SEVENTH FRAMEWORK PROGRAMME

THEME FP7-ICT-2009-C

Instrument	STREP
Project no.	244068
Project acronym	**CROSSTRAP**
Project title	**C**oherently-enhanced **R**aman **O**ne-beam **S**tandoff **S**pectroscopic **TR**acing of **A**irborne **P**ollutants

Deliverable D3.3

Eye-safe OPA

Due date of deliverable	month 40
Actual submission date	24/06/2013
Start date of project	01/02/2010
Duration of the project	40 months
	TU WIEN

CROSSTRAP
Deliverable D3.3

SHORT DESCRIPTION:

Implementation of an eye-safe driver for coherent backscattering was originally planned for the final phase of the project. However, clear advantages of the long-wavelength filament driving demonstrated during the second year of the project have significantly expedited the development of the long-wave laser and modified the original target wavelength from 1.5 µm to 4 µm. Detailed description of the 13-mJ MID-IR parametric system developed at TU Wien for filamentation experiments was given in D3.2. In this deliverable we concentrate on further energy scaling at the output wavelength of 4 µm. The report describes incremental upgrades on the TU Wien system that served as a test bed for the construction of a stand-alone MIR-OPCPA system built by the joint effort of TU Wien and Light Conversion for the Partner MSU who provided its own investment for the creation of a new laser source. This work identified depolarization in the Joule-class Nd:YAG direct picosecond pulse amplifier as a the main technological challenge which can be circumvented by making the picosecond pump system significantly more expensive if proper depolarization compensation is install. Careful engineering of OPCPA stages pumped by individual, appropriately scaled output channels of the picosecond pump laser is required both to reduce the system cost and lower the overall B-integral of the system.

1_ INTRODUCTION

Already during the second year of the project we were able to demonstrate significant advantages of MID-IR filament initiation that provided a much hotter plasma than the NIR sources tried earlier and proved the possibility of obtaining lasing in pure nitrogen as well as a dramatic efficiency enhancement in the case of Bennett scheme nitrogen laser. However, one major drawback of the MID-IR pump pulses with respect to its NIR counterparts was the demand for a much higher pulse energy as the consequence of λ^2 scaling law of the critical power of self-focusing. This circumstance forced us to study free-space lasing from gas in a gas cell, where the gas pressure could be raised to several bars (~5 bar) to compensate the shortage of pulse energy that would be required for filament formation under normal atmospheric pressure. The estimated pulse energy at 4 µm required to achieve filamentation in ambient air is about 40 mJ. Within the last reporting period of the project, we have worked on various system upgrades and system prototyping. TU Wien undertook limited investment (~50kEur) from its own resources to finance upgrades of the pump laser and the OPCPA stages. Unfortunately, this level internal funding was not sufficient to reach the desired output energy at 4 µm because of the difficulties with having just a single high-energy picosecond pump laser head. Fortunately, at the final stage of the project, the MID-IR driver source development progressed very rapidly because ILC MSU has funded purchases of critical OPCPA component that it is installing in its own lab in Moscow. This report is organized as follows: first it describes the study of the OPCPA energy upgrade undertook on the TU Wien own OPCPA system. Next, we present the OPCPA concept implemented in the system built by TU Wien and LC for MSU. The latter system, at the time of writing, is awaiting its commissioning at the site in Moscow.

2_ Pump system upgrade of MID-IR OPCPA

In order to increase the output energy of our 4-µm OPCPA system an additional amplification stage in the picosecond Nd:YAG amplifier was installed. The amplification stage is based on a Ø18 mm-diameter, 1.1%-doped Nd:YAG rod pumped by four flash-lamps. The newly installed amplification stage was seeded with the output of the previous third amplification stage (Fig.1). Before the seeding a fraction of the output of the third amplification stage was split for pumping of the first OPCPA1 stage. This resulted in >200 mJ seed energy. In the amplifier the exit surface of the Ø10mm Nd:YAG rod is 2f-to-2f reimaged on the input surface of the Ø18mm Nd:YAG rod with x1.77 magnification by using f=450 mm and f=800 mm plano-convex lenses. In order to reduce the intensity in the amplifier crystal, polarization of the seed before the amplifier was set circular with a help of a quarter wavelength retardation plate. After the amplifier a linear polarization was restored by a subsequently placed quarter wavelength retardation plate. In this arrangement the depolarized light carries a donut shape and is filtered by a thin film polarizer, while the transmitted by the polarizer light possesses uniform transvers distribution.

