LasKin 5.0

User's Manual

About

LasKin

Software for solid-state laser simulation.

LasKin software is a tool for computational modeling of solid-state laser kinetics in free running and Q-switched modes with pulsed and CW optical pumping. The laser scheme has a linear configuration containing:

– rear (HR) mirror and output coupler;

– longitudinal or transverse pump source (collimated uniform CW pump beam or pump pulse with specified waveform);

- laser element equipped with retro reflector for unabsorbed pump light placed opposite to the pump source;

– optical system for changing laser beam cross-section ratio in active element and Q-switch ("Telescope");

– Q-switch (passive (PQS)/active (AQS) or combination of AQS+PQS); Q-switching with variable off time and Q-switching by variable output coupling.

Overview

General algorithm of data setting and calculations run is :

A) Choice of an active medium (general laser scheme or Er-Yb:glass, Nd:host, Yb:host), input of characteristic data (decay rates of energy levels, energy transfer parameters, absorption and emission cross sections);

B) Setting of resonator parameters (total length, active and passive intracavity losses, overlap efficiency of active element excited volume with active lasing (resonator transverse mode) volume, geometrical dimensions of an active element field where pump radiation is effectively absorbed into - e.g. conditional dimensions of an active element);

C) Choice of pump scheme (transverse or longitudinal), setting of a pump source total radiation power, pump pulse duration, efficiency of pump radiation delivery to the active element (coupling efficiency). Finding an average effective value of an active element pump power density with the use of data set in #A. Calculations are made allowing for possible partial pump radiation reflection Rp that is not absorbed at first pass through the active element;

D) Active or passive Q-switch parameters settings for Q-switch operation mode;

E) LasKin calculates lasing within point model frame and displays a list of main output parameters and computer oscillograms of output laser power, population in the active media and intracavity losses . Simulations and plotting of output values vs. parametric input data (i.e. output energy vs losses, output pulse duration vs pump power etc.) is also available.

F) Both input data file and calculation results can be saved for future use.

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Installation

Installation

System requirements:

Windows XP SP2 or newer, 512 Mb RAM (1 Gb recommended), 800 MHz processor .

Net Framework 3.5 and DirectX are required.

Setup procedure:

Insert Setup Disk or download LK_setup.exe;

Run file SETUP.EXE on this drive;

Follow up the instructions.

When the setup procedure finishes, the following files appear in the directory selected during installation (LasKin home directory, by default, C:\Program Files\ LasKin 5.0):

- laskin.exe (shell file) – main program file providing end-user interface;
- laskin.chm – current version of Help File;
- *.cfg – configuration file for LasKin (editing is not recommended);
- *.lmd – customized file for LasKin (editing is not recommended).

Supplementary files:

- *.dll – DLL's for LasKin;
- *.lk3, *.lk4 – input data files for LasKin;
- *.pdf – User manual files.

Registration

Registration:

To register a copy of LasKin software and get access to full-operation mode, please:

1. Select menu item Help->Register;
2. Send your Request code together with the purchasing information to distributor to obtain the Final Registration Code;
3. When your receive the Final Registration Code select menu item Help->Register;
4. Enter your Final Registration Code;
5. Click Ok;
6. Restart the program (for working in full mode).

Tutorial

Here is a quick overview of the LasKin interface. For detailed description of the program capabilities view Worksheets section below.

1. Run the program.

2. Click <Select> button (or “File->Laser Medium Select” menu item).

3. Select laser medium in additional window (Fig. 1). For example - Nd:YAG. Click <Ok>.

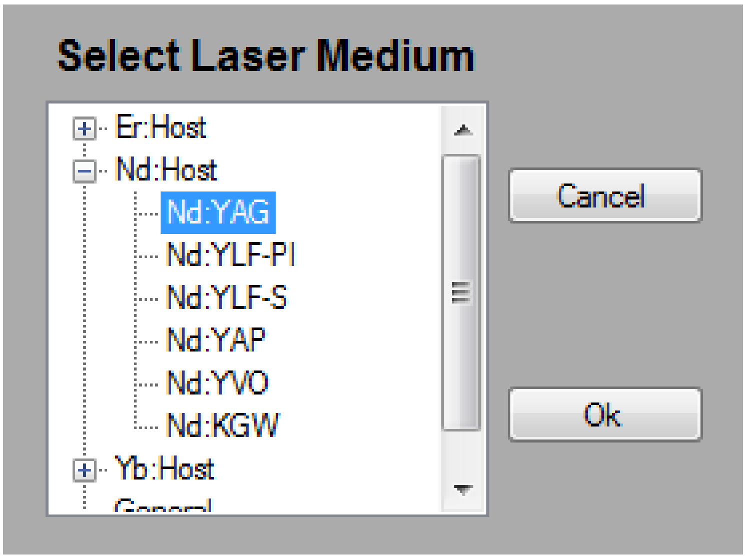


Fig. 1 “Select laser medium” menu

4. Set the necessary parameters in the windows (“Laser Medium”, “CONFIGURATION”, “PUMP”, “Q-switch”, ”Special”):

Warning!

After changing parameters <Apply> button enables. Click <Apply> button to confirm changing parameters, otherwise all changes would be canceled.

– Dopant concentration and other active medium parameters can be set in “Laser medium” window.

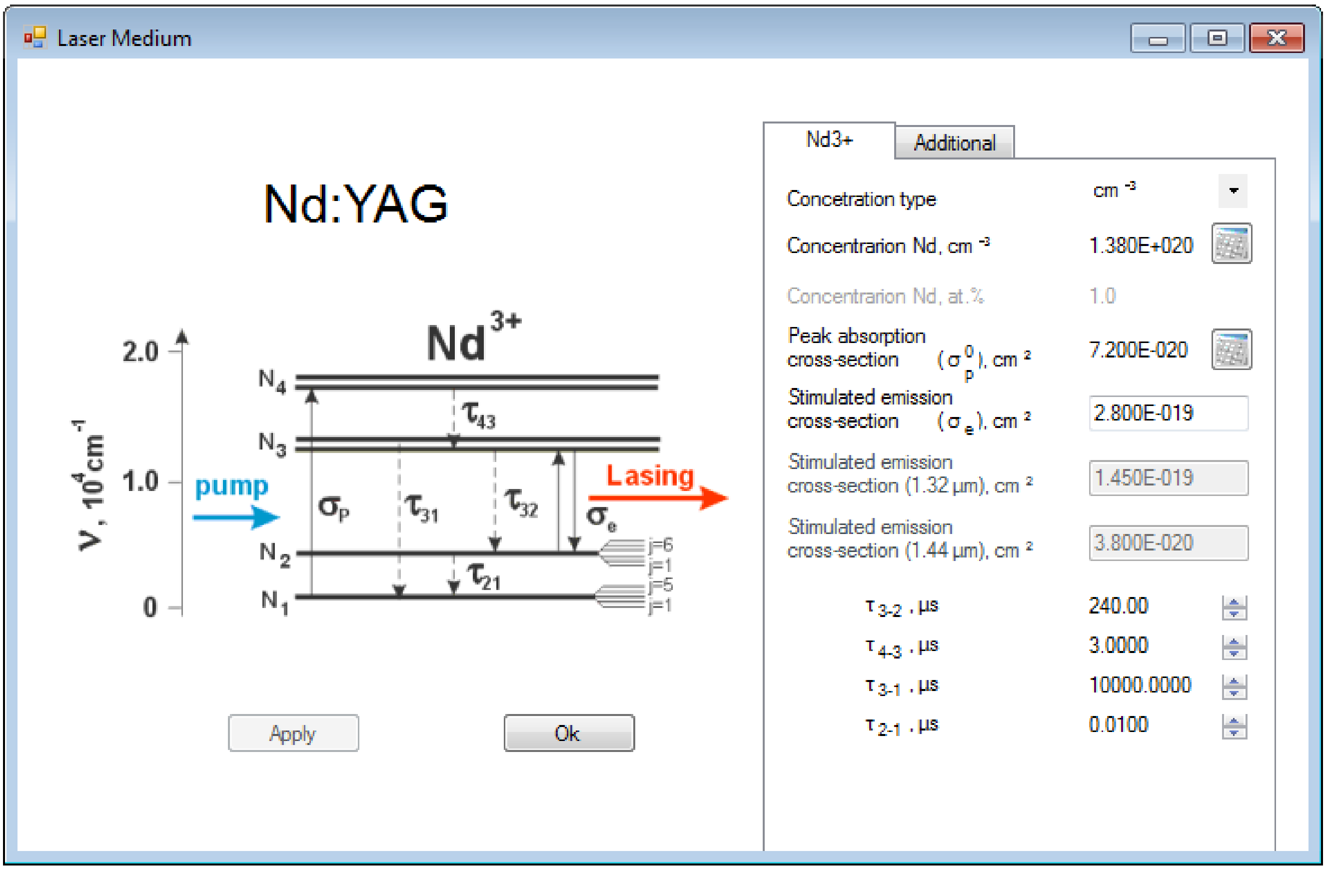


Fig. 2. “Laser Medium” window

– Active medium size, cavity length and other cavity parameters can be set in “Configuration” window.

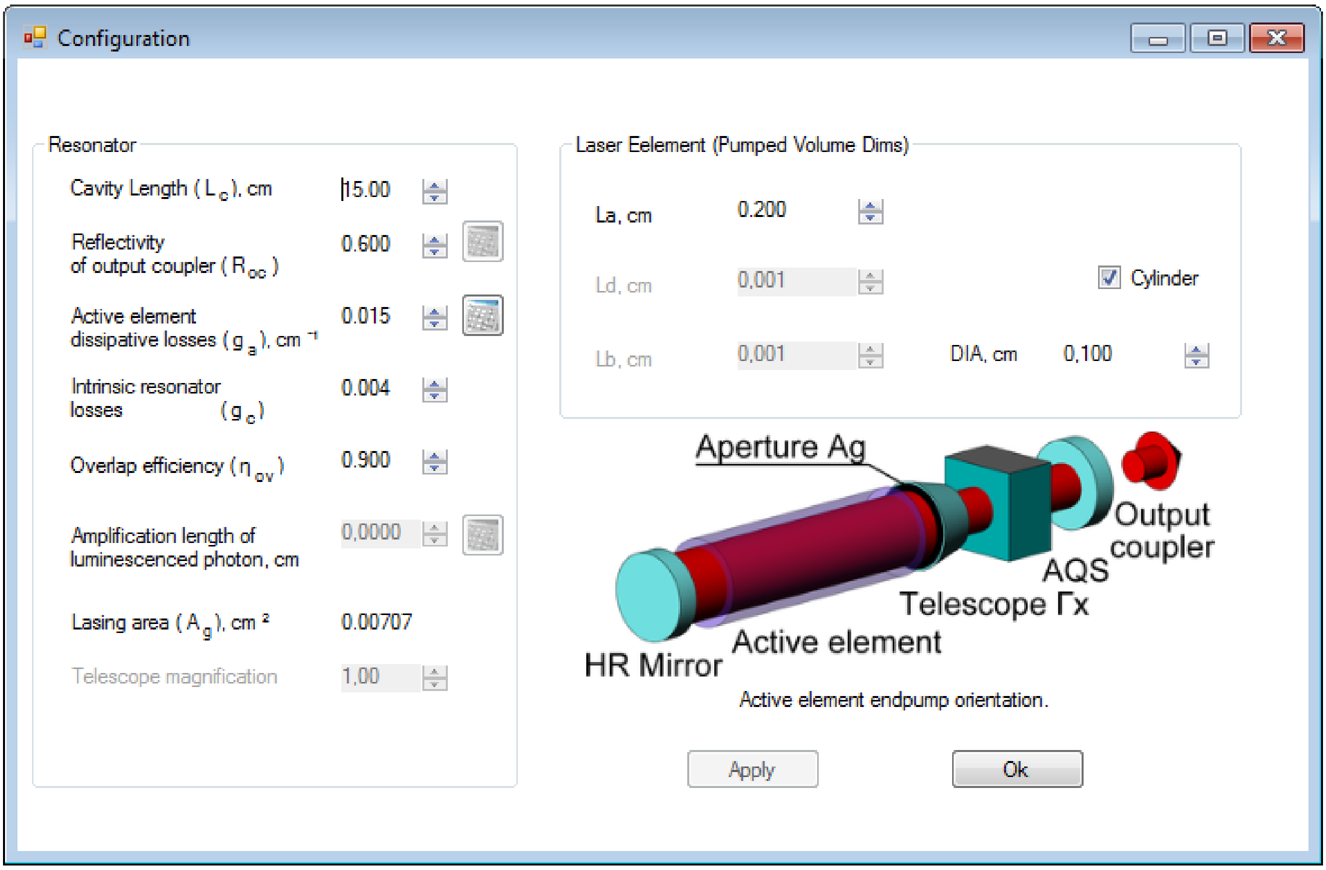


Fig. 3. “Configuration” window

– To set varying pump waveform click <Change> button in “Pump” window (Fig. 4), select “Varying” (Fig. 5), click <Edit pump form> and set necessary parameters (Fig. 6).

