Laser4DIY Nd:YVO4 laser source

[English version] [zur deutschen Version]

This page describes an outdated design. The up-to-date version can be found here.

Laser setup

The laser source of the LASER4DIY project is a diode pumped solid state laser with a Neodymium-doped yttrium orthovanadate (Nd:YVO4) crystal. This widely-used laser is especially suitable for this usecase, since the Nd:YVO4 cristal is cheap, easy to obtain and also, based on the use of the so called bounce geometry, very powerful. In figure 1 you can see the setup of the laser system, which is very similar to the puplication by Thomas and Damzen, 2011 [1]

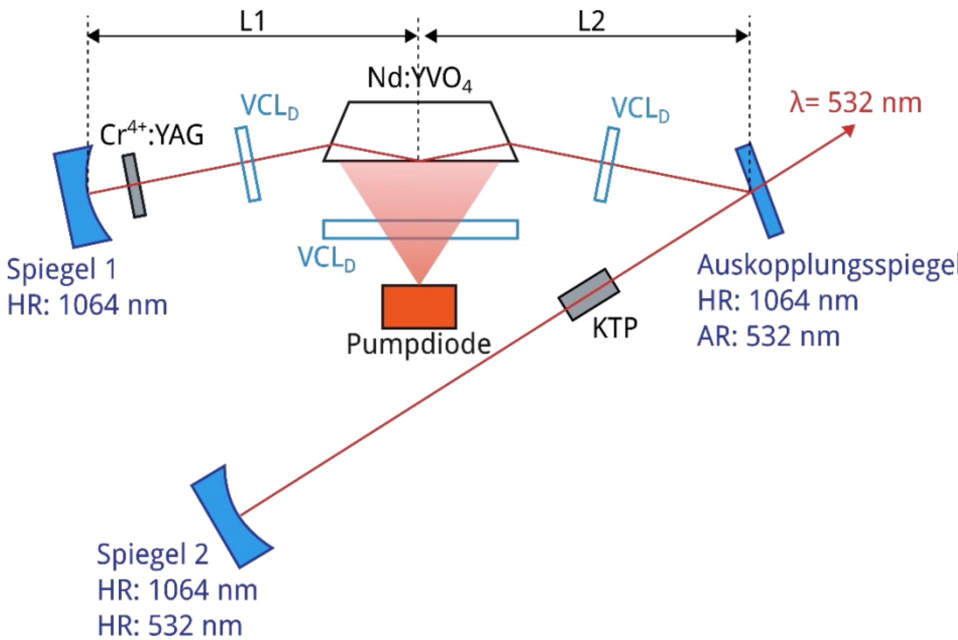

Figure 1: Schematic representation of the Nd:YVO4 laser with a passive Q-switch
and a Cr4+:YAG saturable absorber crystal and a additional KTP crystal for frequency doubling [1]

The measurements of the trapezoid Nd:YVO4 crystal are 15 x 5 x 2mm. To avoid a parasitic internal reflection in the crystal, the end planes are tilted inwardes by 4 degrees and also are anti reflection coated for the wavelength of 1064nm. The cylindric laser diode array emits a wavelength of 808nm with maximum optical power of P = 60W with a efficiency rate of 50%. With a vertical cylindric lens (VCLD) the pump light is focused with a focus length of 10mm into the crystal. The Nd:YVO4 crystal emits light at = 1064nm and converts some of the energy into heat. Because of this and the fact, that the laser diode shifts its wavelength about 1nm per 3K temperature change away from the for the Nd:YVO4 optimal pump wavelength of 808nm, the laserdiode and the crystal need cooling to keep them at a steady temperature. This is done by copper plates which are mounted on both side of the crystal, which themselves are cooled by a peltier element and CPU coolers.

To get to high peak powers of the laser a Q-switch is put into the laser cavity. This saturable absorber is a Cr4+:YAG crystal with the dimensions 5 x 5 x 3 mm and placed near mirror 1.

