Optica Applicata, Vol. XXX, No. 1, 2000

Compact, alignment-free autocorrelator for femtosecond laser pulses

Piotr Wasylczyk

Institute of Experimental Physics, Warsaw University, ul. Hoża 69, 00-681 Warszawa, Poland.

A compact device based on modified Mach-Zehnder interferometer was built to monitor the output of a $Ti:Al_2O_3$ femtosecond oscillator. Once aligned it is insensitive to the input beam position and direction. With a single 9 V power supply the autocorrelation of interferometric resolution is obtained to be watched directly on the oscilloscope.

While laser sources capable of delivering femtosecond pulses evolved from complex systems into compact and reliable commercially available tools there has also been a constant progress in the measurement techniques for the short light pulses. Currently there are two methods (FROG [1] and SPIDER [2]) that are commonly used to provide complete amplitude and phase information on ultrashort laser pulses. In many cases, however, it is sufficient to determine the pulse duration only. This is routinely done by measuring the second order autocorrelation function. In a typical autocorrelator set-up [3] the laser beam is split in the Michelson interferometer and the two replicas overlap in a detector with the response which is a quadratic function of the incident light intensity.

If the detector response is now recorded as a function of the delay τ between the pulses travelling in the interferometer arms we obtain

$$S(\tau) = \int\{|E(t)+E(t+\tau)|^2\}^2 \mathrm{d}t \qquad (1)$$

where: $S(\tau)$ is the interferometric autocorrelation function, τ – the time delay between the two replicas, and $E(t)$ – the pulse electric field. The time integration is due to the detector slow response.

From formula (1) one can see that for a laser pulse of a finite duration, the $S(\tau)$ function width FWHM is related to the pulse width FWHM via the deconvolution factor depending on the assumed pulse shape (*e.g.*, 1.55 for sech^2 pulse). From the autocorrelation trace one can also qualitatively deduce the amount of the pulse chirp [4].

In this paper an autocorrelator based on new optical arrangement is described. Its compactness and simplicity together with some advantages discussed later make it an ideal tool for fast and reliable estimation of the laser pulse widths in the femtosecond range. It has also proved to be very useful during the optimisation of femtosecond Ti:Sapphire oscillators.

A schematic of the autocorrelator set-up is presented in Fig. 1. Two mirrors and two beam-splitters form a double Mach–Zehnder interferometer. The time-varying delay between the two beams is provided by a rotating glass plate placed at the beams crossing. The plate is set on a small electric motor axis rotating at around 20 Hz. This frequency allows for a real-time readout still providing high resolution. Besides, in a typical electric motor a smooth operation required for accurate autocorrelation measurement is achieved only above a certain speed.

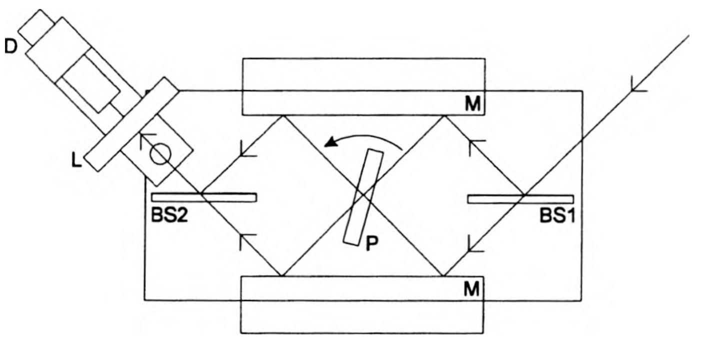

Fig. 1. Schematic of the autocorrelator set-up. BS1, BS2 – beam-splitters, M – mirrors, P – rotating glass plate, L – focusing lens, D – red LED.

In the vicinity of the position perpendicular to the mirrors the plate provides the delay proportional to the angle (and thus also to the time if the angular speed is constant). At that moment a trigger signal is generated for the oscilloscope. The output of the interferometer is focused on a red LED diode junction that serves as the nonlinear-response detector [5]. The diode voltage, proportional to the autocorrelation function, is viewed directly on the oscilloscope. The use of GaAsP diodes as nonlinear detectors has been carefully studied in [6]. Theoretically, the diode spectral response is limited from the short wavelength side by the band gap width (around 680 nm) and from the long wavelength side by half the band gap. The measured spectral dependence of the generated two-photon current turned out to vary by less than a factor of two within 700–950 nm range. This means a few times larger bandwidth than with a typical, a few tens of microns thick, nonlinear crystal. As for the sensitivity, the diode current proportional to the square of the incident beam intensity can be measured for pulse energies as low as 2 pJ (with 100 fs pulses).

The autocorrelator measures $11 \times 9 \times 15$ cm^3 and is mounted in custom-made gimbal mount. The latter enables rotation around the vertical and horizontal axes crossing at the point of beam incidence on the first beam-splitter.

The calibration of an autocorrelator typically requires that a known delay is added in one arm and the shift of the autocorrelation function on the time scale is measured corresponding to this delay. In the calibration of our device the delay is introduced by inserting additional glass plate of a known thickness and group velocity index into one of the beams. The precision of such calibration is limited by the precision of the plate thickness measurement only.

