

The unique combination of simulation tools for LASer Cavity Analysis and Design

LASCAD™ is an industry-leading software package providing multiphysics analysis of the complicated interaction between thermal and optical fields in solid state lasers commonly known as thermal lensing effect. Modelling of this effect and its influence on beam quality, cavity stability and laser efficiency is essential for analysis and optimization of laser resonators. All the simulation tools necessary for this purpose are integrated into LAS-CAD's award-winning program.

LASCAD™ offers:

- Thermal and Structural Finite Element Analysis
- ABCD Gaussian Beam Propagation Code
- Wave Optics Beam Propagation Code
- Numerical Eigenmode Analysis
- Beam Propagation outside Cavity

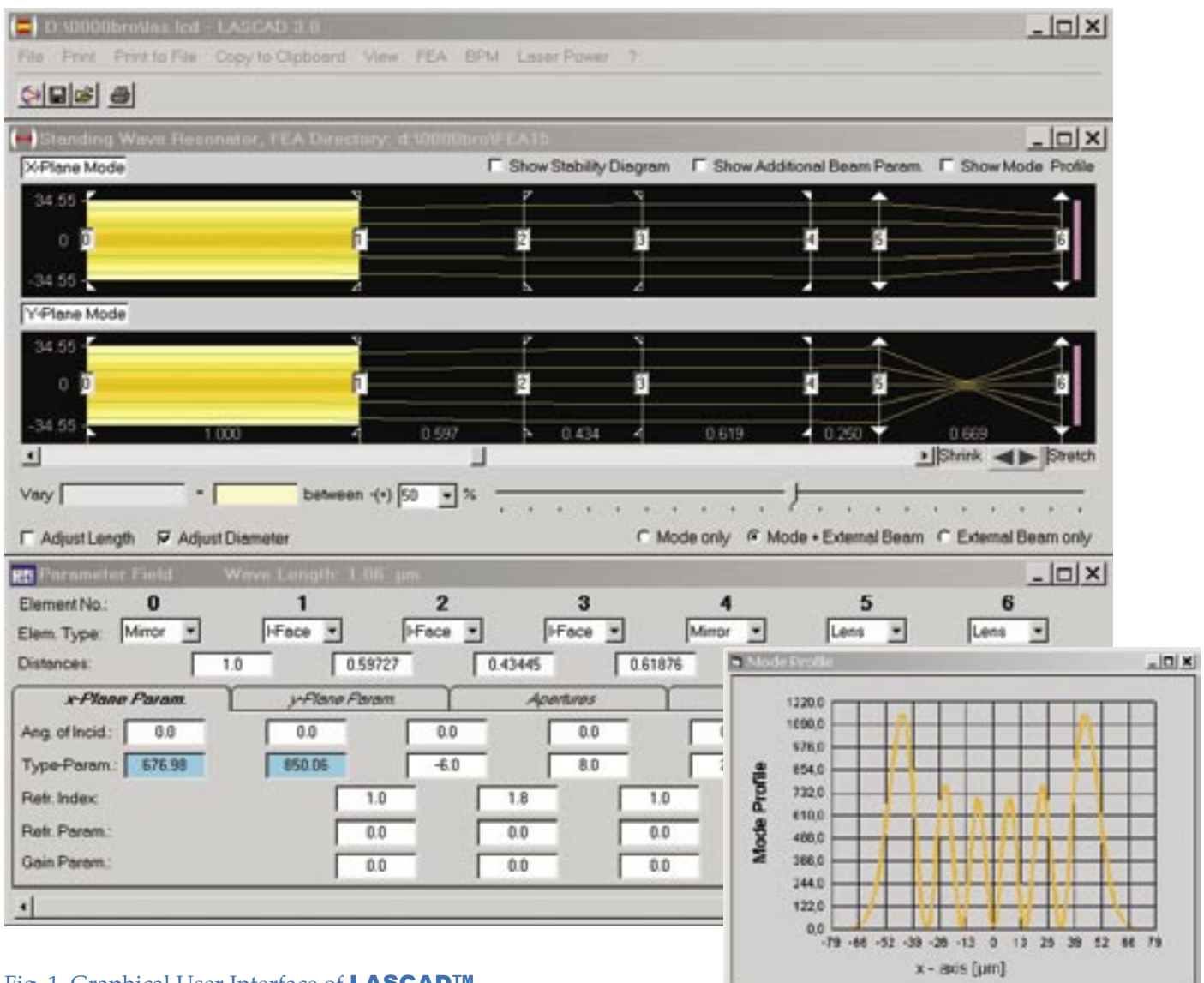


Fig. 1 Graphical User Interface of **LASCAD™**

LASCAD™

The Optical Workbench on the PC

LASCAD™ provides complex engineering tools, developed intentionally for ease-of-operation. The graphical user interface of the program shown in *Fig. 1* can be used like an optical workbench on the PC, allowing intuitive design of laser resonators. In this way **LASCAD™** helps users in laboratories and workshops process experimental results without wasting valuable time studying complicated manuals:

- **Optical elements such as mirrors, lenses, or crystals can be added, combined, adjusted, or removed with a mouse click.**
- **LASCAD™ automatically accounts for astigmatism of resonator and crystal.**
- **Finite element analysis, ABCD and wave optics code, computation of laser stability and efficiency are available on the menu.**

LASCAD™

The Laser Engineering Tool

Thermal lensing is of growing importance due to the tendency to miniaturize laser systems while simultaneously increasing their power output, causing 3D interaction of strong fields in tiny crystal volumes. The effect strongly depends on system characteristics such as material parameters, resonator geometry, pump beam distribution, and cooling layout. It interferes with gain guiding and other effects, which control beam quality and laser efficiency in a complicated manner. Based on a numerical simulation of these effects, **LASCAD™** provides laser engineers with a quantitative understanding of the system characteristics prior to committing hardware.

Finite Element Analysis (FEA) is used to compute temperature distribution, deformation, and stress or fracture mechanics in laser crystals, dependent on material properties, pump and cooling geometry. FEA is a well known method to solve partial differential equations of technical physics such as the equation of conduction of heat numerically. Though indispensable and applied with great success in other engineering