Would the radiation with = 1064 nm emmited by the Nd:YVO4 crystal directy hit the copper surface, not much would haben since the copper is a very good reflector (up to 95%9 in the infrared (= 780 nm bis 1 mm). This is the reason because a frequency doubler must build into the resonator which halves the wavelength from = 1064 nm to = 532 nm. At this wavelength the absorbtion rate of copper is 10 times bigger, so the laser can heat up the copper and evaporate it. The frequency doubler used here is a Potassium titanyl phosphate (KTP) crystal, which has the dimensions 3 x 3 x 5 mm. As you can see in figure 1 the beam emitted by the laser crystal is reflected by a special mirror into the KTP crystal. This mirror is a output coupler which has high reflectivity at 1064nm (infrared) and a anti reflection coating at 532 nm (green), so its possible for the green laser light to leave the resonator here.

Because the pump light is only exciting a part of the Nd:YVO crystal and therefore a temparture gradient is formed, a thermal lense occurs. Dependend on how big the temperature gradient is, a different refractory index occurs, which let the emitted radiation leave the crystal under a different angle. To tune the laser beam to maximum power than the lengths L1 and L2 (see figure 1) has to be adjusted to this angle.

Simulation of the laser source

Simulation was done using the program LASCAD. A finite element analysis (FEA) for the thermal effects of the Nd:YVO4 crystal is possible with it, allowing to determine the exact geometry of the resonator. Especially the distances of mirror 1 and the uncoupling mirror to the crystal (see figure 1) are important for the construction later on. Additionally the simulation program can calculate the average power in CW mode (continuous wave mode), as well as the peak power of the laser source when using the Q switch. The simulation was done without frequency doubler, as it is less important for the laser geometry.

In order to do the simulation with the used program, we had to simplify the laser setup. Firstly, the simulation was done with a rectangular crystal instead of a trapedzoid one. Secondly, the program assumed a 100% anti reflection in the crystal, being about 99,9% in reality. Additionally, it was not possible to simulate a bounce geometry in the crystal. Therefore the laser beam was set to the lower end of the crystal, as the temperature gradient in this area is comparable best with the real bounce geometry (see figure 2). The thermal lens is quite large with the bounce geometry and extends through the whole beam path. As the thermal stress is uniform in every point in the beam path, the thermal lens is compensated well and a high radiated power can be achived. With a side pumped laser the thermal lens is quite strong and the thermal stress varies along the beam path, leading to a high power reduction of the generated laser beam. The efficiency then lies at about 10% only, whereas bounce geometry reaches an efficiency of 50%. Because of this we needed to do a better adaption for the simulation in order simulate the bounce geometry more precise. As the laser reaches the crystal with an inclined angle using the bounce geometry and is reflected with the same angle there, the laser geometry at that spot can be considered as done in figure 3. Is the geometry mirrored at the crystal surface then, you get a laser running in a straight line with uniform distribution of thermal stress in the crystal. This can be simulated in the used program by pumping the crystal from the side at the lower end (see figure 2). In this pumping area a smaller thermal lens is created, leading to thermal stress similar to the bounce geometry. figure 4 and 5 show the temperature distribution in a side pumped crystal and one based on the bounce geometry, respectively.