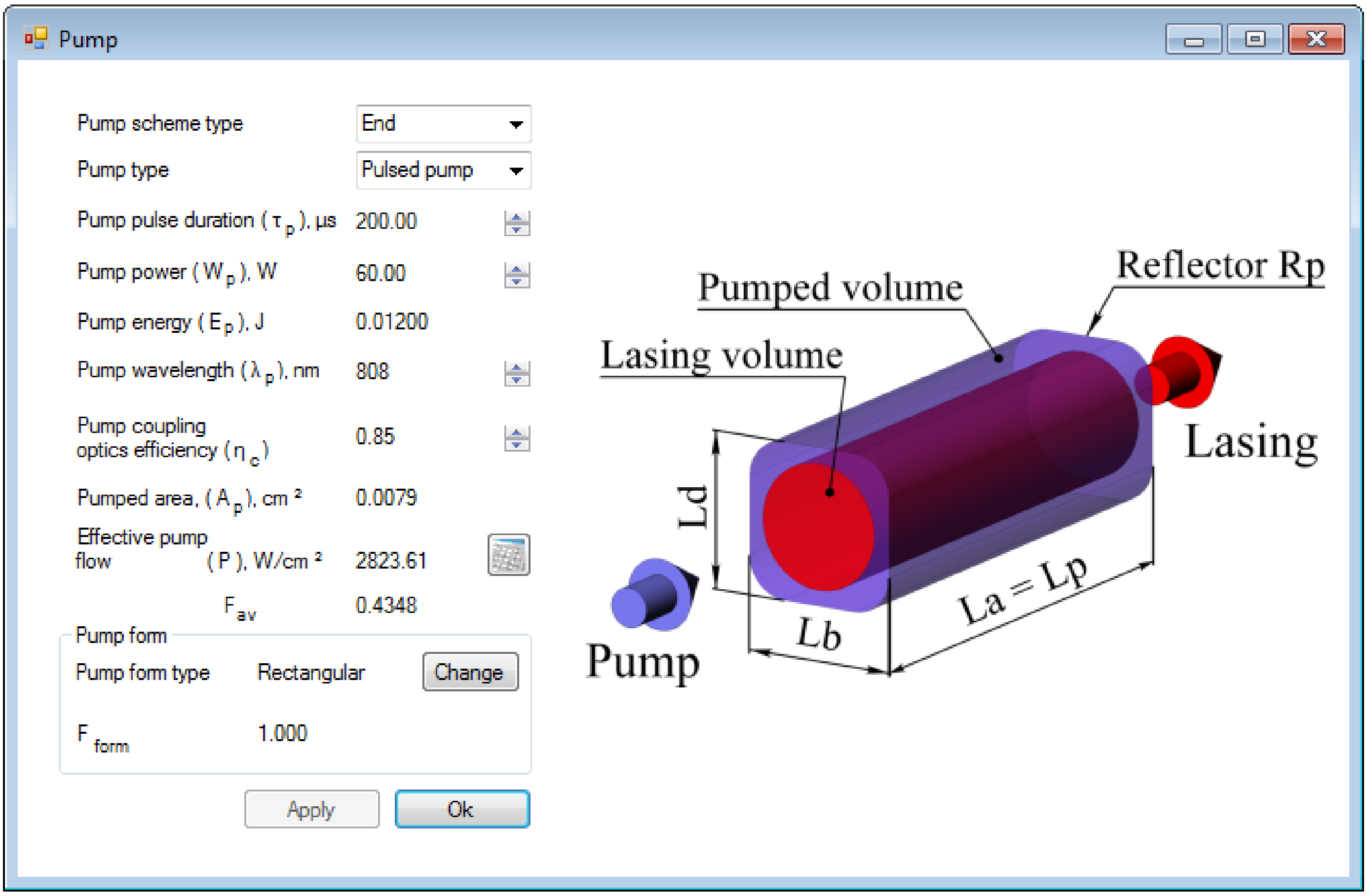


Fig. 4 “Pump” window

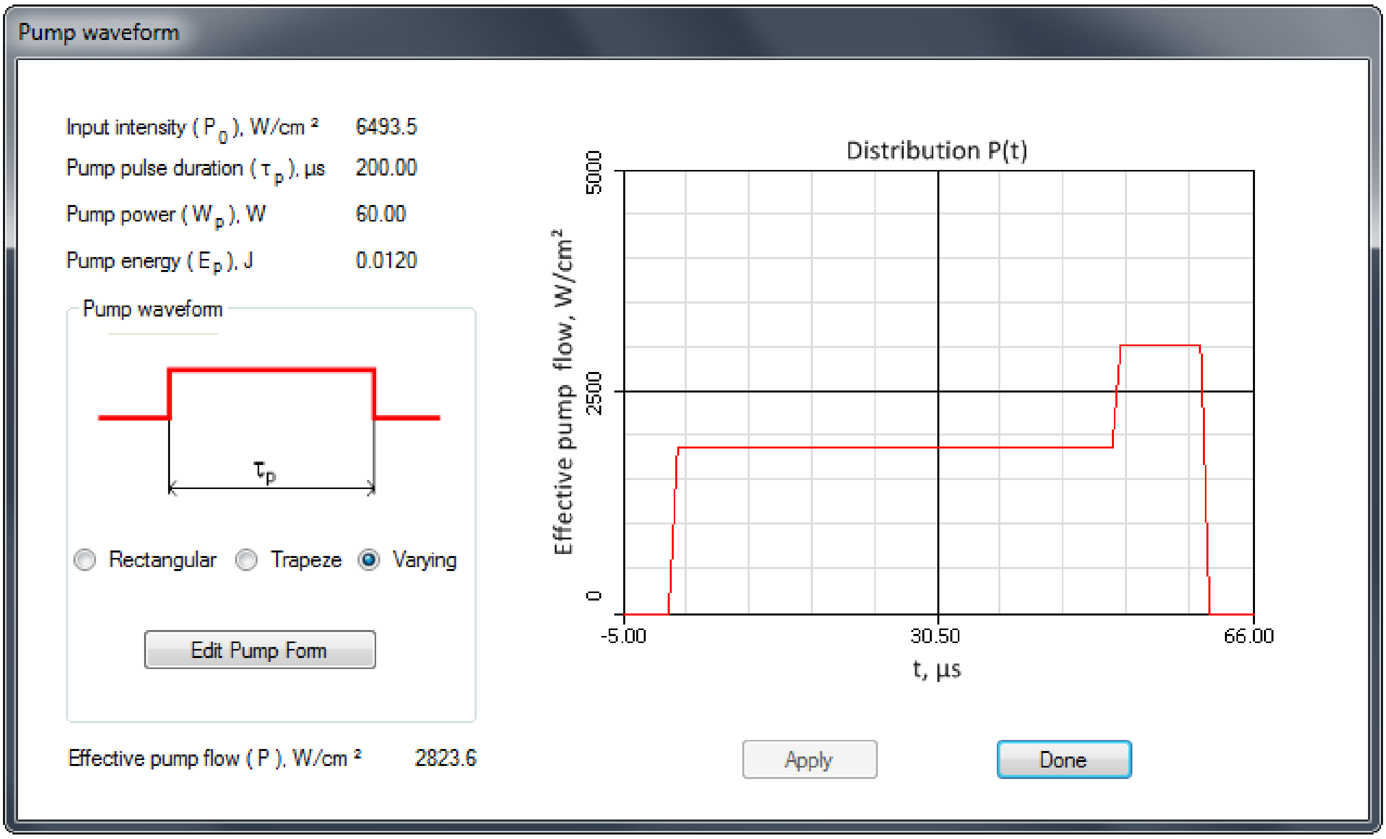


Fig. 5 “Pump waveform” window

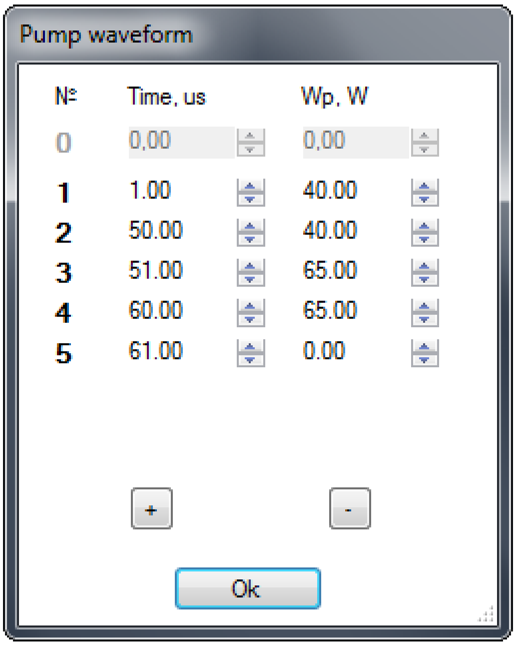


Fig. 6 “Pump waveform” configuration window

– Uncheck “AQS is installed” and “PQS is installed” in “Q-switch” window (Figure 7 a, b) for free running mode. Check for the desired Q-switched mode: Active/Passive or Active + Passive).

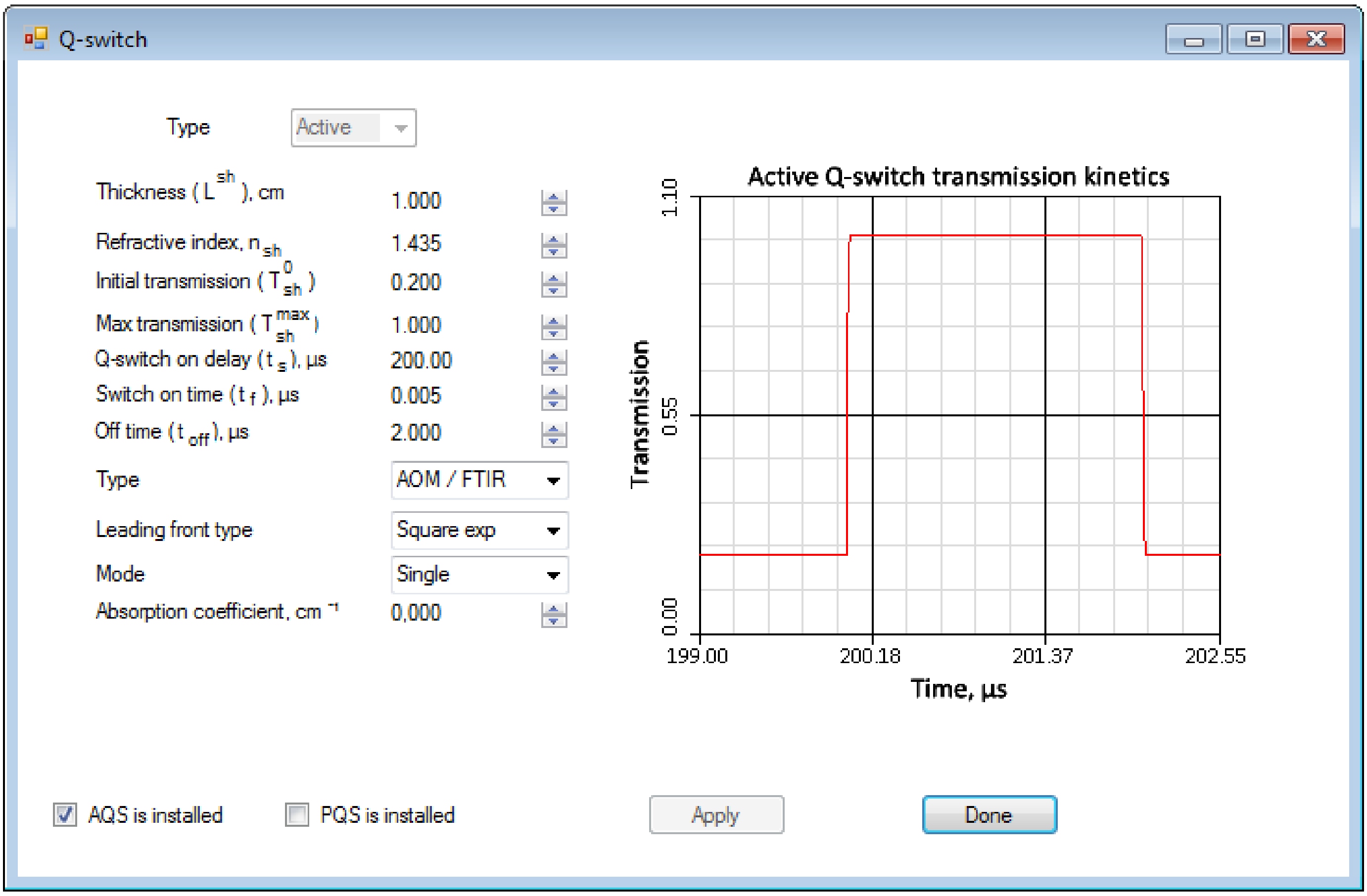


Fig. 7 a “Q-switch” window (AQS)

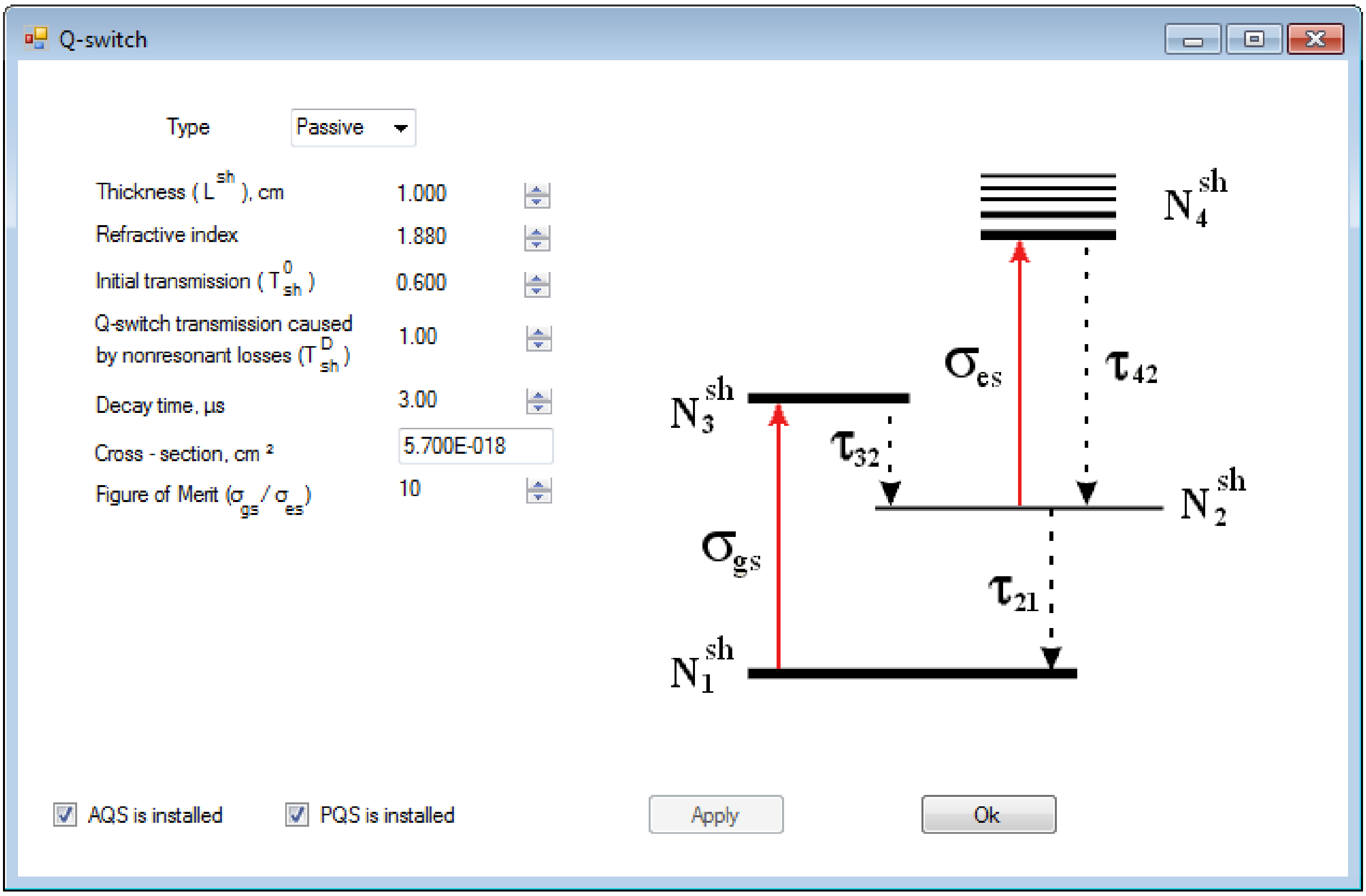


Fig. 7 b “Q-switch” window (PQS)

– To calculate dependencies of laser performance on input parameters (output energy vs output coupler reflectivity, etc.) and proper optimization of used components check “Show dependence function” in “Optimization” window (Fig. 8). Set desirable range of the varied parameters.

