

Laboratory work No. KE – 3

Research of the passively Q-switched Nd:YAG laser

Methodical instructions



Attention! Laser radiation sources are used during work – it is necessary to familiarize and strictly follow the respective rules of safety



It is necessary to use laser safety goggles

Purpose of the experiment

Investigate the passively Q-switched Nd:YAG laser operation and measure its radiation characteristics.

Experiment tasks

1. Align the Nd:YAG laser without the passive Q-switch using the laser diode module.
2. Determine the free-running mode threshold energy.
3. Measure the generated laser pulse energy dependence on pump energy.
4. Insert Cr⁴⁺:YAG passive Q-switch which has 80% transmittance in the laser resonator and determine the Q-switching mode threshold energy.
5. Measure the generated “giant” pulse energy dependence on the pump energy.
6. Determine pump energies at which laser generates 1, 2, 3 or 4 “giant” pulses.
7. Determine temporal duration between 1st and 2nd, 2nd and 3rd pulses dependence on the pump energy at the pump energy interval when laser generates 2 and 3 “giant” pulses.
8. Repeat tasks 4 - 7 with passive Q-switch Cr⁴⁺:YAG crystals which have 60% and 40% transmittance.

Theoretical topics

1. Energy levels of the Nd:YAG laser.
2. What is laser Q-switching?
3. Active and passive Q-switching.
4. Principles of Cr⁴⁺:YAG passive Q-switch operation.
5. Laser peak power.
6. Dynamics of pulse generation in the Q-switched laser.
7. Spectral parameters of a Q-switched laser. Differences between actively and passively Q-switched laser.

Energy meter (Pyroelectric PE25-C sensor)

Software guide


Preparation of the energy meter for work.

Connect the sensor to the sensor input on the USB interface PULSAR. Connect the PULSAR device to the computer via USB. Connect the 12V power cable to the main line and to the 12VDC input on the device. The POWER/LINK LED lights.



Fig. 1: Laser energy meter.

Software instructions

Start the StarLab application by clicking the StarLab icon  on the desktop. The main window and **Select Device(s)** window are opened. Select the device to be used by clicking in the choice box. Then press **Together** or **Separated**.

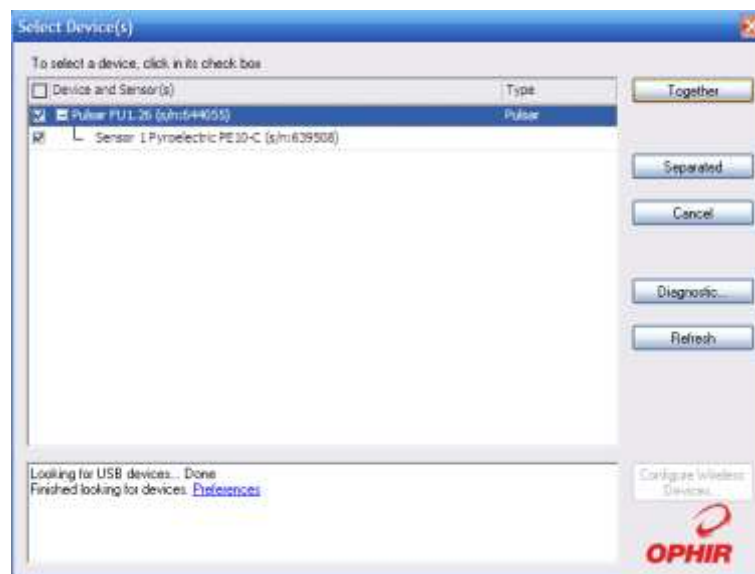


Fig. 2: Selection window of the energy meter detector.

The application window with **Channels**, **Channel ... Measurement**, **Statistics**, **Data Logging** and **Graph setup** tabs opens. In **Together** mode when more than one device is selected, each device gets a channel, but they appear together in one graphic window. In **Separated** mode each device gets a separate graphic window. In **Together** mode a user can also create an additional channel to perform mathematical operations with the measured data (press **Add Math Channel**). In the **Settings** tabs a user can select to measure a power or an energy (in this case **Measuring: Energy**), set the wavelength (**Wavelength: 1064 nm**), the range of measurement (**Range**), the pulse duration (in this case set **Pulse Width: 1 ms**). In the numeric display tab (**Channel ... Measurement**) energy meter readings are displayed as numeric value. In the graph display tab the energy meter readings are displayed as a plot. In the graph display settings tab (**Graph Setup**) a user can set various display parameters: time limits, the energy range.

