

New approaches in teaching laser engineering classes – modeling and building up a laser

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ABSTRACT

We present a simulation tool to model performance of a bulk solid state laser and propose several ways how this tool can be used to enhance educational experience of the student studying laser technology. In one of the possible approaches, the ASLD software can complement available educational laser kits to provide the students with more universal practical training. In the second approach, which is the primary focus of this contribution, the ASLD software can be used as a development tool that allows students to verify their understanding of the subject as well as to propose and verify their own design ideas. The software can be extremely helpful if an experimental setup has to be built from already present optical components in order to reduce the cost of training or if specific design objectives have to be attained.

Keywords: Laser resonator modeling, ASLD software, ultrafast lasers

1. INTRODUCTION

As of now lasers became an indispensable tool in science, technology, and regular life. This fact got reflected in the educational curriculum of many universities and as of now students have a wide selection of options how to obtain theoretical knowledge about lasers - through classroom lectures, textbooks, online materials, etc. While this part of the educational process is well established, gaining practical skills how to design and build a laser remains a not completely resolved challenge for a number of reasons. Laser modeling tools are not common and tend to be expensive, commercial lasers are optimized for convenience of use not for convenience of training. There are on the market laser kits that are specifically sold for student training but they tend to be quite rigid in terms of design and application flexibility, additionally they are not easily affordable. From the authors perspective these challenges can be address by building up a customized educational laser setup. In this contribution we demonstrate how such a setup can be developed, modeled, and analyzed using the ASLD software tool developed at the Friedrich-Alexander University Erlangen-Nürnberg, Germany [1]. The software allows to setup and analyze different pumping approaches, cavity layouts, cw and pulse operation modes. It has an intuitive graphical user interface permitting the students to adapt to it quickly. As an example we consider how the ASLD modeling tool can be used to analyze performance of a Z-shaped resonator cavity. An ultrafast (picosecond) oscillator has been developed based on this model and its hardware implementation together with the output parameters have been reported earlier [2].

2. MODEL SETUP

The ASLD software is primarily developed to model diode pumped bulk solid state lasers which simplifies the task of setting up a proper model. The modeling tool contains a database of several most common laser materials such as Nd:YAG, Nd:YVO₄ and can be also extended with new materials if needed. The crystal shape, size, doping level, and the cut (*a*-cut or *c*-cut), if applicable, are specified by the user and can be easily matched to either an available or desired crystal. The software also allows to specify cooling method for each crystal surface in order to reflect actual mounting design. In the example presented in this paper as well as in Ref. [2], a 5 mm long 3 mm in diameter, 1% doping level Nd:YVO₄ crystal is held in the middle of a Ø25 mm copper mount, which is equivalent (at low pumping levels) to a boundary condition of constant temperature at the cylindrical surface and no cooling at the side facets. In general, this software feature (cooling method) can be a useful tool for demonstration and visualization of various thermal effects that can take place in a laser. In the presented example the pumping levels are relatively low and the thermal effects such as

thremolensing and thermal deformations are small and not considered in detail. The next step includes setting up a proper pumping configuration, which is done using the pumping editor. Fig. 1 shows a screenshot of the used pumping configuration, here, one (left) side pumping is assumed.

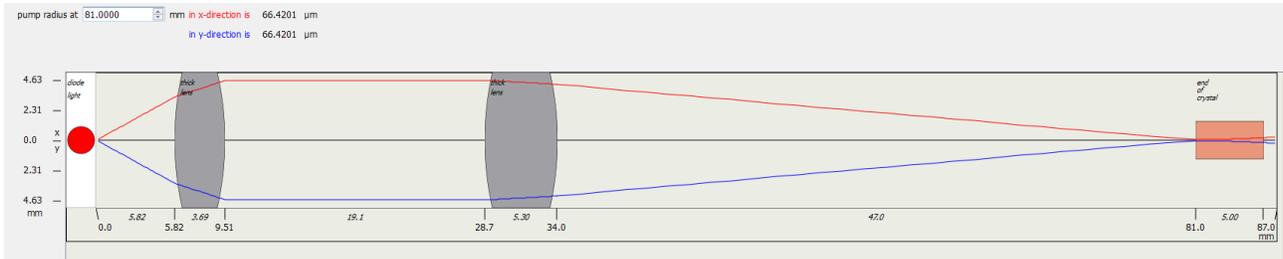


Figure 1. Screenshot of a sample pumping configuration consisting of a pump diode, collimating and focusing lenses, and the crystal. Optical properties of each element can be edited via a corresponding dialog window.