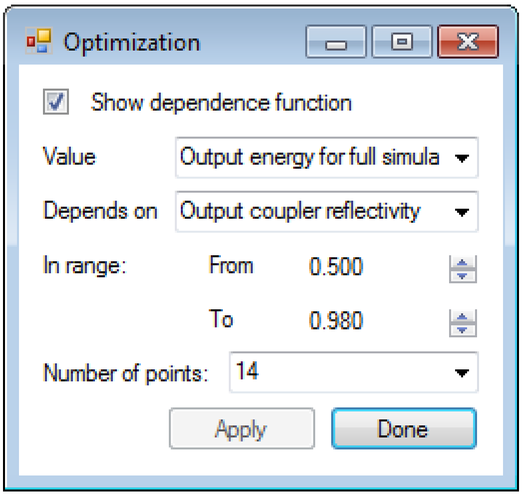


Fig. 8 “Optimization” window

Warning!

If the calculated dependence curve does not look «smooth» check temporal profile in singular points or change step of argument. In some cases fine changes in the temporal structure are caused by finite values of the lowest lasing level lifetime. For rough estimations set the values as low as possible.

5. Click <Start> button.

6. View result in “Preview Result” window (Fig. 9).

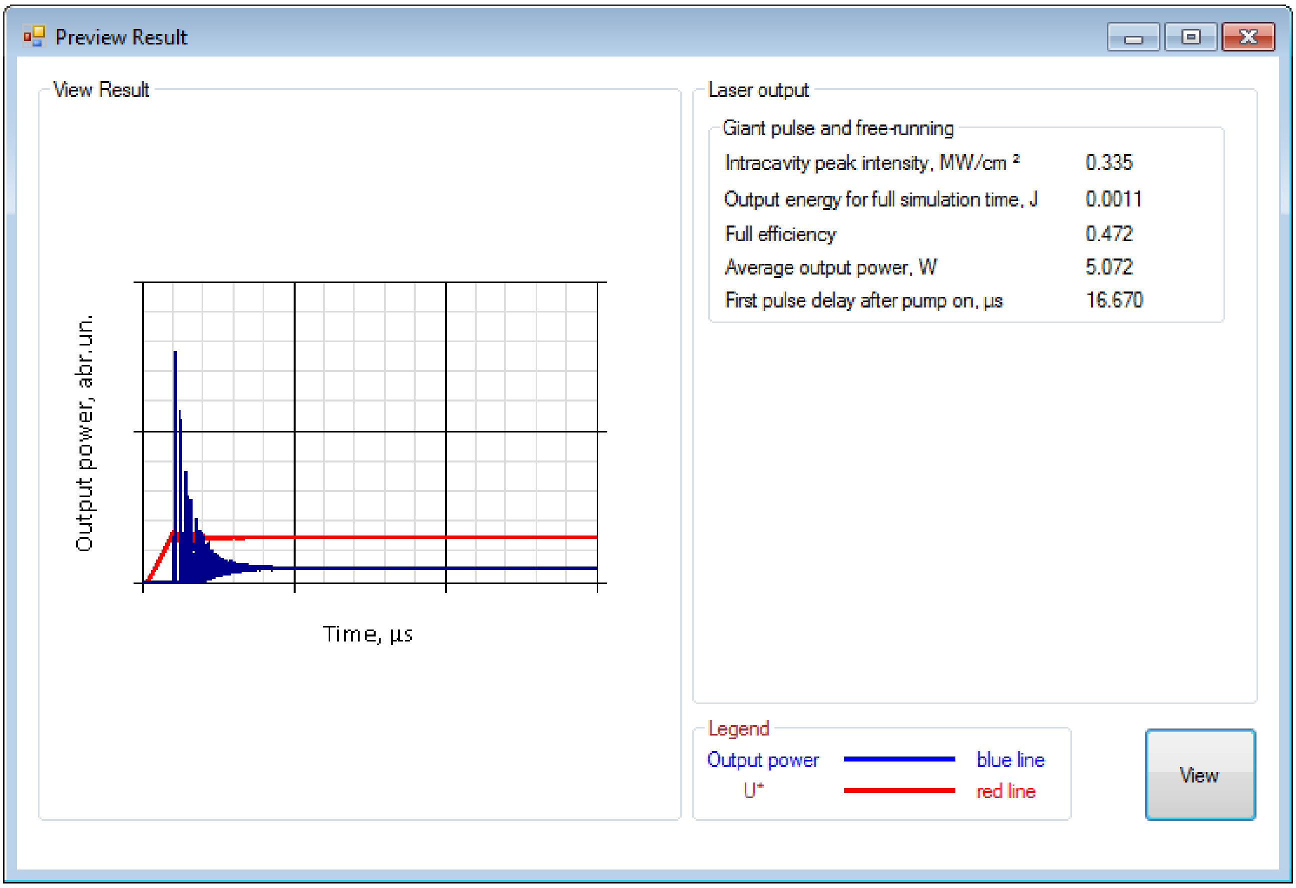


Fig. 9 “Preview Result” window

7. Double click on graph (or click <View> button) to switch to full view of the results.

8. View Result in “Result” window (Fig. 10).

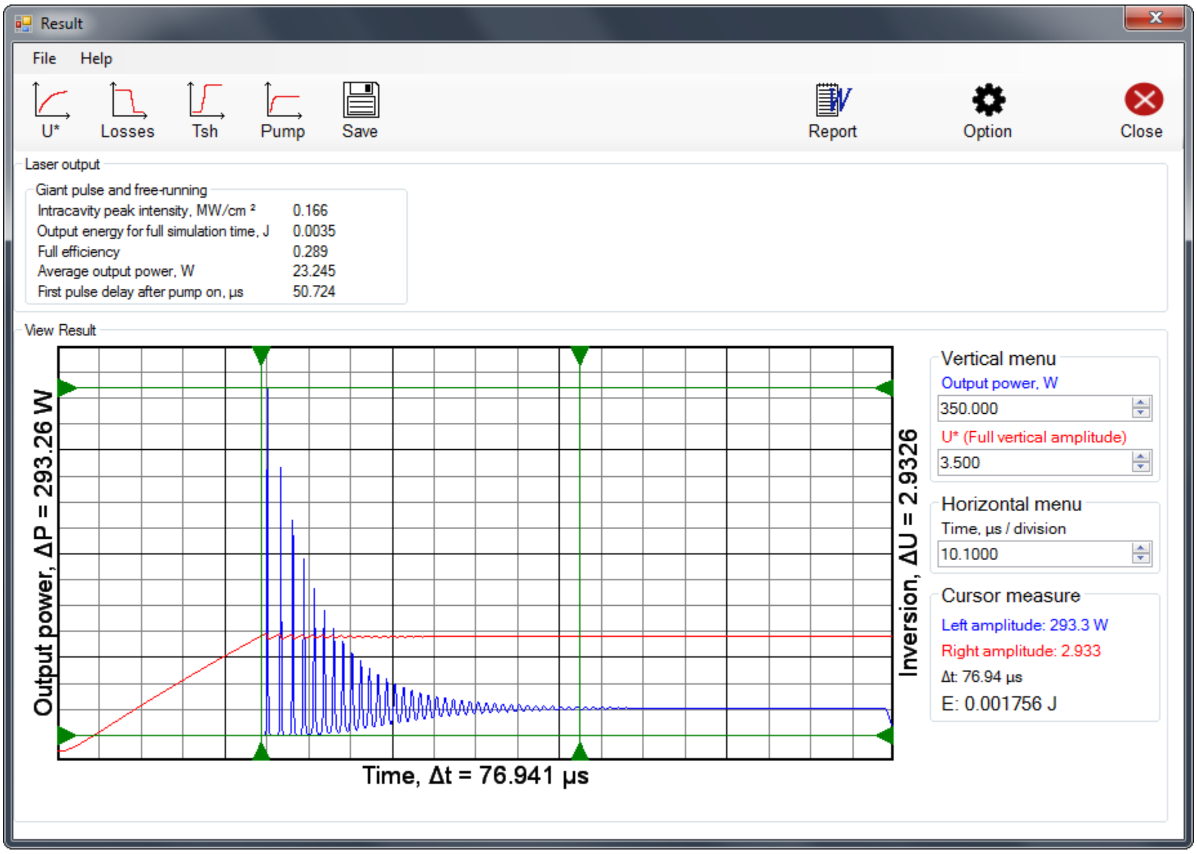


Fig. 10 “Result” window

9. Use the mouse to customize the graph or double click on the graph field and set necessary parameters in additional “Plot Option” window (Fig. 11) for more detailed customiztion.

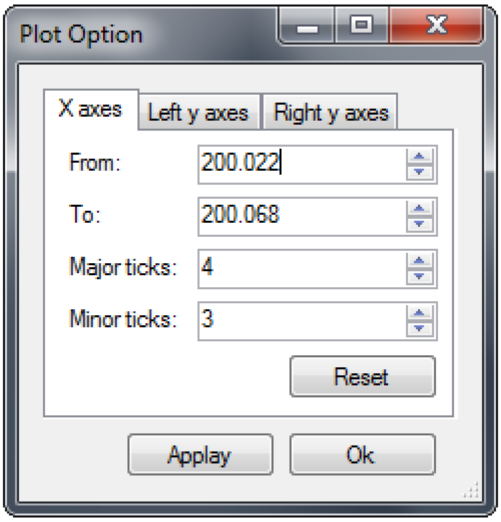


Fig. 11 “Plot Option” window

10. Click <Report> button to create file with output report.

11. Click <Save> button to save all input data (output parameters and calculation matrix in .*txt format and graph in *.bmp format).

12. Close “Result” window, save intermediate input data in named file (default filename result.lk3) and start new simulation cycle if desired.

Worksheets

There are 6 main windows in the program:

- Laser Media
- Configuration
- Pump
- Q-Switch
- Special
- Result

Laser Medium

In this window (Fig. 10) an energy levels diagram is displayed and active media parameters such as concentration of activator ions (N, cm^{-3} or atomic %), peak absorption cross section ($\sigma^0{}_p$, cm^2), emission cross section ($\sigma^0{}_e$, cm^2), absorption coefficient (α, cm^{-1}), decay times (τ_{i-j}, μs) etc. can be entered.

