RAPID

Industrial, High Repetition Rate Picosecond Laser

High Power: RAPID is a very cost efficient, compact, diode pumped Nd:YVO_4 picosecond laser with 2 W average power at 1064 nm. Its 10 ps-pulses have high pulse energy (up to 30 µJ) and high peak power of up to 3 MW. The excellent beam quality (M^2<1.2) allows for focussing the beam onto very small areas to easily reach peak power densities in the TW/cm² range sufficient for micromachining virtually any material.

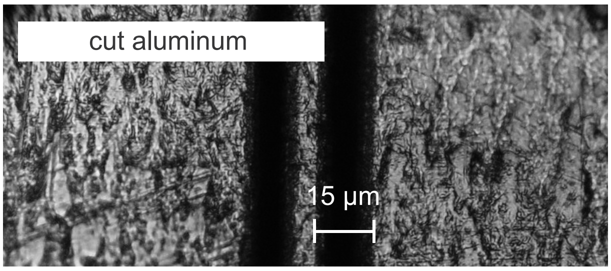
Reliable, High Rep Rate Pulses: The outstanding repetition rate of 500 kHz translates into micromachining with high throughput and into cutting cost per part. At all repetition rates the beam quality is excellent. External TTL pulses can trigger single pulses or pulse sequences. Designed for hands-off operation, the RAPID offers a maximum of reliability. The system is hermetically sealed; the complete laser head is thermalized. Its compact design makes machine integration straightforward. Laser functions are PC-controlled and accessible via RS232 interface. Harmonics at 532 and 355 nm and additional amplifier modules are optionally available.

Features:

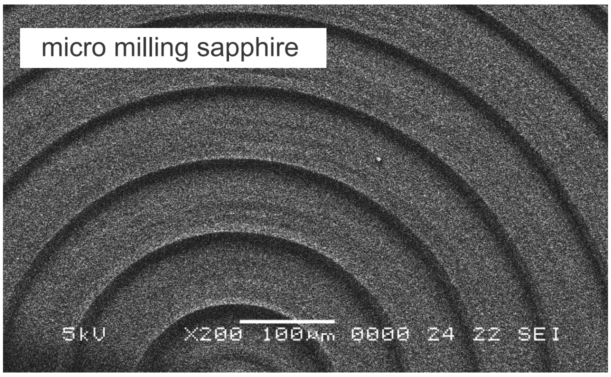
- **Up to 500 kHz repetition rate, single pulse, programmable pulse sequences, TTL-trigger**
- **Picosecond pulses up to 30 µJ, up to about 3 MW peak power**
- **High power stability in a spatially excellent beam, M^2<1.2, at all rep rates**
- **Reliable, hands-off operation, compact design, computer control and interface**
- **Low maintenance and low cost of ownership**
- **Single phase mains electrical connection (85-260 V, 50-60 Hz, <2 kVA)**
- **No external cooling water requirement, easy machine integration**

Applications: Materials processing with high ablation quality: Selective drilling, cutting, structuring, surface structuring, specifically in semiconductor technology. Metals, semiconductors, ceramics, glass and other materials have been micromachined in very high quality and efficiently in LUMERA LASER´s application lab with ~10 ps pulses at energy densities in the order of 1 J/cm². For target areas of ~10x10 µm² this translates to ~1 µJ pulse energy.
Increasing the pulse repetition rate up to 500 kHz increases the material removal rate linearly (with constant pulse energy and geometry). Applications, in addition to micromachining, include: R/D, NLO, THz-generation, ps-spectroscopy, satellite ranging and material research.


cut 100 µm steel mask



cut aluminum



micro milling sapphire

Specifications	RAPID
Wavelength	1064 nm
Pulse duration	<15 ps
Average power	2W @ 500 kHz
Pulse energy	30 µJ @10 kHz, 4 µJ @500 kHz
Pulse energy stability	<1% rms at 500 kHz
Pulse energy contrast @500kHz	>200:1
Repetition rate	0-500 kHz, TTL-trigger, pulse on demand
Beam quality M^2	<1.2
Polarization	p, 1000:1
Harmonics options	532 nm (p), 355 nm (s)
Electric supply	85-260 V, 50-60 Hz, 2 kVA
Control unit	W 553 x D 600 x H 612+70 mm³; ~80 kg
Laser head	W 440 x D 888 x H 117 mm³, ~46 kg
Beam position	H 67+ mm; IR 127, SHG 97 mm from left