Fig. 2a

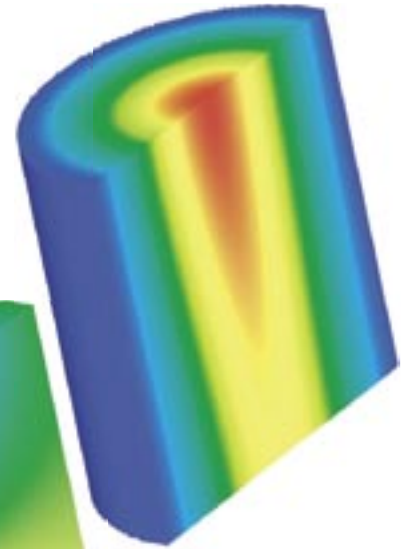


Fig. 2b

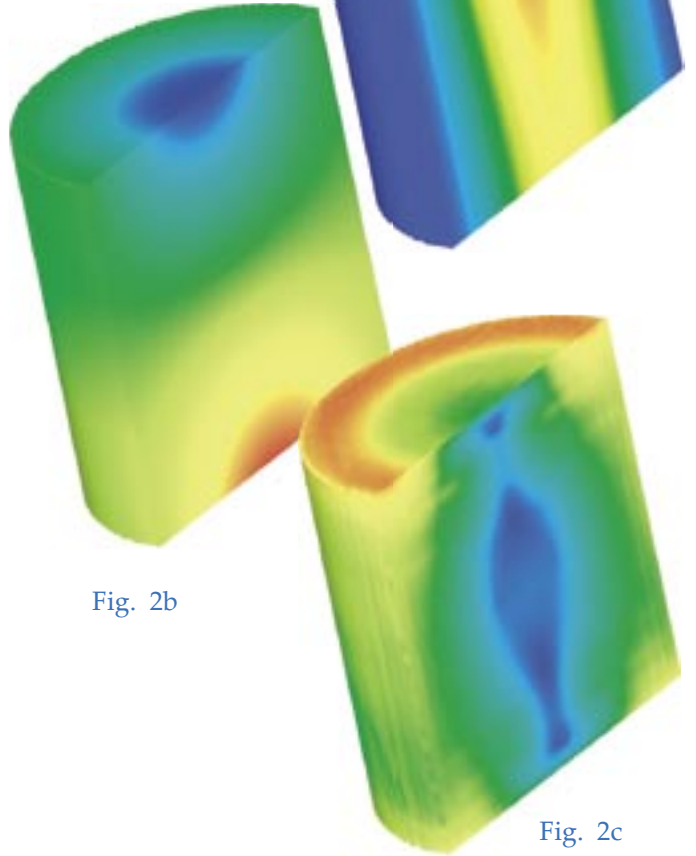


Fig. 2c

disciplines, it seems that the benefits of FEA for laser technology have not been fully recognized. In order to make this powerful analytical tool available for laser cavity design, **LASCAD™** offers predesigned FEA models for important configurations such as end and side pumped rods, slabs, or thin disk lasers. Models are also available for crystals composed of various materials, or of doped and undoped regions, such as undoped end caps. The user can customize dimensions, FEA mesh, boundary conditions, and other parameters within the models. Temperature dependence of material parameters can be taken into account by the use