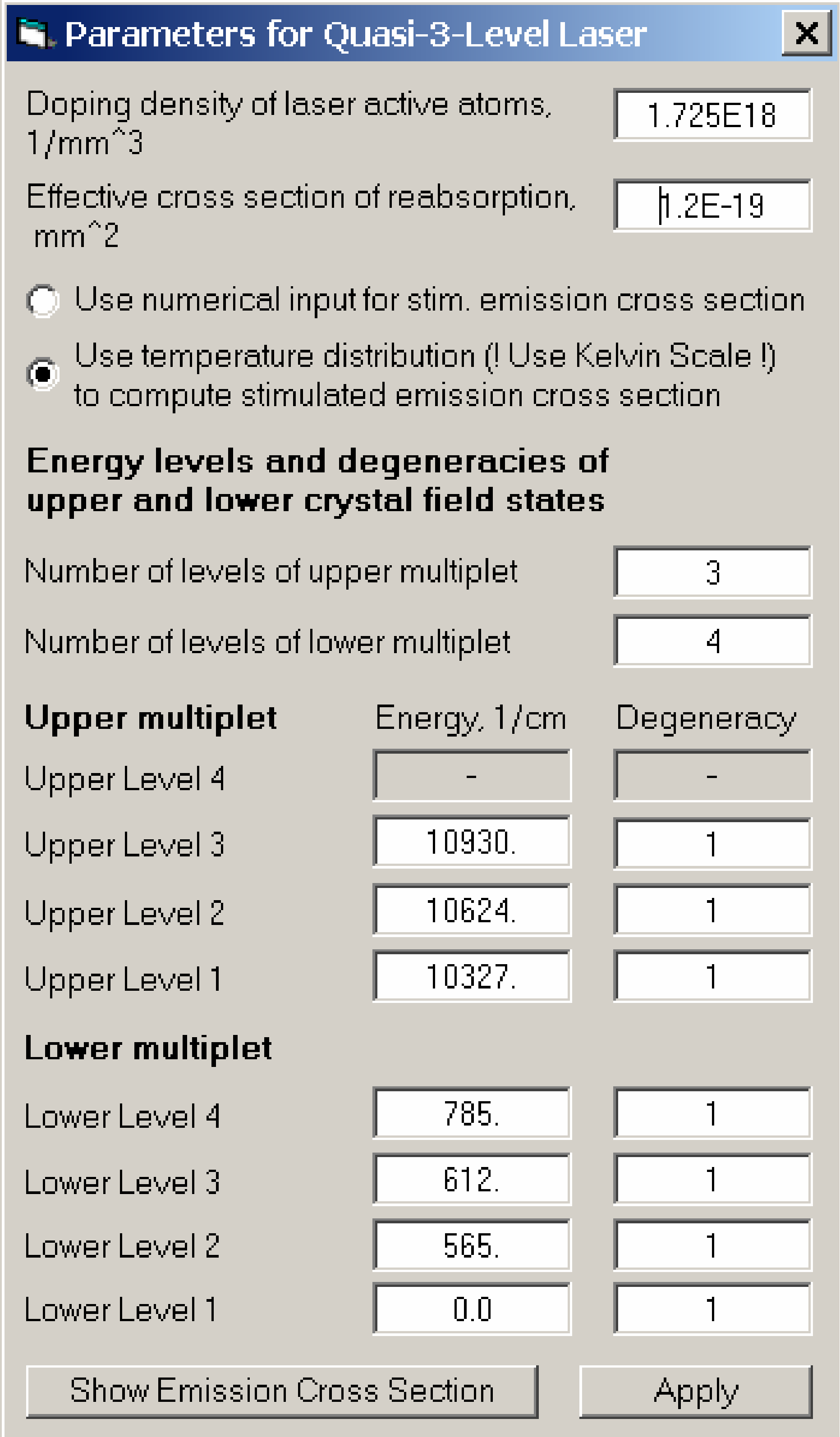
Parameters for Quasi-3-Level Laser
Doping density of laser active atoms, 1/mm^3
1.725E18
Effective cross section of reabsorption, mm^2
1.2E-19
Use numerical input for stim. emission cross section
Use temperature distribution (! Use Kelvin Scale !) to compute stimulated emission cross section
Energy levels 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 is providing a physical optics beam propagation code. This code 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 how to start the BPM code, for details the reader is referred to the manual.