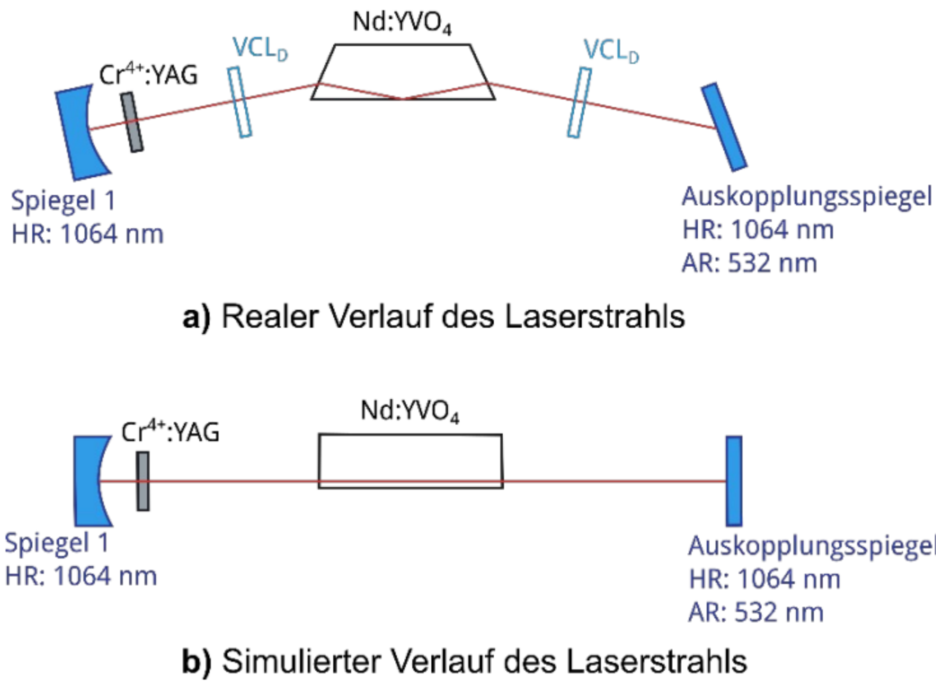

Figure 2: Real (a) and simulated (b) path of the laser beam

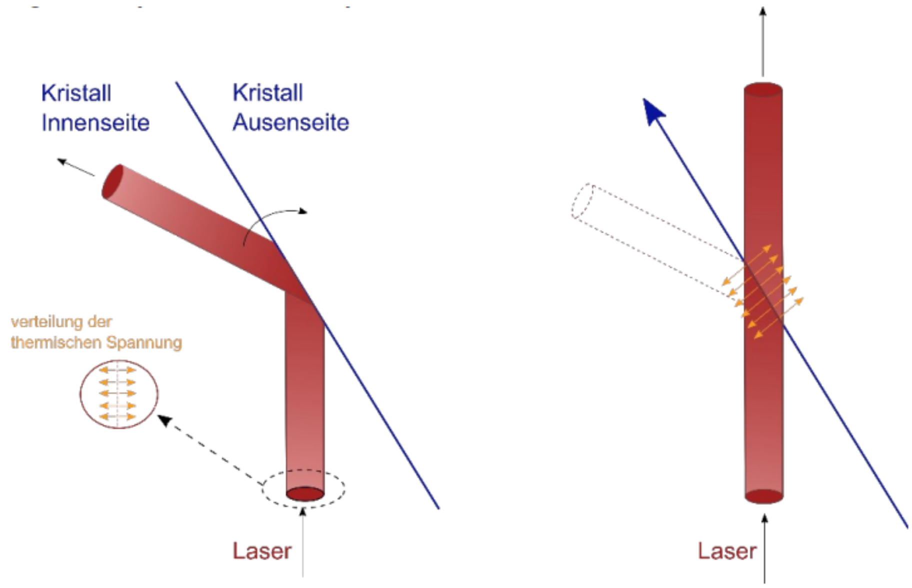

Figure 3: Scematic view of the beam path with bounce geometry (left)
and beam path adapted for simulation (right)