of analytical expressions provided by the user. Analytical approximations based on supergaussian functions are used to model pump light distribution. Numerical modelling of pump light, such as needed for flash lamp pumped lasers, is under development. Results of FEA as well as pump light distribution and boundary conditions are shown by the use of a 3D Visualizer based on

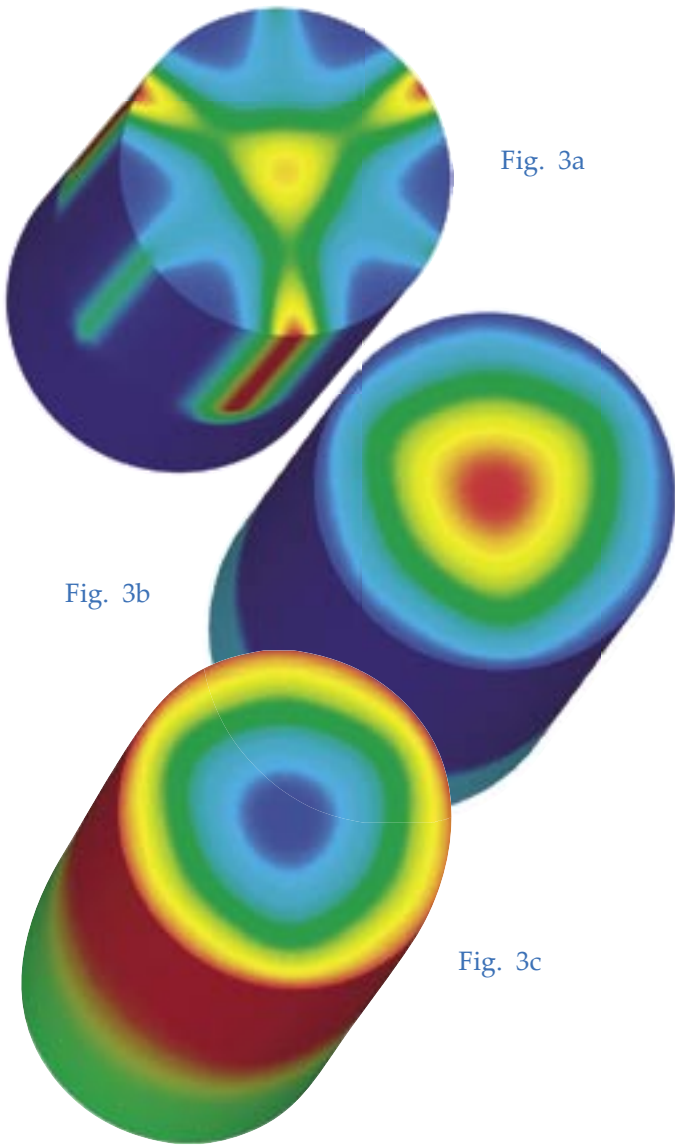


Fig. 3a

Fig. 3b

Fig. 3c

OpenGL. Figures 2 a to c show plots of temperature distribution, deformation, and stress intensity, respectively, in an end pumped, cylindrical rod. Figures 3 a to c show the distributions of pump light, temperature, and the zz-component of the stress tensor, respectively, in a side pumped rod.

