Measurement and Characterization of sub-5 fs Broadband UV Pulses in the 230-350 nm Range

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Abstract: We report a new design of all-reflective 3rd-order frequency resolved optical gating setup (FROG) for measurement and characterization of ultrashort UV-pulses in the 230-350 nm range and tested it using 7.3 fs pulses generated in the 250-300 nm range. This setup allows also heterodyne detection which significantly increases its sensitivity.
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1. Introduction

Time-resolved spectroscopy in the UV-range, in particular 2D-spectroscopy of DNA and proteins, requires development of broadband femtosecond UV-sources and corresponding diagnostic devices for direct measurement and characterization of light pulses. Among existing different methods the most appropriate for the 230 – 350 nm range is 3rd-order FROG [1] allowing "standalone" measurement and characterization of femtosecond pulses, without involving additional external pulses (as, e.g., in X-FROG and ZPA-SPIDER techniques [2,3]). While the design of 3rd-order FROG is more complicated as compared to the 2nd-order FROG, registration and managing of second harmonic of 230-350 nm is much more difficult (115-175 nm belongs to the "vacuum" UV). In addition, there are no crystals available for generation of second harmonic in this spectral region.

Traditional design of 3rd-order FROG-apparatus is based on at least two conventional beam splitters made using thin substrates (0.5-1 mm); however, for the UV-range they are not appropriate due to strong stretching of pulses: for example, by passing a 7-fs pulse centered at 275 nm through 1-mm UV-grade fused silica plate it will be stretched to 110 fs. In order to avoid parasite phase distortions in measured pulses in refractive media, we developed an all-reflective FROG design based on a diffractive optic beam splitter (DO). This design is optimized for the UV spectral range of 230-350 nm (spectral window ~ 15000 cm^{-1}). Temporal resolution is currently limited by the spectral window of the spectrometer used and spectral width of DO. The estimated temporal resolution of the current setup is 3-4 fs; the shortest UV-pulse which we detected was 6 fs FWHM (spectral width of 40 nm FWHM, centered at 275 nm).

2. Experimental layout

Figure 1 shows the design of the all-reflective UV-FROG developed in our laboratory. The incoming beam, reflected by an auxiliary mirror towards an off-axis parabolic mirror $OAPM_1$ (Newport), is focused on the DO which is placed in the focal plane of OAPM (f = 150 mm).

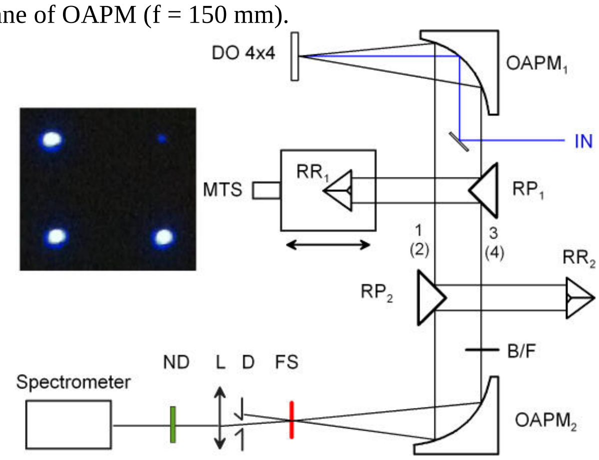

Fig. 1. Experimental layout of FROG setup. Inset shows a photograph of incoming beams and FROG-signal (left-upper corner).

