Installation of the Mid-IR OPCPA Laser in the RCaH CLF Laboratories

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Introduction

The Artemis / ULTRA upgrade continued this year with the relocation of the Artemis laboratory to the RCaH. The relocation included the introduction of third generation ultrafast laser technology to these facilities. The installed system has passed the major milestone of factory acceptance, demonstrating its capability, and is now located in the RCaH, for installation and site acceptance in January 2020. The system is comprised of a high average power pump laser, based on an Yb:YAG thin disk regenerative amplifier frontend and an OPCPA. The different sections of the latter are depicted in Fig. 1.

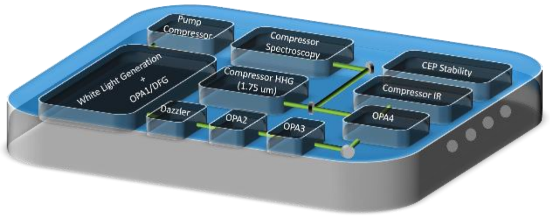

Figure 1 Cartoon layout with the different sections of the new OPCPA system.

High Average Power Pump Laser

The OPCPA system is pumped by a 200 W, 100 kHz, < 1ps, regenerative amplifier (Trumpf Scientific Lasers), based on thin-disk amplifier Yb:YAG, Fig. 2. This system is seeded by a rack-mounted fibre oscillator with preamplifier (OneFive). With its short pulse seeding and pumping of the OPCPA system, this type of industrial-grade laser technology will bring high average power and robust capability to the facility's scientific laser applications.

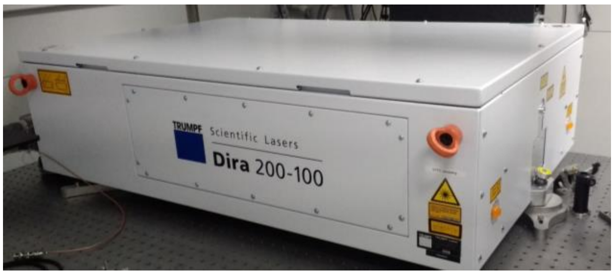

Figure 2 A picture of the frontend laser for the OPCPA system.

While this pump laser is primarily set to pump the OPCPA system, it can also stand alone to support other activities of the facility, e.g. in Raman spectroscopy. Compared to typical < 100 fs Ti:Sapphire-based lasers across the facility, this system provides narrower bandwidth intrinsic to the longer pulses (~ 1 ps), which can be applied to Raman spectroscopy. While the energy level is comparable with the ULTRA Kerr-gated Raman setup, the repetition rate is 10x higher, increasing the rate of data acquisition. Additionally, the longer wavelength, will allow extension of the Kerr-gating into the NIR spectrum, providing capability complementary to ULTRA. Furthermore, there are several emerging technologies [1,2], which the ULTRA and Artemis groups are currently exploring, to reduce the pulse duration and keep similar high average power.

Mid-IR OPCPA

The Mid-IR OPCPA laser (Fastlite) provides unique flexibility for facility operation. Generating up to 20 and 10 W of power in signal and idler outputs (respectively), the system has wide wavelength tunability (1.4 – 3.8 μm) and rapid spectral phase and bandwidth control, through its integrated acousto-optic programmable dispersive filter (Dazzler, Fastlite). During the critical Factory Acceptance Tests the system demonstrated excellent performance in terms of power, CEP and pointing stability, which are essential for the long term measurements required for several of the planned experiments. While the detailed performances will be the subject of a forthcoming publication, we show here an example of the spatial profile of the OPCPA signal output, with $M^2 < 1.2$ Fig. 2.

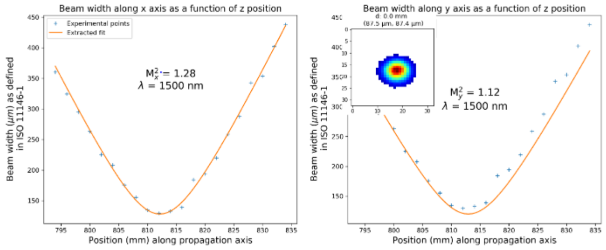

Figure 3 Typical beam profile measurements of the tunable signal output. In the inset the spatial profile recorded with a Silicon camera in the far field.

New Pulse Characterization Diagnostics

To enable characterization of the new laser, new diagnostics are now available in the laboratory. In particular, the ability to measure pulse durations, using a frequency resolved optical gating (FROG) device, in the wavelength range between 0.8 um and 9 um will serve not only as a comprehensive test for the OPCPA, but will assist also different setups across the CLF facilities.