The pump energy was adjusted by tuning the output voltage of a dual power supply. Single power supply has a capacity of 60 µF, which results in pump energy exceeding 75 J at the output voltage of 1600 V (Fig.2). In order to avoid an optical damage of the amplifier rod and other optical elements in the system and to operate the amplifier in the safe regime, we have limited the output voltage of the two power supplies to 1400V. This resulted in 117.6 J of overall pump pulse energy for the last amplification stage.

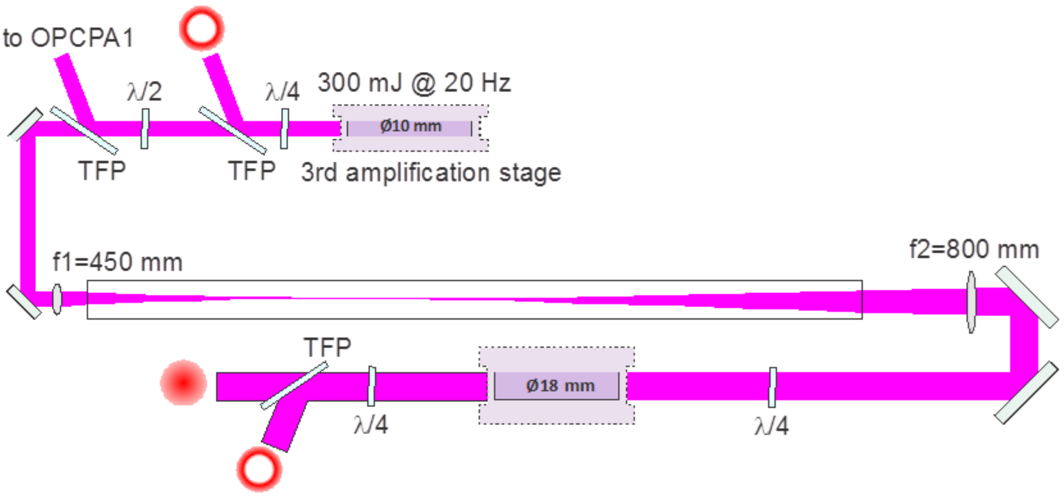

Fig. 1. Experimental arrangement of the last amplification stage. The input of the last amplification stage is provided by the output of the previous amplification stage, after the splitting of a portion of energy for the pumping of the first OPCPA1 stage. TFP are thin film polarizers, λ/2 and λ/4 are half and quarter wavelength retardation plates, respectively.

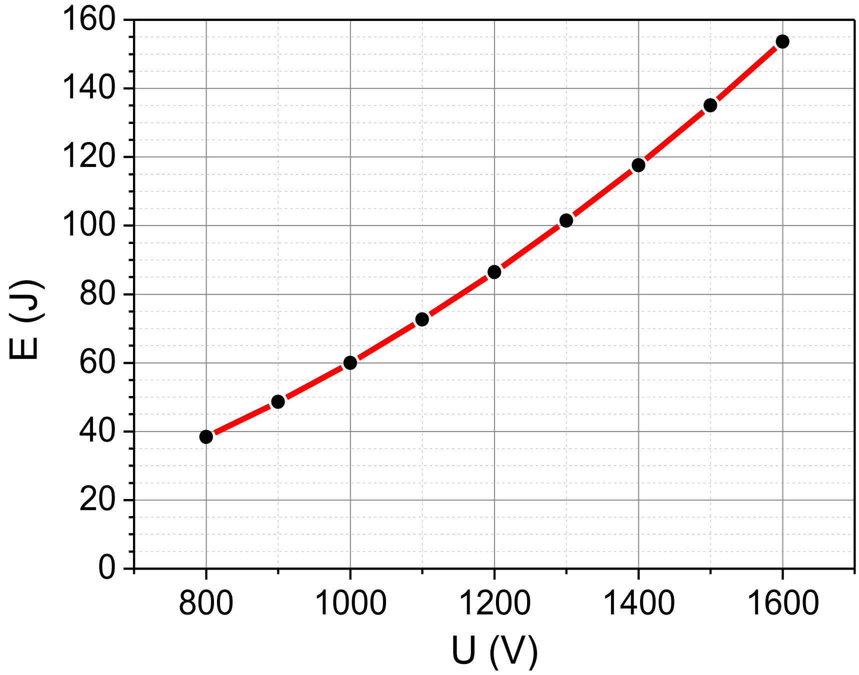

Fig. 2. The dependence of pump pulse energy on the output voltage of the dual power supply.

