Nd:YAG Laser

(Duration: 4h)

Do not touch the setup until the assistant finished the demonstration.
Do *never* touch an optical surface (lens, mirror, filter…)

Text after the -> signs refers to points that have to be mentioned in the report that you need to hand in before leaving. (Report writing is included in the 4h-duration of the practical works.)

Keywords: Working principle of lasers, stability of laser cavities, Q-switching, laser safety, dielectric mirrors.

Introduction and safety issues:

The Nd:YAG laser is still one of the most widespread lasers in industrial applications. It was the first reliable all solid state laser and is built today with powers ranging from mW to kW and pulse durations from ps to cw (continuous wave).
The laser active material is Neodymium-ion doped Yttrium-Aluminum-Garnet ($Y_3Al_5O_{12}$) and the doping level is in the percent range. *All scientific text books on lasers give more details.*

The stimulation of the material is obtained by optically pumping with Xe-lamps or laser diodes. Diode based pumping has the advantage of reducing the thermal load of the active material as only the absorbed wavelength is emitted by the pumping diodes.

Both, the pump diode emission and the laser emission are invisible to the human eye, but at the used high intensities the light will damage your eyes. Thus, be careful:

- Wear the protection goggles (glasses) at all times when the pump diode is on.
- Make sure that the door is closed and the laser warning light is switched on.
- The person switching on the pump diode, make sure everybody in the room has the protection goggles on.
- Knock at the door and wait for response before entering the room with the setup.
- People in the laser room, respond with clear indications, if somebody is knocking.
- Everybody entering the room remove any jewelry, watches etc.
- Take care to block the light every time you want to use a tool on the setup. This is the most common laser accident: reflecting the laser with a tool in the eyes of a colleague!

For more information refer to a laser safety training/course.

The laser alignment requires a great amount of care and precision. A laser resonator is nearly as sensitive as an interferometer to perturbations caused mechanical deformation of the table and the optical elements. Thus take care of the optics mechanics and do not lean on the table. Screw and unscrew all sliders on the optical bench in the same way every time you need to move them.

All optical elements have to be clean to work efficiently, so *be careful not to touch any optical surfaces*. Be also aware of the electrical risk in the lab. This is a self-made setup; hence possibly not all electrical connections are perfectly isolated.

List of elements:

- Optical rail with sliders (Do not dismount any elements from their sliders, they may become impossible to align.)

- Alignment pinhole
- HeNe alignment laser (5mW, class IIIb)
  (Operation instructions: switch one once the power supply and then use the shutter in front of the laser head. Once the Nd:YAG laser is working you may switch of the HeNe using the power supply.)
- Allan-key for HeNe alignment
- Pumping diode with its beam forming and collimating optics
- Laser protection glasses
- 3 Different focusing lenses
- Nd:YAG crystal
  (one face coated for high reflection at 1064 nm and high transmission at 810 nm)
- Spherical mirror (HR 1064nm)
- Colored glass filters: RG850, NG4
- Filter holder(s)
- IR detector card
- CCD camera with power supply and video monitor
  (Make sure to unplug the power supply cable of the camera before leaving.)
- Photodiode with display electronics
  (It may serve as power meter or measure the temporal pulse profile.)
- Acousto-optic modulator with its electronics
  (Power supply, function generator and high frequency oscillator)
- Oscilloscope

1. First alignment steps

Our Nd:YAG laser will be set-up using an *end-pumped* architecture (Figure 1).

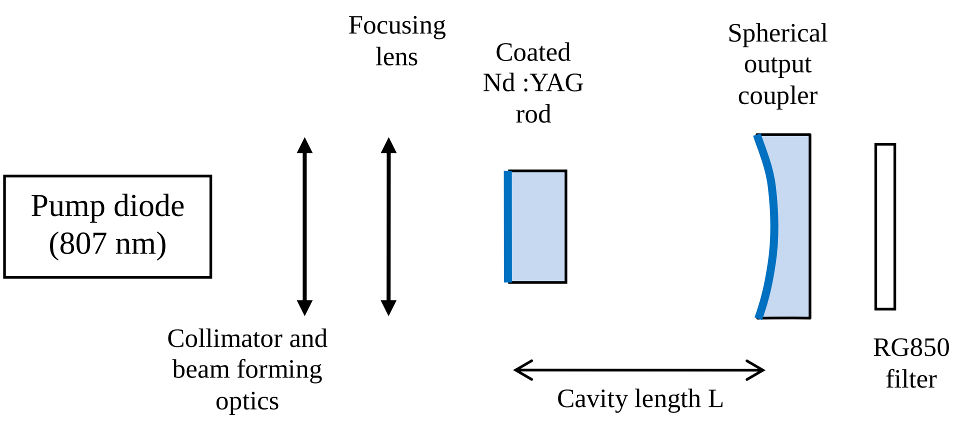

Figure 1 : Schematic drawing of the laser. Thick lines indicate mirror coating locations.