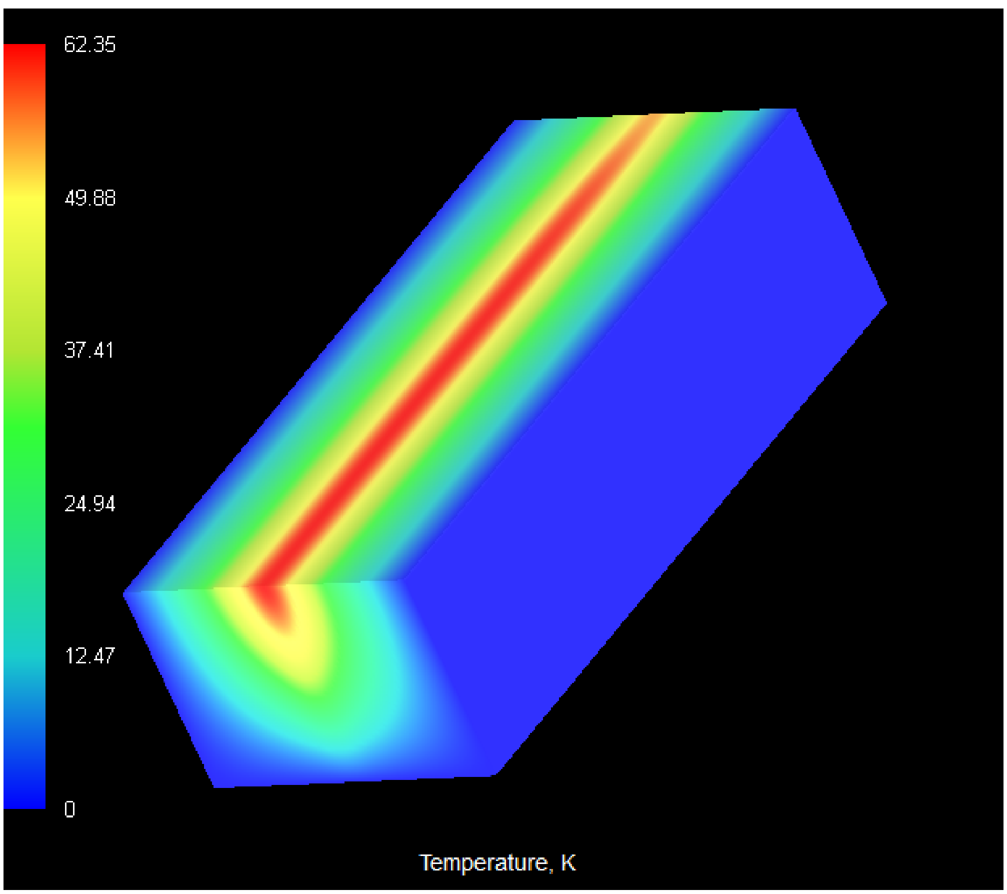

Figure 4: Temperature distribution for side pumped crystal

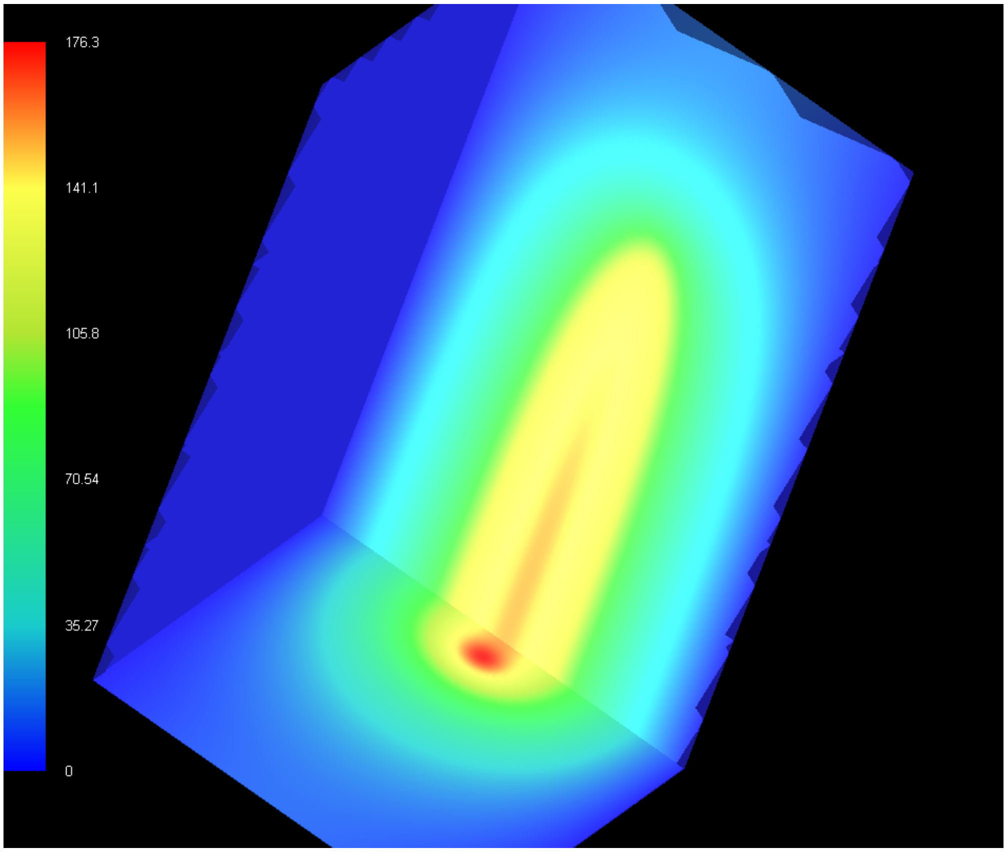

Figure 5: Temperature distribution for simulated crystal

Simulation Results

The following simulatino results were calculated with distances L1 = L2 = 25 mm between the reflection mirrors and the crystal. As only an approximation of the bounce geometry could be simulated, a deviation of up to 50% with the resulting output pwoer figures must be considered.

In figure 5 the average output power of the laser beam in CW mode is shown as a function of the absorbed pumping power. The reflecivity of the uncoupling mirror was set to R=0.9. The beam power approximately increases linearly to the absorbed pumping power up to 35W and then turn into an exponential function up to a pumping power of 51W, where the maximum output power of 24W is reached. Thus, a effiency of about 50% is achieved. *Tho mas and Damzen, 2011* reached an output power of 13.8W (with R=0.7) and efficiency of only 30%.

