Free-running and Q-switched Nd:YAG laser system, laser amplifier and second harmonic generation

Goals

- Set-up and optimize Nd:YAG laser system in free-running red. Find the optimal output coupler reflectivity for maximum output energy from the set of three mirrors. Perform measurements and comparisons of energetic, temporal, and spatial laser beam characteristics.
- Determine the amplification coefficient G of an optical single-pass Nd:YAG amplifier.
- Set-up and run Nd:YAG laser system in passive Q-switch mode. Measure energetic and temporal laser beam characteristics.
- Set the KDP crystal to achieve the generation of the second harmonic frequency in the Q-switch mode. Observe the change in second harmonic radiation intensity (conversion efficiency) on the shade with changing the angle of rotation of the KDP crystal.

Experimental setup

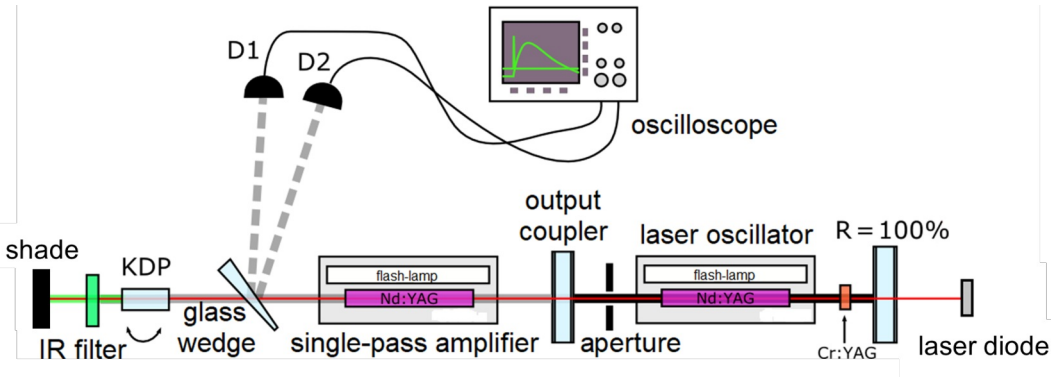

Figure 1: Simplified experimental setup.

Instructions

A) Laser characteristics in multi-mode free-running mode

1. Set up the center of laser crystal into the red laser diode beam.
2. Set up the laser resonator by beam coupling.
3. Place the optical wedge behind the output mirror of the resonator, adjust the reflections of the laser diode radiation to detectors D1, D2.
4. Run the laser (according to additional oral tutor instructions) and tune it on maximum output energy. Adjust the beam profile, recorded on a luminescent card or photosensitive paper, so that it is as close to a circular cross-section as possible.
5. Read the oscillator source voltage (the conversion table is on the last page) and compute the energy stored in the capacitors (C = 100 μF) representing pumping energy E_p.
6. Find the threshold pumping energy E_{th} for free-running mode. Measure the laser output energy E as a function of pumping energy E_p. Determine the maximum output energy E_{max} for the free-running mode.
7. Change the output coupler (R = 7 %, 48 %, and 74 % at 1064 nm) and repeat point 6.

8. In all other measurements, continue with the optimal output mirror (the highest E_{max} value).
9. Record the beam profile at maximum output energy E_{max} on black photosensitive paper. Determine its area S necessary to calculate the surface energy density $W_{max} = E_{max}/S$.
10. Observe the generated radiation temporal evolution on oscilloscope and estimate generation time τ_{FR} for various pumping energies:
    - **i)** just above $E_{th,}$
    - **ii)** for middle of interval used $E_{p,}$
    - **iii)** for maximal E_p

Note: - For free-running mode, the τ_{FR} is the total duration of pulse envelope.
- Reflectance of the wedge prism is R = 4%.
- Transmittance of the ground-glass on the pyroelectric detector is T = 62%.
- Sensitivity of the pyroelectric detector is 15.8 V/J.

B) Laser amplification

1. Setup laser amplifier active element to optical axis of justified oscillator.
2. Setup up the wedge prism at the output of the Nd:YAG amplifier and displace energy detector to a new position (see Figure 1).
3. Measure the output amplified energy E_{out} as a function of pumping energy E_p and compute an amplification coefficient $G = I_{out}/I_{in} = E_{out}/E_{in}$. Use the values of E_p for which you measured the energy $E = E_{in}$ in the previous measurement (task A, point 6).

C) Laser characteristics in Q-switched mode

1. Insert the Cr:YAG crystal for passive Q-switching into the resonator (using altitudinal feed) to have the red laser diode guide beam in the center and along the crystal axis.
2. Transfer the wedge prism back to the original position beyond the output coupler and rearrange the energy detector to its previous location.
4. Set the laser in Q-switched mode to generate one pulse per one pumping pulse. Observe and record one oscilloscope screenshot of the time evolution of the Q-switched pulse.
5. Determine the average length, energy and peak power, and their deviations of one Q-switched pulse (use at least 10 measurements). Don't forget to also record the beam profile to determine the surface energy density. Note: For the generation of Q-switched pulses, the pulse length τ_Q means the full width at half maximum (FWHM) of the pulse amplitude.

D) Second harmonic generation

1. Continue with Q-switched mode and turn on the laser amplifier.
2. Adjust the KDP crystal to achieve second harmonic frequency generation.
3. Observe the green radiation corresponding to the second harmonic frequency on the shade and try to change its intensity by changing the angle of rotation of the KDP crystal.

Requested results

A) Graph of the dependence of the maximum output energy E_{max} on the reflectivity of the output mirror R_{OC}. For all tested mirrors, graph and table of the dependence of the output energy E and efficiency $\eta = E/E_p$ on the excitation energy E_p. For the optimal output mirror, graph and table of the dependence of the pulse length τ_{FR}, and the average power $P = E/\tau_{FR}$ on the

excitation energy E_p. Include the figures of the time evolution of radiation and the energy density at the maximum energy $W_{max} = E_{max}/S$ (in J/cm^2).

B) Graph of the dependence of the amplification coefficient G on the excitation energy of the laser oscillator E_p for the optimal output mirror.

C) Measurement results of the length τ_Q, energy E_Q, peak power P_Q (all with deviation), surface energy density W_Q of Q-switched pulses and time evolution recording (from an oscilloscope) of a Q-switched pulse. Compare the surface energy density of the pulse in Q-switched mode and in free-running mode.

References

Yariv, A., Quantum Electronics, chapters 7.3 – 7.4 rare-earth lasers
MEOS - Q-switch theory (pages 9,10)
https://www.repairfaq.org/sam/MEOS/EXP0578.pdf

Appendix

Table 1: Conversion table between the numerical setting of the source voltage and the real value of the excitation voltage of the laser oscillator source. Source capacitor capacity: C = 100 μF.

Set voltage [-]	Real voltage [V]	Set voltage [-]	Real voltage [V]
200	369	480	498
210	370	490	506
220	371	500	515
230	373	510	524
240	374	520	534
250	376	530	543
260	378	540	553
270	381	550	563
280	384	560	574
290	387	570	585
300	390	580	596
310	394	590	607
320	398	600	619
330	402	610	631
340	406	620	643
350	411	630	655
360	416	640	668
370	421	650	681
380	427	660	694
390	433	670	708
400	439	680	722
410	445	690	736
420	452	700	750
430	459	710	765
440	466	720	780
450	473	730	795
460	481	740	810
470	489	750	826