To start the BPM code click **"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 **"Use half width of computational window"** in the frame **"Use of Apertures"** in Fig. 11 and 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.

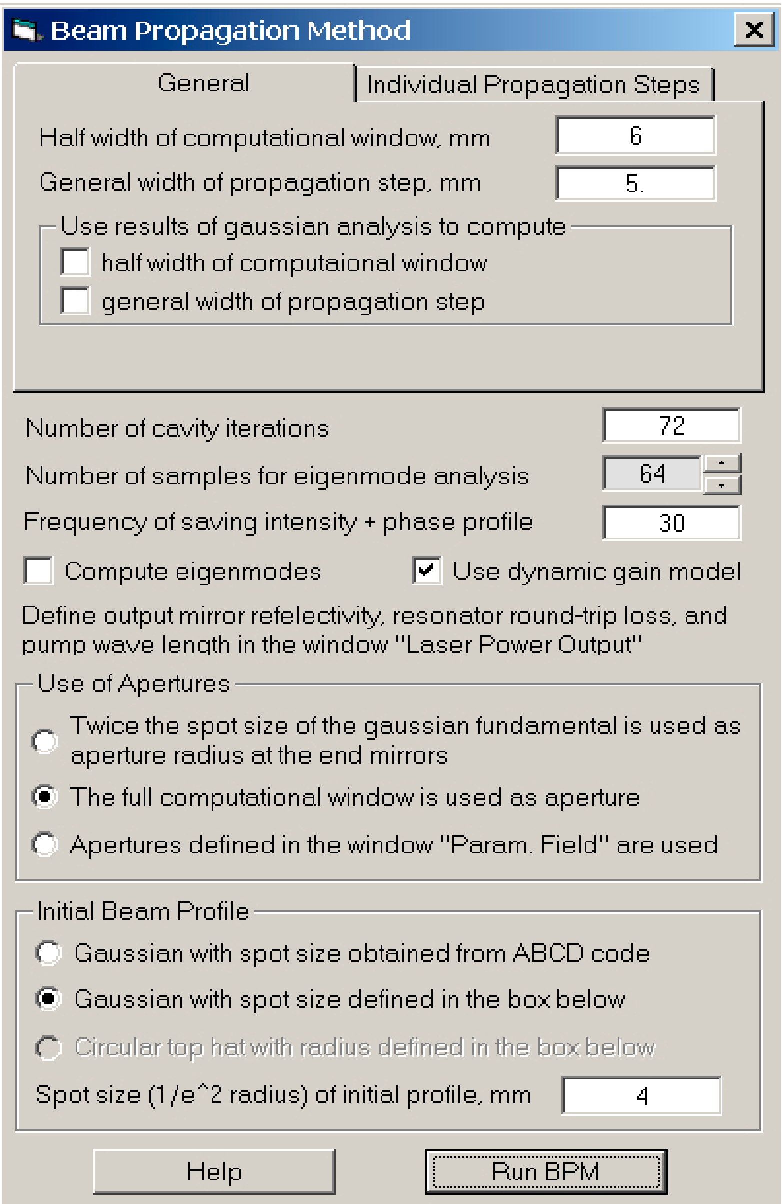

Fig. 11

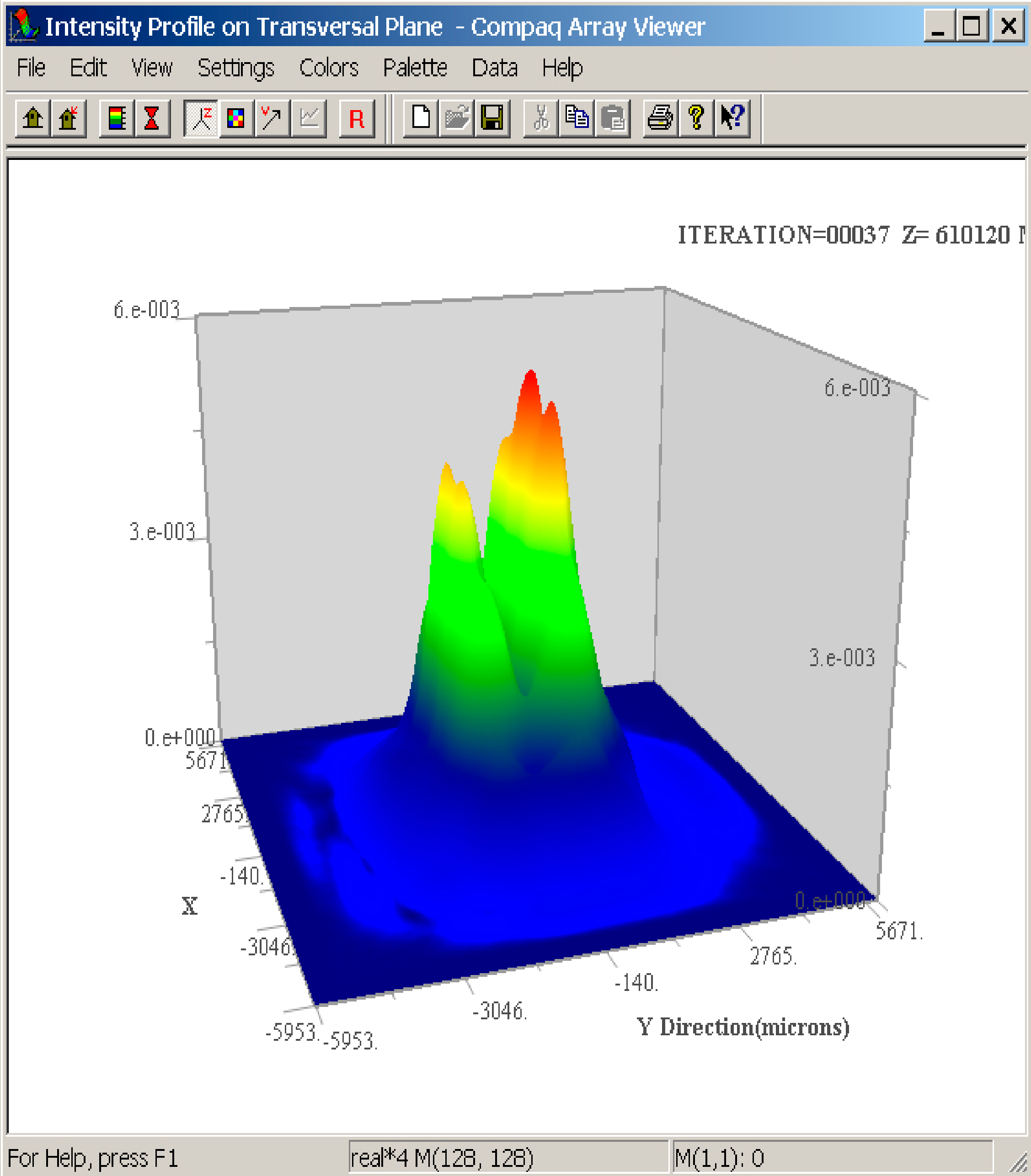
Intensity Profile on Transversal Plane - Compaq Array Viewer
File
Edit
View
Settings
Colors
Palette
Data
Help
ITERATION=00037 Z= 610120
6.e-003
3.e-003
0.e+000
6.e-003
3.e-003
0.e+000
X
5671.
2765.
-140.
-3046.
-5953.
-5953.
-3046.
-140.
2765.
5671.
Y Direction(microns)
For Help, press F1
real*4 M(128, 128)
M(1,1): 0

Fig. 12