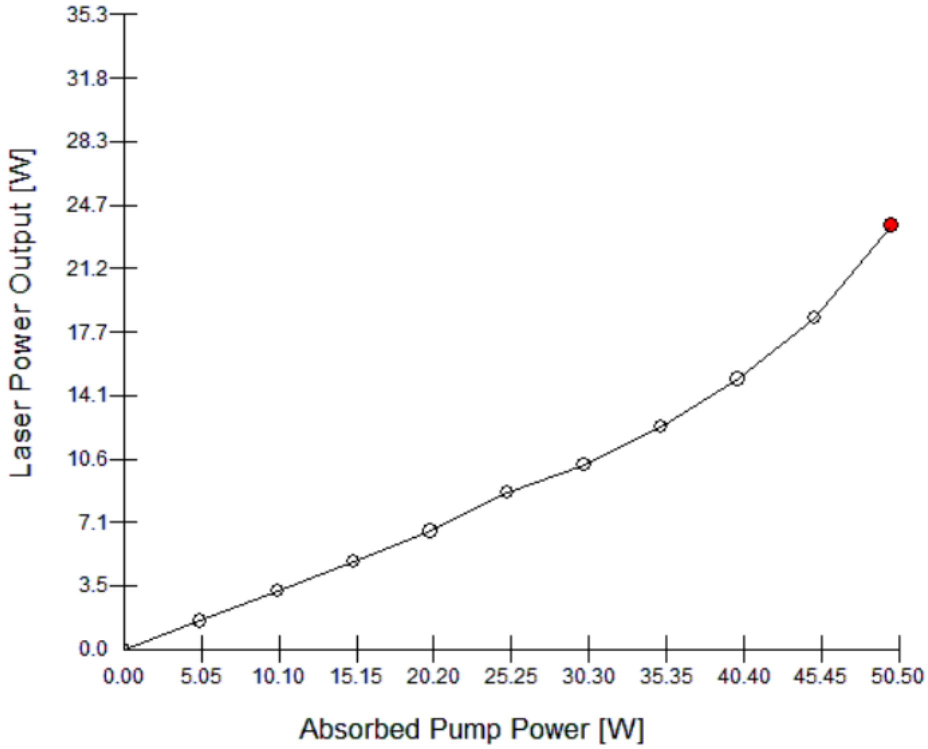

Figure 6: Simulated average output power of the laser beam as a function of the absorbed pumping power; CW mode with R=0.9

Additionally, a simulation with Q switch was performed (figure 7). Here, too, a linear dependency of average output power and absorbed pumping power can be observed, as in CW mode. This simulation resulted in an output power of 17W at a maximum pumping power of 51W. Compared to *Thomas and Damzen, 2011*, where an output power of 11W at R=0.7 was measured, this computed value is much higher. The cause of this is the lack of a real bounce geometry in the simulation. A lower output power needs to be expected in reality, therefore, as in CW mode.

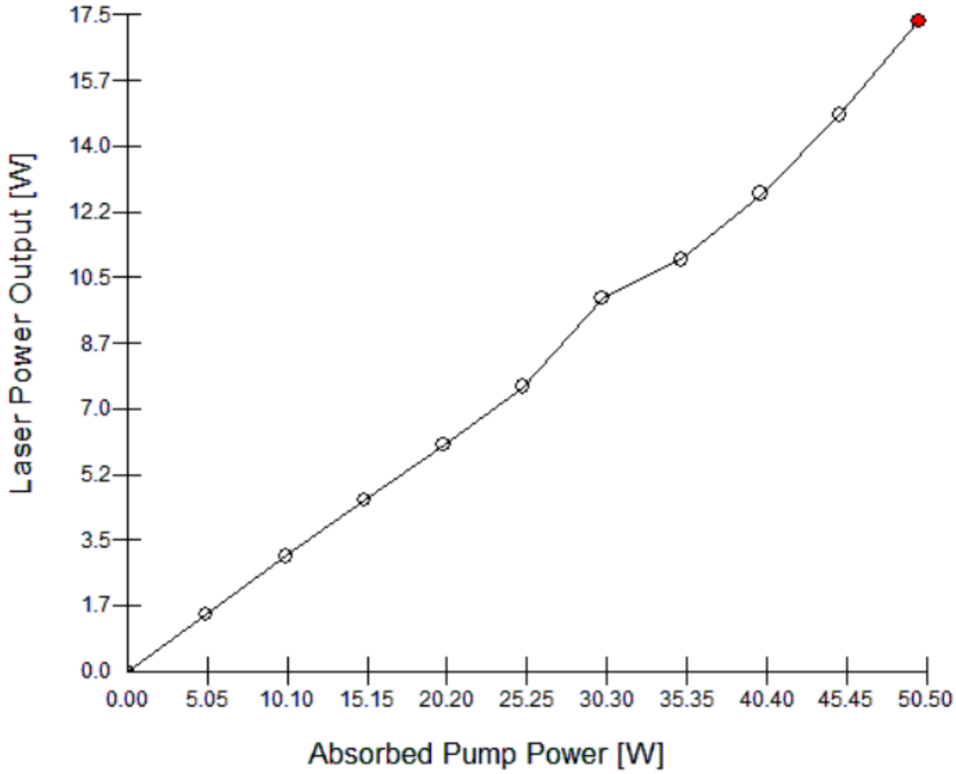

Figure 7: Simulated average output power of the laser beam as a function of the absorbed pumping power; with Q switch and R=0.9

The simulation was also used to calculate the average output power as a function of the reflecitity ouf the output mirror. Figure 8 shows a power reduction with increasing reflectifity. Taking the results of *Thomas and Damzen, 2011* in consideration, here we can expect a less intense reduction of the power in experimental test runs, too.

