Ultra-short pulse characteristics measured with GRENOUILLE

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Abstract

The measurement and characterization of ultrashort laser pulses remains an arduous task which can still be achieved with simple devices. The most commonly used pulse-measurement method is known as FROG (Frequency-Resolved Optical Gating) and another version with some experimental simplification and low-priced setup is known as GRENOUILLE (GRating-Eliminated No-nonsense Observation of Ultrafast Incident Laser Light E-fields). Nevertheless remains the interest on a simpler and cheaper setup with equal or better assets. So, in this work we introduce other modifications on the GRENOUILLE method where we replace the original Fresnel biprism by two mirrors and a beam splitter, also using a webcam instead of a digital camera and image grabber board. We present results on the characterization of three different pulse classes: Fourier transform limited; double; and chirped. We compare the recovered E field with further spectral and second order correlation data of the corresponding pulses.

Introduction

Measuring ultra short laser pulses, has always been a challenge for spectroscopists. For many years it was possible to create ultra short pulses but not to characterize them completely. The precise knowledge of the pulse evolution is necessary for verifying theoretical models of pulse generation. Also, in order to make even shorter pulses it is essential to understand the distortions that limit the length of currently available pulses. Finally, in experiments using these pulses it is always important to know at least the pulse duration in order to determine the temporal resolution of a given experiment. Moreover, in many experiments (studies of molecular vibrations, for example) additional details of the pulse's structure play an important role in determining the outcome of the experiment. The coherent control achieved by molding light pulses to have rather specific interactions with specific material systems has called the attention to the science of shaping and measuring light fields to steer natural phenomena. Fortunately, remarkable progress has occurred in the development of techniques for the measurement of ultra short laser pulses. The most commonly used pulse-measurement methods able to go down to the few-cycle regime are FROG (frequency resolved optical gating)[1],[2] and spectral phase interferometry for direct electric-field reconstruction (SPIDER)[7],[8] both of which exist in numerous variants, showing to achieve high accuracy [9] and high precision matching the reconstructed electric field [10]. A variation of the FROG method is the GRENOUILLE (Grating-eliminated no-nonsense observation of ultra fast incident laser light E-fields)[3] where some experimental simplification is introduced. In this wok we show a modified version of GRENOUILLE where further improvements were added like the replacement of the Fresnel biprism by two simple mirrors. As in GRENOUILLE we use a thick BBO as an SHG crystal. The idea is to have a simple and cheap as possible equipment and at the same time that has a simple alignment.

Experimental Setup

Like GRENOUILLE we use a thick (6x5x8mm, cut 28^0) SHG crystal (BBO-beta-barium borate) that performs the self-gating process (see figure 1, top view; figure 2, side view). A significant simplification is achieved in the standard setup where beams that are split and crossed by a Fresnel biprism, are automatically aligned in space and in time. Alternatively in our setup the two beams, created by the beam-splitter, cross in the crystal with a variable delay, along the X-coordinate, given by the cross angle and the diameter of the beams. One of the mirrors and the beam splitter are fixed and so we need to align them only once. The other mirror can be used to change the crossing angle of the beams (this angle defines the delay range when the beams cross in the SHG crystal, is but fixed for the biprism) and also to generate additional delay between the pulses generated by the mirror translation. The thick crystal has a relatively small phase-matching bandwidth, so the phase-matched wavelength produced by it varies with angle. Along the Y-coordinate the beams are focused with a cylindrical lens (f=100mm), so that the convergence angle is great enough to accommodate all the wavelengths that constitute the pulse. Thus, the thick crystal also acts as a spectrometer. The group-velocity mismatch, GVM, accumulates a dephasing along the crystal length, *L*, between fundamental and second harmonic. Therefore if τ_p

is the pulse length GVM • $L >> \tau_p$ is the condition to achieve the necessary spectral resolution. In order to avoid pulse spread in time, group-velocity dispersion, GVD, must also satisfy GVD • $L << \tau_c$, where τ_c is the pulse coherence time. Together those relations are fulfilled if GVM / GVD >> τ_p/τ_c , where the ratio is also known as the time-bandwidth product (TBP) of the pulse.

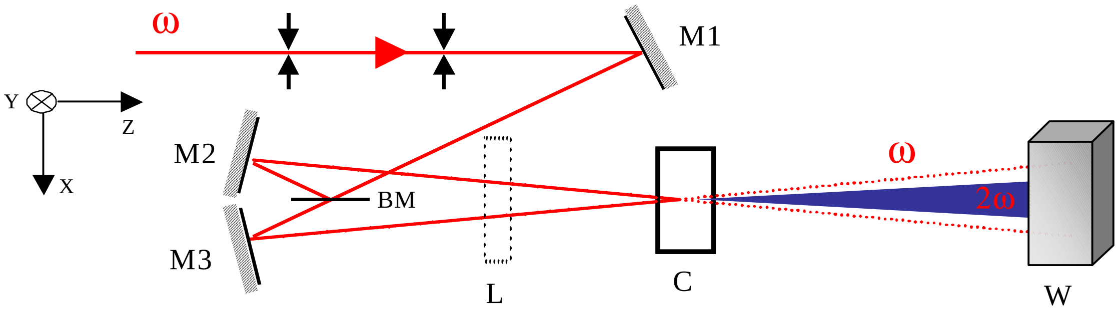


Figure 1 – M1, M2, and M3: mirrors; BM: beam splitter; L: cylindrical lens; C: BBO crystal; W: web-cam.