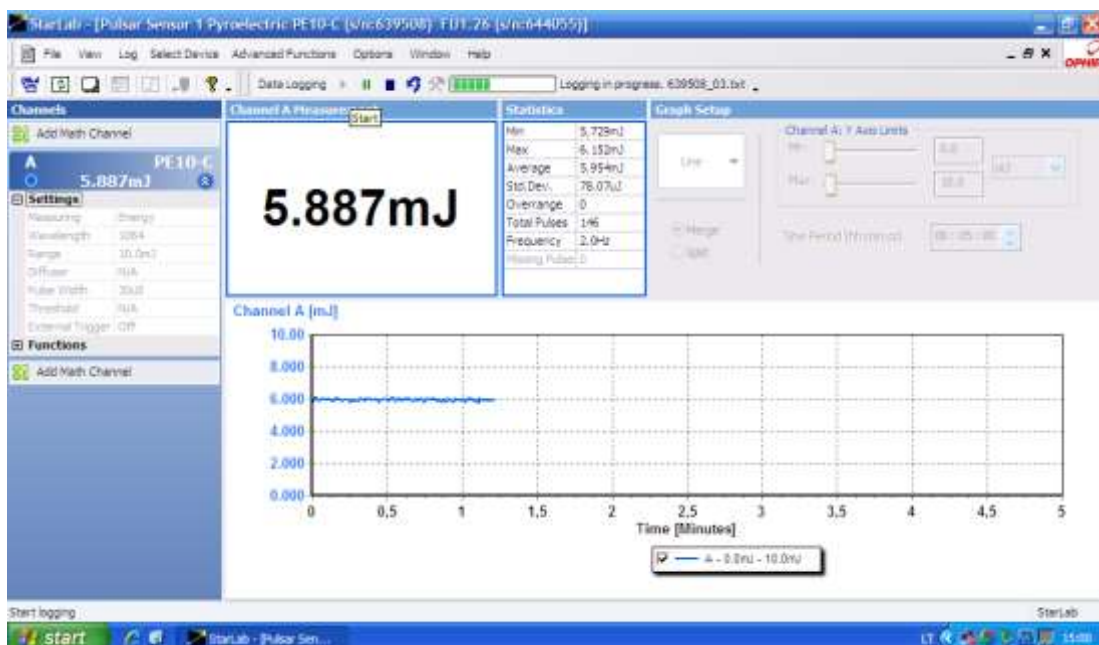



Fig. 3: Main **StarLab** window.

In the statistics tab (**Statistics**) are displayed: **Min** - the minimum measurement taken, **Max** – the maximum measurement taken, **Average** – the average measurement taken, **Std. Dev.** – the standard deviation value, **Overtime** – the number of readings that were over the maximum value for the chosen range, **Total Pulses** – the total number of measurement taken, **Frequency** – the frequency at which the laser is firing and **Missing Pulses** - the number of missed pulses when using the External Trigger. In the registration tab (**Data Logging**) the registration file is configured and data registration is launched/stopped.

The average value (**Average**) should be use for measurements. The new measurement is started by pressing . The measurement range (**Range**) is set during the measurement. The measured pulse energy cannot be higher than the maximum value for the chosen range or

lower than the maximum value for the lower range (Table 1).

Table 1. The measurement range and the corresponding pulse energies.

Range	Pulse energy to measure
200 mJ	>15 mJ
20 mJ	15 mJ – 1.5 mJ
2 mJ	<1.5 mJ

Experiment procedure

The experimental setup is shown in Fig. 4. The laser medium is a Nd:YAG rod ($\text{\O}4 \times 65$ mm size) with 1.1% Nd^{3+} concentration. The laser rod is pumped with a xenon flash-lamp INP - 5/60. The laser resonator consists of a flat mirror V1 with high reflectivity (99.6%) and a flat output coupler V2 with 55% reflection coefficient. To achieve polarized laser radiation, the dielectric polarizer (DP) is placed in the resonator. It is oriented such that the electric field vector of the generated light oscillates in the horizontal plane. For the passive Q-switching saturable absorbers Cr^{4+} :YAG (PM) are used. The modulator switch in the laser allows to change saturable absorbers (PM) which have different transmittance.