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2 Overview and Technical Background

The RAPID is a 2 W picosecond laser generating 10 ps pulse at 1064 nm with a freely selectable pulse rate as high as 500 kHz and pulse energies of more than 30 µJ at repetition rates ≤10 kHz. It consists of a mode-locked oscillator, a fast electro - optical pulse picker, an amplifier and (optional) a second and third harmonic generator. The laser head is a rugged monolithic aluminium structure and is actively temperature controlled. The RAPID laser is intended for industrial applications and as an OEM laser source.

2.1 Oscillator

The oscillator is a diode-pumped passively mode-locked Nd:Vanadate laser generating high average power picosecond pulses with a repetition rate of 50 MHz. Therefore the time between the picosecond pulses is 1/50 MHz = 20 ns. The typical pulse width is 8 ps and the average power is about 3 W. The oscillator is pumped by a fibre-coupled single bar laser diode. The fibre cable is connected to the oscillator via SMA fibre connector FC1.

2.2 Pulse Picking

The fast electro-optical pulse picker selects a number of pulses out of the picosecond pulse-train to reduce the effective pulse rate. The selected pulses will be amplified in the next step to gain the required energy. The advanced LUMERA LASER pulse picker provides a choice of different pulse patterns to be amplified:

a) Single pulses at repetition rates from 0 to 500 kHz

b) One group of pulses (selected number, here 3, every 20 ns) repeated from 0 to 500 kHz

c) Sequences of pulses (in 2 groups, variable delay, selected number of pulse every 20ns in each group, here 2 and 1) repeated with 0-250 kHz

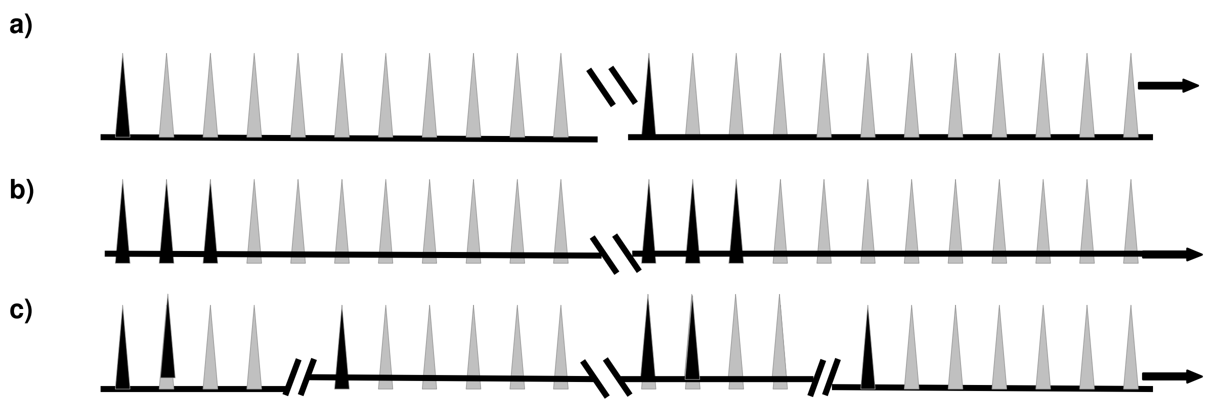

Fig. 1 Illustration of picked (black) pulse patterns out of the 50 MHz pulse train (gray) from the oscillator. The user can choose between single pulses (a), a group (b) and sequences (c).

A more detailed description of the pulse picker, including the advanced internal and external triggering is given in a later chapter

2.3. Amplification

In order to get higher energies the selected pulses are amplified in a transient amplifier. The amplifier use the same gain material as the oscillator, neodymium doped Vanadate, which is well known for a high gain cross section leading to a very high amplification. The amplification factor can exceed 500, depending on the repetition frequency of the pulse sequence and the setting in the pulse sequence. The energy of a ps pulse is increased from 60 nJ (~3W, 50 MHz) to a maximum of more than 30 µJ for less then 10 kHz.
Additional amplification stages can be supplied optionally.

