Z16 - Laser Nd:YAG

Physics Laboratory II
Faculty of Physics, Astronomy and Applied Computer Science, Jagiellonian University

The goal of this experiment is to learn the basics of laser light generation using a modular Nd:YAG laser. Students investigate the effects of optical cavity (resonator) parameters and excitation rate on the output beam power at 1064 nm, including the cavity stability conditions. Maximum laser power is analyzed as a function of outcoupling mirror reflectivity, which allows calculating cavity losses and active medium gain. Subsequently, laser light at the second harmonic is generated in the frequency doubling process with the intracavity crystal. Finally, beam profile and divergence are analyzed.

Preparatory questions

1. Principles of lasing, inversion of populations in the 3- and 4-level schemes, basic components of a laser [1]
2. Optical cavity modes (longitudinal and transverse)[1]
3. Phase matching conditions for second harmonic generation (basics) [1, ?]
4. Laser (Gaussian) beam diameter and the knife-edge technique for its measurements [3]

Computational assignments

1. Determine populations of Nd^{3+} energy levels involved in lasing relative to the ground state. Assume thermodynamic equilibrium and plot the results in the $200K$ to $320K$ range.
2. For the optical resonator with two concave mirrors ($r1 = 50cm, r2 = 100cm$) find the maximal stable cavity length.
3. Write the formula for the two-dimensional Gaussian profile with the amplitude A and widths (measured at $1/e2$ of the height) equal w_x and w_y. Calculate the integral $\int_{-\infty}^{x_0} dx \int_{-\infty}^{\infty} dy$, where x_0 is a parameter.

Apparatus and materials

The available equipment (Fig.1) includes: small optical table, optical mounting rail, diode laser module (wavelength $\lambda = 808nm$, nominal power: $P = 1.6W$), concave mirrors (curvature radius: $r = -80mm$, reflectivity: $R = 90\%$), alignment laser ($\lambda = 670nm$, $P < 5mW$), infrared viewer, thermal power meter, KTP doubling crystal, polarizing beam splitter cube, quarter-wave plate, flat high-reflectivity mirror, translation stage for moving flat edge aperture, and protective eyewear.

Experiment

Initial setup

1. Remove all other elements and turn on the pumping diode laser ($\lambda = 808nm$). Determine the output power dependence on diode current. Switch the laser off.
2. Install the alignment laser ($\lambda = 670nm$) at the far end of the laser optical rail.
3. Install the Nd:YAG crystal around $5mm$ from the pump module. Turn the pump laser on for $1A$ and using the protective laser eyewear observe the Nd:YAG fluorescence. Move the crystal to the position with maximum fluorescence.//

Obtaining the lasing effect, optimization of beam power and mode

4. Use the alignment laser and note the position of the reflection from the YAG crystal. Install the spherical mirror ($R = 90\%$, $r = -80mm$) abut $50mm$ away form the YAG crystal. Observe the reflection of the alignment laser from this mirror and using kinematic mount align the mirror such that reflections from crystal and mirror coincide.
5. Install infrared viewer after the mirror and turn on the pump for 2 A. Fine tune the spherical mirror angles to obtain the maximum power and TEM00 mode generation.
6. Find the dependence of output power on the pumping diode current value.

Verification of cavity stability criterion

7. Determine the maximum output power of the laser for the distance of 20 to $110mm$ between the crystal and spherical mirror. Optimize the cavity after each mirror position change.

Finding the optimum transmission of the outcoupling mirror

8. Replace the spherical mirror with the set of polarizing beamsplitting cube (PBS), quarter-wave

plate (QWP) and flat high-reflectivity mirror. Align the cavity again using red laser. Place the IR viewer on the side of the PBS and turn-on the pump laser at $2.0A$.

9. Rotate the QWP such that the reflection observed at the IR converter is maximal. Replace the converter with power meter and determine the laser power dependence on the QWP angle.

