Measurement of Ti:Sa pulse duration and fast metrology

abstract

In recent years, thanks to the development of fs lasers, we are able to investigate new frontiers concerning particle acceleration, non-linear laser-matter interactions and atomic studies.
Measurement of fs pulse is crucial in order to control laser-matter interaction in ultra-high intensity regime.
In this scenario we are planning a visit at the High Intensity Laser Lab at the Hebrew University of Jerusalem. In this laboratory a Ti:Sa laser system is installed. It consists of a 70 fsec Spectra Physics Tsunami oscillator, followed by a regenerative amplifier, followed by a multi-pass amplifier (4-pass). The end of the amplifying process consists of a compressor, yielding a pulse of approximately 100 fs duration, 50 mJ per pulse, wavelength of 798nm, and a repetition rate of 10Hz. The beam diameter is approximately 1.2 cm. The aim of my visit is to work on the laser diagnostics, in particular with a Frequency Resolved Optical Gating (FROG).
In order to measure the pulse duration a part of the laser beam is converted in second harmonic into a non linear medium, a BBO crystal. The pulse is divided in two beams: one called probe beam and the other one gated beam.
The pulses follow to different optic path and are recombined inside the BBO crystal where the convertion in second harmonic takes place. When the two pulses are present together inside the crystal we are able to observe the conversion. Varying the delay between the pulses we obtain an intensity profile of the converted pulse.
The autocorrelation product, which is the convolution of the pulse's envelope function with itself, is analyzed in a spectrometer. This yields both the pulse's temporal and spectral structure simultaneously.

Autocorrelation

The autocorrelation was the first idea to measure an ultra-short light pulse. The main idea is to use the pulse to measure itself. To do this the pulse has to be split in two part and spatially overlapped.
They have to interact into a non linear medium and the study of the response gives us the information required.
The non linear medium consist in a Second Harmonic Generation crystal (SHG) which produces a signal of light with a frequency doubled with respect to the fundamental one.
The envelope of the field can be expressed as:

$$E(t,\tau) \propto E(t)E(t-\tau)$$

The intensity is proportional to the field and follow the same rule.
A detector can not resolve in time the pulse due to his intrinsic limit and so what it measure will be a quantity A:

$$A'' = \int_{-\infty}^{+\infty} I(t)I(t-\tau)\,dt$$

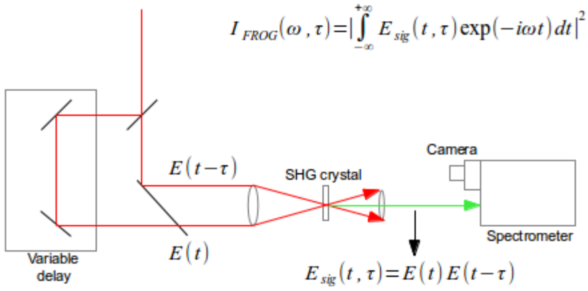
where “ '' ” indicate the second order of the autocorrelation.
The main problem is the different pulse structure can give the same signal. It is not possible to solve this “ambiguity”. Some assumption has to be take into account to solve the problem, nevertheless then a pulse has a complex structure, we can't with this simple technique rebuild the original one.

FROG

FROG (Frequency Resolved Optical Gating) it's a technique to measure ultra-short pulses which operates in the time-frequency domain.
From the mathematical point of view we can write the function called spectrogram:

$$\sum_E(\omega,\tau) \equiv \left| \int_{-\infty}^{+\infty} E(t)\, g(t-\tau) \exp(-i\omega t)\, dt \right|^2$$

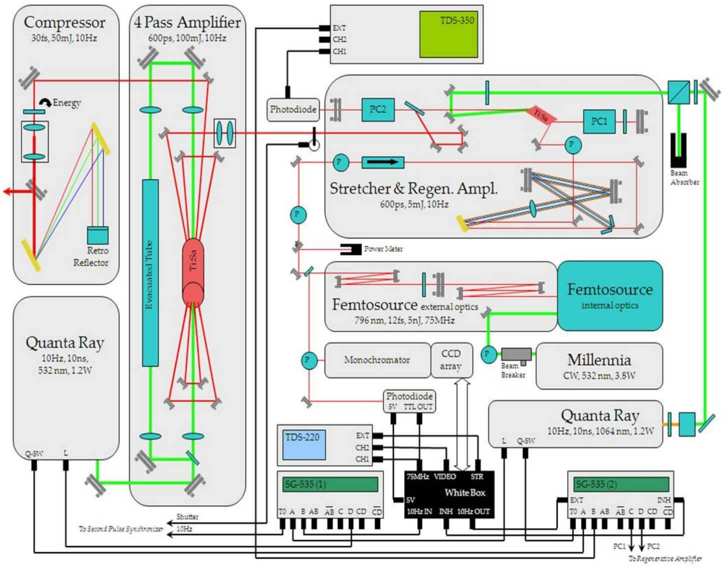
which is a function of ω and τ and g(t-τ) is the variable-delay gate. Without it the spectrogram should be simply the spectrum of the signal.