2.4. Second Harmonic Generation

The optional second harmonic generation (frequency doubling) occurs in nonlinear optical crystals. It is a method to generate a new laser beam out of a fundamental beam with half the wavelength of the fundamental beam. In general, the frequency doubling efficiency in a nonlinear crystal is a function of the intensity of the fundamental radiation squared. Since ps pulses already have a relative high peak power the requirements for frequency doubling are not very restrictive (as in the case of doubling cw radiation). Here, frequency doubling has low sensitivity to passive losses and phase mismatching due to angular or temperature mismatching.
The intensity of the amplified ps-pulses can lead to conversion efficiencies as high as 50%.
Another advantage is the suppression of the fundamental background radiation which has, due to the square law, a very low conversion efficiency compared to the amplified ps-pulses. Therefore the frequency doubled beam has even far less background radiation than the1064nm radiation.

2.5 Third Harmonic Generation

The optional third harmonic is generated by sum-frequency-mixing of the fundamental IR beam and the green beam in a nonlinear crystal. This sum-frequency-mixing generates a laser output in the UV (355 nm, one third of the fundamental at 1064 nm) with conversion efficiencies better than 20% vs. IR.

With the ps - laser RAPID it is possible to generate programmed pulse sequences (of one or two pulses groups, each group may contain several ps-pulses with 20ns separation). The pulses are picked by an electro - optic modulator (EOM) or “Pockels-cell”, which is driven by digital delay generators. The following section describes the background of the pulse - picker and the driver electronics.

The pulse-picker is an electro - optic modulator (EOM): A fast high voltage (HV) pulse is applied to the electro - optical crystal (“Pockels cell”). Pockels cells are characterized by fast response, since the Pockels effect is largely an electronic effect. It produces a linear change in refractive index when an electric field is applied. The direction of polarization of the light leaving the crystal is rotated. If the half wave voltage for the particular crystal is applied, a phase shift of π occurs, equal to a polarisation rotation of 90°. If the half wave voltage is applied, the Pockels cell acts as a half wave plate rotating s-polarized light into p-polarized light. In conjunction with a polarizer the light intensity is modulated with the applied HV repetition frequency (Fig. 31: Principle physics of pulse picking). This can be done very fast (typical rise time 5 ns) and with a repetition frequency (up to 500 kHz), limited by the driver.

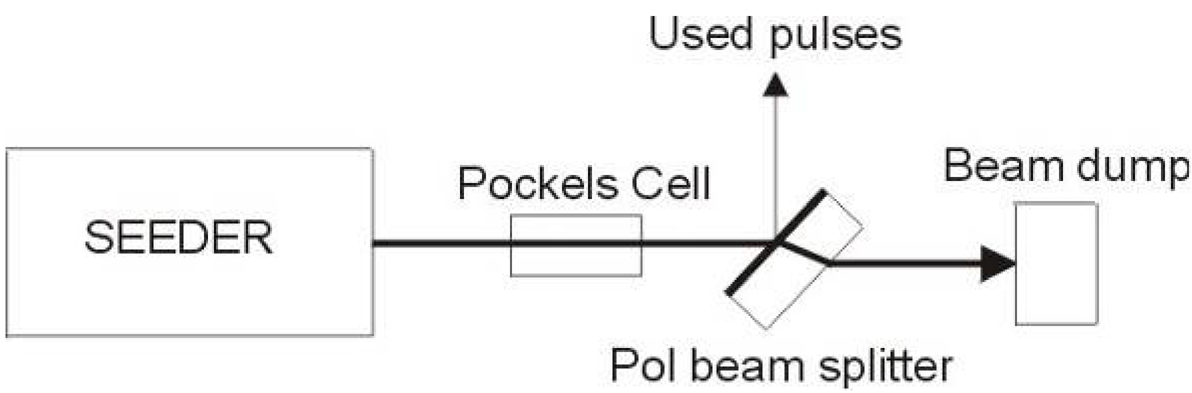

Fig. 31: Principle physics of pulse picking

- **(a)** **Mode-locked pulse train. Characteristic times: τ pulse width of ps-pulse, T time between pulse-sequences (1/T= repetition frequency).**
- **(b)** **Mode-locked pulse train and HV pulses.**
- **(c)** **Selected ps pulses. Time between selected pulses is T2.**
- **(d)** **Polarisation of mode-locked train of ps pulses.**
- **(e)** **HV pulses versus time.**
- **(f)** **Rotated polarisation for selected ps pulses.**

