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Efficient optical Kerr gating property of fluorotellurite glass

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ABSTRACT

We investigated the ultrafast optical Kerr effect of the fluorotellurite glass (Ft glass), the nonlinear response time of which was measured to be less than 230 fs, while the nonlinear refractive index was estimated to be 9.62×10^{-16} cm^2/W. Using optical Kerr gate (OKG) technique with Ft glass as Kerr medium, we obtained narrow-bandwidth and symmetric gated spectra from a supercontinuum (SC) generated by a femtosecond laser. Experimental results indicated that Ft glass was a good candidate for an OKG medium due to its fast response time, large nonlinearity, and high transparency.

1. Introduction

Supercontinuum (SC) generation is a well-known nonlinear optical phenomenon, in which narrow-band incident pulses undergo extreme nonlinear spectral broadening to yield a broadband spectrally continuous output. This phenomenon has been the subject of numerous investigations in a wide variety of gases [1], organic and inorganic liquids [2], solids [3], and various types of waveguide [4] under different experimental conditions. At present, it is generally accepted that Raman scattering, four-wave mixing dominate the initial steps of SC generation [5,6]. It is well known that the SC has a strong chirp owing to dispersion by the material in which SC is generated. Until now, the sum-frequency generation cross-correlation method [7], two-photo absorption [8] and the optical Kerr gate (OKG) technique [9] have been used to investigate its chirp characteristics. Comparing with other techniques, the OKG technique has a lot of advantages, such as ultrafast switching time, high precision and no need of the phrase-matching condition, and so on.

Ultrafast OKG technique has been extensively utilized as a powerful tool to investigate ballistic light imaging [10], ultrafast luminescence spectroscopy [11], high time-resolved imaging [12], and Kerr gated fluorescence microscopy [13] and ultrafast gated imaging [14], etc. In the OKG technique, solutions or liquids such as CS_2 have been generally used as Kerr media [15]. In recent reports, many transparent glasses have been used as the Kerr media due to their large nonlinearities, high transparency, and fast response time. Fluorotellurite glass (Ft glass) is a promising material, which offering transmission from ultraviolet to mid-infrared, high optical nonlinearity and the ability to include active dopants, offering the potential for developing optical components with a wide range of functionality [16].

In our experiments, utilizing femtosecond optical Kerr effect measurements, we investigated the nonlinear response of the Ft glass with a composition of $60TeO_2$-$30ZnF_2$-10NaF (TZNF60, mol%). The switching time of Ft glass is measured to be less than 230 fs, and the nonlinear refractive index is estimated to be about 9.62×10^{-16} cm^2/W. We obtained narrow-bandwidth and symmetric gated spectra from a SC generated in distilled water using OKG technique with a Ft glass as Kerr medium. The experimental results indicated that the gated spectra obtained using OKG with the Ft glass as the Kerr medium have superiority, compared to those obtained with bismuth (Bi) glass and CS_2, demonstrating that Ft glass is a promising OKG material, which have fast response time, large nonlinearities, and high transparency.

2. Experiments

In this paper, Ft glass with a composition of $60TeO_2$-$30ZnF_2$-10NaF (TZNF60, mol%), was prepared using a traditional

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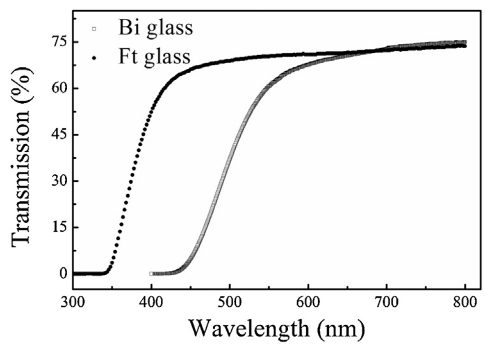

Fig. 1. Transmission spectrum of Bi glass and Ft glass.

melting-quenching method. The details about the preparation of the material were given in Ref. [16]. The sample was polished to be 1 mm thick. As references, a 1 mm thick Bi glass was used, which has been proven to be of large nonlinearity and ultrafast response [17]. Besides, CS_2 filled in a 1 mm thick cell was also used. The transmission spectra of Bi glass and Ft glass of 1 mm-thickness are shown in Fig. 1. We can see that the absorption edge is located at about 380 nm for Ft glass and 500 nm for Bi glass, respectively. There is no clear absorption below the absorption edge of each glass.

A laser with 65 fs pulse duration at 800 nm operating at 1 kHz was employed in our experiments. The output of the laser was split into two beams, one of which was used as the gating beam, and the other was used as the probe beam. The Kerr sample was positioned between a polarizer and an analyzer in a crossed Nicole polarizer configuration. The two beams were focused into the sample at an angle of 10° and the spots of the focused beams were spatially overlapped carefully. A computer controlled delay line was introduced into the optical path of the gating beam. The OKG signal was detected by a photomultiplier tube (PMT). To optimum the OKG signals, the polarization of the gating beam was rotated by 45° with respect to the linear polarization of the probe beam.