The FEA code of **LASCAD™** has been specifically developed to meet the demands of laser simulation. It uses an automatic meshing algorithm to generate a semi-unstructured grid. This term means that the grid has regular and equidistant structure inside the crystal that is invaluable for use of the FEA results with optical codes:

When using the FEA results with the ABCD matrix code the temperature distribution multiplied by the temperature dependence of the refractive index is fitted parabolically at right angles to the optical axis using the finite ele-

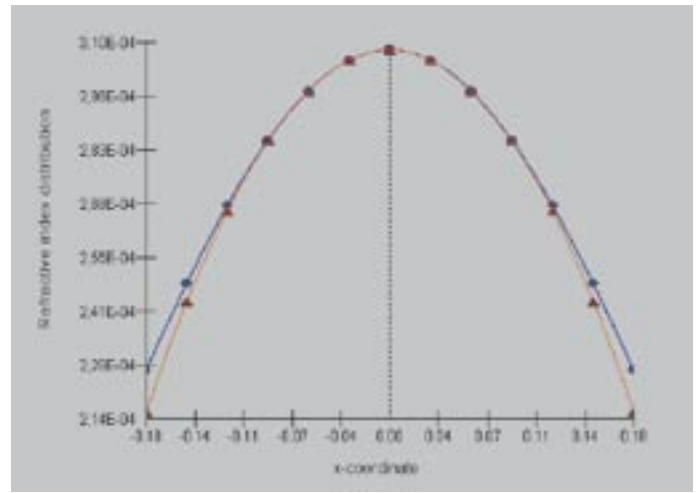


Fig. 4 / FEA Result / Parabolic Fit

ment mesh subdivisions, as shown in Fig. 4. In the same way, a fit of the deformed end faces of the crystal is carried through. For many configurations - end pumped rods for example - this approximation is very close to reality, delivering reliable results for the laser mode. To visualize the results of the ABCD matrix code, the fundamental mode spot size as well as the phase front curvature along the resonator axis can be shown. Also higher order Hermite-Gaussian polynomials, as shown in Fig. 1, and the beam diameter dependent on the beam quality M^2 can be displayed. The ABCD matrix code uses complex valued matrices, which allow for consideration of parabolic transverse gain distributions. To take into account astigmatism the computations are carried through simultaneously in two planes perpendicular to the resonator axis.

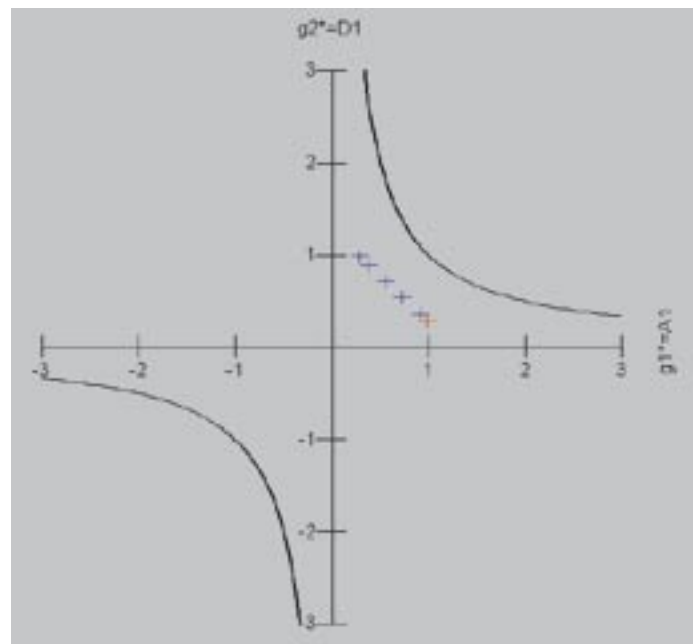


Fig. 5. Stability Diagram

In case of standing-wave resonators a stability diagram computed by utilizing generalized g-parameters can be unfolded as shown in Fig. 5.