Second harmonic generation

10. Install the KTP crystal ($4x4x2mm$, labeled intracavity) as an outcoupling mirror (distance from the Nd:YAG not more than a few mm). Align the cavity using red laser.

11. For pump current of $2.0A$, optimize the cavity alignment using IR converter. Determine the SHG power dependence on the pump diode current.

Spatial profile and divergence measurement

12. Prepare the laser with the $r = -80mm$ mirror (fundamental wavelength). Measure the cavity elements positions. Place the power detector at the longest possible distance from the laser (beam may be folded using the flat HR mirror, but the whole beam has to enter the detector).

13. Install the translation stage and verify it blocks the beam completely when moved. Measure the detected power as a function of the aperture position. Caution: the beam reflected of the aperture should be blocked with the IR viewer for safety reasons.

14. Repeat the beam profile measurement for several different locations. Remember to note the distance from the laser cavity!

Data analysis

1. Plot the dependence of pumping diode ($808nm$) power vs current. Determine the lasing current threshold.

2. Plot the Nd:YAG laser power as a function of pump power (use the previous result). Comment on this dependence (Is there a threshold? Is it a 3-level or 4-level system?)

3. Determine the optimum cavity length (max power) and the stability region. Compare the latter with theoretical predictions. Discuss the possible additional effect of thermal lensing.

4. Plot the dependence of laser power vs outcoupling-mirror transmissivity (using the Snell's law). Find the optimum transmissivity. Determine the gain and cavity losses.

5. Plot the SHG power as a function of pump power. Determine the optical conversion efficiency.

6. Find the beam waist/diameter using all recorded profiles. Plot the beam diameter vs distance and determine beam divergence in mrad.

Safety rules

Obey the following safety rules at all times:

- Take metallic and reflective objects (jewelry and the watch, in particular) off your hands before working with the laser.

- Avoid directing the laser beam towards the face. Also beware of leaning down when laser is on.

- Use the protective laser glasses with filters for appropriate wavelengths.

- Never touch the surface of an optical element.

- Apart from the Nd:YAG crystal and IR viewer, do not place any other elements closer than 15 mm from the pump module.

- Avoid reflections of the laser beam going outside of the optical table. Make sure every person in the laboratory is using the protective eyewear when operating the laser.

References

[1] B.E.A. Saleh, M.C. Teich, *Fundamentals of Photonics* (Wiley 2007)

[2] LASKIT-500 ALPHALAS Theory + Experiment (User manual)

[3] materials available on the Laboratory website

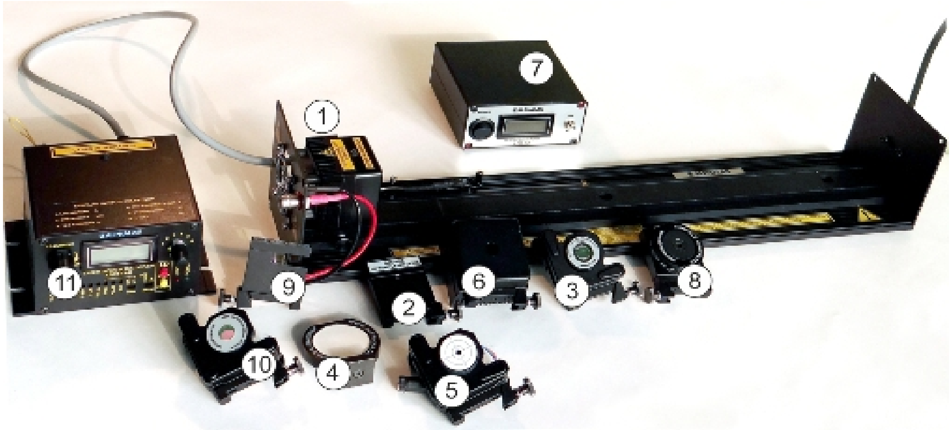

Figure 1: Elements of the Nd:YAG laser kit (LASKIT-500, Alphalas GmbH).