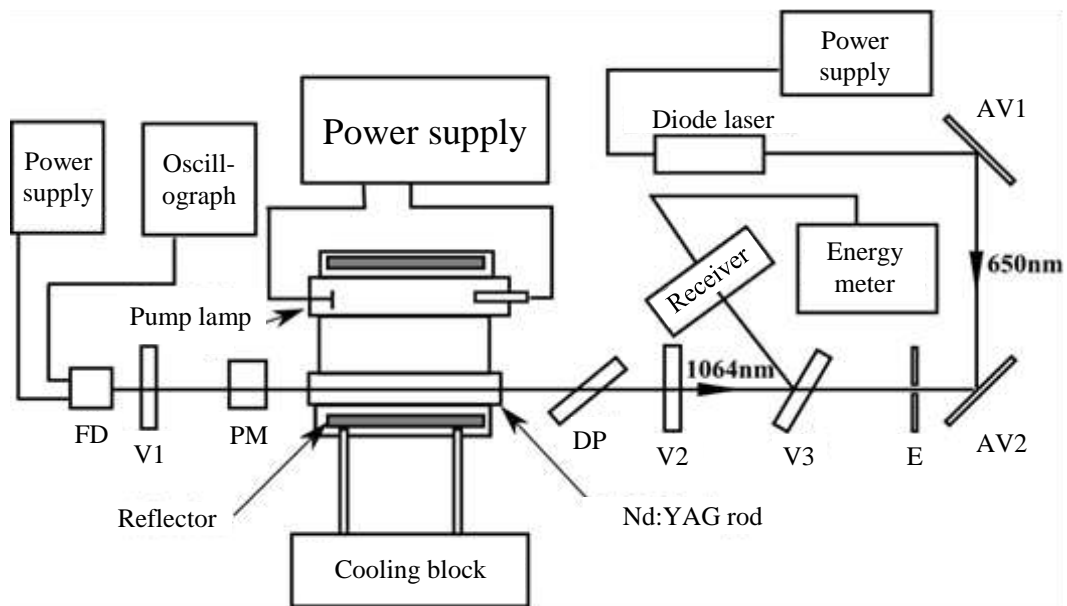


Fig. 4: Principal view of experimental setup.

The generated laser radiation, after passing the output coupler and reflected from the highly reflective (99.6%) mirror V3, is directed to the energy meter detector (Fig. 3). The sensor measures energy of the generated pulses. A part of pump lamp and the generated laser radiation which leaves through mirror V1 goes to the photodiode FD - 24 K and is used for the estimation of the pump flash and generated laser pulses parameters and the indication of

the laser generation. An electric signal from the photodiode is observed in the oscilloscope screen.

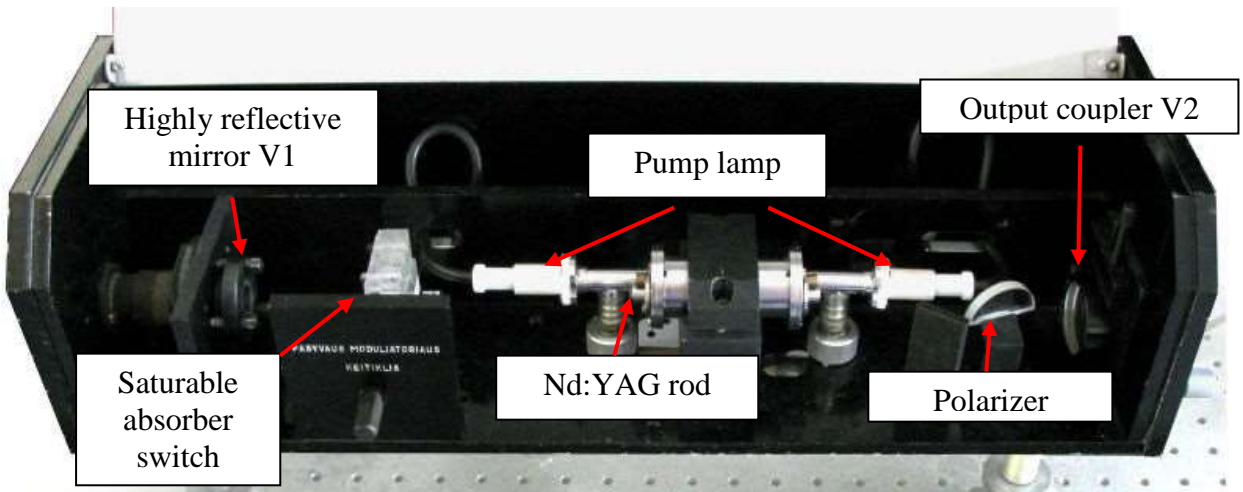


Fig. 5: The laser.