The obtained gaussian mode shape and the pump light distribution are used to compute the laser power output. Solution of the laser rate equations is computed by iterative integration over the crystal volume. Fig. 6 shows an example with results for an end pumped Nd:YAG rod. The circles represent results of the simulation, the green triangles are measurements. Since the solution of the rate equations also delivers the distribution of the local population inversion, the latter is being fitted parabolically like the refractive index profile. The coefficients of this fit are used in a recursive computation procedure to take into account gain in the ABCD code in a parabolic approximation.

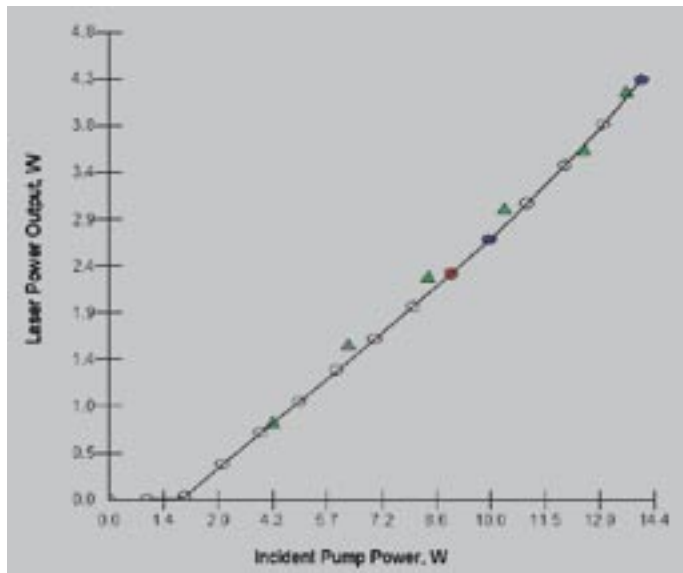


Fig. 6. Laser Power Output

Parabolic approximation and ABCD matrix code are not always sufficient, however. In these cases FEA results can alternatively be used as input for a wave optics beam propagation code. This code provides full 3D simulation of the interaction of a propagating wavefront in the hot, thermally deformed crystal, without using parabolic approximation. For this purpose the code uses a FFT beam propagation method (BPM) to propagate the wavefront in small steps through the crystal, taking into account the distribution of the local refractive index, as well as the deformed end faces of the crystal, as obtained by FEA. Based on the principle of Fox and Li, a series of roundtrips through the resonator is computed, which finally converges to the fun-

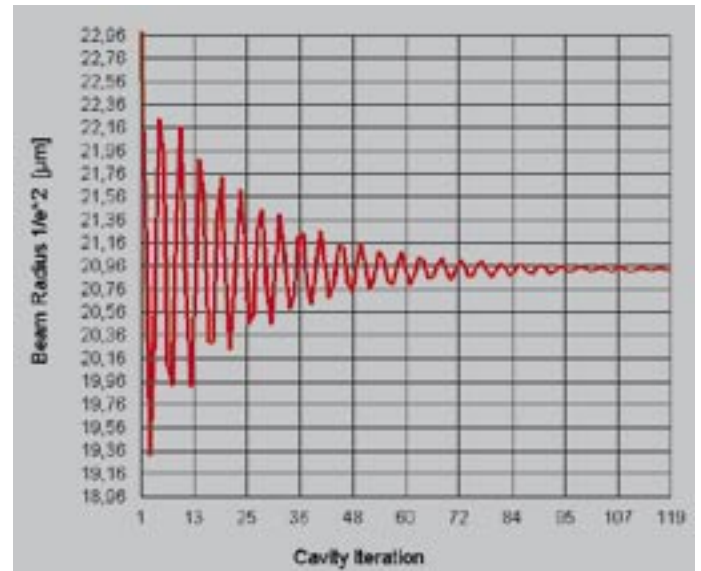


Fig. 7. Convergence of Beam Radius with Cavity Iteration

damental or to a superposition of higher order transversal modes. Two graphics windows are opened simultaneously with the running computation. One of them shows the intensity profile at the output mirror as it develops with increasing number of iterations. The other window displays the convergence of the spot size with cavity iteration as shown in Fig. 7.