The pumping editor allows the user to specify optical properties of the pump diode (s), the lens system, and the crystal position. In the given example the pump focal spot is position on the left facet of the crystal, but in general it can be moved either before or after the facet. The pumping editor allows to introduce several types of optical elements into the beam path such as thin / thin lenses and mirrors. The optical powers of these optical elements can be different in the orthogonal x/y directions permitting to introduce cylindrical lenses, if needed. The thick lens parameters such as thickness, material index of refraction, and surface radii of curvature can be entered into the proper dialog box. Such information is usually provided by the lens manufacture allowing to create a very accurate pumping setup. Fig. 2 shows a dialog window used to specify properties of the pump, for instance its physical shape, size, and numerical aperture (NA) along both directions.

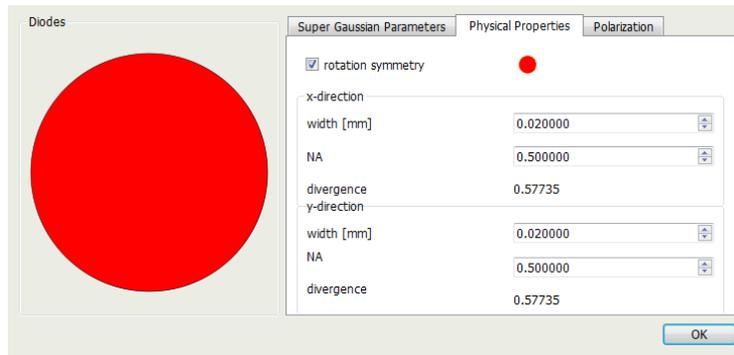


Figure 2. Pump diode dialog window.

Nominal diode parameters such as the size and the beam divergence (it can be recalculated into NA) are typically provided by the diode manufacture and can be directly entered into the dialog box to be used as a starting point. Meanwhile, we found out that more accurate approach it to slightly adjust the diode divergence in such a way that the simulated pump focal spot size matches the actual focal spot dimensions that are measured using a beam profiler. The same dialog window (“Super Gaussian Parameters” tab) can be used to specify the intensity profile distribution via changing the Super Gaussian index ($n = 2$ corresponds to the fundamental Gaussian mode). If the actual focal spot intensity distribution is known, then the index can be adjusted to match the simulated and the experimental shapes. Otherwise, we recommend setting the index to a value higher than 2 since pump diodes typically emit highly multimodal beams.

The next steps include setting up a laser resonator to be analyzed and adding an amplifier (optional and will not be considered in the paper). Fig. 3 shows a schematic model of a resonator used to build an ultrafast laser oscillator described in ref. [2]. It consists of a laser crystal, a high reflector, two concave mirrors slightly tilted with respect to the resonator optical axis, and an output coupler (Fig. 4 shows a schematic layout of the modeled laser). The positions of the

optical elements in the model are specified by entering the separation distances. For example, the high reflector – laser crystal separation is entered as 0, since it is directly coated on one of the crystal flat facets. In the shown example, the concave mirrors (positions 402 mm and 670 mm) are used to control the resonator modes and assumed to be spherical by taking the same radii of curvature in both directions (radius of curvature for both mirrors is the same -200 mm). Their tilt is adjusted to match the physical layout of the resonator. The actual resonator has a Z shape resulting in slight x/y astigmatism, which has been observed in both experimental and simulation results. The software calculates the mode spot sizes in both orthogonal directions and shows them in the output windows using different color coding. For example, in Fig. 3 the output laser beam (resonator position 1056 mm) appears to be slightly elongated along the horizontal axis: $r_x \sim 100 \mu\text{m}$ vs. $r_y \sim 70 \mu\text{m}$. The last optical element in this setup is a flat output coupler.

