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Single femtosecond laser beam pumped transient diffraction and transient lens effects for ultrafast measurement in background-free geometry

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ABSTRACT

We proposed an ultrafast optical gating configuration for ultrafast measuring the characters of a supercontinuum (SC) probe beam. Single femtosecond laser beam pumped transient diffraction (TrD) and transient lens (TrL) effects were realized at the same time, which ensured the measurement in background-free geometry. Experimental results showed that the proposed ultrafast optical gating was robust for very high signal-to-noise ratio (SNR) detecting.

1. Introduction

The measurement of the ultrafast dynamics of laser-matter interaction is essentially important for understanding the nature of materials. Benefiting from the very fast development of ultrashort laser pulse generation systems, various techniques based on femtosecond laser have been proposed to characterize the ultrafast dynamics in materials, such as four-wave mixing [1], broadband pump-probe [2], and coherent Raman scattering [3]. Meanwhile, the understanding of the characteristics of ultrashort laser pulse itself is increasingly important, from which the pulse duration related temporal resolution could be known at least.

For a superior technique in ultrafast measurements, the basic requirement is high signal-to-noise ratio (SNR) and simple optical configuration. A typical technique for characterizing ultrashort laser pulse is the frequency-resolved optical gating (FROG) supporting the measurement of pulse intensity and phase at the same time [4,5]. In FROG measurements, the optical signal generated through frequency-mixing process is of high SNR due to the background-free detecting. However, the conversion bandwidth is restrained by the phase matching condition, which limits it to the application of broad optical wavelength range. Transient grating (TrG) technique [6–8] derived from FROG technique would break free from phase matching, in which the optical signal is diffracted from a transient phase grating interfered by two ultrafast gating pulses with the same frequency [9]. The diffracted signal, which is spatially separated from the probe and the gating light, will be detected in background-free geometry. However, the adjustment of the temporal overlap between the gating pulses and the four-wave mixing-like configuration lead to complex operation in actual applications. Another robust technique named femtosecond optical Kerr gating (OKG) [10], based on the optical Kerr birefringence effect, has been widely applied in ultrafast measurements [11–14]. However, in the OKG configuration, the leakage of the probe light passing through the polarizer will form the background. Therefore, a further work should be done to extract the useful optical signals by subtracting the background from the detected signals. Though the recently developed single beam pumped ultrafast optical gating techniques based on transient Kerr lens effect, and transient beam deflection effect are more convenient than FROG, TrG and OKG, the effective optical parameters should still be extracted from the differences between the detected and the background light [15–18]. For the techniques discussed above, it seems a paradox that background-free detecting could not been realized only pumped by a single beam. Therefore, designing and achieving a single beam pumped ultrafast optical gating with background-free detecting geometry become a challenge.

In this paper, we proposed an optical gating for ultrafast measuring a supercontinuum (SC) pulse in background-free geometry. Optical gated spectra were spatially separated from initial SC beam through single beam pumped TrD and TrL effects. The single beam pumped ultrafast TrD-TrL gating, which showed very high SNR, simple configuration, and broadband response, will have tremendous applications for weak light detection.

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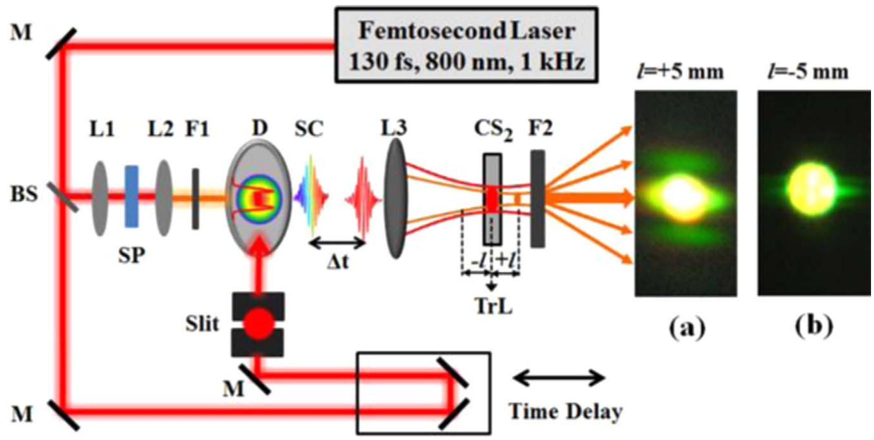

Fig. 1. Experimental setup for ultrafast "Slit"-TrL gating. M: silver mirrors; BS: beam splitter; L: lens; SP: sapphire plate; D: dichroic mirror; F: fundamental filter; The insets (a) Diffraction pattern at positive "focal mismatch", and (b) Diffraction pattern at negative "focal mismatch".