Test experiments on the amplification at different energies of pump and seed pulses have been performed (Fig.3). The results of the investigation reveal that up to 0.9 J of the output pulse energy can be achieved with 200 mJ of the seed and at the flash-lamp pump pulse energy of 117.6 J. As it can be seen from the comparison of the transients taken at different seed energies, at the above mentioned conditions no evident gain saturation has been observed. This is also revealed by the near-linear dependence of the output energy of the last amplification stage on the seed pulse energy in the case of the maximum applied pump flash-lamp pulse energy of 117.6 J (Fig.4). However the use of full energy of the 0.9-J amplified seed for pumping of the second and third OPCPA stages was hampered due to the pump-induced depolarization. As it is shown in Fig.5 only 500 mJ of the output of the last amplification stage can be used for pumping of the OPCPA stages. The rest of the energy (~400 mJ at the highest applied flash-lamp pump energy of 117.6J) is emitted in the opposite polarization possessing a donut shape spatial distribution, which is hardly usable for pumping of a parametric amplifier.

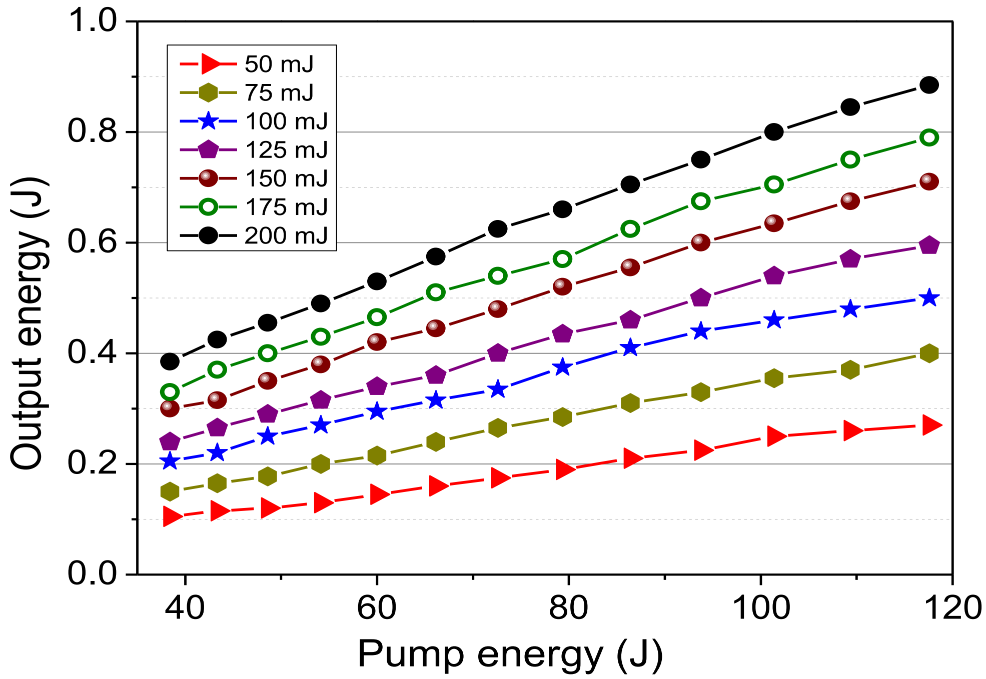

Fig.3. Dependence of the output energy of the last amplification stage on pump energy at different seed pulse energy (indicated in the figure).