1.1. The optical axis of the laser (z-direction) will be defined by the rail. First of all, you need to align the HeNe laser has precisely collinear with this axis using the alignment pinhole.
Later on all elements will be positioned with respect to the HeNe laser. The aim of this first step is to precisely define the direction of the optical axis and, a bit less precisely, the position of the optical axis.

1.2. The next step is to align the spherical mirror with the optical axis. (This is necessary to avoid the oscillator axis forming an angle with the rail. The adjustment of the output coupler would we very difficult is this case)

1.2.1. Align the spherical mirror perpendicular to the HeNe laser (using the back reflection from the plane side of the mirror). The z-direction screw points towards the HeNe laser.

> **Note:** The tip tilt mount of the spherical mirror (like some other mounts) has a coarse and a fine adjustment screw. *Unscrewing the fine adjustment screw too far* (red line visible) *may damage the mount!* First, place the fine adjustment screw at the center position (black line) and use the coarse adjustment, block it and only then fine adjust.

1.2.2. After 1.2.1, the mirror orientation is not changed any more. Now the HeNe laser is *shifted* to obtain a perfect alignment of its point of impingement with the apex of the spherical mirror. The goal is reached if the reflection from the plane side goes right back to the HeNe, and the reflection from the concave side is centered on the reflection of the plane side and this for all possible positions of the mirror on the rail..

2. Lasing in continuous wave mode

<u>**2.1.** Checks before switching on the pump diode:</u>

- Turn the “bias level” (or “average current”) regulator to its minimum position.

(If necessary make several full rotations of the button)

- Switch the power on using the key switch. The “current limit” is displayed. For the SDL 2**43**2H1 pump diode model adjust to maximum using the “current limit” regulator. For the 2**35**2H1 pump diode model the current limit should be set to 750mA and the regulator is protected by a cup. (The model number is printed on the golden part of the pump diode.)
- Display the “setpoint temp” using the push button right of the display, and adjust to 11°C using the “setpoint temp” regulator.

<u>**2.2.** Switching on the pump diode:</u>

- Display the “average current” using the push button right of the display. PUT ON THE LASER PROTECTION GLASSES etc. Then push the “laser” button at the right hand side of the power supply. The “setup”-led should blink for 20 seconds and at the end the “on”-led should be on. If latter is not the case, repeat this point.
- Increase the “average current” and use the IR indicator card to check for emission.

> **Note:** The indicator card works with stimulated emission too. It has to be pumped using blue light or neon light. Once it emitted the visible wavelength at one location it cannot emit it again from this location before having been pumped again. Usually the operator moves this kind of cards during observation of the beam.

<u>**2.3.** Alignment of the pump diode optics.</u>

The pump diode optics should deliver a vertically parallel and symmetric beam of pump light that is centered on the optical axis defined by the HeNe light. Repeat the three steps below several times to successively approach good alignment.

It might be useful to adjust the pump diode current and the room lighting to obtain a good visualization of the IR light.

ATTENTION, absolutely avoid collision between the pump diode and the collimating and beam forming optics.

- Adjust the pump light *position* to be centered on the HeNe beam a short distance after the collimating and beam forming optics by using the screws under the pump diode itself.
- Adjust the pump light *direction* to be parallel to the optical axis all along the rail by using the lateral screws of the collimating and beam forming optics.
- Adjust the pump light *collimation* to obtain a spot of the same height all along the rail by using

the z-direction screw of the collimating and beam forming optics. It may be useful to first focus the pump light and then move the focus to infinity.
(You might use the etalon-like interference pattern of the HeNe light reflected by the front and back surface of the pump diode for alignment.)
- Finally, switch off the pump diode AFTER having decreased the pump diode current to minimum level.