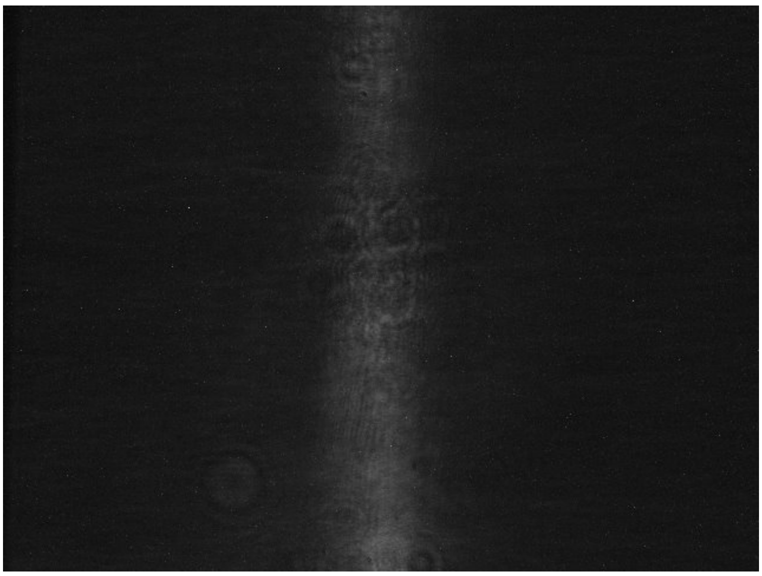
As shown in figure the setup for FROG consist in a delay line, a non linear medium (SHG crystal) a spectrometer and a camera.
FROG from the mathematical point of view is a two-dimensional phase-retrieval problem.
The one-dimensional phase-retrieval problem, due to the presence of many ambiguities, is unsolvable (as for the case of pure autocorrelation).
Nevertheless the two-dimensional phase-retrieval problem with the informations that we can get from the measurement limit the number of solution. In fact FROG can measure the pulse shape of standard pulse and gives a good approximation for complex pulse.

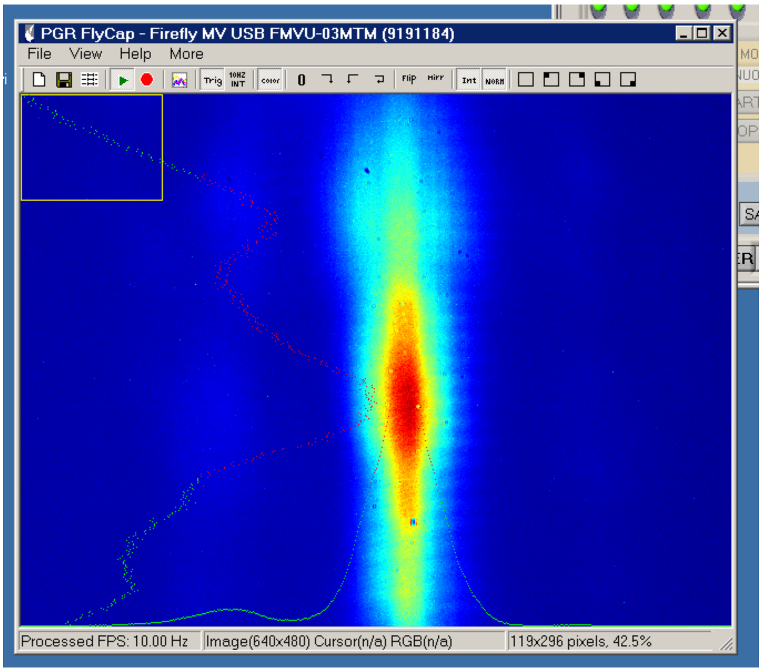
The High Intensity Laser Lab at The Hebrew University of Jerusalem

The High Intensity Laser Lab at the Hebrew University of Jerusalem has a Ti:Sa CPA laser system. To measure the pulse duration a FROG is used.



The laser consist in a oscillator Spectra Physic Tsunami with a pulse duration of ~70 fs. After the oscillator there is a regenerative amplifier. The last amplification step consist in a 4-pass amplifier. After this a compressor is placed. The final pulse has a pulse duration of approximately 100 fs, 50 mJ of energy, 798 nm of wavelength and a repetition rate of 10 Hz. The output beam diameter is 1.2 cm.
An image acquired using FROG system in Jerusalem is shown in figure.





Working on the delay line the strip in figure moves right and left. The movement in the real space is measured so it is possible obtain the delay in time (dividing by the speed of light). This permit to convert from pixel to femtoseconds. The width of the autocorrelation can be directly measured. Assuming a well known shape for the pulse (in our case Gaussian) we have just to divide the width measured by a numerical factor (corresponding to the pulse shape chosen) that for a Gaussian is 1.41. In this way we obtain the information required.

Conclusion

During my visit at The Hebrew University of Jerusalem I had the opportunity to work on the laser system at the High Intensity Laser Lab. In particular I had the opportunity to work with the FROG system installed.
We worked on the practical aspects (alignment, calibrations, etc..) for the measurement of an ultra-short pulse measuring the time duration of a Ti:Sa laser system.
This experience gave to me the opportunity to work with experienced people in Israel, under the collaboration of our institution.