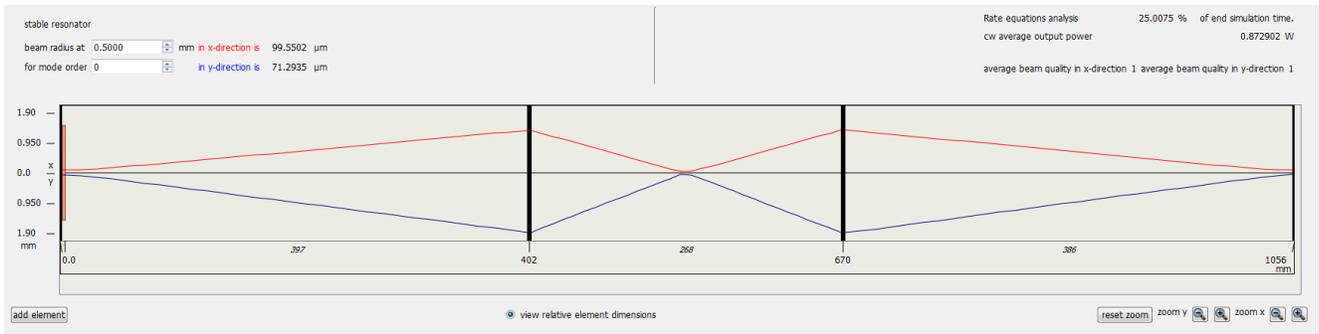


Figure 3. A schematic model of a resonator described in this paper.

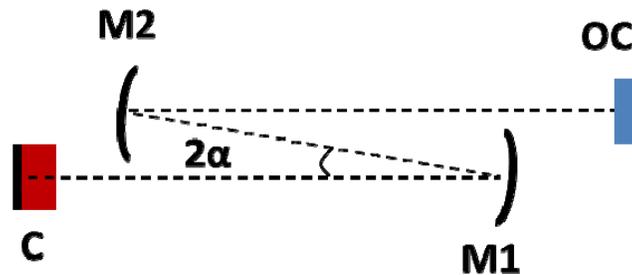


Figure 4. Schematic layout of the modeled laser, C – crystal, M1 and M2 identical concave mirrors, OC – output coupler.

It should be kept in mind that the ASLD software does not provide any guidance how to setup a laser resonator. The latter should be based on some physical, design, *etc.* considerations that shall allow the user to achieve the desired objectives. In this sense the ASLD tool should be rather used for verification of those considerations. Various optical elements and modes of operation can be added to a laser model via the “Add optical element” dialog box, if needed. Fig. 5 shows a sample “Add optical dialog” window for a thick lens.

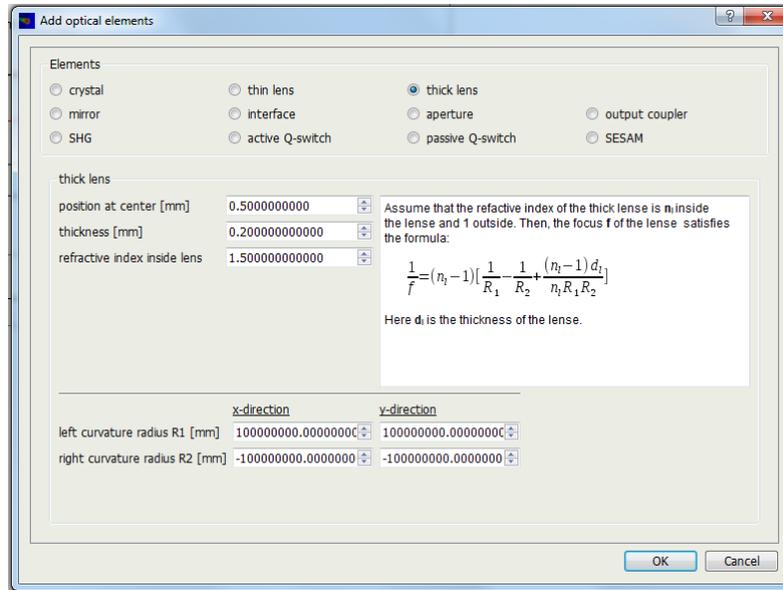


Figure 5. Add optical element” dialog box for a thick lens.