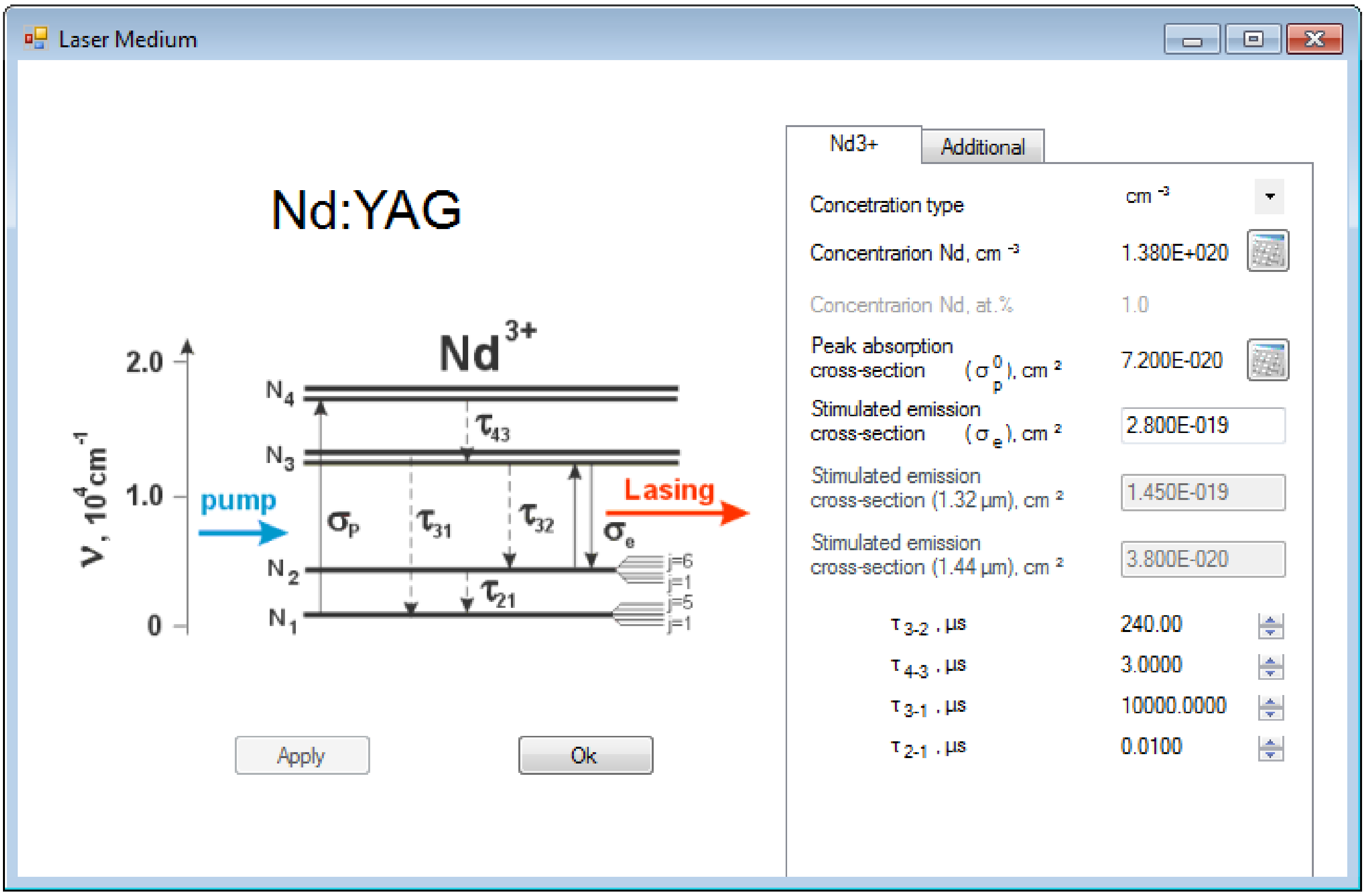


Fig. 10. “Laser Medium” window

One can find out effective value of absorption cross section (σ_p, cm^2) while using the absorbing ions concentration (N, cm^{-3}) and experimental value of absorption coefficient at pumping wavelengths range for the used active element (α, cm^{-1}). Spectra overlap (Fig. 11) coefficient (k_s) binds reference value of peak absorption cross section at known wavelength ($\sigma_p{}^0$, cm^2) and calculated value of effective absorption cross section for the used pumping source spectrum. For narrow band pump peaked at corresponding absorption maximum k_s=1

$$\sigma_p = N \cdot \alpha$$

$$k_s = \sigma_p / \sigma_p{}^0$$

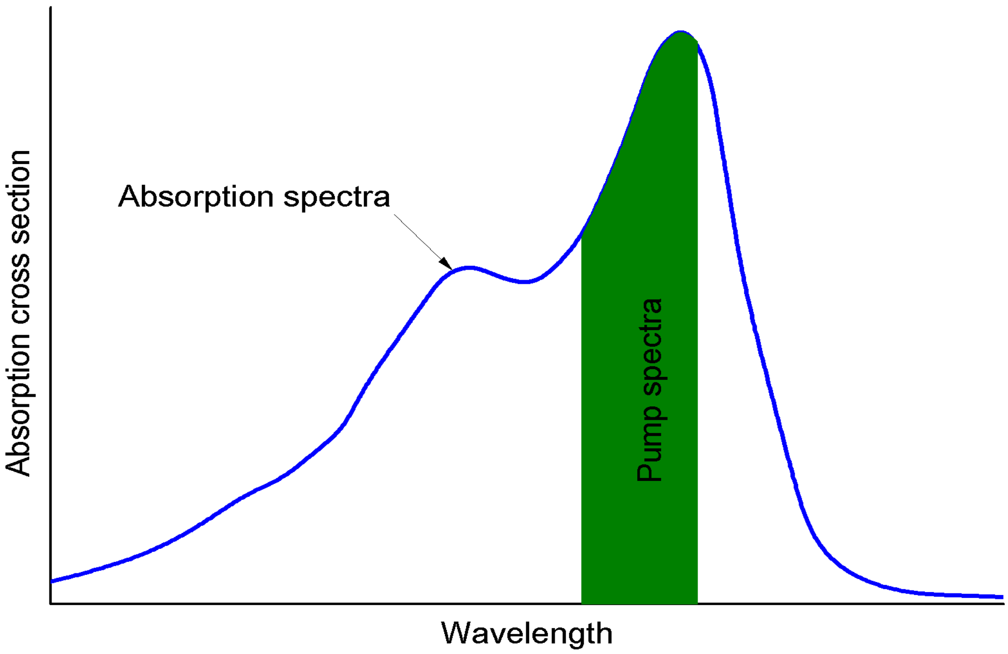


Fig. 11. Pump and absorption spectra overlap

Configuration

In this window (Fig. 11) the following parameters can be set:

- active media shape (slab-like or cylinder-like)*
- active media dimensions: length (La, cm), width (Lb, cm) and height (Ld, cm) for the slab, diameter (DIA, cm) for cylinder
- physical cavity length (Lc, [cm])
- output coupler reflectivity (R_{oc},[100%])
- intrinsic resonator losses (g_c,[100%])
- active element dissipative losses (g_a, cm^{-1}), including variable losses (Fig. 12) to allow for intracavity losses dynamics in pump pulse width time scale. To set variable losses press button next to dissipative losses field.
- lasing and pumped area overlap efficiency (η_{ov})
- magnification of intracavity telescope (TM).

* Active media in LasKin corresponds to the optically pumped volume

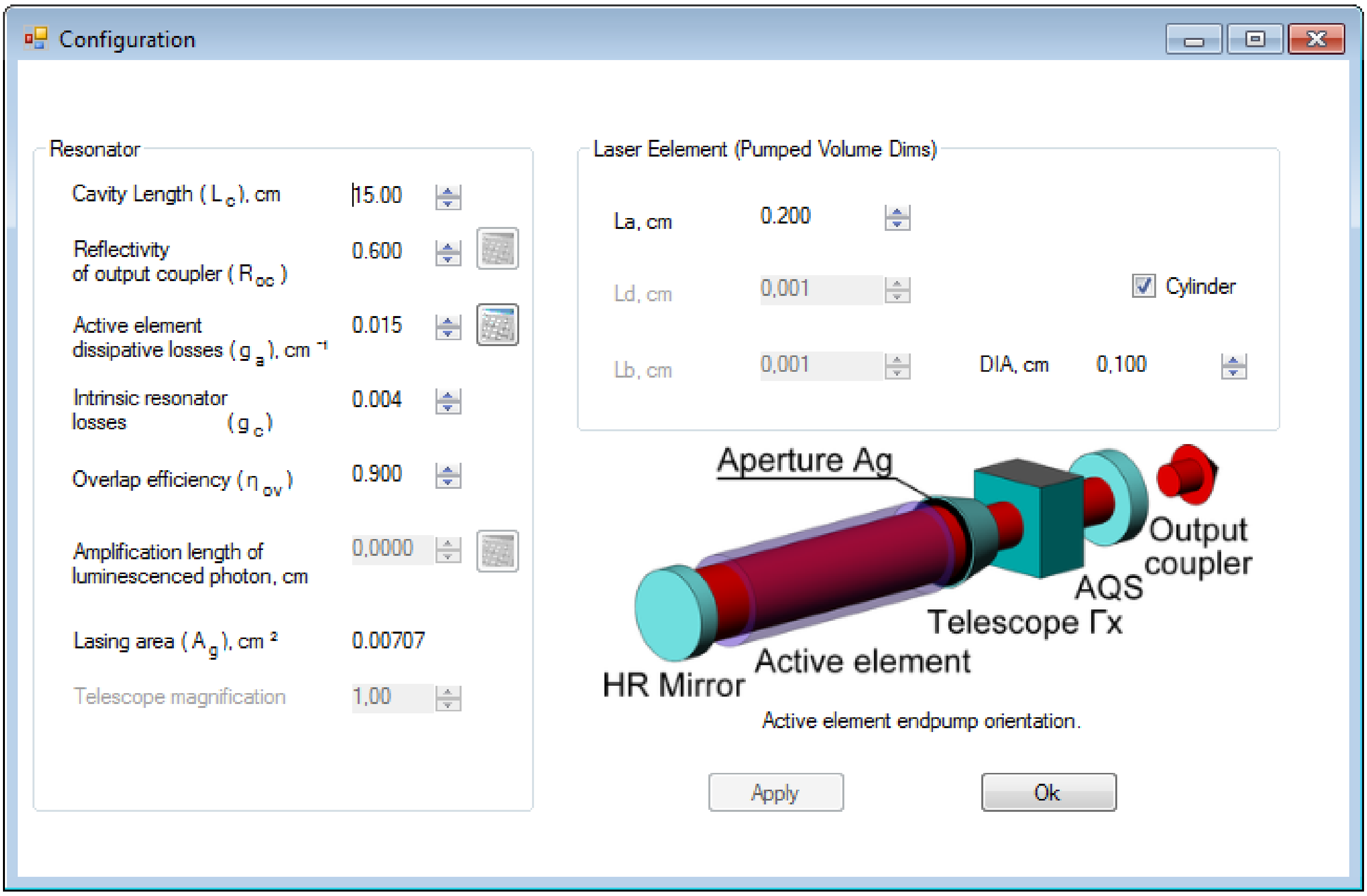


Fig. 11. “Configuration” window

To simulate possible changes of intracavity losses while pump pulse is applied (thermal lensing, depolarization etc.,) one can set the changes by points array. It can be loaded from file, where Time and Losses values should be separated by space or tabulation symbol and each point starts at a new line.

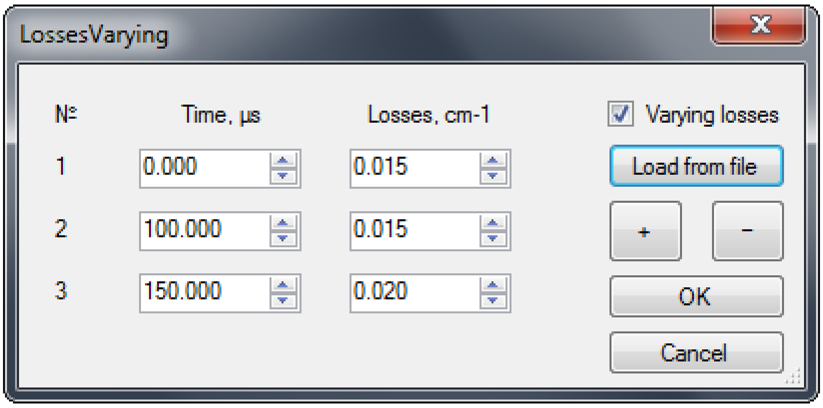


Fig. 12. Variable losses window

Additional buttons for the output coupler reflectivity and amplification length of luminescence photon are available for modeling of lasers operating at secondary lasing transitions (like $^4F_{3/2}$ — $^4{}_{13/2}$) for Nd:host lasers) and will be discussed later.

Pump

Pump parameters (type of pumping scheme), pump pulse duration (τ_p, [μs]), pump power (W_p, [W]), pump wavelength (λ_p, [nm]), Pump coupling optics efficiency (η_c,[100%]) etc.) can be set in this window (Fig. 13).

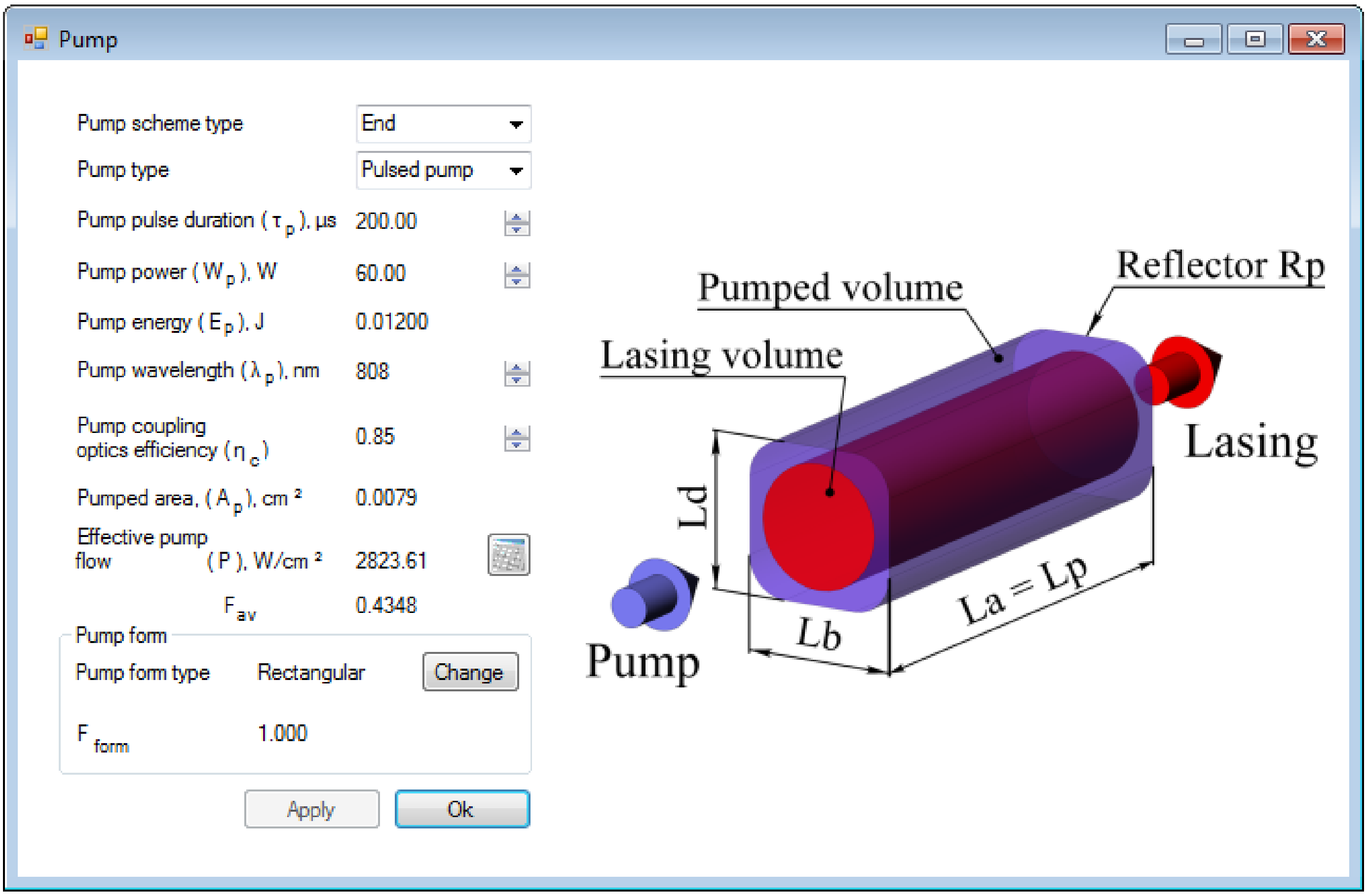


Fig. 13. "Pump" window

LasKin uses averaged effective value of Pump flow . Details of averaging procedure and values of some additional parameters are provided in "Pump fluence averaging" window (Fig. 14). It can be opened with the button located next to Effective pump flow field.