A laser diode module emitting 650 nm wavelength radiation is used for the alignment of laser mirrors. After reflection from two aluminium mirrors AV1 and AV2, the laser diode beam is directed to propagate along the axis of the laser resonator. The mirror V3 is transparent for 650 nm wavelength radiation while mirrors V1 and V2 are semi-reflective. The alignment of the laser is performed by observing positions of reflections from mirrors on the screen (E).

Turning on the laser:

1. Rotate the water valve which is connected to the laser cooling block.

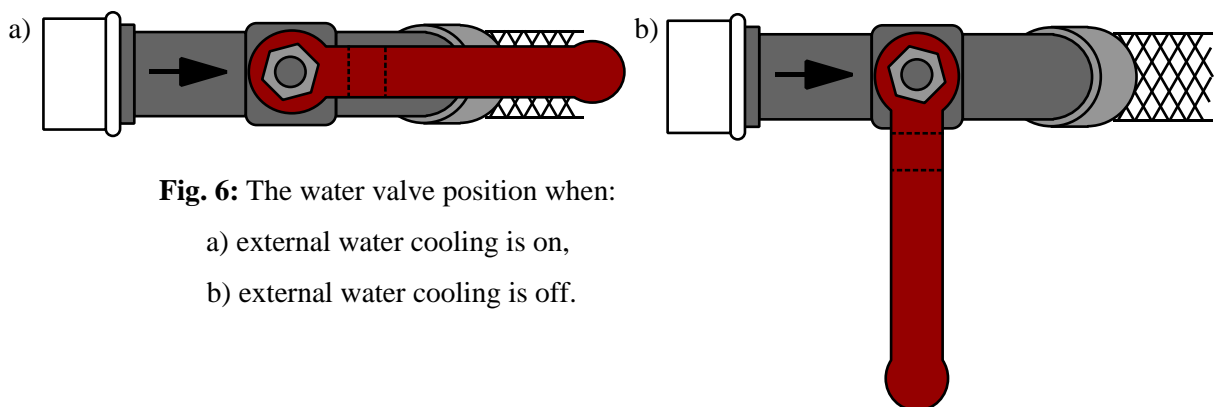


Fig. 6: The water valve position when:

- a) external water cooling is on,
- b) external water cooling is off.

2. Turn on the laser cooling block “PS 1222CO COOLING UNIT” with the “POWER” switch on the block.
3. Make sure that the water is circulating in the inner contour of the cooling block. Wait for ~1 minute until the pump starts pumping the water through the laser head.

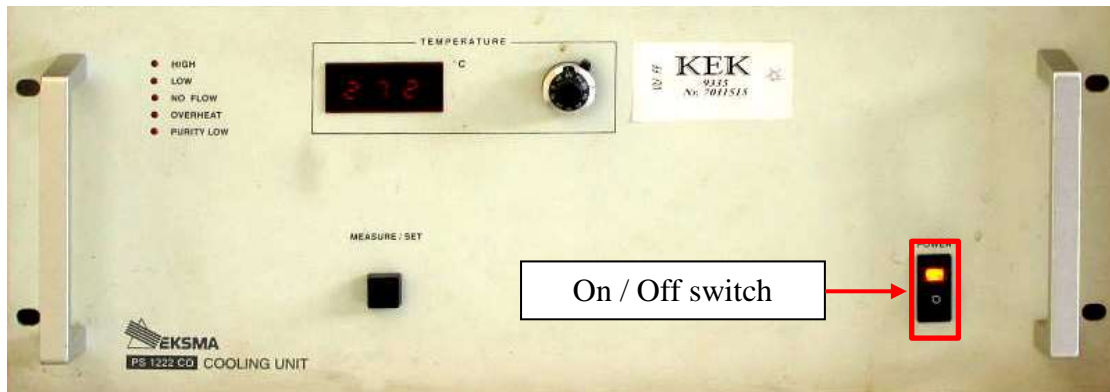


Fig. 7: The laser cooling block.

4. Connect the socket “Fotodiodo maitinimas 9V” which is on the laser block with the photodiode power supply box. Turn on the photodiode power supply by switching to the position “I”.
5. Turn on the oscilloscope.
6. Connect the socket "Fotodiodo signalas" which is on the laser block with the oscilloscope Channel 1 input socket.

