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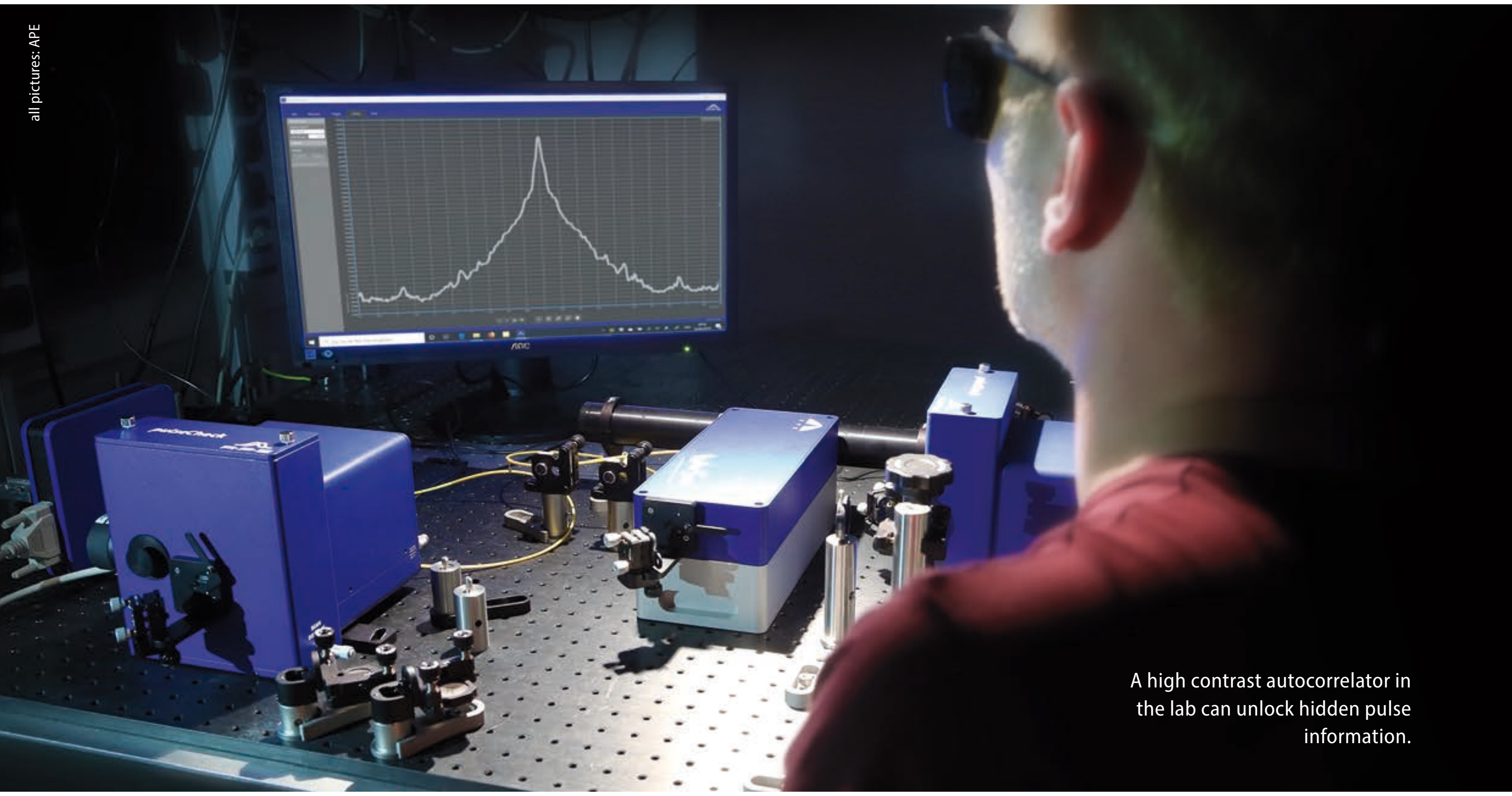

A high contrast autocorrelator in the lab can unlock hidden pulse information.