HHG Tests at 1.75 μm

Previous HHG sources applied in the Artemis facility have been driven mainly by 800nm, few-mJ-level pulses. The benefits of driving the high order harmonic generation with longer wavelengths have been documented in the literature [3,4]. Among others they include the saturation intensities, the harmonics cut-off and the attainable pulse durations. Yet, the experiments are challenging leaving still enough room to actually demonstrate them in real conditions. As one of the outputs of the OPCPA was specified for 1.75 um, it was necessary to explore the feasibility of driving HHG with longer wavelength, lower energy sources. The Artemis lab is equipped with a hollow fiber system and a TOPAS. Thus by combing these two setups we could experimentally simulate the pulses of one of the outputs of the OPCPA (which is planned to carry most of the workload in the HHG measurements), at 1 kHz and compare with the anticipated 100 kHz. We explored the feasibility of producing high order harmonics with 1.75 µm (with an excellent spatial mode) and with its second harmonic at 0.85 um (SHG conversion efficiency found to be ≈ 40%), Fig. 4, using the Red Dragon laser. Reducing the wavelength to 0.85 um had a twofold benefit: a) As mentioned above, the majority of the experiments had been performed with 0.8 um so we have benchmark measurements and procedures for this wavelength and b) the photon flux at specific wavelengths in the XUV region actually increases as one decreases the driving wavelength.

The irradiation conditions were kept the same as the specifications (energy, spatial mode) of the OPCPA and the results were very promising, see Fig. 3. Specifically, we easily achieved similar characteristics for the harmonics, in terms of conversion efficiency (≈3 times less, which can be easily overcome by utilizing the 2 orders of magnitude higher repetition rate) and divergence, as when the 0.8 um from the Ti:Sapphire was used.

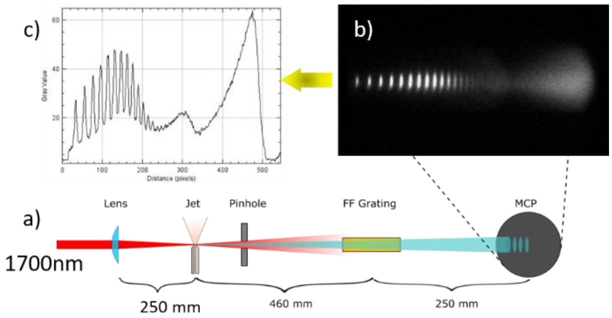

Figure 4 Schematic layout of the setup for the HHG measurements obtained with the 1.7um pulses. b) Spatial profile of the detected harmonics. c) Integrated spectral intensity of the corresponding harmonics deduced from the previous image.

Longer Wavelength IR Generation

Vibrational spectroscopy applications of the ULTRA facility, require > 4 µm broadband capability. Typical routes to this spectral region with ultrafast lasers are through DFG of the signal and idler of an OPA, or NIR-pumped OPAs. The present system provides new challenges, as the average powers increase, along with new opportunities to generate high average power, robust, < 100 fs mid-IR pulse capabilities.

Preparations are underway to explore promising non-linear materials for mid-IR generation (CSP, LGS, ZGP). Simulations of supercontinuum generation using IR and mid-IR pulses provide invaluable information towards this direction. For example in Fig. 5 we can see simulations of the supercontinuum spectrum after the propagation of a mid-IR pulse at 3.1um inside 4 mm YAG, BaF2 and ZnS crystals.

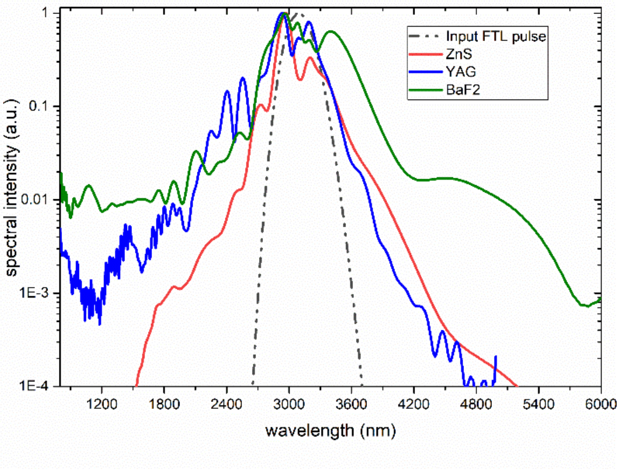

Figure 5 Supercontinuum generation simulations after propagation of mid-IR pulses through different materials, as indicated in the legend. Laser energy was set at 10 µJ and pulse duration at 125 fs.

Conclusions

In conclusion, we report here on the installation of the MIR-OPCPA in the RCaH CLF laboratory and the actions undertaken towards a smooth and successful transition to experimental operations in ULTRA and Artemis facilities. This is a state of the art system which provides a wide range of capabilities for the user community and the CLF staff, and the opportunity to evaluate and develop new experimental approaches towards both extremes of the EM spectrum, the XUV and the mid-IR.

Acknowledgements

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