2.4. Positioning of all elements
- First, put the focusing lens (on a micrometer stage) at approximately 10-20 cm after the collimating and beam forming optics of the pump diode and center the lens by checking the position of the HeNe laser on the collimating optics (or the alignment pinhole). The z-direction screw has to be *outside* the resonator.
- Then unscrew nearly completely the z-direction screw and move the focusing lens as close as possible to the collimating optics (without making contact) and fix it. Then check that the pump light focus is well centered onto the HeNe-laser. (Attention, putting something absorbing to the pump focus may produce smoke or fire.)

- Now position the coated Nd:YAG rod perpendicularly to the HeNe laser and move it close to the pump focusing lens (without touching it).

- Finally position the spherical mirror. The distance between the mounts of the spherical mirror and the Nd:YAG rod should be approximately 7 cm. The cavity should be just long enough to place the acousto-optic modulator in it.

2.5. Obtaining laser emission
- Hide the HeNe-laser light.
- Gradually go to the full power of the pump diode permitted on your setup.
- Move the pump focusing lens in z-direction and simultaneously check for laser output. Best do this after the RG850 filter that may be added after the spherical mirror. Laser output is recognizable because of the low divergence of the light. If the laser works fine the laser light will be visible on the IR card even with the room lighting on. There may however be several intensity maxima if the cavity is not perfectly aligned.

If no laser emission is obtained it might be useful to:
- Check the diode temperature.
- Check the vertical alignment of the focusing lens: (i) Move the z-position of the focusing lens until you found the region where the transmitted pump light intensity varies. (ii) Move the vertical position of the focusing lens to obtain the maximal transmitted pump light.
- Or you need to repeat the whole alignment procedure.

2.6. Questions:

-> Briefly describe the alignment procedure that you used to make sure NeNe laser and optical axis are collinear.

-> Show the part of the setup illuminated by 807 nm light and the part of the setup illuminated by 1064 nm light in a schematic drawing.

-> Shortly explain the role of each component used to realize this laser.

-> What is the limiting length for a stable plano-convex resonator as we use it here?

(The stability condition is $0 < g_1 * g_2 < 1$, where $g_i = 1 - \frac{L}{R_i}$. L is the cavity length and R is the radius of curvature of the spherical mirror.)

-> Briefly mention the problems you encountered and the solutions you came up with.

3. Measurements on the continuous wave laser

Once laser emission is obtained, it is relatively easy to optimize the laser and observe different transversal modes of the cavity

3.1. Using the power meter

- The power meter is operated at -12V.
- Do not exceed 100µA! You will eventually need to use an attenuator to stay below this value.
- Consider using the "audible" mode, like this you can keep your eyes on the alignment and hear the power variations.
- As the laser beam profile is larger that the active area of the detector the light has to be focused onto the power meter.

3.2. Observing the transversal beam profiles

- Put a beam mirror and an attenuator in the setup so that the CCD camera positioned perpendicularly to the optical axis captures the beam profile of the laser output.
- Slightly adjust the output coupler in order to obtain different transversal laser modes. Try to realize TEM_{00}, TEM_{02} and TEM_{21}.

-> Make a schematic drawing of the obtained modes and note the adjustments that were necessary to switch from one mode to the next.

3.3. Optimize laser output power and laser threshold

Pay attention to the 100 µA limit for the power meter. Use attenuators if necessary.

- optimize the laser output power by varying the cavity alignment
- optimize the laser output power by varying the pump diode temperature (7-17°C)

-> Note the obtained minimum lasing threshold current together with the model number of your pumping diode.

4. Q-switched laser operation

4.1. Very short (qualitative) theory: In the term 'Q-switching' the Q refers to the quality factor of the cavity. In other words, during Q-switching the *losses* of the cavity are artificially enhanced during pumping of the active material. Due to the high losses no lasing can occur in these conditions and only spontaneous emission relaxes the excited laser active Nd-ions. Thus, a high population inversion can be achieved. Once this high inversion is achieved, the losses are abruptly decreased (switched within a few nanoseconds). Now lasing can occur and this with very high amplification due to the high initial inversion. Thus a short (ns duration) and energetic (mJ) pulse is emitted by the laser. This pulse has high peak power and can be used for nonlinear optics including nonlinear absorption leading to more efficient laser matter interaction.