Advanced Ultrashort-Pulse Laser Diagnostics

High-contrast autocorrelation provides deeper insights on pulsed fiber lasers.

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The simplest and most common method for the characterization of the duration of an ultrashort pulse laser is to measure an autocorrelation function. However, especially with modern high-power fiber lasers, in some cases the sensitivity and dynamic range of standard autocorrelators are not sufficient and require more sophisticated measurement methods. With type II autocorrelators, a cost-efficient high-contrast technique is available that can provide more detailed insights into a pulse topography than normal autocorrelators.

Today's development of lasers, especially in material processing, is moving in the direction of high energy lasers with high repetition rates and ultrashort pulse durations. Very popular types of such lasers are based on ytterbium-doped gain materials such as Yb^{3+}:YAG. Those fiber lasers simplify the application of ultrashort pulses on the one hand but also complicate it on the other hand. The reason is that the physics of the pulse generation process includes various nonlinear effects which may easily corrupt the pulse performance.

Cost-efficient autocorrelators are widely used when the knowledge of the temporal duration of a pulse is required. But in some cases the sensitivity and the dynamic range of a standard autocorrelator might not be sufficient and more sophisticated methods are needed.

High contrast measurements are essential in the field of ultrashort pulse lasers delivering high pulse energies. It is important that the entire pulse energy reaches the sample within a very (ultra-)short time period. If the pulse energy is timely distributed among the wings, pedestals and secondary pulses, the desired interaction between pulses and material cannot always be ensured anymore.

High-contrast measurements are essential for investigating high energy laser pulses, as they allow the simultaneous display of the largest main peak and the smallest secondary peaks in an autocorrelation measurement.

The contrast, as it refers to a pulse duration measurement, is the difference between the highest and the lowest intensities, and often the lower intensities are covered by background signal. Autocorrelator measurements with high contrast information require a modified autocorrelator, a common approach is the so-called type II (or type 2) layout.

Autocorrelation with high contrast

A set of autocorrelation measurements illustrates the difference between a common autocorrelation and a high contrast autocorrelation (**Fig. 1**). A high-contrast autocorrelator (pulseCheck 50 Type 2, APE) and an additional reference autocorrelator with a typical contrast range (pulseCheck 50, APE) were used. All data sets have been normalized to the same peak intensity for a better comparison of the dynamic range of both autocorrelators. The measurements were taken on a commercial high energy fiber laser with a repetition rate of 1 MHz and a nominal pulse duration of 300 fs. The output pulse duration of the laser is variably adjustable via an internal grating compressor.

The autocorrelation measurements were performed at different pulse compression levels. **Fig. 1a** shows the shortest possible pulse achieved with the laser under the best compression conditions. **Figs.1b** and **1c** were recorded at stretched pulses, the pulse stretching was created using the internal grating compressor.

The dynamic range of the type 2 autocorrelator is about 10^5 and therefore up to three orders of magnitude larger than that of the reference autocorrelator.

Pedestals become visible in the high contrast measurement, which are clearly temporally separated from the main peak. Please remember that the duration of the main pulse is actually a pulse in the hundreds of femtosecond regime.

There is an additional pulse at about ±20 ps, which is revealed by the high contrast measurement. Since it is not moving with the compressor setting, this is probably a duplicate of the main pulse. Such duplicates are caused, for example, by coating defects of laser mirrors.

The measurement also shows a small secondary pulse, whose distance to the main pulse increases with increasing stretching of the pulse. The pulse is located at approximately ±2 ps (**Fig. 1a**), ±7 ps (**Fig. 1b**) and ±12 ps (**Fig. 1c**). The analysis of this shows that the origin of this “moving” small feature is a spectrally and temporally separated part of the laser output. By an additional measurement of the spectrum it would even be possible to clarify whether the laser output contains a red shifted post-pulse or a blue shifted pre-pulse. The pulse at ±20 ps does not change its temporal position with increasing stretching, only the pulse duration changes.