The BPM code takes into account diffraction effects due to light stops or the finite transversal extension of optical elements. Mirrors with locally varying reflectivity can also be

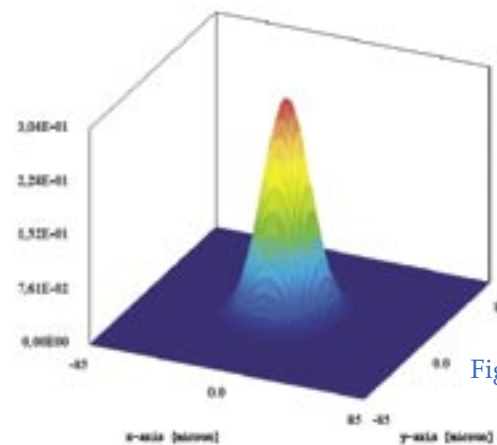


Fig. 8a Intensity

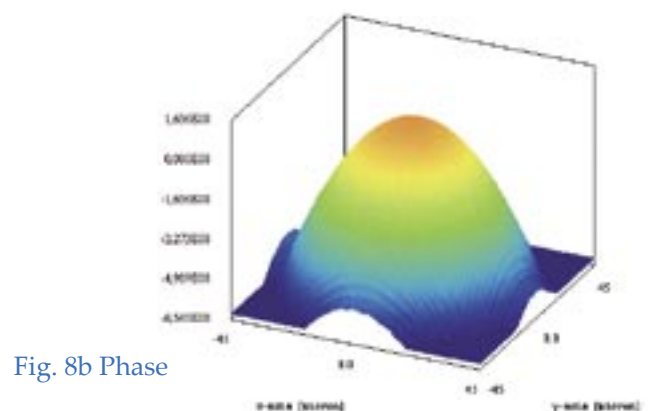


Fig. 8b Phase

considered. Another important feature of the BPM code is the simulation of misalignment effects, which cannot be done as effectively by the ABCD matrix code. Laser power output and dynamic gain are computed in a manner similar to the ABCD matrix code, but by the use of the mode shape obtained by the BPM code.

After finishing the computation, intensity and phase distribution are available for graphical presentation as well as for numerical evaluation providing important information about beam quality. This information may then be compared directly with physical wavefront measurements. *Figures 8 a and b* show examples of intensity and phase distribution at the output mirror. The BPM code is also capable of numerically computing

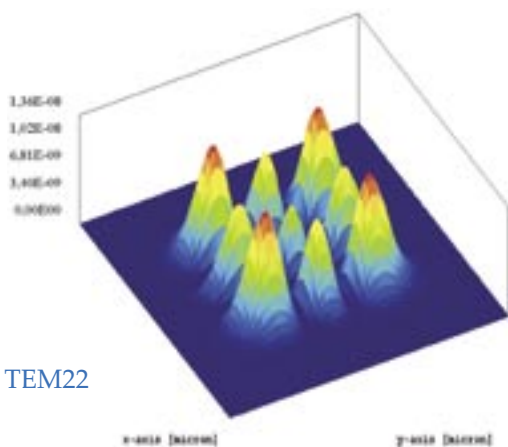


Fig. 9 Mode TEM22

the spectrum of resonator eigenvalues and the shape of the transverse eigenmodes. An example for a numerically computed higher order Hermite-Gaussian mode is shown in *Fig. 9*.

The BPM code can be started from the **LASCAD™** main menu and automatically uses the optical elements defined for the ABCD matrix code.