Button <Change> in Pump form field opens window (Fig. 15), where you can choose the waveform of the pump pulse. Available waveforms are:

- Rectangular
- Trapeze, where you can set the pulse rise time
- Varying, where pump waveform can be defined by points in a similar way as were variable losses, described in the Configuration section above.

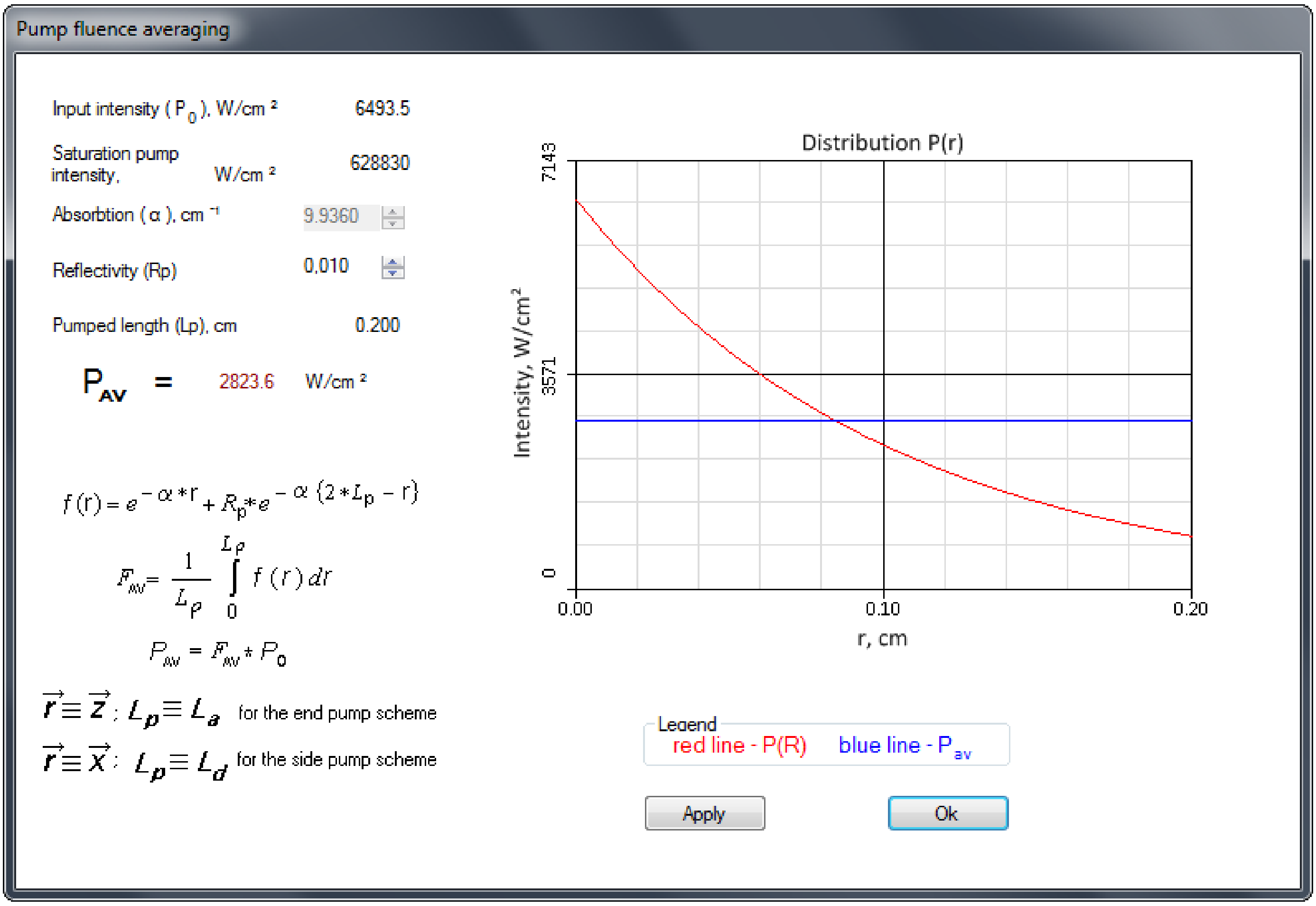


Fig. 14. “Pump fluence averaging” window

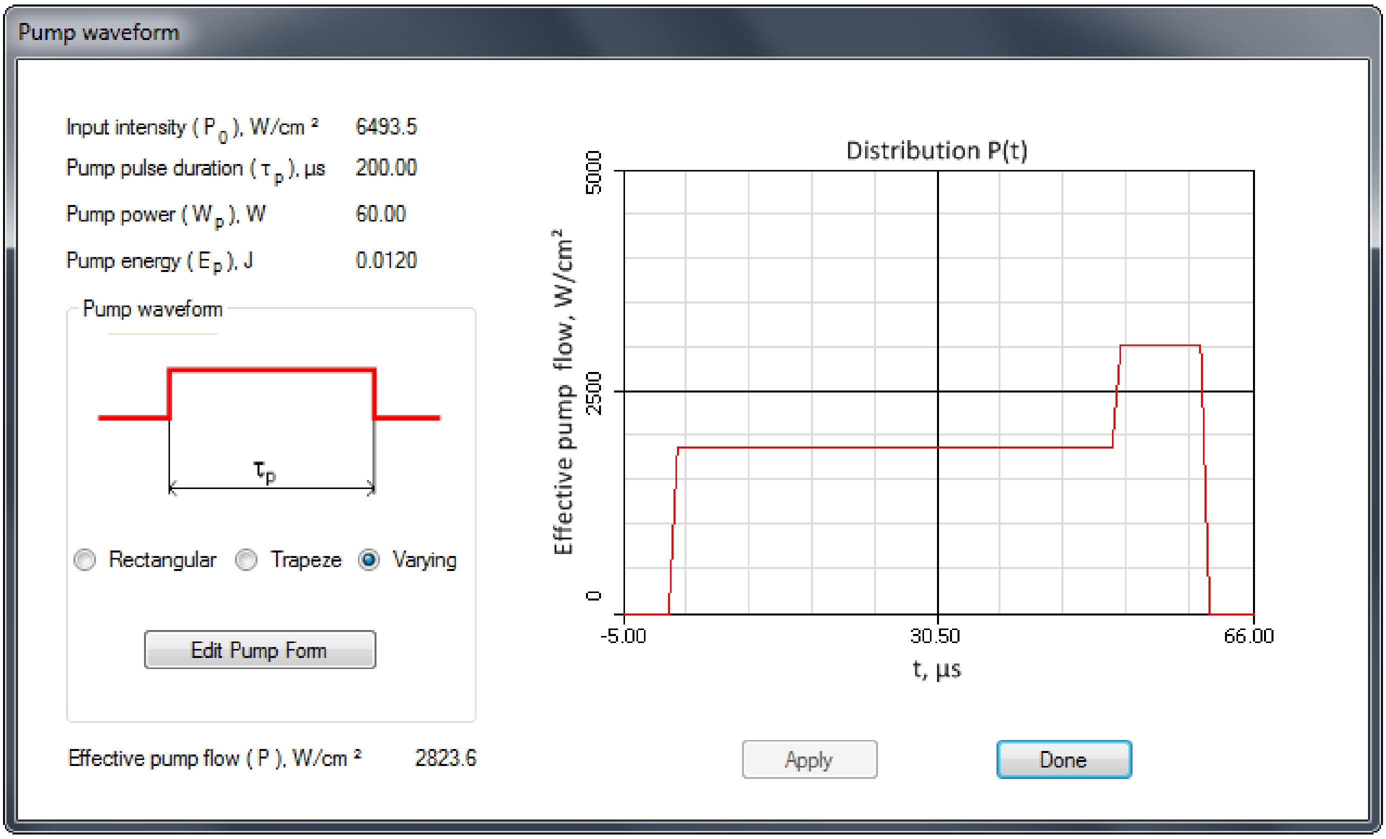


Fig. 15. “Pump waveform” window

Q-switch

To achieve giant laser pulses formation Q-switches are added into laser configuration. Active and passive Q-switches can be installed separately or simultaneously. Variable output coupling mode is also available with LasKin. It is realized as a type of active Q-switching. Q-switch window with installed active Q-switch is shown below (Fig. 16).

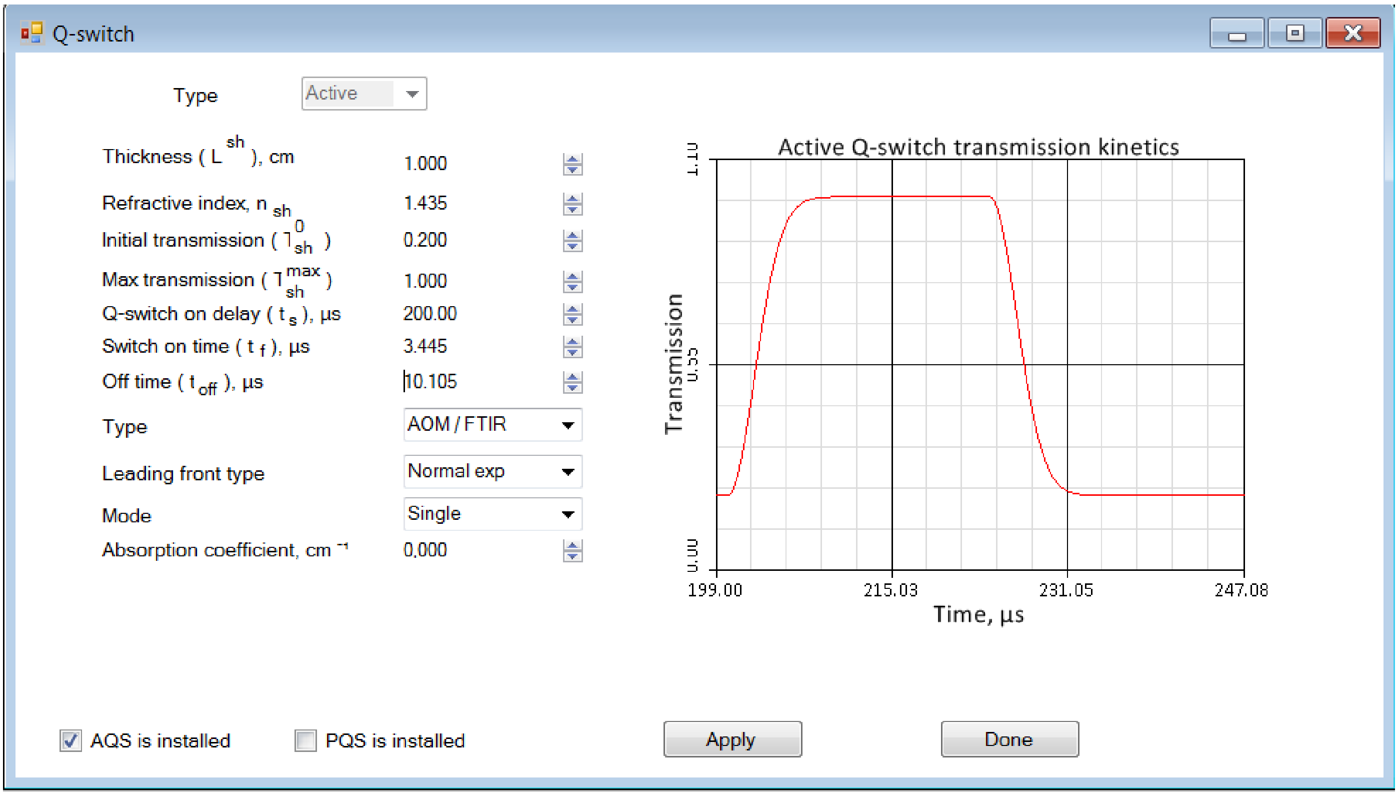


Fig. 16. Active Q-switch window .

Active Q-switch configurations available with LasKin 5 are listed below:

- AQS with round-trip Q-switch losses = (1-Tsh). In the Q-switch Type window it is called EO Q-switch type. An example of such a device is electro-optic Q-switch in quarter wave configuration. The value Tsh corresponds to transmission of light throughout polarizer, Pockels or Kerr Cell, retardation plate and backwards.
- AQS with full intracavity round-trip losses depending on squared value of current Q-switch transmission ($1\text{-}Tsh^2$). Examples of such type devices are the acousto-optic and FTIR* shutters and electo-optical Q-switches in half wave configuration.
- AQS in cavity with variable output coupling (VOC Q-switch mode).

* Q-switch based on Frustrated Total Internal Reflection

Variable Output Coupling Q-switch mode.

In Q-Switch window one can also choose variable output coupling mode (VOCI,II-modes). This modes mean to simulate situations when output coupling changes while lasing builds up. Equivalent output coupler consists of Q-Switch cell with variable transmission T_{sh} . It divides beam into transmitted and reflected parts with the ratio of $T_{sh}/(1-T_{sh})$ (Fig. 17). Cavity dumping mode is a particular case of VOC, with $T_{sh}^0 = 1$, $T_{sh}^{max} = 0$ for VOC-I scheme and $T_{sh}^0 = 0$, $T_{sh}^{max} = 1$ for VOC-II scheme .