High contrast layout vs. common layout

The basic principle of an autocorrelator for pulse duration measurements is to overlay a pulse with a variable time-delayed copy of itself. Both pulses interact in a nonlinear crystal. The variation of the time-delay leads to a variable degree of temporal overlapping of the two pulses at the interaction area, and thus to different intensities resulting from their interaction. The autocorrelation function (ACF) is then measured by recording the interaction intensity dependence as a function of the distance (delay) variation.

For the interaction of both pulses in the nonlinear crystal different scenarios can be described: the type I case and the type II case.

Type I autocorrelation

Both pulses overlap with their identical frequencies ω and identical polarization e and pass through the nonlinear type I crystal. The type I phase matching scheme (**Fig. 2**) results in the sum frequency 2ω with the polarization o. This part of the beam is used to record the ACF.

In addition to the two overlapping pulses, each individual pulse generates an additional signal with the frequencies $\omega + 2\omega$. Here, 2ω is the result of the nonlinear effect in the crystal and ω is the unconverted part of the incident beam.

Technically it is difficult to separate the desired beam 2ω and the unwanted beams $\omega + 2\omega$ by placing a detector behind the crystal so that it only measures the 2ω part that is generated by the two overlapping pulses. Instead, a portion from $\omega + 2\omega$ is detected and generates a certain level of background signal. The ACF trace will then always contain some amount of background signal even if the pulses do not overlap.

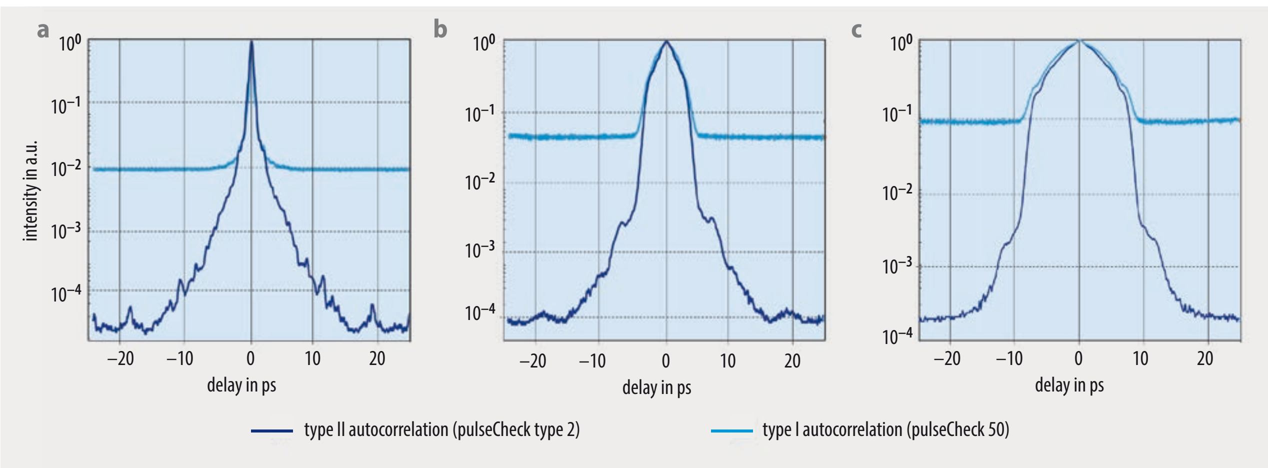

Fig. 1 A type II autocorrelator allows measurements with significantly higher contrast compared to a conventional autocorrelator (type I).