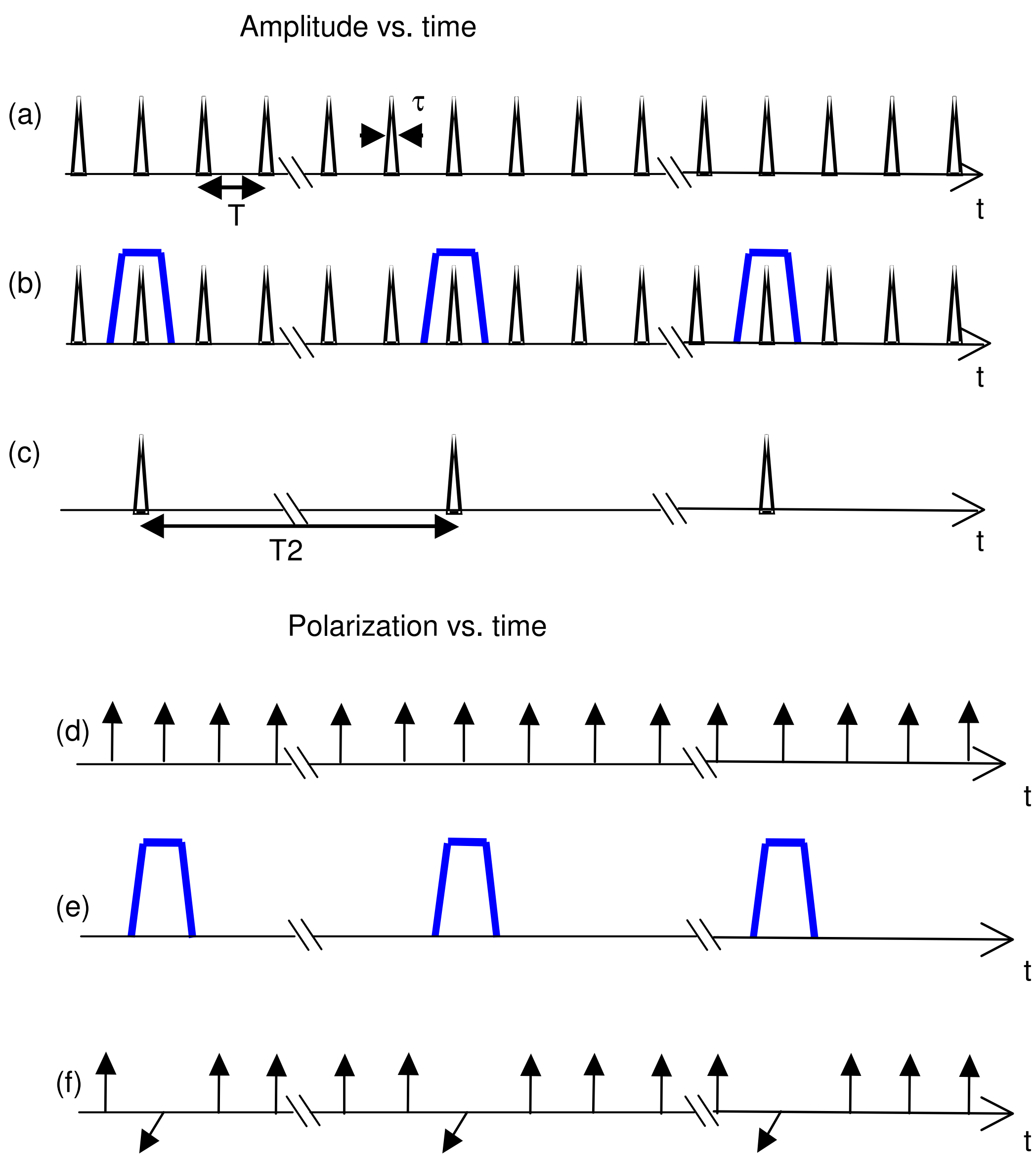

Fig. 32: Principle of pulse picking; polarisation and amplitude of pulses vs time

A special feature of the RAPID laser is a so called ***"double-switch",*** which generates ***two*** HV - pulses in one cycle. These HV - pulses can create a sequence of two groups of laser pulses, named **A** and **B.** Each sequence is triggered either by one external signal (TTL-Signal input on BNC - connector "Gate") or by the internal trigger. The timing for the two events "A and B" can be set separately, so that the user can define the delays and the number of pulses in each group. The sketch of this timing is shown in Fig. 33.