To complete setting up the model three more parameters has to be specified. The first one is the input pump power, which should reflect the actual light power reaching the crystal, not the nominal power of the pump diode. The former can be noticeably lower due to multiple reasons such as parasitic back reflection, absorption in optical elements, partial beam clipping, etc. In the presented example the pump power is set at 1.8 W. The next parameter is the output coupler reflectivity, which can be either taken to match an existing value or a parametric run can be performed to find an optimal value for the reflectivity. The last parameter is the “round trip resonator loss” and it appears to be the most challenging to quantify. The most straightforward approach would be to add up losses from all individual optical elements such as mirrors, crystal, etc. but unfortunately the information provided by the suppliers is rather general. That can result in overestimation or underestimation of the loss and corresponding undervaluing or overvaluing of the output laser power. We recommend to use the nominal losses as a starting point and empirically adjust the “round trip resonator loss” parameter later to achieve a close match between the simulated and experimental results using a simple test setup. For example, the mirror manufacture states that their reflectivity is better than 99% and if nominal total loss of 0.05 is taken, then the ASLD software strongly underestimate the laser performance stating that the output laser power is only 0.85 W with a 10 % high reflector. If the mirror reflectivity is assumed to be 99.5 %, which corresponds to 0.025 loss, the ASLD software predicts the output laser power of 1.1 W, consistent with the experimental results. The ASLD software ASLD uses the dynamic mode analysis for power computation [3].

3. DISCUSSION

In addition to estimation of the output laser power, the developed model also allows an easy analysis of the resonator mode sizes in the crystal and on the output coupler. Since the laser operates very close to the stability boundary (Fig. 6) understanding how the beam size changes when either of the optical component is being displaced may be very important for a number of applications. Although such a displacement may not significantly affect the output laser power (unless the laser goes into the unstable regime) it will strongly change the laser fluence / intensity within the crystal and on the output coupler. The latter (fluence) becomes the key parameter in designing a stable mode-locked ultrafast laser oscillator based on the semiconductor saturable absorber technique if the ordinary output coupler is replaced with a semiconductor saturable output coupler [2]. Depending on the inter-cavity laser beam fluence, which is primarily controlled via the mode size, the laser can be operating in the continuous wave (cw), Q-switch mode-locking, or cw mode-locking modes. In this case the model becomes an essential element not only during the design phase but also for the experimental work if the laser behavior deviated from the desired one.

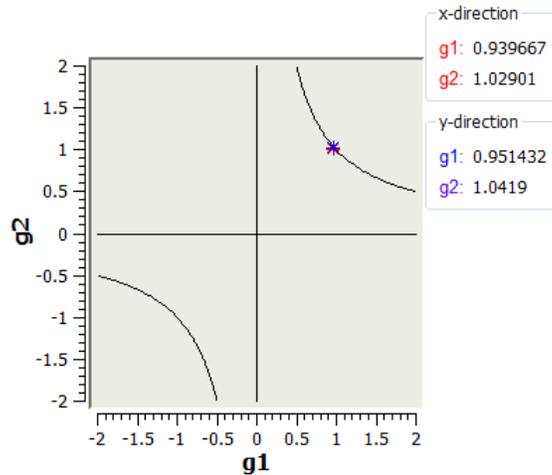


Figure 6. Stability diagram for the considered laser setup. The stability parameters are calculated for both orthogonal x/y directions.

4. CONCLUSION

Incorporation of laser modeling software such as the ASLD tool into the educational process can strongly enhance the student learning experience. On the fundamental levels the modeling can assist the lecturer in explanation and demonstration of various concepts of laser physics. It can be an indispensable tool for demonstration of design tradeoffs, which is usually not a simple task from the experimental perspective. But primarily, the ASLD software can be used to develop customized practical laser trainings that will accommodate technical and financial capabilities of the educational institute.

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REFERENCES

- [1] ASLD laser simulation software: www.asldweb.de.
- [2] I. Alexeev, A. Ugurlu, G. Seerdar, and C. Pflaum "Ultrafast (picosecond) laser oscillator for educational use" *European Journal of Physics* 37, 045301 (2016).
- [3] M. Wohlmuth, C. Pflaum, K. Altmann, M. Paster, and C. Hahn "Dynamic multimode analysis of Q-switched solid state laser cavities" *Optics Express* 17, 17303 (2009).

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