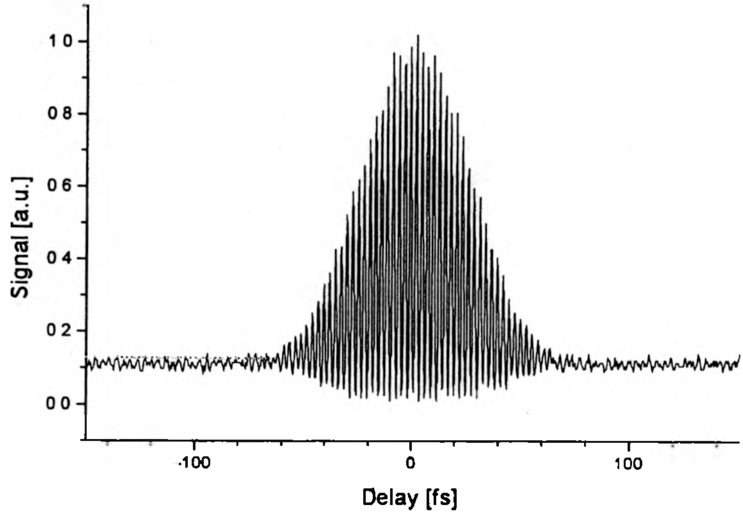

Fig. 2. Interferometric autocorrelation record of the pulses from a home-made Kerr Lens Mode-Locked Ti:Sapphire oscillator. Calculated pulse width FWHM is 38 fs (assuming $sech^2$ pulse shape).

Figure 2 shows a typical oscilloscope trace obtained with the pulses emerging from a home-made Kerr Lens Mode-Locked Ti:Sapphire oscillator. The fringes are clearly resolved and the contrast ratio is 8:1 as expected for the second order interferometric autocorrelation.

Compared to the previous set-ups, including those commercially available, the new autocorrelator design has the following advantages:

– the only movable element is the output beam-splitter, while a Michelson-interferometer-based autocorrelator requires many optical components, all of them in precise mounts,

– there is no need for computer-controlled stepper motor driving a delay line and the results are displayed directly on the oscilloscope,

– there is no retroreflected beam that could disturb the femtosecond laser operation,

– the LED-based autocorrelation measurement, contrary to those using a non-linear crystal, is insensitive to the input beam polarisation.

In the autocorrelation measurement it is important to have two identical replicas at the output of the interferometer. When one is dealing with ultrashort laser pulses this can be obtained only if both arms consist of the same set of optical elements. This is the case in our autocorrelator with any kind of beam-splitters used (not necessarily 50/50). The transmittance of beam-splitters different from 50% only affects the device sensitivity by reducing the light intensity on the detector.

The Michelson interferometer requires precise alignment every time the input beam is shifted or tilted. The new set-up, once aligned, is insensitive to the input beam position and direction as long as the beam focus is within the LED junction area. Due to odd number of reflections (three) the beam direction at the interferometer output may change but both beams remain parallel. This fact proved to be especially useful as the autocorrelator could have been moved from one point of the experimental set-up to another with no need for precise positioning and alignment.

As for the rotating plate, one can show that the delay introduced is a linear function of the plate angle only for a certain range in the vicinity of the position parallel or perpendicular to the mirrors. At the same time, the amount of the delay introduced within this range depends on the product of the plate thickness and its group velocity index. As a result, the temporal range of the autocorrelator can be changed by changing the plates if the pulses of different duration (*e.g.*, picosecond) are to be measured. For the measurements of laser pulses from our Ti:Sapphire oscillator a 1 mm thick plate made of BK7 glass was chosen. Since the calculated deviation from linear delay-angle dependence is less than 1% within ± 30 deg range around the symmetric position, the available time range of the autocorrelator is determined by the rotating plate width and by the change in reflection for large incidence angles.

The resolution of the autocorrelator is limited by the rotating plate itself. While introducing the variable delay, it may also affect the pulse length and chirp by the group velocity dispersion and nonlinear process. Fortunately, the shorter the pulses, the thinner plate can be used, as described above. However, one should remember that for really short pulses (of duration below 10 fs) even a few millimeters of glass inserted into the laser beam will result in severe phase distortions leading to considerable pulse broadening.

Summing up, a new optical design of the autocorrelator for femtosecond laser pulses has been presented. The device consists of few optical elements and is particularly easy to align. The autocorrelation function of interferometric resolution is viewed in real time on the oscilloscope. Measurement of 38 fs pulses from Ti:Sapphire oscillator has been demonstrated.

References

[1] TREBINO R., KANE D.J., J. Opt. Soc. Am. A **10** (1993), 1101.
[2] IACONIS C., WALMSLEY I.A., Opt. Lett. **23** (1998), 792.
[3] SALA K.L., KENNEY-WALLACE G.A., HALL G.E, IEEE J. Quantum Electron. **16** (1980), 9.
[4] DIELS J.-C.M., FONTAINE J.J., MCMICHAEL I.C., SIMONI F., Appl. Opt. **24** (1985), 1270.
[5] REID D.T., PADGETT M., MCGROWAN C., SLEAT W.E., SIBBET W., Opt. Lett. **22** (1997), 233.
[6] RANKA J.K., GAETA A., BALTUSKA A., PSHENICHNIKOV M.S., WIERSMA D.A., Opt. Lett. **22** (1997), 1344.

Received November 13, 1999
in revised form January 24, 2000