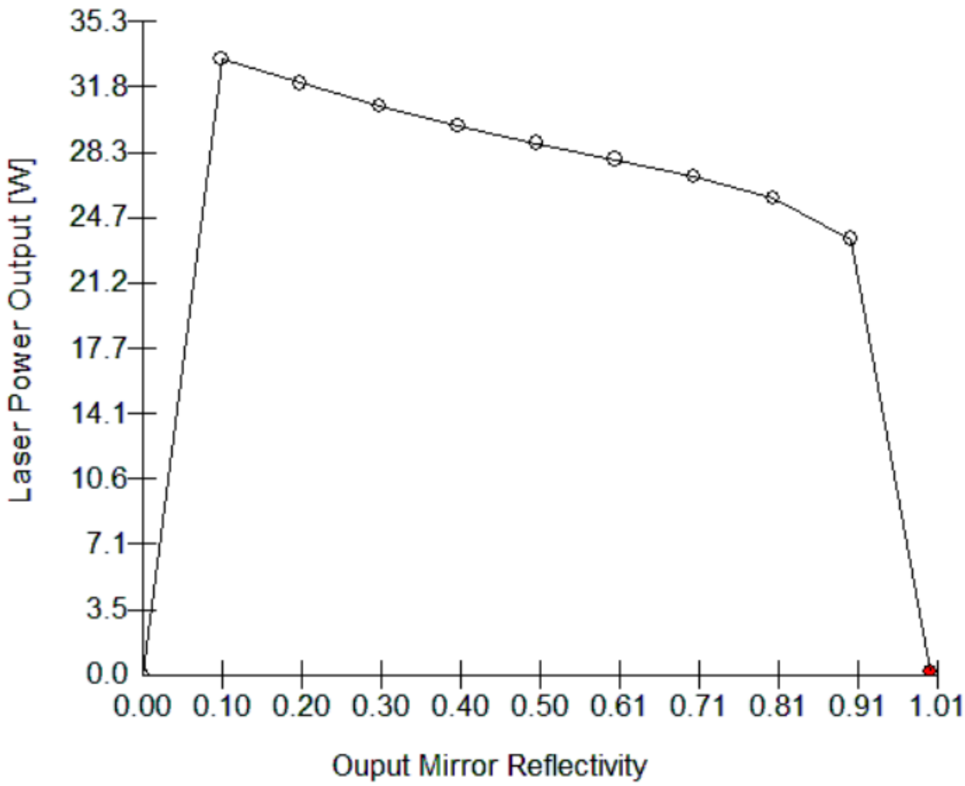

Abbildung 8: Simulated average output power of the laser beam as a function of the output mirror reflectivity with a pumping power of 51W

Figure 9 shows a peak power of 16kW with a pulse length of 9.39ns. Taking account the appoximate factor for the bounce geometry, in this simulation also results in a significantly higher peak power of Ps 24kW compared to *Thomas und* Damzen*, 2011,* where a peak power of 1.9kW was measured in experiments.