Propagation of the laser beam through an optical system **outside the cavity** can be carried through with the ABCD matrix as well as with the BPM code.

LASCAD™ The Educational Tool

Though primarily designed for laser engineering, it's easy-to-use GUI makes **LASCAD™** ideally suited for educational purposes for students, as well as for practicing scientists and engineers.

The principles of Gaussian beam optics can be studied interactively and the behavior of complicated heterogeneous resonator configurations or the combined effects of thermal lensing and gain guiding are clearly demonstrated.

Verification of Results and Outlook

The Bavarian Research Foundation has awarded a grant for further development of **LASCAD™**. The main objectives of this project are the simulation of laser dynamics and the experimental verification of the results of simulation. For this purpose *LAS-CAD GmbH* is cooperating with German universities and laser companies like *ROFIN SINAR*, *LASOS*, *AZURA LASER*, or *PHOTON ENERGY AWL*.

The laser group of Prof. Richard Wallenstein at the University of Kaiserslautern, Germany has been using the program for several years for analysis and optimization of composite crystals in diode-pumped, high-power picosecond lasers and amplifiers. A detailed series of measurements was carried through which have determined the laser parameters carefully and verified the results of simulation to a high degree (*S. Reuter, R. Knappe, R. Wallenstein, and K. Altmann, Proc. DPG(VI) 35 (2000)*). **LASCAD™** is increasingly used in industry, research, and education by a worldwide community including users in the US, Canada, UK, France, Germany, Spain, The Netherlands, Greece, Japan, Korea, and China.

In order to compare simulated models with measurements of physical systems, *LAS-CAD GmbH* and *WaveFront Sciences, Albuquerque NM, USA* are cooperating to allow easy translation of data between **LASCAD™** and *WaveFront Sciences' Complete Light Analysis System (CLAS™-2D)*. The integration of these two optical tools provides the laser engineer with everything he needs to simulate, construct and verify the performance of his design and model.

Further information on **LASCAD™** is available at <http://www.las-cad.com> where a demonstration version, a guided tour to **LASCAD™**, and the manual can be downloaded.

LASCAD™ was featured by *Laser Focus World*, in May 2000.

The Authors of **LASCAD™**



Dr. Konrad Altmann, president of **LAS-CAD GmbH**, founded the company in 1993 with the vision of providing laser engineers all the simulation tools necessary for a quantitative understanding of the complicated effects of the multiphysics interaction in diode pumped solid state lasers. The result was **LASCAD™**. Dr. Altmann has over 25 years of progressively responsible experience in computational physics, especially in the field of optics. He has written more than 25 scientific publications in molecular physics, propagation engineering, and laser technology, and applied for more than 25 patents, of which 11 have been granted. From 1977 to 91, Dr. Altmann developed a simulation program for the gasdynamic high energy laser project of Messerschmitt-Bölkow-Blohm AG, Munich. He has also written programs for the simulation of laser beam propagation in the atmosphere. Dr. Altmann has been featured in Marquis' Who's Who in the World.



Prof. Dr. Christoph Pflaum presently works at the University Erlangen, Germany, Department of Computer Science, Systems Simulation. He is engaged in projects concerning transport equation, parallelization, and multilevel methods. Dr. Pflaum has presented 27 papers and other contributions to scientific conferences, especially on numerical solution of partial differential equations. He wrote a habilitation thesis on "Fast and Robust Multilevel Algorithms". Dr. Pflaum contributed the FEA code to **LASCAD™** which is based on a multilevel algorithm and semi-unstructured grids.

Prof. Dr. Raphael Yahel has many years of extensive experience in computational physics, including hydrodynamics, radiation transport, and electromagnetic waves propagation. Dr. Yahel contributed essential parts to the wave optics code of **LASCAD™**, and has written more than 15 scientific publications on propagation engineering.



Georg Altmann is a well qualified software engineer, especially experienced in the design of Windows® MFC® applications. He developed valuable contributions to **LASCAD™** in order to control the interaction of different program codes.

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