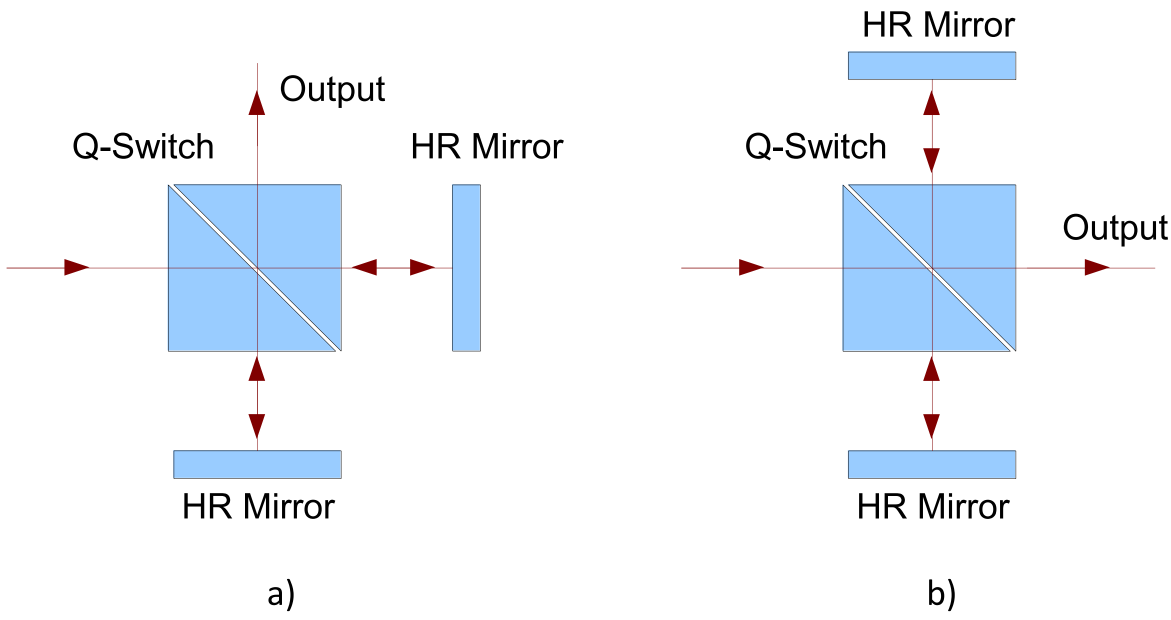


Fig. 17. a) VOC-I b) VOC-II scheme

Available temporal control modes of Q-switching are :

- Single – Q-switch activated once
- Frequency – Q-switch activated several times with defined period (frequency)
- Linear – Q-switch activated several times with defined period/frequency and Q-switch off-time changes linearly (defined by formula $T_{off} = a \cdot (t - t_s) + b$, where co-efficients a and b are defined by user).

Active Q-switch transmission function with full set of used parameters is shown in Fig.18:

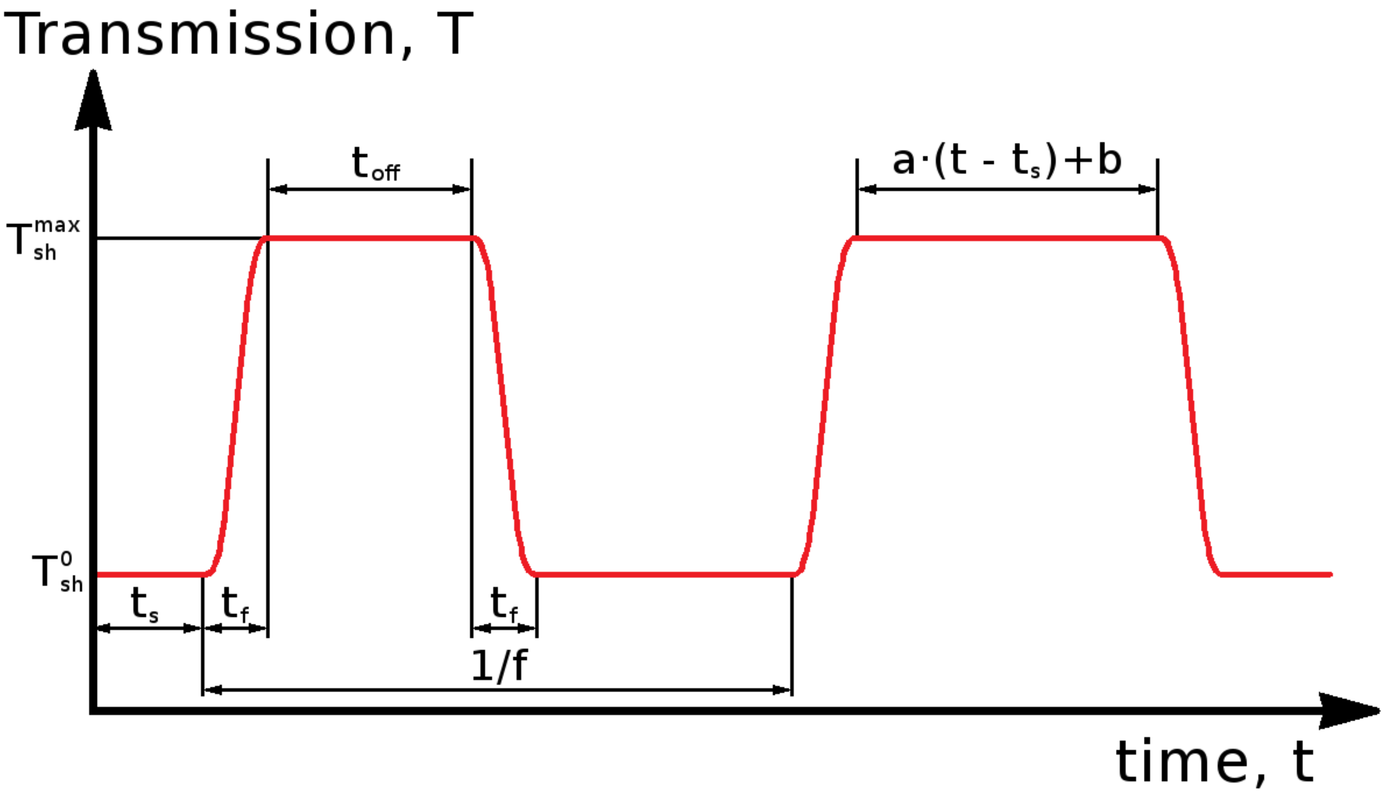


Fig. 18. Active Q-switch transmission function

Passive Q-switch

Passive Q-switches are used in lasers as light controlled shutters {PQS1-5}. Window for passive Q-switch PQS (Fig. 19) shows 4-level energy diagram for saturable absorber typical for widely used PQS based on Cr^{4+}: HOST crystals and allows for the following parameter settings:

- Geometrical thickness of the used PQS (L_{PQS}) [cm]
- refractive index (n_{QS})
- Initial transmission of the used PQS: $T_{sh}^{0} = \dfrac{I_{out}(t)}{I_{in}(t)} = T_{sh}^{D} \cdot T_{PQS}^{0}$

Where T_{sh}^{D} - passive Q-switch transmission caused by nonresonant dissipative losses g_s (nonresonant absorption and scattering in the used PQS volume). By default T_{sh}^{D} = 0 and this type of loss is accounted for as general intracavity dissipative losses (see window "Configuration"),

$T_{PQS}^{0} = T_{PQS}(Is = 0)$ is a resonant part of the PQS transmission for low average intra cavity intensity, Is = I+ + I- (summarized direct and backward photon flows I+ , I-)

- Decay time—decay time τ_{21}
- Cross section— absorption cross section for the transition from ground state σ_{gs}
- Figure of merit (or PQS contrast if T_{sh}^{D} = 0) FOM = σ_{gs}/σ_e = $\ln(T_{PQS}^{0}) / \ln(T_{PQS})$ (at saturation fluence)

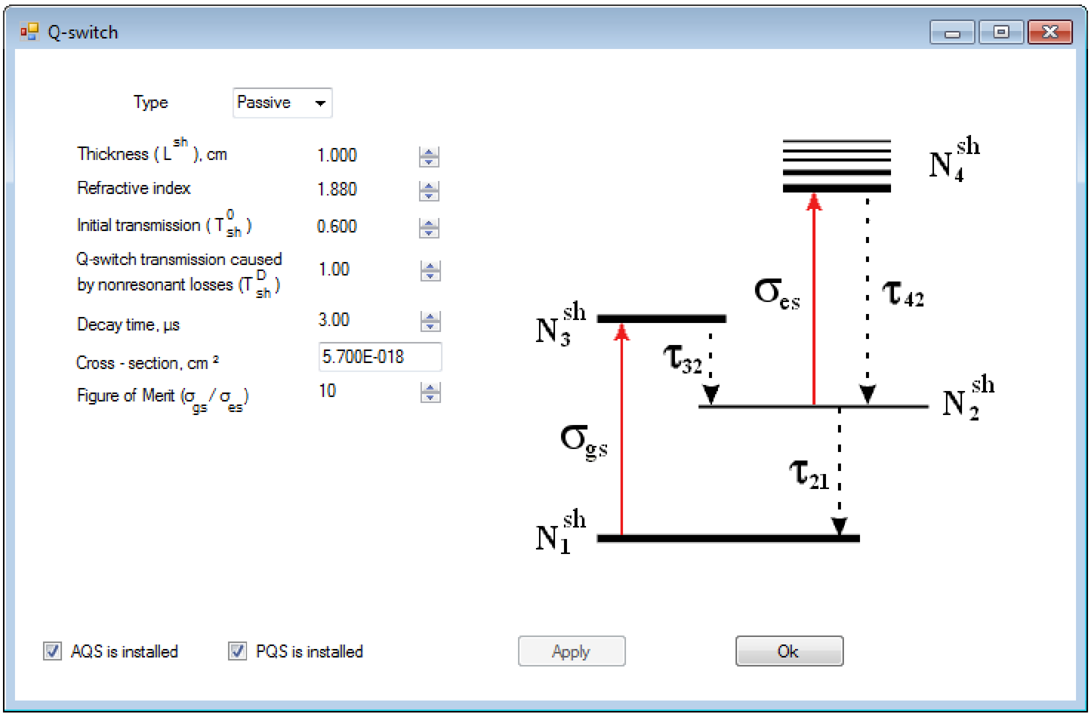


Fig. 19. Passive Q-switch window.

Special

In this window one can choose to calculate a dependence of selected output parameter on a certain input parameter. In order to use this option, activate checkbox “Show dependence function”. Select desired output parameter at “Value”, input parameter at “Depends on”. Set the range for the input parameter from the list and the number of points to calculate.

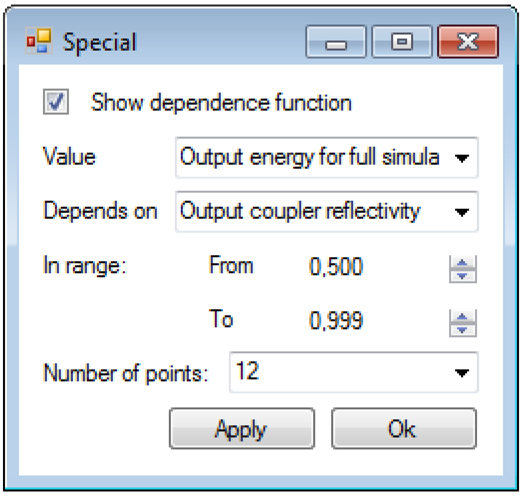


Fig. 20. “Special” window

Result

When all necessary parameters are set press Start button to start calculation. After completing, “Preview result” window is displayed (Fig. 21) . It contains calculated table of laser output parameters and general view of calculated lasing generation dynamics graphic (blue line) and inversion dynamics (red line).

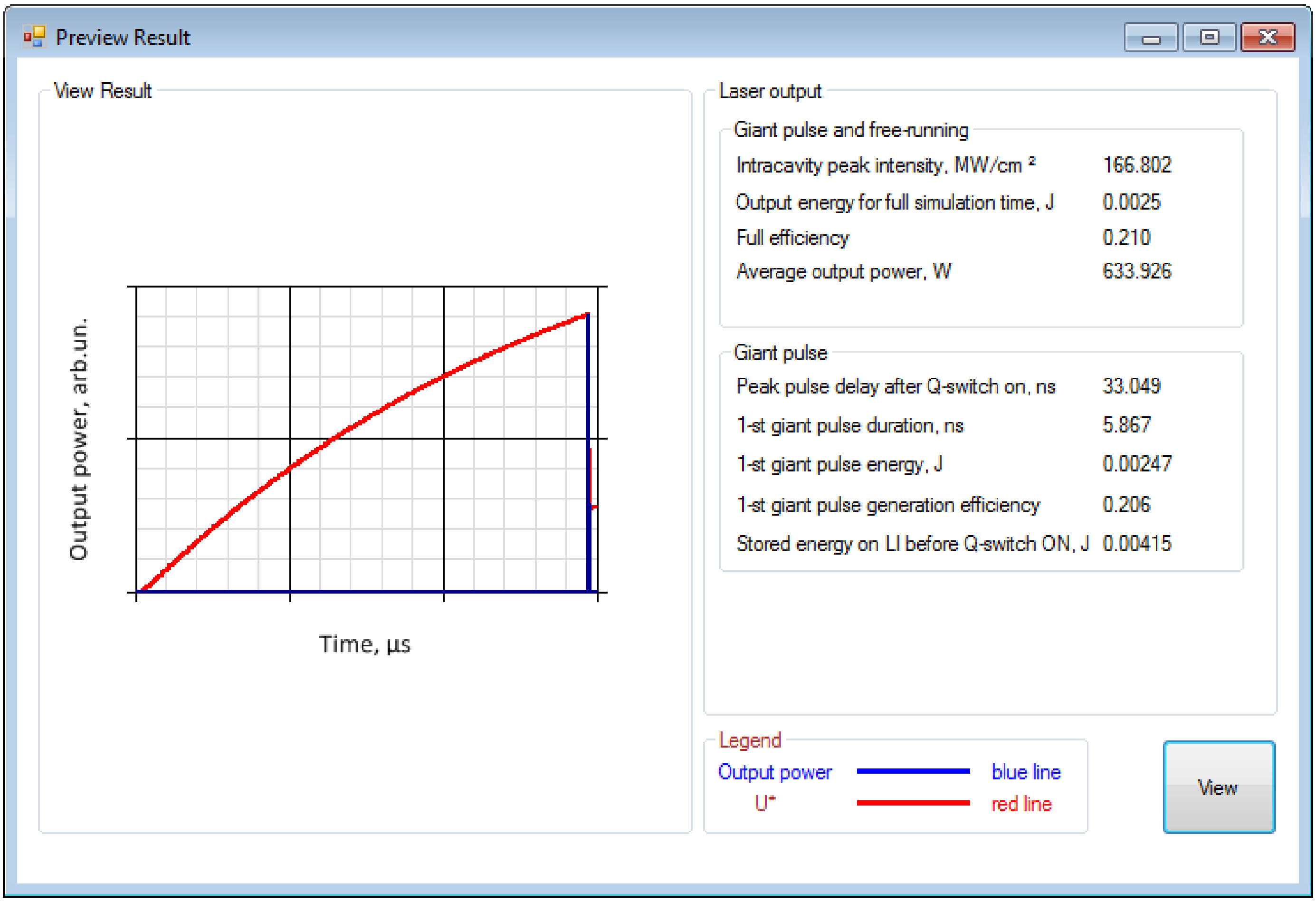


Fig. 21. “Preview result” window

By clicking on “View” button or double click on plot field “Result” window (Fig. 22) can be opened. There you can see detailed plot, zoom it, switch inversion plot to losses, Q-switch transmission or pump plot by clicking corresponding buttons, save calculated results and create report in Microsoft Word .