The experimental setup of acquisition of gated spectra using OKG technique is schematically represented in Fig. 2. To generate the SC, the fundamental probe pulse was focused into a 10-mm cell filled with distilled water using a 100-mm lens. A short-wave pass filter was used to remove the 800 nm light and the infrared part. The SC was focused into the Kerr medium along with the gating pulse. When the Kerr gate was opened by the gating pulse, gated spectra passing through the analyzer were collected by lenses and finally detected by a PMT and an optical multi-channel analyzer (OMA).

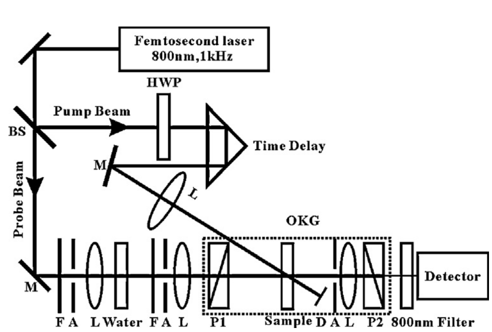

Fig. 2. Experimental setup for acquisition of gated spectra using OKG technique. BS, beam splitter; HWP, half-wave plate; F, filter; M, mirror; L, lens; S, sample; A, aperture; P, polarizer.

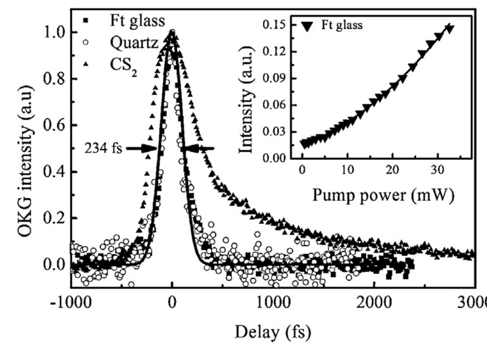

Fig. 3. Experimental measurements of Ft glass, quartz and CS_2 using time-resolved OKG technique. The horizontal axis is the time delay between the gating and the probe pulses, and the vertical axis is the OKG intensity of the arbitrary unit. The closed triangles in the inset show the optical Kerr signals as a function of the power of the gating light.

3. Experimental results

Firstly, we measured time-resolved OKG signals for CS_2, quartz and Ft glass. As shown in Fig. 3, the closed squares and open circles show the time-resolved optical Kerr signals for Ft glass and fused silica, respectively. We can see that the temporal profile of OKG in Ft glass quartz and fused silica is symmetrical with a full width at half maximum (FWHM) of ~230 fs. The temporal profile of the Kerr signals in Ft glass can be well fitted using the Gaussian function, as shown by the solid line in Fig. 3. While the CS_2 gate has an asymmetrical decay tail lasting about 2.5 ps decay time mainly attributed to the molecular orientation [18]. The closed triangles in the set of Fig. 3 show the optical Kerr signals as a function of the power of the gating light. The solid line indicates the quadratic dependence of the optical Kerr signal on the gating pulse energy [19].

Using the following equation, we calculated the third-order nonlinear refractive index n_2 of the Ft glass:

$$n_{2,s} = \left(\frac{I_s}{I_r}\right)^{1/2} n_{2,r}, \tag{1}$$

where the subscripts of s and r stand for sample and reference sample of quartz, respectively. I is the intensity of the OKG signal. The nonlinear refractive index n_2 of the Ft glass was calculated to be about 9.62×10^{-16} cm^2/W by comparison with that of fused silica of 2.5×10^{-16} cm^2/W at 804 nm, which was used as a calibration standard [20].

We measured the temporal profile of SC pulse generated in distilled water by the femtosecond laser using OKG method. The inset of Fig. 4 shows the SC spectrum generated in distilled water. After passing through a low-pass filter, the fundamental laser component

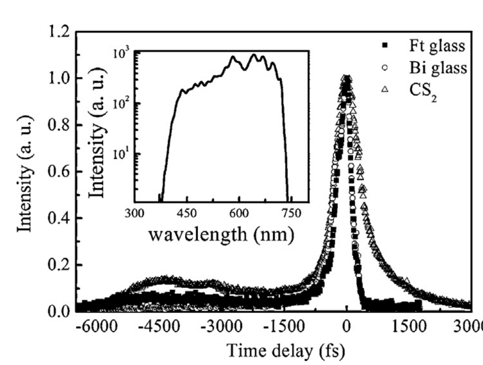

Fig. 4. Temporal profile of SC pulse measured using OKG with Ft glass, Bi glass and CS_2, respectively. The horizontal axis is the time delay between the gating (800 nm) and the SC (from 380 nm to 740 nm) pulses, and the vertical axis is the OKG intensity of the arbitrary unit.