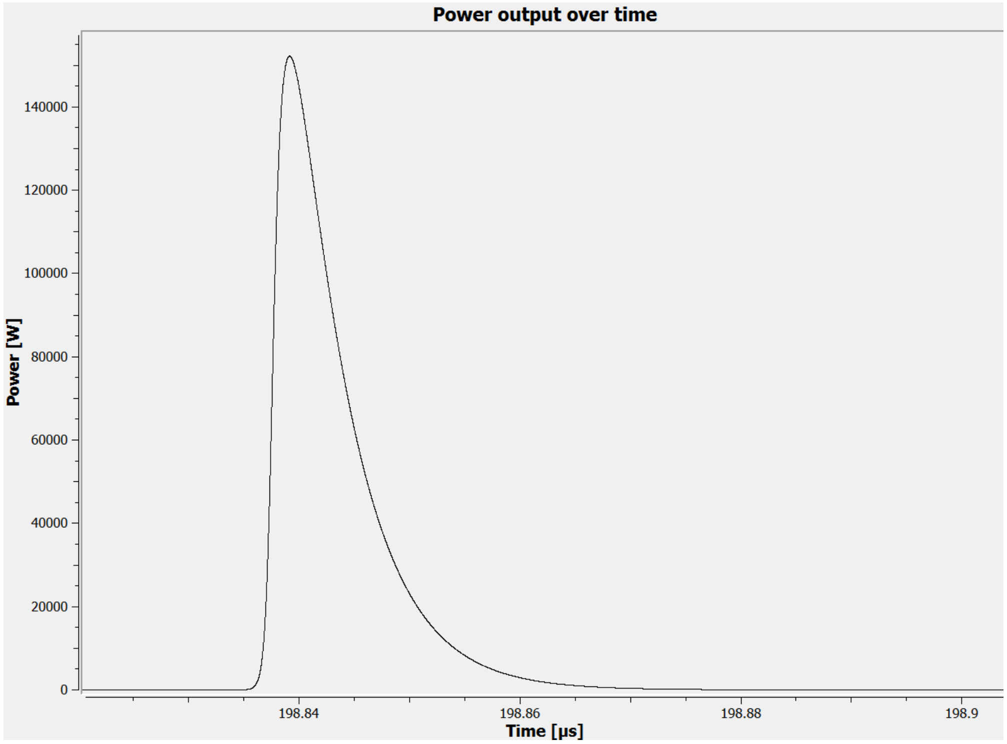

Figure 9: Simulated peak power as a function of pulse length with a output mirrow reflectivity of 0.9 and a pumping power of 51W

The results of the performed simulations show much higher output power figures than to be expected regarding the experiments done by *Thomas und* Dam zen*, 2011.* Nevertheless the results can serve as a starting point for the setup of the mirrors when building the resonator. Additionally, the simulation showed, that the used setup of the laser with a Nd:YVO4 crystal can provide enough power for the ablation of copper.

Conclusion

The results from the simulation performed generally showed significantly higher output powers than could be expected under real conditions according to [1]. In an experiment, we have shown that this setup works in principle and is also suitable for generating laser pulses with peak powers that are sufficiently high for the ablation of copper, even if the values from the simulation – as expected – could not be achieved.

However, practical weaknesses of the setup were also identified:

- A high output power of the pump diode is decisive for the output power of the laser. The use of 60W diodes was planned. However, the procurement of these diodes turned out to be difficult. Tested specimens could not meet the specifications. In order not to unnecessarily delay the progress of the project, a laser diode from a premium supplier was used for further tests. The diode can meet the requirements, but its price exceeds the targeted material costs.
- The use of weaker pump diodes causes a lower output power and jeopardizes the achievement of the project goal, namely the possibility of copper ablation.
- An auxiliary laser is required to adjust the laser structure; we used an Nd:Yag laser. However, the cost of this laser drives up the cost and adjusting the setup is complicated. This reduces the attractiveness of the project.

For these reasons, we looked for an alternative setup that on the one hand increases the possible peak performance and on the other hand makes it easier to adjust the system. The resulting setup is described here.

Literature:

[1] G. M. Thomas and M. J. Damzen, “Passively Q-switched Nd: YVO 4 laser with greater than 11W average power,” Opt. Express, vol. 19, no. 5, pp. 4577–4582, 2011.
[2] “Betrieb von Lasereinrichtungen,” Berufsgenossenschaft der Feinmechanik und Elektrotechnik, Berufsgenossenschaftliche Informationen für Sicherheit und Gesundheit bei der Arbe 832, 2003.