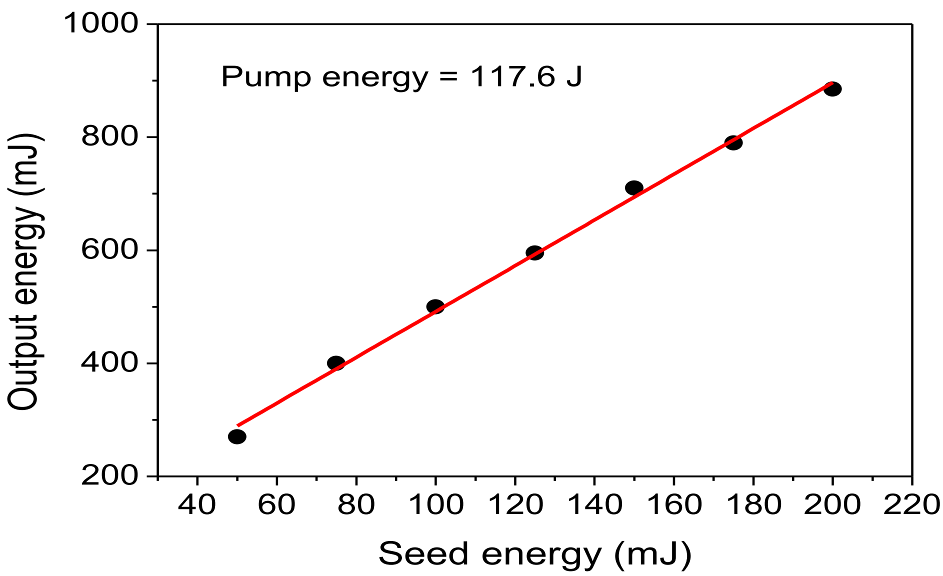

Fig.4. Evolution of amplification with increasing of pump pulse energy at different seed pulse energies; dots represent experimental data, the line is a linear fit.

Two possible solutions for the compensation of the depolarization were considered: first, an installation of a Faraday rotator in a double-pass amplifier based on the Ø18mm Nd:YAG rod, and second, a replacing of the amplifier stage based on the Ø18mm Nd:YAG rod with two in-line positioned amplifier stages based on Ø12mm Nd:YAG rods with a polarization rotator installed between the laser heads.

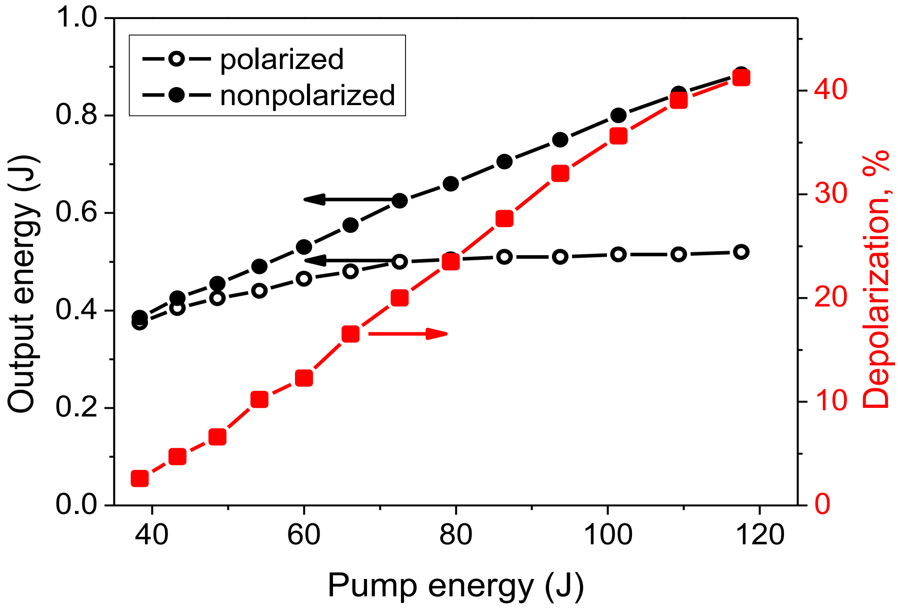

Fig.5. Dependence of the total output energy (left ordinate axis, solid black circles) and energy contained in the p-polarized pulse (left ordinate axis, open black circles); by the red squares the percentage ratio of depolarized light (right ordinate axis), which is separated by the TFP and possess donut-structure (Fig.1) is presented.

The second choice was opted because of the following reasons: 1) a 25-mm diameter Faraday rotator is rather exotic and expensive item; 2) since a 100% compensation of the depolarization with a Faraday rotator is practically unreachable, even a minor leakage of the depolarized light into the preceding amplification stages might cause an optical damage of the optical elements; the danger is additionally increased by the fact that lens-based image enlarging system is used for the transfer of enlarged image of the output surface of a preceding laser rod to a laser rod of the next amplification stage; 3) a higher amplification factor is expected in the case of 2x Ø12mm Nd:YAG rod laser heads as compared to a single Ø18mm Nd:YAG rod laser head (this would make possible to pump the first and the second OPCPA stages with the part of the output of the third Ø10mm Nd:YAG amplification stage while directing a part of the output into the 2x Ø12mm Nd:YAG rod laser amplifier).