In “Result” window press <Save> to save matrix file with detailed calculated data, including temporal behavior of population, Passive Q-Switch transmission (if installed) and laser generation.

To build graphs in Origin:

Open Origin

Press File->Import->Single ASCII

In opened dialogue window select *.txt file type and open your matrix file.

Plot in "Result" window is provided with measure cursors used to measure amplitudes and time intervals in the plot.

When your mouse is placed over the plot you can change x-axes values range. One can drag plot or use mouse wheel to zoom over x-axis. Click <Option> button or double click on the plot field to open "Plot Option" window (Fig. 23) where you can set desired x, y values range.

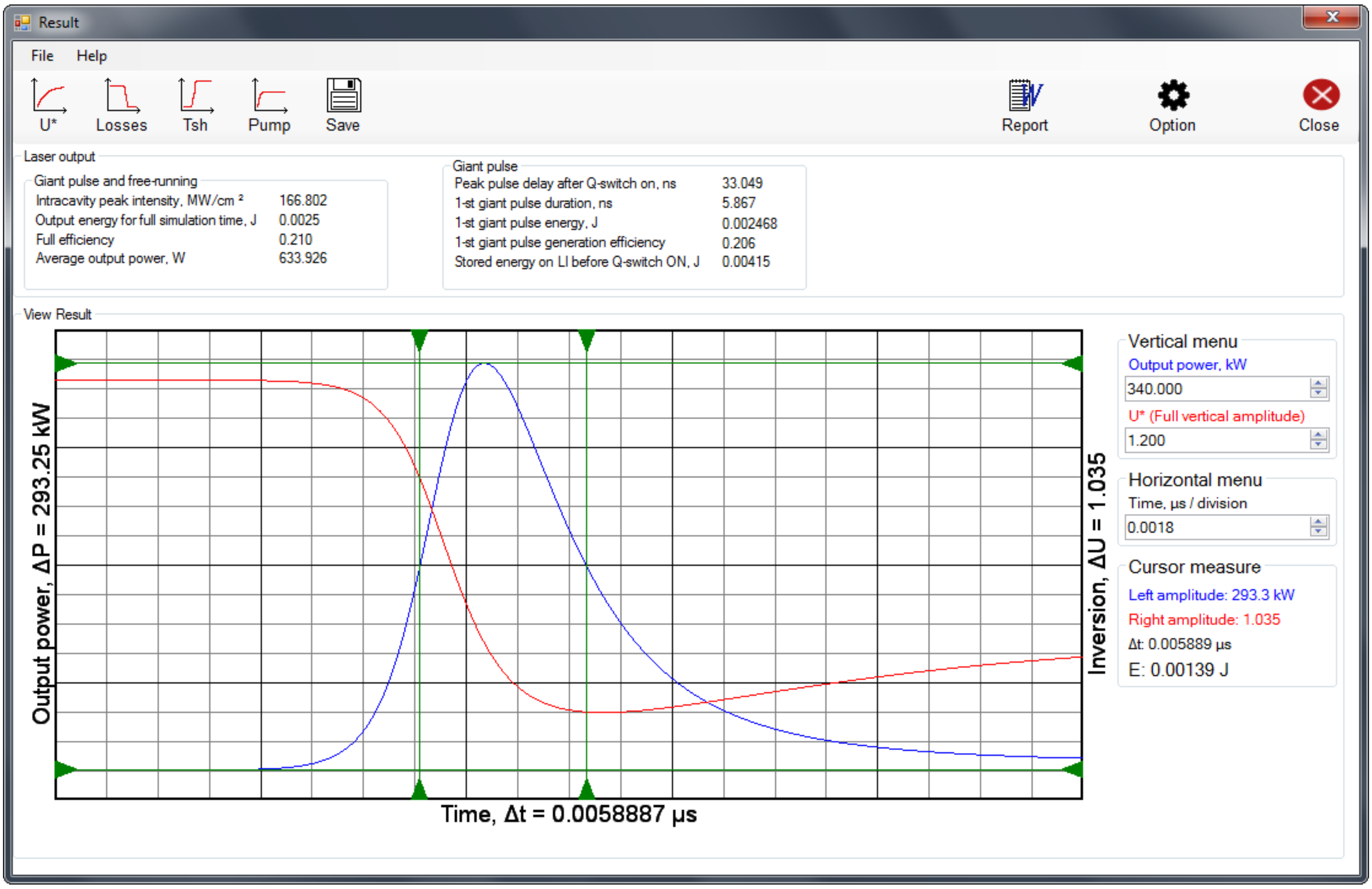


Fig. 22. "Result" window

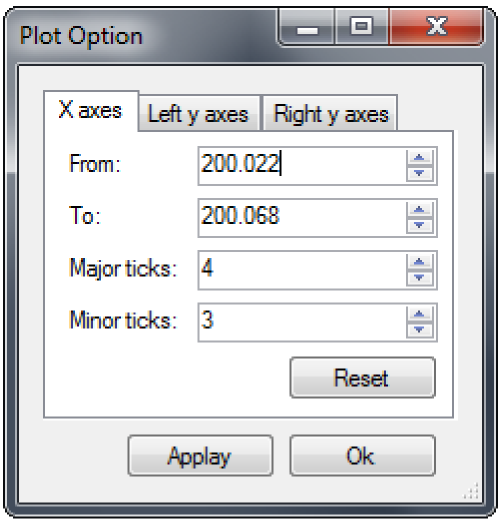


Fig. 23 "Plot Option" window

Additional features

In some cases lasing ions have a number of possible lasing transitions from metastable upper level to existing manifold of lower levels. The transitions differ in oscillator power (or value of stimulated emission cross section) and fluorescence wavelength. The strongest transition is called Main Transition. Lasing at the main transition wavelength is a winner in a competition for exited centers.

Secondary transitions are weaker in oscillator power. Lasing at these transitions takes place if selective losses suppress lasing at main transition. LasKin permits to evaluate possible competitive lasing for some simple cases.

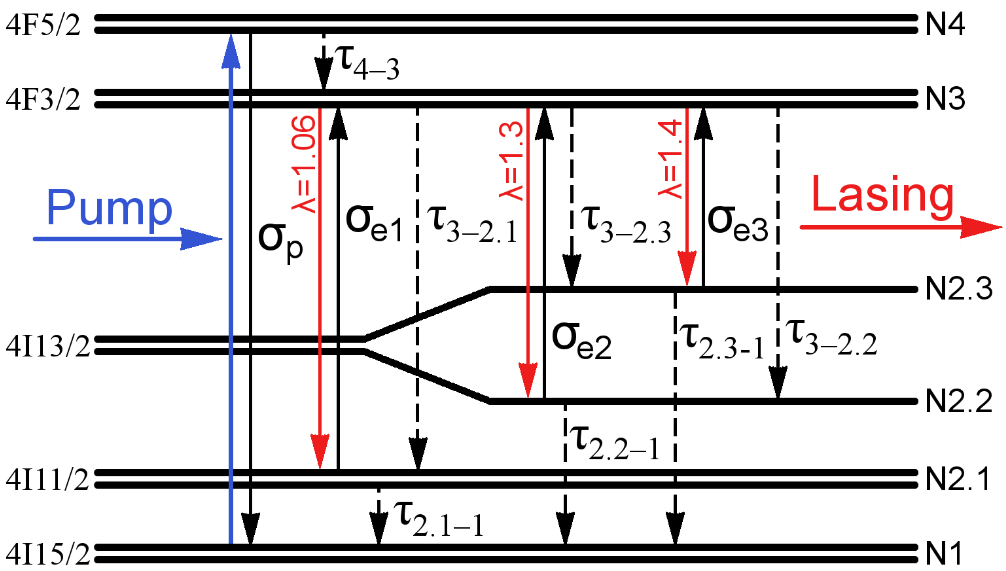
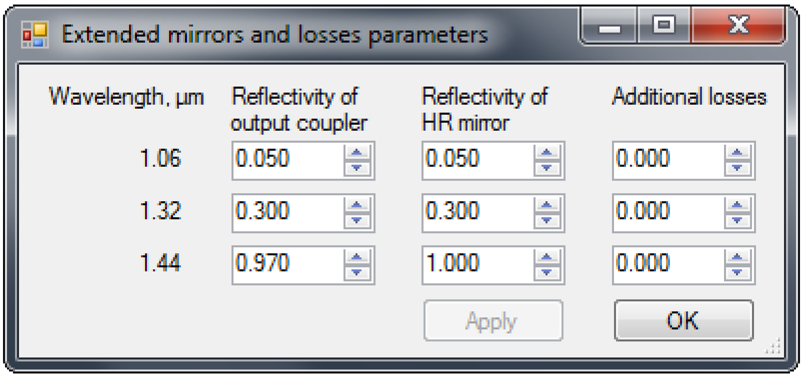


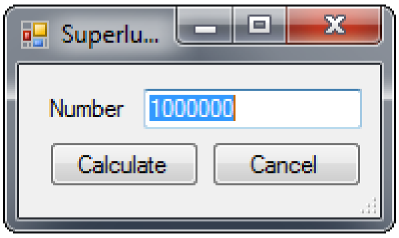
Fig. 23. Nd:host energy diagram with competitive lasing transactions

For instance Nd:host lasers can generate at main lasing transition $^4F_{3/2}$ level to $^4I_{11/2}$, λ~1.06 µm) and two secondary ones ($^4F_{3/2}$ -> sublevels $^4I_{13/2}$, at λ~1.3 µm and λ~1.4 µm).

To suppress lasing at main wavelength with introduced selective losses (Fig. 24 a) click the button next to Reflectivity of output coupler field in “Configuration” window. Even with suppressed generation superluminescence at competitive wavelength can significantly affect lasing efficiency. In order to properly consider superluminescence in calculation after active media dimensions been set click button next to Amplification length of superluminescenced photon field. In opened window (Fig. 24 b) set the number for statistical calculation (bigger number – more accurate calculation, default value is usually enough) and press calculate.



a)



b)

Fig. 24. Selective losses (a) and Superluminescence amplification length calculation (b) windows

Amplifier

For Nd:Host laser medium calculation of single pass and multi-pass amplifiers is available in LasKin 5. Scheme of circular multi-pass amplifier (number of trips more than 1) is shown in Fig. 25. It is a multi-pass ring scheme with variable transmission for output radiation at mirror M1 that serves as a beam splitter (polarizer, for instance). In this case a Pockels Cell installed after the amplifier can work as a variable retardation wave plate. It provides desirable dividing coefficient at polarizer - a ratio between the system output and the portion returned back to enter the pumped active media for the next pass. Phase shift and corresponding M1 transmission can be switched on/off or controlled with desirable algorithm by external optical or electrical signal including negative or positive feedbacks.

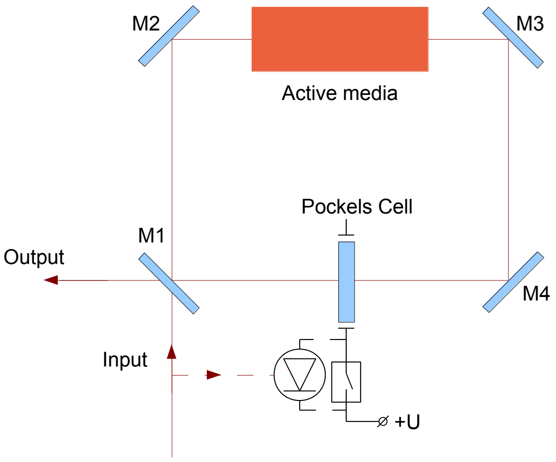


Fig. 25. Multi-pass ring amplifier scheme

In the "Amplifier" window (Fig. 26) one can set the length of full optical pass throughout the amplifier system. Parameters of pumped active element can be set in "Configuration" and "Laser Media" windows, as you do for Lasing calculation. For incident pulse you can set its energy, duration and choose waveform (Gaussian or Sinc^2). To calculate multi-pass mode activate "Multi-pass" checkbox and press "Define". In opened window (Fig. 26) you can set number of passes and transmission of M1 for each pass.