The detailed pulse shape depends on the properties of the cavity as well as on the properties of the laser active material that are described by the rate equations. The interplay between population inversion and instantaneous laser intensity are the same for the formation of the Q-switched pulse or ‘spiking’ that is observed when switching on a cw-laser. These processes are described in Figure 2.

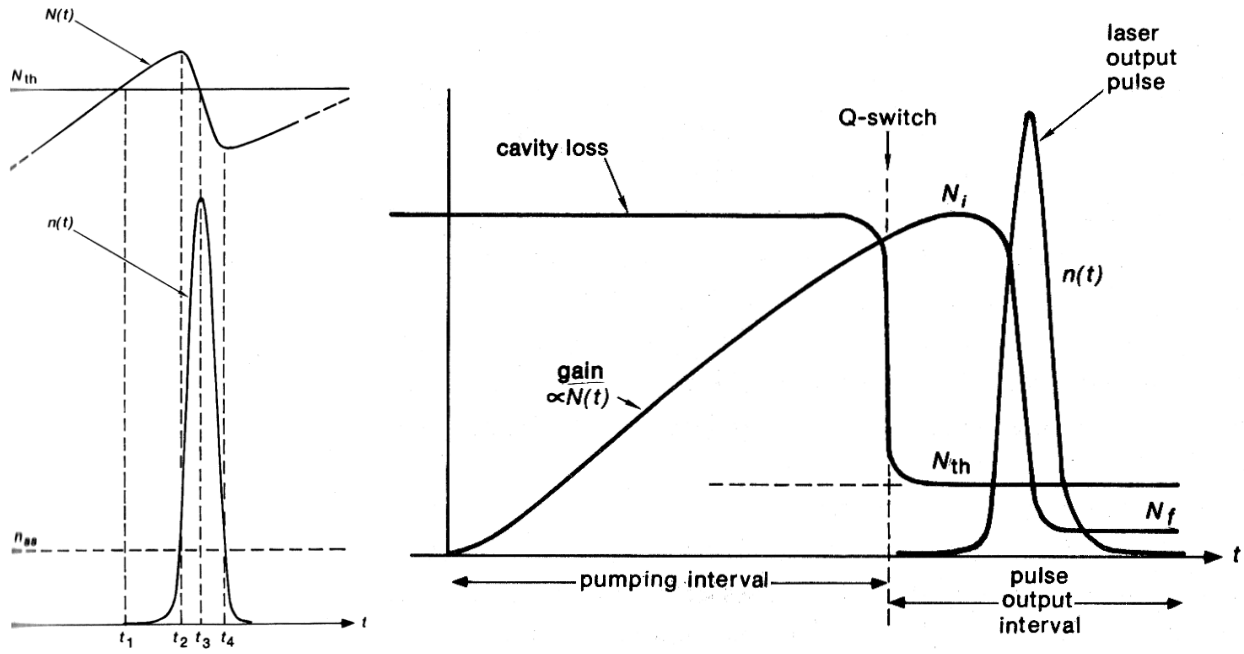

Figure 2 : Left: interplay between population inversion N and photon number in the cavity n when switching on a cw laser (spiking). n_{ss} *is the steady state photon number,* N_{th} *is the inversion at lasing threshold. Right: interplay between population inversion N, photon number in the cavity n and cavity losses, when Q-switching a flash-lamp pumped laser. (Source: Siegman ‘Lasers’)*

4.2. The acousto-optic modulator will be used for Q-switching our laser. The electronics has to be set to the following values before connecting the HF oscillator to the function generator.
- Power supply: 19V
- Function generator to 0V/5V pulses of 500 Hz of ‘high’ duration of 1 ms. (Check with oscilloscope)

4.3. Check the acousto-optic modulator with the HeNe beam. Observe the effect it has on the light and how you can choose which order of diffraction has the highest intensity.

4.4. Align the acousto-optic modulator so that the reflected 0 order goes back to the HeNe and put it carefully in the laser cavity. (Adjustment screws oriented to the HeNe.)

4.5. Check at high pump current that the laser is still working with modulator off. Optimize the cavity using the output coupler.

4.6. Slightly turn the modulator and adjust the cavity to keep it running while operating the modulator and watching the temporal characteristics of the laser output on the oscilloscope (channel 2)

-> Draw a graph of a typical temporal pulse profile of your Q-switched laser pulse.

-> As a conclusion of this work, sum up the conditions that have to be fulfilled to build a laser.