An aluminum-coated reflective DO (crossed grating, Holoeye, custom design) diffracts the incoming beam into 4 first orders with efficiency of 60%, then they are collimated and form 4 collinear beams separated by 12.5 x 12.5

mm. Upper beams 1&3 and lower beams (2)& (4) are passed through retroreflectors $RR_{1,2}$ (PLX) and reflected from aluminum-coated right-angle prisms $RP_{1,2}$ (custom design) then focused onto a 150 µm thick UV-grade fused silica plate by $OAPM_2$ (Newport, f = 150 mm) for generating 3rd-order signal. Measured signal is generated by four-wave mixing of beams 1, (2) and 3; the fourth beam (4) is blocked (B/F). Due to the symmetry of the optical design, beams 1 and (2) automatically coincide in time and have zero delay between them; acquiring of FROG-trace is done by moving RR_1 placed on a motorized translation stage MTS equipped with an encoder (VP-25XL, Newport). Generated 3rd-order signal is passed through the block-diaphragm D and directed to a spectrometer (Avantes). For achieving high sensitivity the generated beam is directly focused onto a spectrometer input slit (25 µm). A neutral density filter ND adjusts the magnitude of measured signal. In the current configuration this FROG setup allows confident measurement of sub-10 fs UV-pulses with an incoming energy of less than 30 nJ. This setup is very robust, doesn't needs any "tweaking" within several months, and is insensitive to the pointing variations of incoming beam.

3. Representative results

The sub-8 fs UV-pulses have been generated using achromatic frequency doubling (the design is similar to the one published in [4]) of broadband VIS-pulses, generated by two-cascade home-built non-collinear optical parametric amplifier (NOPA) pumped by a Coherent Elite USP laser system. NOPA delivers light pulses with a spectral width of 490-600 nm and energy of 8 µJ. Generated UV-pulses with energy of 600 nJ were passed to the FROG setup.

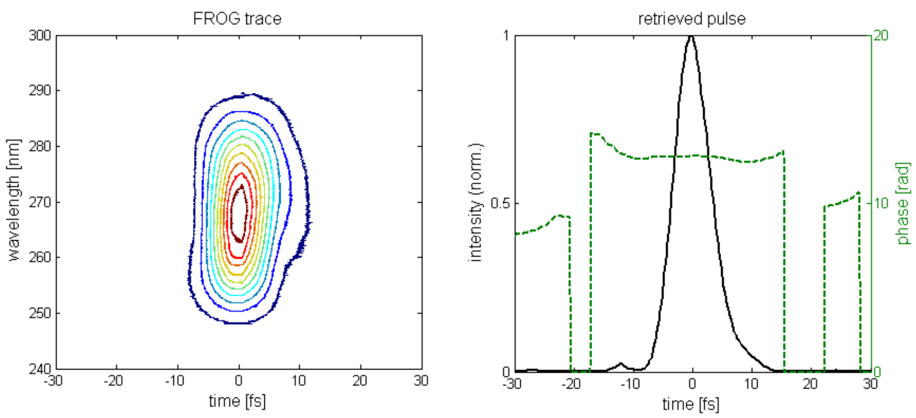

Fig. 2. FROG trace and retrieved temporal profile of pulse (solid) together with it phase (dashed).

Figure 2 shows frequency-resolved FROG trace and retrieved pulse with phase. For retrieving the pulse shape we used a commercial program (Femtosoft Technologies). Measured UV-pulse with the spectral FWHM of 32 nm (center at 272 nm) has duration of 7.3 fs, almost flat phase profile (Fig. 2 right), and is closed to transform-limited pulse ($\Delta\nu\Delta\tau \sim 0.6$). Some distortions in temporal profile (at beginning of pulse) are due to residuals in phase not compensated by deformable mirror used (Flexible Optical BV). To our knowledge, this is the shortest directly measured UV-pulse in the 250-300 nm spectral range.

It is necessary to note that replacing the beam blocker by a thin neutral density filter (position B/F) allows heterodyne measurement of FROG signals which significantly increases the sensitivity of the setup. Using a 200-µm thick filter with OD = 2, we were able to detect and measure FROG-signals with incoming pulse energies of ~3 nJ, i.e. by one order of magnitude better than for homodyne-detected FROGs. However, currently there are no appropriate algorithms for retrieving the pulse shape and phase from heterodyne-measured FROG traces.

4. References

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