1. Alignment of the Nd:YAG laser without a saturable absorber using the laser diode module.

Set the modulator switch to "0" position. Using two aluminium mirrors AV1 and AV2, direct the laser diode module beam so that it would propagate along the laser rod axis and would be perpendicular to highly reflective mirror V1 (in the experimental setup positions and orientations of aluminium mirrors AV1 and AV2 and positions of the screen E are aligned such that the laser diode module beam propagate along the resonator axis, so do not change their position if it is not necessary). The reflection from the parallel surface of the mirror V1 must match the pinhole on the screen through which the beam propagates. By using vertical and horizontal optical mount alignment knobs align the output coupler V2 so that a reflection from it would match the pinhole on the screen E.

2. Estimation of the free-running mode threshold energy.

Turn on the laser power supply unit “PS 5010 POWER SUPPLY” by pressing the “Power” switch. “READY” and “SIMMER ON” indicator lights should turn on at the front panel of the power supply. After setting voltage value to 400 V with the regulator knob “VOLTAGE SET”, press and hold button “TRIGGERING ON” for 2-3 seconds: periodic pump lamp flashes should start. Then increase the voltage value (do not exceed 950 V) until the laser generation starts.

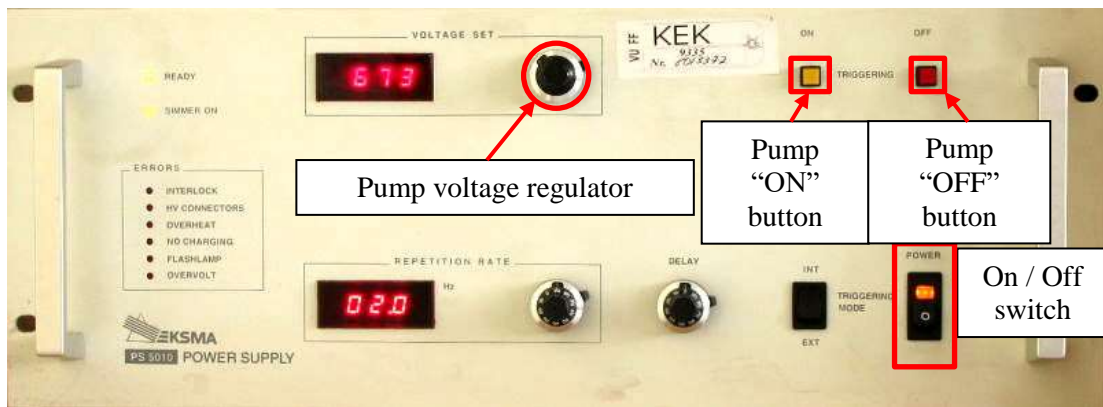


Fig. 8: The laser power supply unit.

Initially, only the pump flash pulse is observed on the oscilloscope screen. When the laser generation starts, a short laser pulse adds to the pump pulse. In the trigger menu (“Trig menu” button) select CH1 and using the trigger “Level” knob set the appropriate level. Using “VOLTS/DIV” and “SEC/DIV” regulator knob can be set the resolution of the amplitude and the time. By clicking “ACQUIRE” select the single pulse sampling (“SAMPLE”). The registration is launched/stopped by clicking “RUN/STOP” buttons.

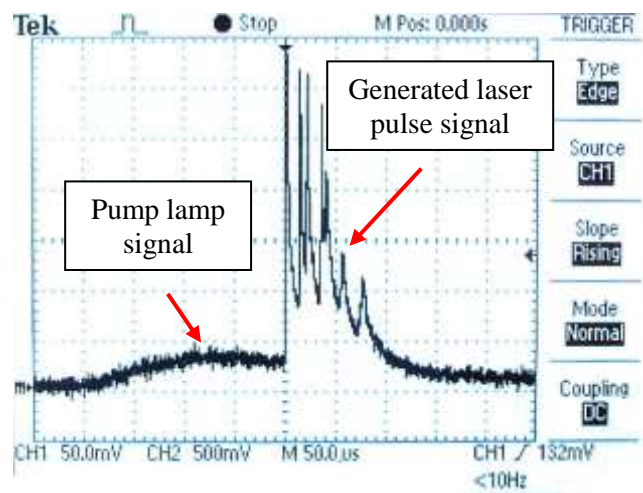


Fig. 9: Laser pulse signal observed on the oscilloscope screen.