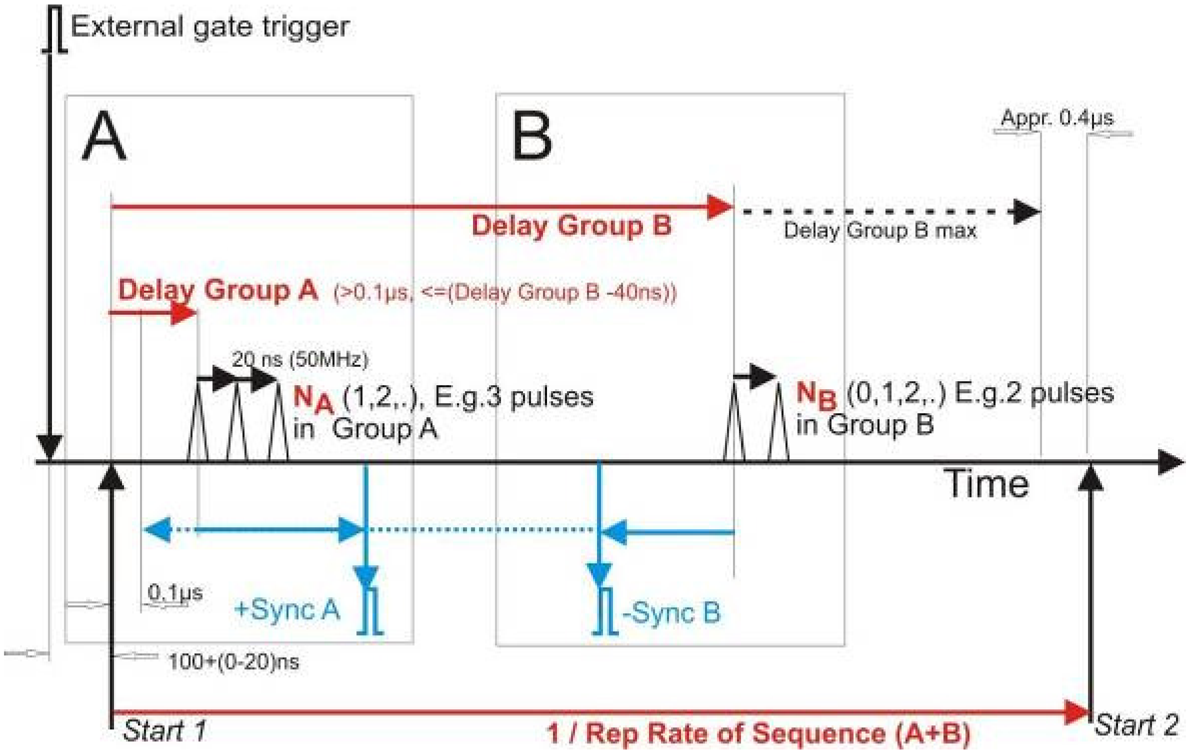

Fig. 33: E.g. Generating pulse groups A (3 pulses) and B (2 pulses) by one external triggering signal on "Gate" input.

The two different groups are named A and B. In this example group A has three pulses and B two pulses. The time between the pulses in the group is always 20 ns, which is the time between the pulses from the seed-laser.

After getting the **Start 1** signal, which can be caused by the internal trigger or an external TTL trigger signal on "Gate", the laser waits the "Delay Group A/B" time till it begins to emit the pulses. The number of pulses in the group can be choose independently for A (1,2,3..) and B (0,1,2..).