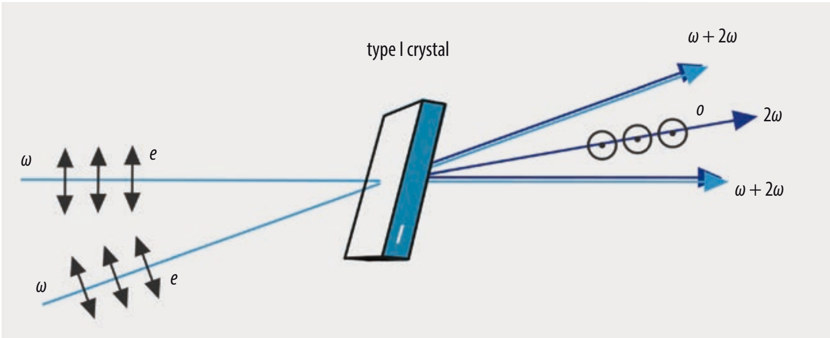

Fig. 2 A common type I autocorrelation setup results in the sum frequency 2ω with the polarization *o*.

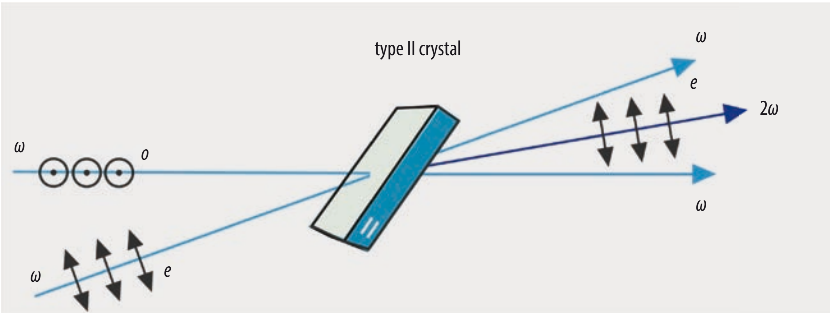

Fig. 3 A high-contrast type II autocorrelation setup results in the sum frequency 2ω with the polarization *e*.

Type II autocorrelation

In order to achieve high contrast between the peak of the autocorrelation signal and the baseline (i.e. when no pulse energy is present), the autocorrelator must be optically designed so that signal is only generated when the pulses overlap. This is achieved by the so-called type II phase matching scheme (**Fig. 3**). Both pulse trains enter the type II crystal with a polarization orthogonal to each other. Type II phase matching results in the sum frequency 2ω with the polarization *e*. Both incoming pulses must have a different polarization state, i.e. *e* and *o*. Only the two overlapping beams with different polarization states produce the desired sum frequency signal 2ω. An individual beam is not able to induce a nonlinear effect. Therefore, no unwanted background signal by non-overlapping pulses occurs at all.

This makes it possible to visualize the weak signals of satellite pulses and other types of secondary information that would otherwise be covered by background.

Another high contrast layout

For the sake of completeness, another layout should be mentioned. From plasma physics research a different kind of autocorrelator is known which is based on the third harmonic generation, the so-called 3rd order autocorrelator.

Compared to the type I and type II methods, two nonlinear crystals are used in series. The first crystal produces the doubled frequency 2ω. A fraction of the 2ω pulse is then interacting with a delayed fraction of the fundamental pulse, leading to a measured AC signal at the tripled frequency 3ω. This higher technical complexity is rewarded with a dynamic range of up to twelve orders of magnitude.

As third harmonic generation is relatively weak due to lower conversion efficiencies, the method is less sensitive and can only be used for very high pulse energies in the 100 µJ regime. They are therefore – in most cases – not suitable to work with high energy fiber lasers with MHz repetition rates, since significantly lower pulse energies (i.e. in the range of 1 µJ) are achieved here.

In addition, the acquisition costs are up to four or five times higher than an autocorrelator of type I or II.

Summary

With type II autocorrelators, like the pulseCheck Type 2, a cost-efficient high-contrast device is available that can both measure the pulse duration and provide insights into a detailed pulse topography that is not visible with normal autocorrelators.

PulseCheck autocorrelators can be configured in type II layout to be easily operated like traditional autocorrelators.

This makes type II autocorrelators an ideal tool for studying, understanding, and ultimately improving laser pulses of high energy fiber lasers or solid-state lasers to a greater extent.

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