When laser generation is achieved, adjust the output coupler (by rotating the optical mount vertical and horizontal alignment knobs) such that the short laser pulse would be maximized. Then decrease the pump voltage just above the limit when laser pulse is still visible on the oscilloscope screen and align the output coupler again. Repeat align of the output coupler until the lowest pump voltage, for which the laser pulse is still observed on the oscilloscope screen, will be reached. This is the threshold voltage U_{sl} of the laser free-running mode. If the laser generation disappear, increase the pump voltage until the laser generations occurs again.

3. Measurement of the generated pulse energy E_L dependence on the pump energy E_k .

Tune the pump voltage by 20 V steps up to 900 V. Using the energy meter measure the generated laser pulse energy. The pump pulse energy is calculated using this formula:

$E_k = \frac{CU^2}{2}$, here C – the capacitor battery capacity (in this case $C = 100 \mu\text{F}$), U – the capacitor voltage which is set with the regulator. Depict the results graphically.

4. Insert the Cr^{4+} :YAG passive Q-switch modulator which has 80% transmittance in the laser resonator and determine the Q-switch mode threshold energy.

Set the modulator switch to the position “1” to insert the Cr^{4+} :YAG saturable absorber which has 80% transmittance in the laser resonator. Increase the pump voltage (do not exceed 950 V) until the “giant” pulse generation occurs. Then align the output coupler and decrease the pump energy until minimum the pump energy will be reached at which “giant” pulse generation is observed. This is the threshold energy for giant pulse generation – Q-switch threshold energy.

5. Measure the generated “giant” pulse energy dependence on pump energy (tasks 5-7 can be performed simultaneously).

Measure the dependence of the generated laser pulse energy E_L on pump energy E_k . Tune the pump voltage by 3-4 V steps (do not exceed 950 V) until a generation of 5 “giant” pulses is achieved. Tune pump voltage by 1-2 V steps at the threshold pump energy values when 1 or 2, 2 or 3, 3 or 4, 4 or 5 pulses are observed. The energy of generated pulses is measured using the energy meter.

Graphically depict the generated pulse energy dependence on pump energy.

6. Determine pump energies at which laser generates 1, 2, 3 or 4 “giant” pulses.

The part of the pump lamp light and the generated laser radiation goes through mirror V1 to the photodiode FD - 24 K and is used for the estimation of the pump flash and the generated laser pulse parameters and the indication of the laser generation. The electric signal from the photodiode is observed on the oscilloscope screen. When the pump energy is increased, only one “giant” pulse is observed initially, further there is a pump energy range where 1 or 2 “giant” pulses are observed, afterwards a stable generation of 2 “giant” pulses is observed and so on.

7. Determine temporal distance between 1st and 2nd and 2nd and 3rd pulses dependence on pump energy at the pump energy interval when laser generates 2 and 3 “giant” pulses.

The electric signal from the photodiode is observed on the oscilloscope screen. Tune pump voltage by 3-4 V steps. When measuring temporal distances between 1st and 2nd and 2nd and 3rd pulses, click the “ACQUIRE” button on the oscilloscope and select “Average”,

set it equal to 16 or 32. To stop the registration, click the “RUN/STOP” button. The single sequence registration is started with the “SINGLE SEQ” button.



Fig. 10: Measurement of temporal distance between pulses.

To set the temporal distance measurement mode, click the “CURSOR” button, then select “Time” using the “TYPE” button and “CH1” using the “Source” button. By changing positions of cursors with CH1 and CH2 “POSITION” knobs, determine the temporal distance between peaks of pulses (Fig 10). “Delta” indicated the temporal distance between cursor positions. Depict the temporal distance dependence from the pump energy graphically.

8. Repeat tasks 4 - 7 with passive Q-switch Cr^{4+} :YAG crystals which have 60% and 40% transmittance.

Set the modulator switch to the position “2” or “3” to insert in the laser resonator Cr^{4+} :YAG Q-switch crystals which have 60% or 40% transmittance respectively. Perform all measurements following the same instructions as were given for the 80% transmittance Q-switch crystal. Tune the pump voltage by 4-7 V steps for the 60% transmittance Cr^{4+} :YAG passive Q-switch and by 7-10 V steps for the 40% transmittance Cr^{4+} :YAG passive Q-switch until the generation of 5 “giant” pulses is achieved. In both cases do not exceed 950 V.

Literature:

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