A trigger - out for external application is produced on BNC - connectors Sync A and Sync B for each group. One can set the time delay for the sync A/B output relatively to the first ps-laser pulse in Group A/B (minimum "Delay Group A"+0.1µs). The "Delay Group A/B" time, the number of pulses N_A and N_B in the Groups A/B and the "Sync A/B" time can all be set in the LUMERA LASER Rep Rate Control software (Chapter 4.2.4).

6 Mechanical Layout of RAPID

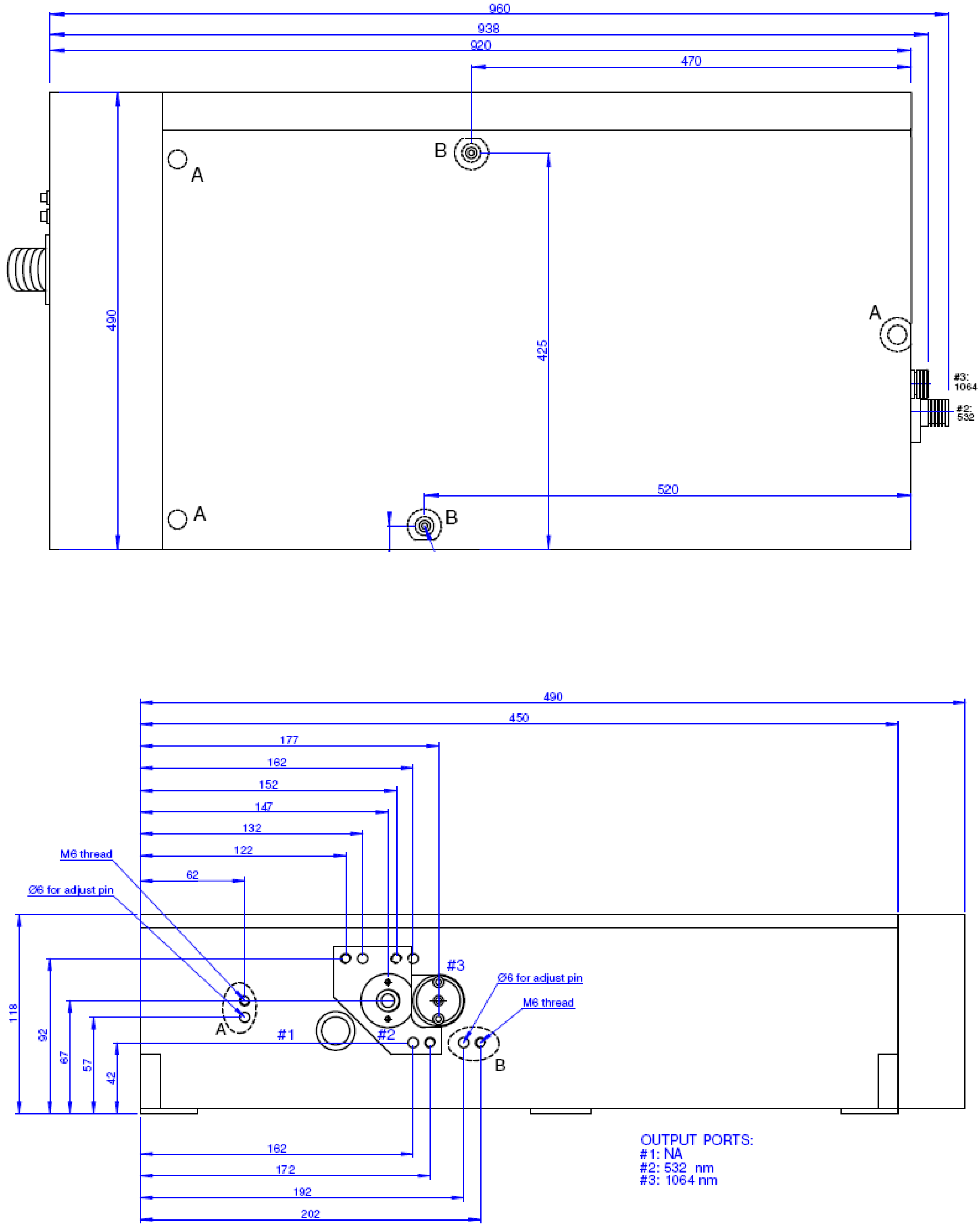

Fig. 55: Mechanical layout of laser head (RAPID, 2W Version)