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What do we mean by measurement of an Ultrafast Laser Pulse?

Ultrafast laser pulses have durations from less than a femtosecond to a few picoseconds. Measurement means obtaining both the intensity (pulse temporal profile) and phase (spectral content) as functions of time. Changes in pulse properties, particularly phase distortions, can significantly complicate ultrafast laser applications including pump-probe experiments, coherent control of molecular reactions, non-linear microscopy, laser machining, and laser development. Common phase distortions include linear chirp, where the phase variation is parabolic across the pulse and the spectral content changes linearly. When the frequency is increasing in time, the pulse is said to have positive chirp; negative chirp has the opposite direction. Higher order chirps are common; but for these, differentiation between spectral and temporal chirp is required because spectral phase and temporal phase are not interchangeable.

Frequency-Resolved Optical Gating

Ideally, we want a femtosecond oscilloscope: an easy-to-use laboratory tool that gives a real time display of the laser pulse properties. Unfortunately, even the fastest electronics cannot respond to ultrafast pulses. We must characterize these pulses indirectly using instantaneous-response optical methods. Perhaps the most popular method is a technique called Frequency Resolved Optical Gating (FROG) that was developed by Kane and Trebino.[1] Complete pulse characterization – temporal and spectral – is possible.

FROG measures the spectrum of a particular temporal component of the pulse (see Fig. 1) by spectrally resolving the signal pulse in an autocorrelation-type experiment using an instantaneously responding nonlinear medium. As shown in Fig. 1, the laser pulses are split into "gate" and "probe" pulses that are recombined in an instantaneously responding $\chi^{(2)}$ or $\chi^{(3)}$ non-linear medium. Any instantaneous nonlinear interaction may be used to implement FROG. Mesa Photonics uses second harmonic generation (SHG) in most of our FROGScan products because $\chi^{(2)}$ processes require much less intensity than do the $\chi^{(3)}$ nonlinearities.

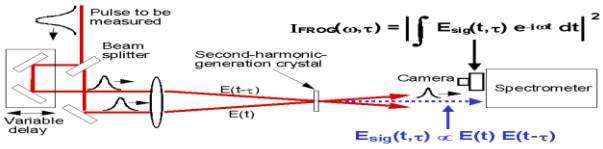

Fig. 1. Schematic diagram of a second harmonic generation (SHG) FROG device. The FROG trace is obtained by spectrally resolving the output from an autocorrelator as a function of time delay between the two pulse replicas.

The second harmonic light is spectrally resolved and the intensity, $I_{FROG}(\omega,\tau)$, recorded by the spectrometer is:

$$I_{FROG}(\omega,\tau) = \left| \int_{-\infty}^{\infty} E(t)E(t-\tau)e^{-i\omega t}\,dt \right|^2$$

The data form a spectrogram of intensity as a function of optical frequency (wavelength) and the time delay, τ, between the gate and probe.

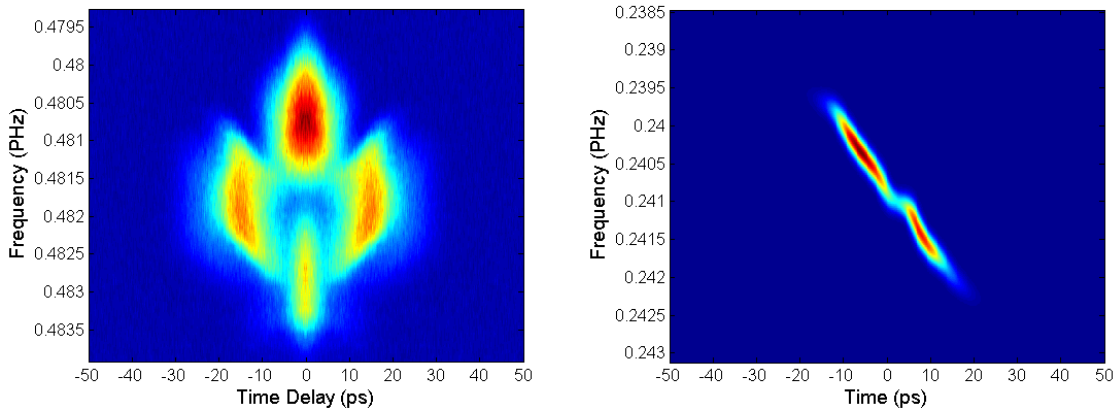

Fig. 2. Above left: an SHG FROG trace of a pulse breaking up in a passively mode-locked quantum dot diode laser. Shown on the right is the spectrogram of the retrieved pulse, constructed from the retrieved pulse. Two distinct pulses can be seen. The temporal spacing of the pulses is about 13 ps while the frequency spacing is just slightly more than 1 THz. The tilt of the spectrogram of the retrieved pulse shows a change in the frequency as a function of time, which indicates chirp.

A two-dimensional phase retrieval algorithm[2] extracts the pulse information from the measured spectrogram. Dr. Daniel J. Kane, the founder of Mesa Photonics, LLC, has developed a fast algorithm called Principal Component Generalized Projections (PCGP) that can achieve 30 Hz pulse characterization rates.[3] Because of the development of the PCGP algorithm, Dr. Daniel J. Kane is the sole inventor of real-time FROG.

References

1. D. J. Kane and R. Trebino, IEEE J. Quantum Electron. 29, 571 (1993).
2. R. Trebino, D. J. Kane, J. Opt. Soc. Am. A 10, 1101 (1993).
3. D. J. Kane, IEEE J. Quantum Electron. 35, 421 (1999).