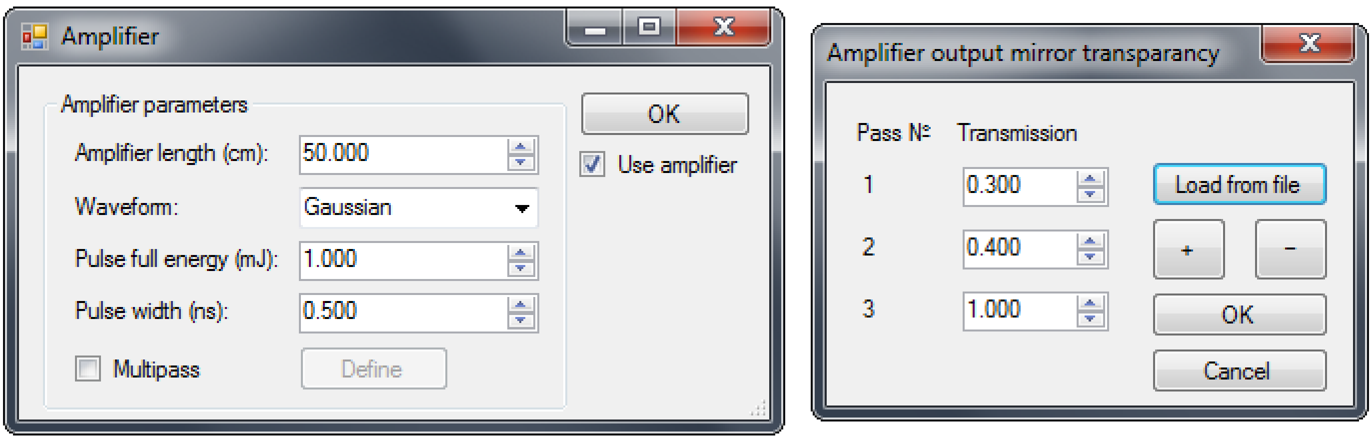


Fig. 26. "Amplifier" window and Amplifier multi-pass parameters window.

One can also load multi-pass parameters from file. File should contain transmission value for each pass separated by space or tabulation symbol.

Note: In multi-pass mode amplifier length should be at least 3 times longer than pulse length (pulse width x light velocity), otherwise pulse of different passes will overlap, which can lead to unreliable results. If this condition was not met you will get a Warning message (Fig. 27).

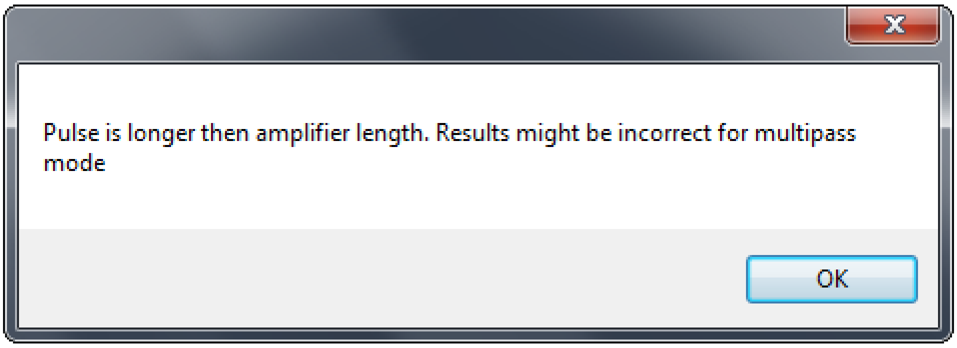


Fig. 27. Warning message.

When all parameters are set, press OK in “Amplifier output mirror transparency” and “Amplifier” window and press Start. After calculation “Amplifier result“ window (Fig. 28) with waveform and calculated parameters of input and output pulses will open.

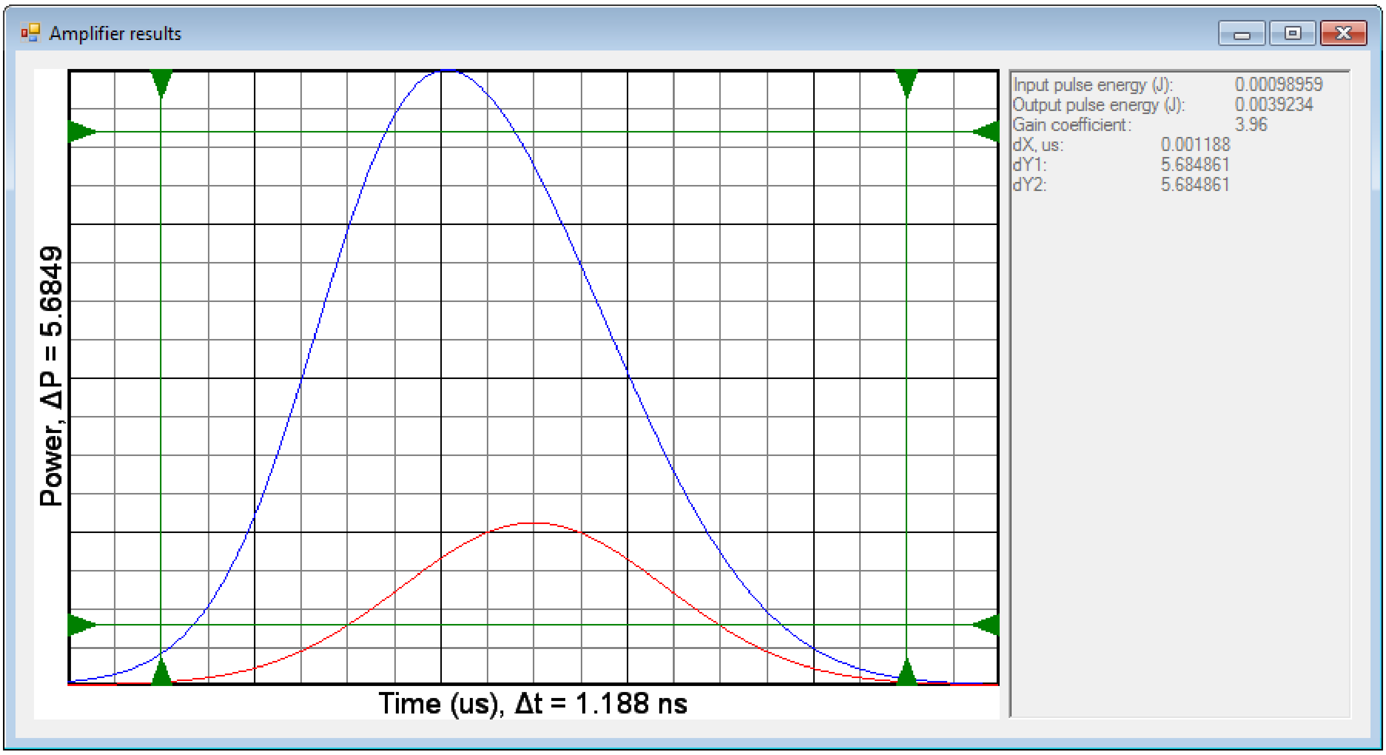


Fig. 28. “Amplifier results” window

Kinetic diagram, model and simulation

In this chapter general 4-level scheme with possible resonant transitions from sensitizer to lasing ions and for exited state absorption is described.

Kinetic diagram:

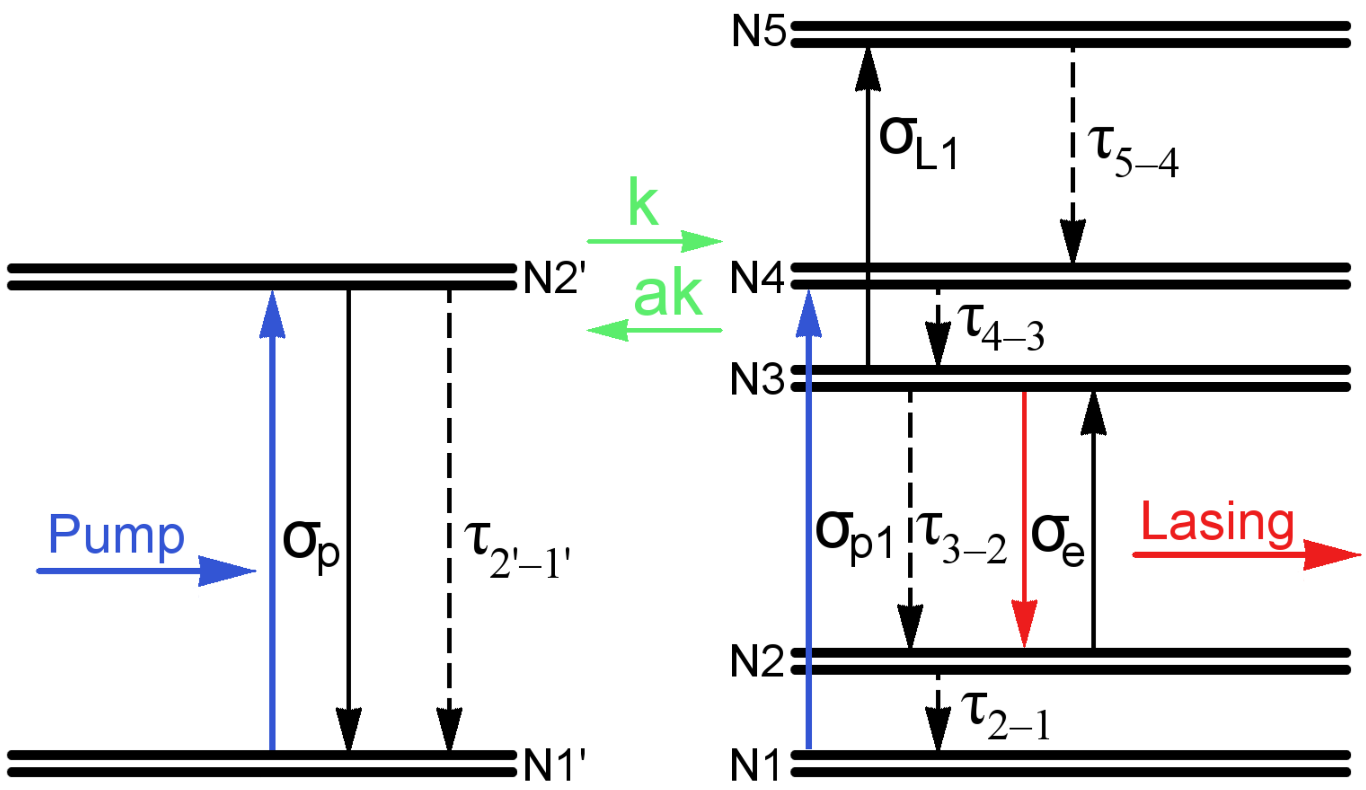


Fig. 29. Energy diagram of 7-level general lasing scheme.

Kinetic model of 4-level general lasing scheme with sensitizer and exited state absorption evaluation

Balance equation for absorption, transfer and relaxation processes that is shown in the energy diagram, can be written as follows:

$$\frac{\partial N'2}{\partial t} = \frac{a \cdot (N'1 - N'2)}{N_{Sion}\alpha} \cdot \frac{Wp \cdot Hc \cdot (-(Rp \cdot \exp(\alpha \cdot Lp) + 1) \cdot (\exp(\alpha \cdot Lp) - 1))}{V \cdot E_{pph}} -$$

$$- k \cdot N'2 \cdot N1 - g_{2'-1'} \cdot N'2 + A0 \cdot k \cdot N4 \cdot N'1$$

$$\frac{\partial N4}{\partial t} = k \cdot N'2 \cdot N1 - A0 \cdot k \cdot N4 \cdot N'1 - N4 \cdot g_{4-3} + N5 \cdot g_{5-4} +$$

$$+ \frac{\sigma_{pump} \cdot (N1 - N4)}{\alpha} \cdot \frac{Wp \cdot Hc \cdot \left(-(Rp \cdot \exp(\alpha) + 1) \cdot (\exp(\alpha) - 1)\right)}{V \cdot E_{pph}}$$

$$\frac{\partial N3}{\partial t} = N4 \cdot g_{4-3} - N3 \cdot (g_{3-2} + g_{3-1}) -$$

$$- I \cdot \left(\sigma_e \cdot (N3 - m0 \cdot N2) + \sigma_{L1} \cdot (N3 - N5)\right)$$

$$\frac{\partial N2}{\partial t} = N3 \cdot g_{3-2} + I \cdot \sigma_e \cdot (N3 - m0 \cdot N2) - g_{2-1} \cdot N2$$

$$\frac{\partial N5}{\partial t} = I \cdot \sigma_e \cdot (N3 - m0 \cdot N2) - N5 \cdot (g_{5-4} + g_{5-1})$$

$$\frac{\partial I}{\partial t} = \frac{La}{L_{c\_opt}} \cdot v_c \cdot I \cdot \left(\sigma_e \cdot (N3 - m0 \cdot N2) - \sigma_{L1} \cdot (N3 - N5)\right) - \frac{I - S0}{\tau_c}$$

Where:

$$\alpha = \frac{a \cdot (N'1 - N'2)}{N_{sion}} + \sigma_{pump} \cdot (N1 - N4)$$

N_i — population of working ions level i [cm^{-3}];

$N`_i$ — population of sensitizer ions level i [cm^{-3}];

N_{sion} — population of sensitizer ion [cm^{-3}];

a — pump absorption coefficient [cm^{-1}];

σ_{pump} — exited state pump absorption cross section [cm^2];

Wp — pump power [W];

Lp — pumped length [cm];

V — active media volume [cm^3];

E_{pph} — pump photon energy;

k — energy transfer parameter;

A_0 — relative coefficient of energy back transfer from working ion to sensitizer ion;

$g_{i\text{-}j}$ — decay rate from level I to level j [s^{-1}];

I — lasing photon density [photons/s×cm^2];

σ_e — emission cross section of lasing transition;

m_0 — degeneracy parameter;

σ_{las_abs} — exited state lasing absorption cross section [cm^2];

L_a — length of active media [cm];

L_{c_opt} — optical length of resonator [cm];

v_c — light velocity [cm/s];

S0 — initial luminescence density;

τ_c — intracavity photons lifetime

For linear resonator scheme

$$\tau_c = \frac{2 \cdot L_{c\_opt}}{v_c} \cdot \frac{1}{-\ln(R_{oc} \cdot T_{sh}(t)^2 \cdot (1-g_c)) + 2 \cdot g_a \cdot L_a};$$

R_{oc} — reflectivity of output coupler;

T_{sh} — Q-switch transmission;

g_c — intrinsic resonator losses;

g_a — active element dissipative losses [cm^{-1}].

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