Single shot autocorrelator for the emPULS laser system

Contact: marco.galimberti@stfc.ac.uk

Y. Hemani, D. Bleiner
Advanced Analytical Technologies,
Swiss Federal Laboratories for Materials Science and University of Zurich,
8600 Dübendorf, Switzerland

M. Galimberti
Central Laser Facility,
Science and Technology Facilities Council,
Rutherford Appleton Laboratory
OX11 0QX, United Kingdom

Abstract

In the Laboratory for Advanced Analytical Technologies of the Swiss Federal Laboratories for Materials Science (Empa) a new terawatt laser facility (emPULS) is under development. The system is a CPA architecture based on Nd:phosphate flash pumped amplifier, similar to the rod chain of the Vulcan laser system. Within the scientific collaboration, a single shot autocorrelator was setup, following the successful design of the pulse front tilt single shot autocorrelator developed at CLF[1].

1 Introduction

To characterize the pulse duration of the emPULS laser system after the compressor, an autoccorrelator is developed. Since the repetition rate of the laser is as low as one shot every few minutes, commercial autocorrelators are not easily available, and one built in lab is more feasible.

Optical autocorrelation is a simple and unique way to characterize an ultrashort laser pulse. An incoming pulse is split into two copies. One of them is delayed in time. They are both mixed in a non-linear crystal to generate second harmonic radiation. The intensity of light obtained by this kind of non-linear process is directly proportional to the combined product of the intensities I(t) of the two pulses overlapping temporally in the crystal [2]. The autocorrelation function $A(t)$ with the relative time delay t is given by:

$$A(t) = \int_{-\infty}^{\infty} I(\tau) I(\tau - t)\, \mathrm{d}\tau. \tag{1}$$

The final duration of the compressed pulse Δt at full width half max (FWHM) can be found out by mathematical fitting with the autocorrelation signal by assuming a pulse shape. In this report, the setup of a second order, single shot auto-correlator is presented which is suitable for characterizing picosecond pulses in a single shot. The autocorrelation setup is calibrated and the trace is retrieved and fitted with a Gaussian curve.

2 Characterization of the Autocorrelator

The working principle of a single shot second harmonic auto-correlator is to split an incoming pulse into two replicas, which will meet non-collinearly at a crossing angle in a non-linear medium. Alignment of the phase matching and the temporal overlapping of the pulses will produce second harmonic generation whose shape and intensity is measured by a spatial detector. The geometry is chosen in the way to provide maximum temporal window and flexibility in alignment of the crossing angle to characterize the pulse duration in a single shot. Figuera et al. [1] have derived the geometrical definitions and the autocorrelation trace in relation to pulse width is given by:

$$\tau = \sqrt{2} \sin\left(\frac{\phi}{2}\right) \frac{n\sigma}{c} \tag{2}$$

where c is the speed of light in vacuum is, n is the refractive index of the non-linear crystal, ϕ is the crossing angle and σ is the pulse width.

As shown in fig. 1(a), the optical assembly for the auto-correlator consists of a few mirrors, a focusing lens, a 1 mm etalon attached to the input surface of a beamsplitter, a delay stage, a BBO (Beta Barium Borate) nonlinear crystal and a grey scale camera. The incoming beam is split via the beamsplitter into a transmitted beam and a reflected beam. The etalon generates another reflected replica which is symmetrical but a little bit lower in amplitude. The motivation to use the etalon is that the optical path delay between the two reflected pulse replicas is useful to define and determine the tem-

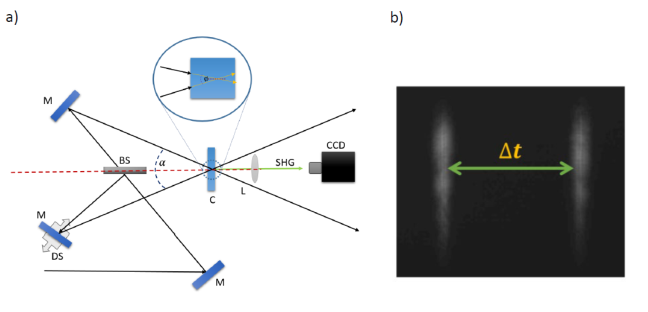

Figure 1: a) Optical design of a single shot auto correlator. It consists of three mirrors (M); of which one is on a delay stage (DS), a beam splitter (BS), a non-linear crystal (C), a focusing lens (L), and camera (CCD). b) An example of an auto-correlator measurement is shown. The separation between two reflected pulses is indicated.

