Measuring ultrashort optical pulses using multi-shot second harmonic generation frequency resolved optical gating

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Frequency resolved optical gating (FROG), is an effective technique for characterizing the ultrafast laser pulses. The multi-shot second harmonic generation (SHG) FROG is the most sensitive one in different FROGs. In this paper we use this technique to measure the femtosecond optical pulses generated by a conventional Ti:sapphire oscillator.

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The frequency-resolved optical gating (FROG) technique[1−5] has become one of the most effective techniques for characterizing the amplitude and phase of the ultrashort optical pulse at present. Unlike other methods of measuring ultrashort laser pulses, such as autocorrelation techniques, FROG may completely characterize the optical pulse. The multi-shot second harmonic generation (SHG) FROG is the most sensitive one in different FROGs. Figure 1 is a conventional SHG FROG.

The principle of multi-shot SHG FROG is: an ultrashort laser beam is split into two beams by a beam splitter; one beam is directed to illuminate a moving mirror that is controlled by a micro-motor. The distance that the pulse travels can be changed by moving the mirror closer or farther from the beam splitter. This beam is often called the gating pulse because it is used as a time gate that allows a slice of the reference pulse to pass. The other beam is used as a reference light that is reflected from a stable mirror. Then the two beams are aligned and focused into a nonlinear crystal that produces the signal light, which is scanned by a spectrometry that generates the output intensity (I_{signal}) versus. frequency (ω) and time delay (τ) of the two pulses, given by

$$I_{\mathrm{FROG}}^{\mathrm{SHG}}(\omega,\tau)=\left|\int_{+\infty}^{-\infty}\mathrm{d}tE(t)E(t-\tau)\exp(-i\omega t)\right|^2.$$

This two-dimensional (2D) image is the so called FROG traces. The trace, containing both phase and intensity information, is then processed in a pulse retrieval program to retrieve the ultrashort laser pulse.

In experiments, we setup a multi-shot SHG FROG. The input pulses come from a Ti:sapphire oscillator (Mira-Seed pumped by Verdi6, Coherent) operated at 76 MHz and a center wavelength of 819 nm and bandwidth about 20 nm. The femtosecond optical pulse is split into two pulses by a 700-μm-thick 50/50 beam splitter.

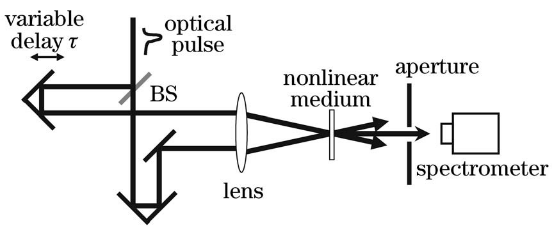

Fig. 1. Setup of the SHG FROG. BS: beam splitter.

The two pulses then go through different arms. A motorized linear stage (Folded MicroMini$^{\mathrm{TM}}$Stage, NAI) controlled by a computer with the resolution of 31 nm/count provides the time delay of two pulses. Then

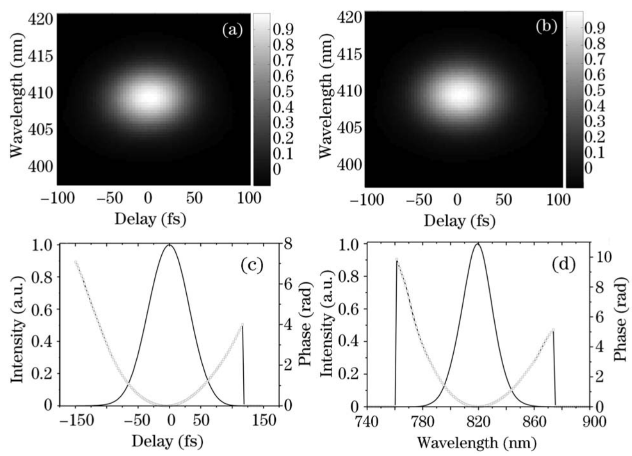

Fig. 2. (a) and (b) are the measured and retrieved FROG traces of chirped pulses, respectively. (c) and (d) are the retrieved intensities (solid curves) and phases (dashed curves) for the time and frequency domains, respectively.

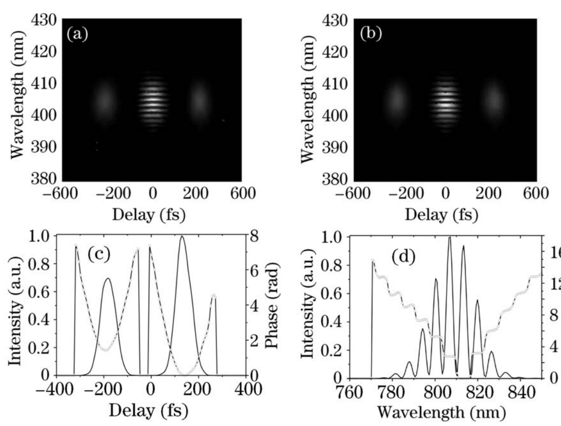

Fig. 3. (a) and (b) are the measured and retrieved FROG traces of double-chirped pulse separated by about three pulse widths, respectively. (c) and (d) are the retrieved intensities (solid curves) and phases (dashed curves) for the time and frequency domains, respectively.

the two beams are focused at an angle of 5° in a 100-μm-thick BBO crystal by a 25-cm focusing lens. The spectrum of the summation frequency light is acquired by a 16-bit spectrometer (InSpectrum, Acton). We measured two types of pulses, one is the single-chirped optical pulses and the other is the double-chirped optical pulses. Figures 2(a) and (b) are the measured and retrieved FROG traces of single-chirped pulses, respectively; (c) and (d) are the retrieved intensities (solid curves) and phases (dashed curves) for the time and frequency domains, respectively. The FROG error for this retrieved pulse was G=9$\times$10^{-4}. The double-chirped optical pulses are generated by a Michelson's interferometer. The width between the two pulses can be changed by adjusting the path of the pulses travel. Figures 3(a) and (b) are the measured and retrieved FROG traces of double-chirped pulse separated by about three pulse widths, respectively; (c) and (d) are the retrieved intensities (solid curves) and phases (dashed curves) for the time and frequency domains, respectively. The FROG error for this retrieved pulse was G=6$\times$10^{-3}.

In conclusion, we reported the measurement of the ultrashort optical pusles by using the SHG FROG technique. Two types of the optical pulses are measured and retrieved with small FROG error.

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