To acquire the far field image instead of a digital camera and required hardware we use an unsophisticated webcam (288 x 352 pixels). The femtosecond pulse source to test our method was a commercial Ti: Sapphire laser system (Mira 900, Coherent) which supplied an average power of 200mW of 180fs pulses at 800nm with a repetition rate of 80 MHz. On the output that pulses are Fourier transform limited. Using them and some additional optics we projected three types of pulses: i) Fourier transform limited; ii) chirped; and iii) double pulse. To produce a chirped pulse we assembled a scheme with two prisms to produce the necessary dispersion. For the double pulse we used a Michelson interferometer producing a delay between the two pulses generated by the division of the original pulse.

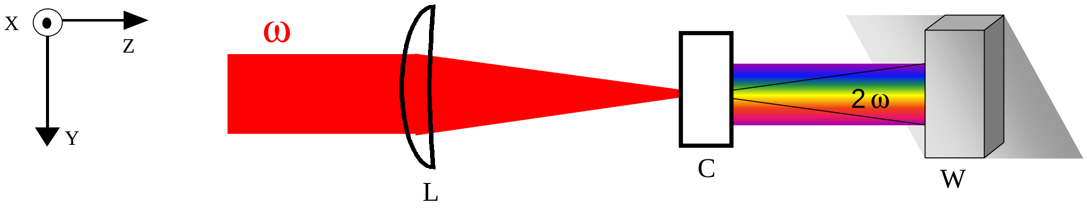


Figure 2 – L: cylindrical lens; C: BBO crystal; W: web-cam.

Results and Discussions

In figure 3 we can see the webcam images obtained with our setup (intensity in false color scale). The first one, (a), corresponds to a transform limited pulse, that is, all the frequencies that made up the pulse are in phase. This is represented by the graphic, under the corresponding picture, that shows a well behaved oscillation. Figure 3(b)

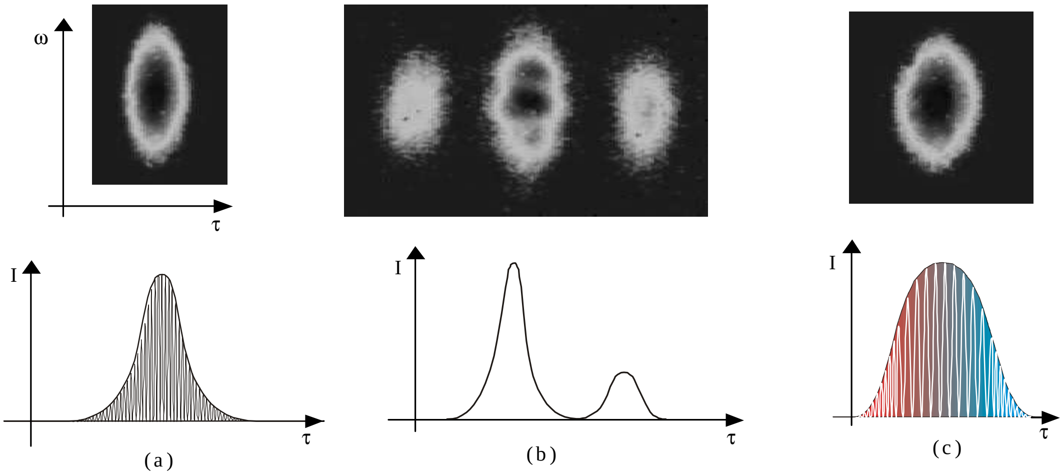
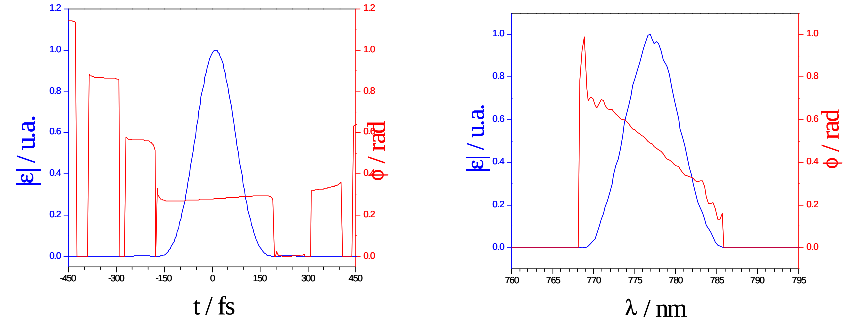