poral pulse separation. The two split pulses are phase matched in the BBO crystal. The relative time delay between the two arms can be modified by moving a mirror in one of the arm. The SHG signal is the function of the crossing angle and the temporal overlapping of both pulses. The output wavelength and intensity is measured with a spectrometer and a camera. The optical path delay between two reflected pulses as shown in fig. 1(b) can give the temporal pulse separation by:

$$\delta t = \frac{d}{c}\frac{2n^2-1}{\sqrt{n^2-\frac{1}{2}}} \tag{3}$$

where d and n are the etalon thickness and refractive index. The FWHM of the autocorrelation Δt_{AC} is given by Gaussian fit while the FWHM pulse duration Δt can be calculated by the formula

$$\Delta t = \frac{\Delta t_{AC}}{\sqrt{2}}. \tag{4}$$

This setup is designed to operate at 1053 nm and calibrated by using the sub 100-femtosecond pulses coming from the main laser oscillator. The input pulse is going into a beamsplitter with a 1 mm thick, fused silica, etalon opticaly contacted on the front surface. Incidence angle is 45° and the reflected beam is resulting in two pulse replicas, while the transmittewd one has only one pulse. The separation between two reflected pulses is $\delta t \simeq 8.44\,\mathrm{ps}$. The transmitted and the reflected pulse both go to the 30 mm diameter, 300 μm-thick BBO crystal such that the external crossing angle $\alpha \simeq 42°$. The SHG light at approximately $\lambda \simeq 526.5\,\mathrm{nm}$ is imaged onto the camera. By the analysis of the autocorrelation signal on the camera, a calibration factor of 244 pxl/ps is obtained. The calibration factor is used to get an autocorrelation trace with a FWHM of $\Delta t_{AC} \simeq 129\,\mathrm{fs}$. The FWHM auto- correlation trace of a Gaussian pulse is always larger by a factor of $\sqrt{2}$, therefore, after the Gaussian fitting, calculation and pulse shape correction, the FWHM of the actual pulse comes out to be $\Delta t \simeq 90\,\mathrm{fs}$ as shown in fig. 2.

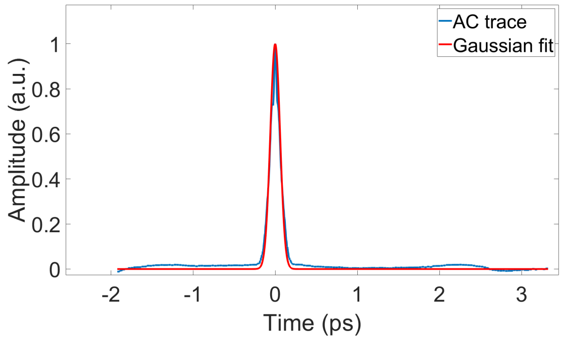

Figure 2: The calibrated autocorrelation trace collected from the camera is shown (in blue) with its Gaussian fit (in red).

3 Conclusion

A single shot autocorrelator was developed at the emPULS laser. The instrument was fully tested and calibrated and it will be a critical laser diagnostic for the facility. Future plan will be to develop this diagnostic also to measure the pulse front tilt of the laser pulse after the compressor.

References

[1] Gonçalo Figueira et al. "Simultaneous measurement of pulse front tilt and pulse duration with a double trace autocorrelator". In: *JOSA B* 36.2 (2019), pp. 366–373.

[2] R Trebino et al. "Highly reliable measurement of ultrashort laser pulses". In: *Journal of Applied Physics* 128.17 (2020), p. 171103.