3_ RUGGEDIZED HIGH-ENERGY MID-IR SYSTEM

As mentioned in the introduction, TU Wien and LC have jointly developed a new 4-µm parametric system for MSU which is projected to deliver about 50 mJ sub-100-fs pulses at a repetition rate of 20 Hz.. Results of the pump power scaling reported in Sec. 2 were of critical importance in determining the pump laser architecture. The schematic of the OPCPA layout is given in Fig. 6.

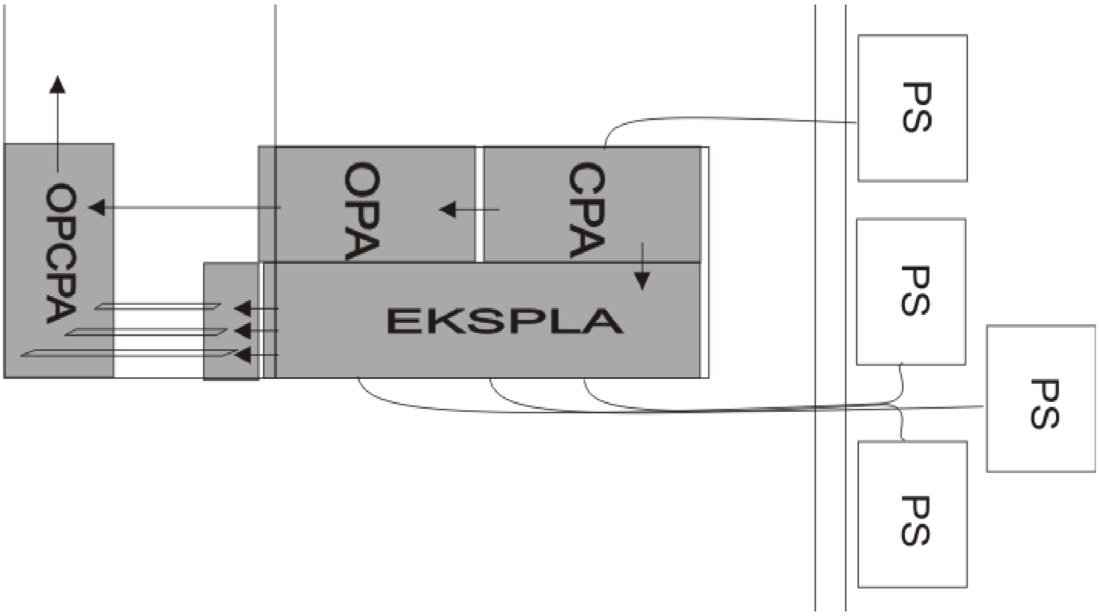

Fig. 6. Layout of the high-energy 20-Hz MID-IR OPCPA to be installed in Moscow. PS, power supply

The flash-lamp pumped 100-ps 20-Hz Nd:YAG laser was ordered from EKSPLA. Differently from the system developed over the years at TU Wien, this pump laser was designed from scratch to fit a single laser head. The photograph of the Nd:YAG laser, taken at the site of the manufacturer, is shown in Fig. 7. Based on the knowledge obtained during the tests with Joule-class pump heads at TU Wien, we have worked in close cooperation with EKSPLA to optimize the number and performance of the power stages. As a result, the pump laser has three outputs, to match the number of OPCPA cascades, with the output energy scaled progressively according to the demands of each cascade. Using this approach we thus were able to significantly reduce the B-integral of the picosecond laser which would be the case if the entire laser output would be first amplified in a single amplifier channel and subsequently divided into three unequal arms. Another benefit of this approach is the ability to avoid the use of very demanding and expensive Ø18 mm laser heads. Instead, the new pump laser has two mutually compensating Ø12 mm heads which still ensure ~700 mJ pump energy at 1064 nm for the final KTA OPCPA cascade.

Fig. 7. 3-Channel 20-Hz 100-ps pump laser built by EKSPLA

The remaining part of the system consist of a femtosecond 10-W 1-kHz femtosecond DPSSL Yb amplifier (CPA) that drives a femtosecond OPA, and a cascaded OPCPA that is pumped by the EKSPLA Nd laser (Fig. 6) The CPA and Nd:YAG lasers are optically synchronized via a common oscillator (Flint, Light Conversion). The femtosecond parts of the system (CPA+OPA) are shown in Fig.8. The last part of the femtosecond OPA is a completely redesigned GRISM pulse stretcher for 1.45-µm pulses that are seeded to the OPCPA. By optimizing the choice of the glass type used in the Brewster-angled prisms and folding the beams differently between the prisms, we have significantly improved the throughput of the GRISM stretcher in comparison with the earlier version without compromising the pulse bandwidth. The photograph of the redesigned stretcher is shown in Fig. 9.