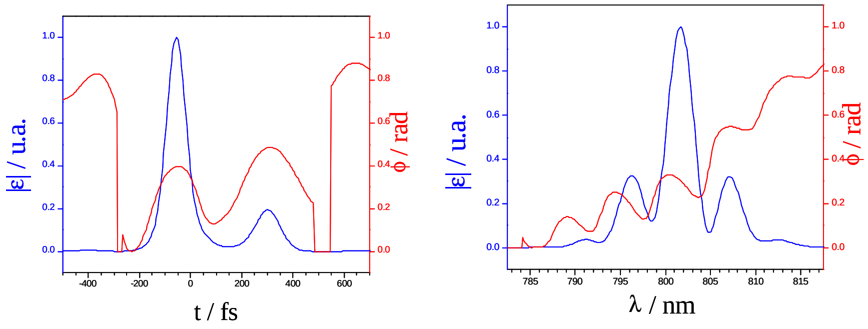
Figure 3 – (a) Fourier transform limited, (b) double pulse, (c) chirped pulse

shows what happens when a double pulse impinges on the GRENOUILLE. On the sides of the central feature are two additional lobes that correspond to the delays -τ and +τ. Finally, figure 3(c) shows a chirped pulse. The second order nonlinearity doesn't distinguish between positive and negative chirp[4], because this nonlinearity is symmetric in time. The graphic on the bottom of that picture shows an oscillation that begins red and ends blue, catching the idea of what chirp is. These results are used as the input of the field envelope recovery program[5],[6]. and the electric field that we are interested to recover has the form $E(t)=\varepsilon(t)e^{i\phi(t)}e^{i\omega_0 t}$. First we recover the Fourier transform limited pulse. Figure 4 shows that the temporal and spectral phases are linear functions of time and wavelength, respectively, as expected for a Fourier transform limited pulse. Figure 5 shows the recovered double pulse and the characteristic frequency domain fringes resembling the two slit interference pattern also remarked by phase jumps. In figure 6 the chirped pulse is retrieved and the spectral and temporal phases of the chirped pulse are quadratic functions of wavelength and time, respectively, as expected for such pulse.



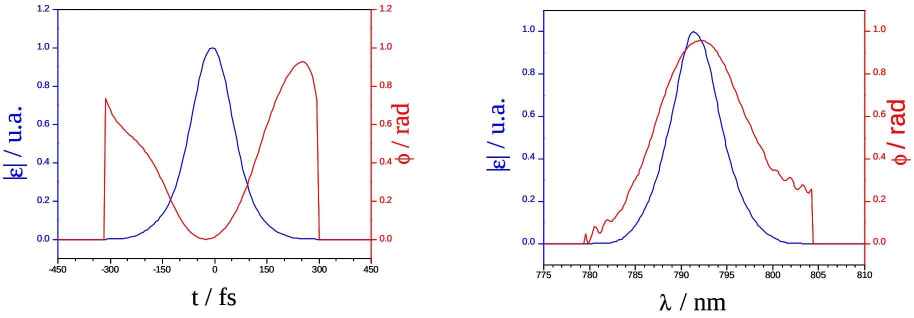
(a) (b)

Figure 4 – Time and frequency recovered Fourier Transform limited pulse. (a) E-field and φ(t) versus time and (b) power spectrum and φ(λ) versus wavelength.



(a) (b)

Figure 5 – Time and frequency recovered double pulse. (a) E-field and φ(t) versus time and (b) power spectrum and φ(λ) versus wavelength.



(a) (b)

Figure 6 – Time and frequency recovered chirped pulse. (a) E-field and ϕ(t) versus time and (b) power spectrum and ϕ(λ) versus wavelength.

Conclusions

Our version of the GRENOIULLE method has all characteristics of the original scheme and some new featrures. The additional degree of freedom that the translating mirror introduces can be used to evaluate the beam profile convolution and also allows the time scan width to be changed (in the original method the time scan is fixed and is given by the biprism angle). Another feature is that we use almost all reflective optics, minimizing GVD that occurs when the beam passes through refractive materials. The webcam imaging presented no artifacs since the beam exposure was controlled to avoid saturation. The only drawback is an additional alignment but this is a very simple alignment and need to be ajusted only once for the chosen crossing angle. We simulated theoretical pulses with the given wavelength bandwidth of our laser setup and obtained temporal widths that are in agreement with our experimental results. Also, this method shows the correct expected phase evolution of the respective pulses. So, the proposed modification of the GRENOUILLE method works well and can be used on the daily problems of laser pulse caracterization.

Acknowledgements

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