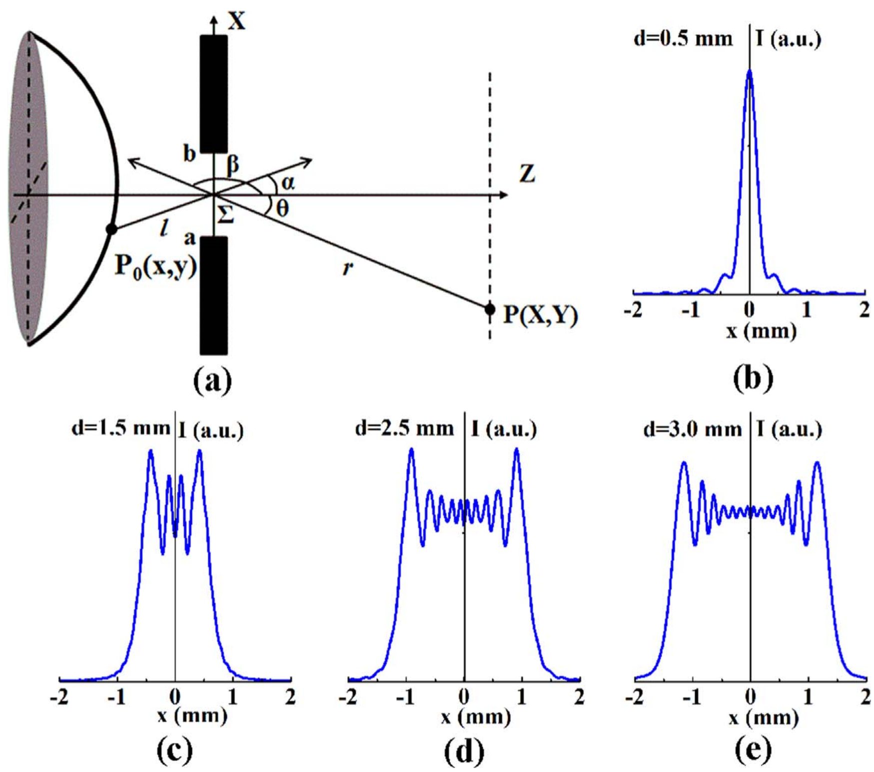

Fig. 2. (a) Illustration for optical field diffracted by a slit. The optical intensity distribution diffracted by a slit with width of (b) 0.5 mm, (c) 1.5 mm, (d) 2.5 mm and (e) 3.0 mm.

2. Experimental setup

The experimental setup of the femtosecond TrD-TrL gating has been performed in our previous research [19,20]. For understanding it clearly, more details have been shown in Fig. 1. A commercial Ti: sapphire regenerative amplifier system (RegA900, Coherent Inc.), which emits 130 fs, 800 nm laser pulses at a repetition rate of 1 kHz, is split into two beams by a 1:1 beam splitter (BS). One beam is focused into a sapphire plate (SP) with 3 mm in thickness by a lens with 100 mm focal-length. Stable SC probe pulses are generated and then collimated after filtering the long-wave components. The other beam which is optically delayed against the probe beam is served as pump beam. A width-tunable slit is put in the middle of the optical path of pump beam. The collimated probe and pump beams collinearly passing through a lens of 300 mm in focal length are focused inside the Kerr medium (a 2 mm thick fused silica cell filled with CS_2). By adjusting the collected lens (L2), the focus of the SC can be moved around the focus of the pump beam.

When the pump beam propagating through the slit, the transmitted optical field shows interference-like (the explanation is shown in "Diffraction model"). Then, the diffraction pattern is Fourier transformed into the Kerr medium by the lens (L3). Due to the high peak power of the femtosecond pump beam, the diffracted pattern can be printed to the nonlinear refractive index change by optical Kerr effect $\Delta n = n_2 I$. As a result, a transient refractive index grating is formed, which induces the transient diffraction of the probe beam.

Another critical parameter in the experiment is the "focal mismatch" *l*, which is defined as the distance between the focal point of the probe beam and the TrL region (Fig. 1) [21,22]. By using a negative *l*=−5 mm, where the probe beam focuses prior to the TrL plane, the transient diffraction of a certain wavelength component from the SC could be observed (Fig. 1(b)). However, due to the TrL focusing effect, the diffracted light is still constrained in the background of the transmitted SC pattern. By using a positive *l*=+5 mm, the condition