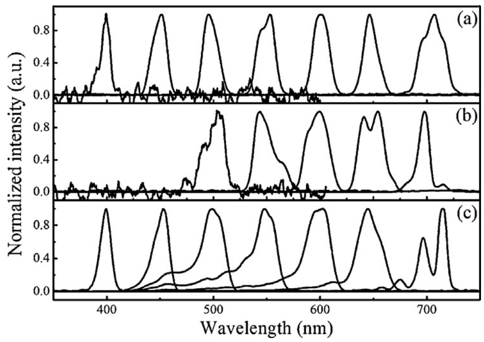

Fig. 5. The Kerr gated spectra from the SC probed at different time delay with (a) Ft glass, (b) Bi glass, and (c) CS_2 as Kerr medium, respectively.

was blocked and the SC spectrum ranged from 380 nm to 740 nm. Fig. 4 shows the temporal profiles of SC pulse measured using Ft glass, Bi glass and CS_2, respectively. The duration of the SC pulse was measured to be about 6.5 ps, as the chirped pulse was broadened by the water and optical elements in the setup due to the group velocity dispersion effect [21]. As shown in Fig. 4, the SC profile acquired using CS_2 had a lasting component at the positive delay time. Due to the slow response of CS_2, the SC pulse would still experience the residual birefringence even when the gating pulse arrived earlier. Furthermore, because the Bi glass had a very low transmittance below 500 nm, the short-wavelength components was not able to pass through the OKG with Bi glass, and the measured SC pulse duration was shorter than that measured with Ft glass as Kerr medium.

Fig. 5(a)–(c) shows the Kerr gated spectra using Ft glass, Bi glass and CS_2 as the Kerr medium, respectively. By controlling the delay line between the gating and the probe pulses, the central wavelength of each spectrum was adjusted to 400 nm, 450 nm, 500 nm, 550 nm, 600 nm and 700 nm, respectively. From Fig. 5, we can see that gated spectra using OKG technique with Ft glass and Bi glass have much narrower bandwidth and better symmetry than those obtained with CS_2. This is because the nonlinear response of CS_2 is much slower than that of Ft glass and Bi glass. Besides, the band tailing is also observed obviously in the gated spectra obtained by the CS_2 OKG. As shown in Fig. 3, the OKG signal of CS_2 had a slower response component compared with that of Ft glass and Bi glass due to its reorientation process. Hence, it is easy to understand the narrow-bandwidth and symmetric properties of the gated spectrum obtained using Ft and Bi glasses.

Although we could obtain narrow and symmetric gated spectrum using both kinds of glasses, Ft glass showed more superiority than Bi glass in the near ultraviolet range. Due to the large absorption of Bi glass below 500 nm, we were not able to acquire the

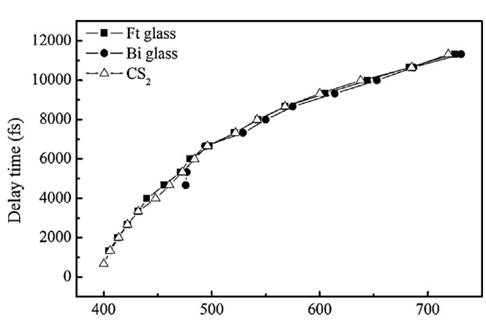

Fig. 6. Chirp structure of SC pulse measured by OKG method with Ft glass, Bi glass and CS_2, respectively.

gated spectrum centered at 400 nm and 450 nm, as shown in Fig. 5(b). In our experiments, Ft glass showed almost the same applicable spectral scope with CS_2, but had a much faster response time.

The closed squares, closed circles and open triangles in Fig. 6 show the chirp property of SC measured using OKG method with Ft glass, Bi glass and CS_2 as Kerr medium, respectively. We can see that the chirp property of SC measured using OKG method with Ft glass and CS_2 have the wavelength ranged from 400 nm to 740 nm, while the chirp property of SC with Bi glass has the wavelength ranged from about 500 nm to 740 nm. These agree with the conclusions in Fig. 5 and the results suggest that Ft glass have the superiorities of the ultrafast nonlinear response and the capability of capturing spectra in the near ultraviolet range.

4. Conclusions

In summary, we experimentally studied the optical Kerr effect for the Ft glass by the OKG technique. The nonlinear response time and the nonlinear refractive index are about 230 fs and 9.62×10^{-16} cm^2/W, respectively. Using the OKG of the Ft glass, narrow-bandwidth and symmetrical gated spectra were obtained from the SC generated in distilled water by a femtosecond laser. The results indicate the gated spectra with the Ft glass have superiority compare with Bi glass and CS_2 solution, such as fast response time, large nonlinearity, and high transparency.

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