The femtosecond part of the system was completely built and aligned in Vienna. Unfortunately, there was not enough lab space to temporarily install the picosecond pump laser in Vienna. As a compromise, OPCPA was preassembled at TU Wien. At the time of writing, the entire OPCPA system is in transit to Moscow. The installation and testing of the system is scheduled for the first week of July 2013.

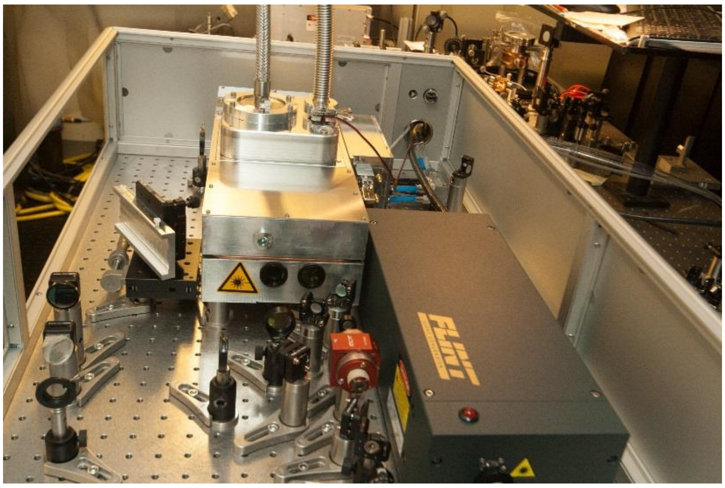

Fig. 8. Left: Femtosecond CPA and OPA at TU Wien before shipment to MSU. Right: zoom on the oscillator built by Light Conversion and the regenerative amplifier developed at TU Wien.

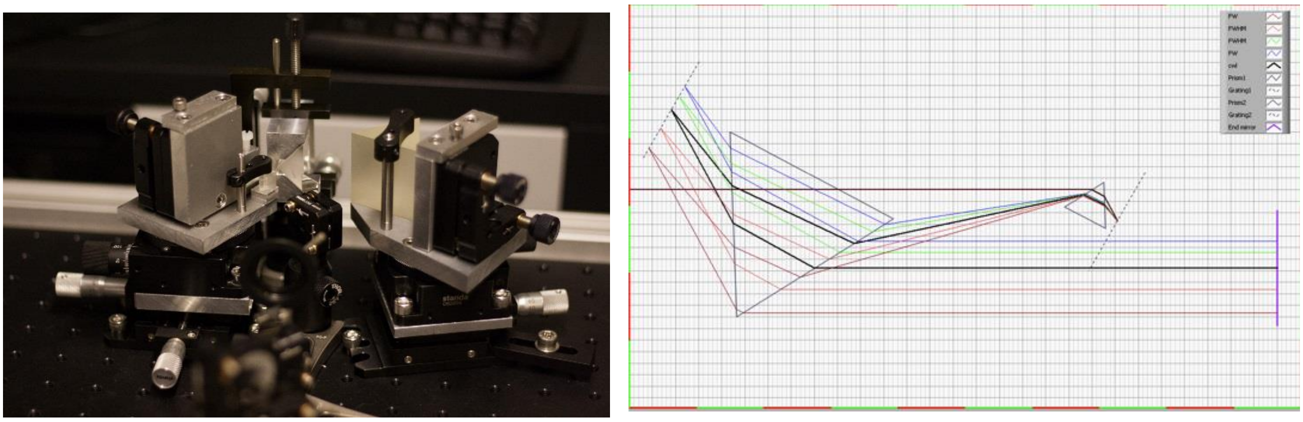

Fig. 9. Newly designed high-throughput 1.46-µm pulse stretcher based on SF11 Brewster-angled prisms. Left: assembled and aligned stretcher. Right: corresponding ray tracing calculation.

4_ CONCLUSIONS

In this deliverable:

- we have performed an experimental study of direct picosecond amplification to explore the limits of straightforward pump energy scaling of the existing MID-IR system;
- we have built a mature MID-IR OPCPA system which currently awaits its installation at the site of the CROSS TRAP partner MSU;
- we have significantly improved dispersion management of OPCPA by designing and optimized high-throughput GRISM stretcher.