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 mode. Find the optimal output coupler reflectivity for maximum output energy from three mirrors. Perform measurements and comparisons of output energy, 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 Q-switch mode. Measure ~~and compare~~ energetic and temporal laser beam characteristics of single- ~~and multi-~~mode regime~~s~~.
- Set the KDP crystal to achieve the generation of the second harmonic frequency in the Q-switch mode. Determine the tilt angle of the KDP crystal required to detune the generation of the second harmonic frequency.

Experimental setup

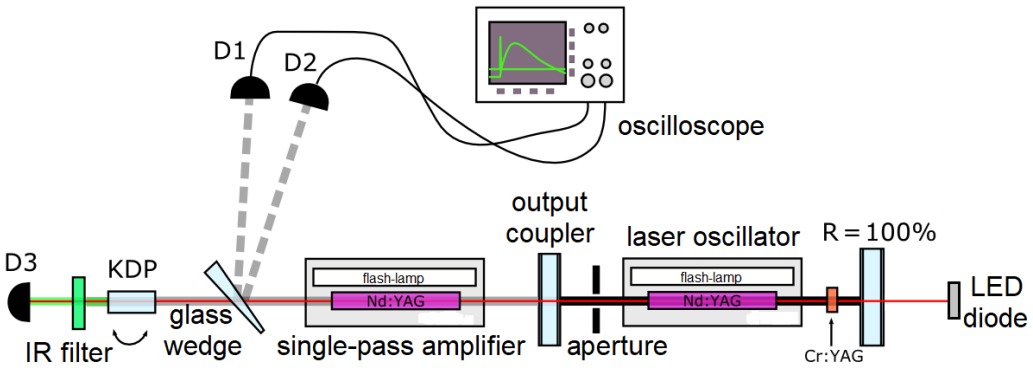

Figure 1 Simplified experimental setup.

Instructions

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

1. Set up the center of laser crystal into the red LED beam.
2. Set up the laser resonator by beam coupling.
3. Run the laser (according to additional oral tutor instructions) and tune it on maximum output energy and as circular profile as possible by finely tilting resonator mirrors.
4. Record the output beam profile on the photosensitive paper (use black paper for free-running mode and gray paper for Q-switched mode) and measure its area *S*.
5. Read the oscillator source voltage (the conversion table is on the source side) 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.
7. Measure the output energy E_{out} as a function of pumping energy E_p.
8. Change the output coupler (R = 7%, 48%, and 86% at 1064 nm) and repeat point 7.
9. For optimal output coupler, observe the generated radiation temporal profile on oscilloscope and estimate generation time τ_{FR} for various pumping energies:

1. just above $E_{th,}$
2. for middle of interval used $E_{p,}$
3. for maximal $E_{p.}$

Rem.: - 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 to the laser amplifier output and displace energy detector to a new position.
3. Measure the output amplified energy E_{out} for variable oscillator pumping energy (E_{in} – measured in previous task A) and compute an amplification coefficient $G = E_{out}/E_{in}$.

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 LED guide beam in the center and along the crystal axis.
2. Setup laser amplifier active element to optical axis of justified oscillator. Setup laser generation in transversally multimode regime (without transversal limitation of resonator)
3. Transfer the wedge prism back to the original position beyond the output coupler and replace the detectors to the corresponding locations.
4. Set the laser to repetitive generation of one Q-switched pulse in multimode (transverse modes) regime. Observe and record the time evolution of the Q-switched pulse in this "multimode" regime.
5. Determine the average length, energy and power, and their deviations of one Q-switched pulse (use at least 10 measurements). Note: For the generation of Q-switched pulses, the pulse length τ_Q means the full width at half maximum of the pulse amplitude.
6. ~~Insert the shutter into the resonator between laser active medium and output coupler to limit the generation of many transverse modes. Observe and record the time dependent evolution of the Q-switched pulse in this "single-mode" regime. Repeat the measurement according to the point 5.~~

D) Second harmonic generation

1. Continue with Q-switched mode and turn on the laser amplifier.
2. Adjust synchronism angle in KDP crystal to obtain maximum SHG energy.
3. Detune the optimal angle to lose the SHG and determine this angle.

Requested results

A) For three different output couplers: dependence of laser output energy E_{out} on the pumping energy E_p, efficiency $\eta = E_{out}/E_p$ and dependence of maximum output energy E_{max} on the reflectivity of the output coupler R_{OC}. For the optimal output coupler with maximal output energy results of surface density of energy $W = E_{out}/S$ and mean power $P_{avg} = E_{out}/\tau_{FR}$. In the tables and graphs state the measured dependences: $E_{out}(E_p)$, $E_{max}(R_{OC})$, $\eta(E_p)$, and

for the optimal output coupler also $\tau_{FR}(E_p)$, $W(E_p)$, $P_{avg}(E_p)$ and the time course of radiation in the free-running mode.

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

C) Results of measurements of pulse duration τ_Q, energy, surface density of energy and peak power of Q-switched pulse in "multimode" ~~and "single mode"~~ regime ~~and their comparison in the table~~. Records (from oscilloscope) of temporal profile of Q-switched pulse ~~in both modes.~~

D) The calculated tilt angle of the KDP crystal required to detune the generation of the second harmonic frequency.

References

- Yariv, A., Quantum Electronics, chapters 7.3 – 7.4 rare-earth lasers
- MEOS - Q-switch theory (pages 9,10)
- https://www.tau.ac.il/~lab3/72_Laser_res/yag_manual.pdf

Appendix

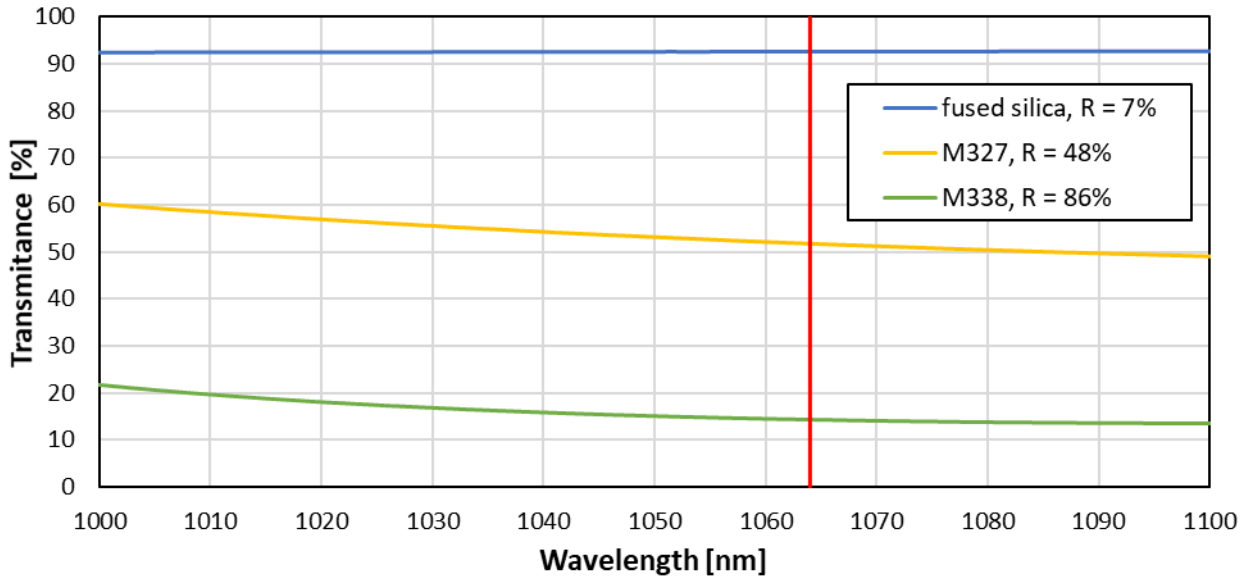

Figure 2 Transmission spectra in the range of 1000–1100 nm of different output coupler mirrors used in this task.

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