Control of the gated spectra with narrow bandwidth from a supercontinuum using ultrafast optical Kerr gate of bismuth glass

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Supercontinuum generation and its application have become one of the attractive research fields in ultrafast optics. We have acquired a series of narrow bandwidth and symmetric gated spectra continuously from the chirped supercontinuum generated in a sapphire plate with a femtosecond laser, using an ultrafast optical Kerr gate (OKG) with $Bi_2O_3-B_2O_3-SiO_2$ oxide glass as the Kerr material. Experimental results show that the gated spectra obtained using OKG of the glass have more superiorities comparing with CS_2. © *2008 American Institute of Physics*.
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Supercontinuum generation is a nonlinear optical phenomenon, in which the spectral width of a laser pulse passing through a transparent optical medium increases drastically. This phenomenon has been observed in lots of gaseous,[1–3] liquid,[4] and solid[5] transparent optical mediums and found extensive applications in femtosecond time-resolved spectroscopy,[6] atmospheric sensing,[7] broadband spectrum lidar,[8] high time-resolved imaging,[9–11] lightning control,[12] and so on.

It is well known that the supercontinuum has a strong chirp owing to dispersion by the material in which it is generated. Until now, the sum-frequency generation cross-correlation method,[13] two-photon absorption[14] and the optical Kerr gate (OKG) technique[15,16] were used to investigate its chirp characteristics. Compared to other methods, the OKG technique has many advantages, such as no need of satisfaction of the phase-matching condition or high intensity of the probe pulse. Based on this technique and the chirp characteristics of the supercontinuum, Yasvi *et al.* proposed a method for simultaneous three-dimensional (3D) imaging.[10] This method makes full use of the advantages of the OKG, but also avoids scanning of the laser. It is applicable for imaging of the shape of moving objects, or surface testing and inspection. However, when going further into the femtosecond region, there is an inherent tradeoff between high sensitivity and fast response in all the application based on the OKG technique.

Among these available nonlinear optical materials, inorganic homogeneous glasses seem to be preferable candidates for the above applications, due to their large nonlinearities, high transparency, and fast response time. In this paper, we used one nonresonant-type $Bi_2O_3-B_2O_3-SiO_2$ oxide glass (here denoted by BI glass) as the Kerr material, which presents both large nonlinearity and ultrafast response time. Using OKG technique, we controlled the chirped supercontinuum generated in a sapphire plate with a femtosecond laser. The experimental results show that the gated spectra obtained using OKG of the BI glass have more superiorities comparing with CS_2, which could improve the time resolution and the longitudinal resolution in the 3D imaging based on OKG.

In the experiment, a multipass amplified Ti:sapphire laser system was employed, which emitted linearly polarized 30 fs, 800 nm pulses at a repetition rate of 1 kHz. The incident fundamental pulse was divided into two pulses by a beam splitter with a split ratio of 2:8. Passing through an optical delay translation stage, the intense one was finally focused onto the Kerr material as a gate pulse. A half-wave plate was used to rotate its polarization by $\pi/4$. The weak one was focused into a 3 mm sapphire plate which was on the geometrical focal plane. Before the sapphire, an iris diaphragm was introduced to adjust the self-focusing condition in the sapphire plate and an adjustable neutral optical attenuator was used to increase generator pulse power gradually to obtain a stable supercontinuum. When the gate pulses opened the gate, the entire transmitted Kerr signals (as we called Kerr gated spectra) were collected using lenses. The polarization of the generated supercontinuum is the same as that of the incident laser. Then the Kerr signals were led to an analyzer with polarization perpendicular to the fundamental laser, and finally detected with a normal photodiode or a miniature fiber optic spectrometer.

As mentioned above, we used the BI glass and the referenced CS_2 solution as the Kerr materials. The BI glass sample of the composition $Bi_2O_3-B_2O_3-SiO_2$, which was prepared by melting $BiO_{1.5}$, SiO_2, B_2O_3, and GeO_2 according to a certain proportion, was employed. The details about the preparation of the sample were given in the reference.[17] The thickness of the glass sample was about 1.5 mm. The CS_2 solution was filled in a glass cuvette with a path length of 1 mm.

Figure 1 shows the time-resolved measurements of Kerr signals of both samples using the fundamental laser. The response time of the BI glass (triangles) is less than 85 fs and much faster than that of the reference sample CS_2 (circles). The origin of nonlinearity of BI glasses and CS_2 were mainly attributed to electronic processes and molecular reorientation, respectively.[18] According to the references,[18,19] the nonlinear refractive-index n_2 of BI glasses is up to 1.6×10^{-14} cm^2/W, which compares favor-

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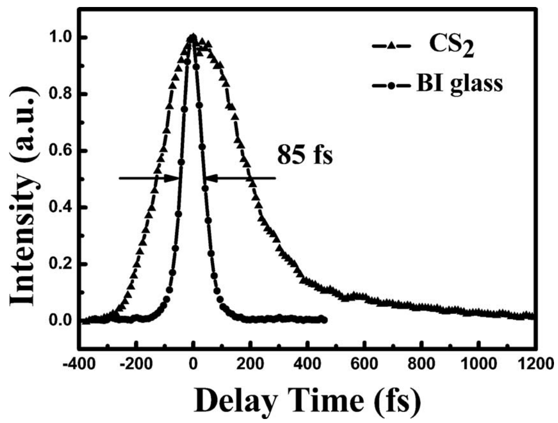

FIG. 1. The femtosecond time-resolved optical Kerr signals of CS_2 and BI glass.

ably with most those for chalcogenide glasses. That ensures we could easily get intense high contrast signals.

We generated the supercontinuum by focusing the fundamental laser in a sapphire plate and measured its spectrum with the fiber optic spectrometer. The intensity of the laser at the sapphire was about 1×10^{11} W/cm^2. As shown in Fig. 2, the supercontinuum spectrum ranged from 450 to 700 nm, in which the long-wave region was filtered by a filter. Time-resolved optical Kerr signals for the supercontinuum pulses were also measured using OKG with the BI glass, and the results are shown in inset of Fig. 2. Based on the time-resolved measurements, the supercontinuum duration was estimated to be about 2 ps.

Then, we adjusted finely the delay between gate pulse and the chirped supercontinuum and acquired a series of gated spectra for the two samples. The results are shown in Fig. 3. The intervals of the gated spectra for CS_2 and the BI glass were set at 52 and 72 fs, respectively. From Fig. 3, we can see that the gated spectra obtained using BI glass have narrower spectrum bandwidth and better symmetry spectrum distribution. This is because the nonlinear response of CS_2 is much slower than that of BI glass. In addition, the experimental results show that the distribution of the gated spectra for both samples is dense in the short-wave region, indicating that the supercontinuum has low chirp in the short-wave region.

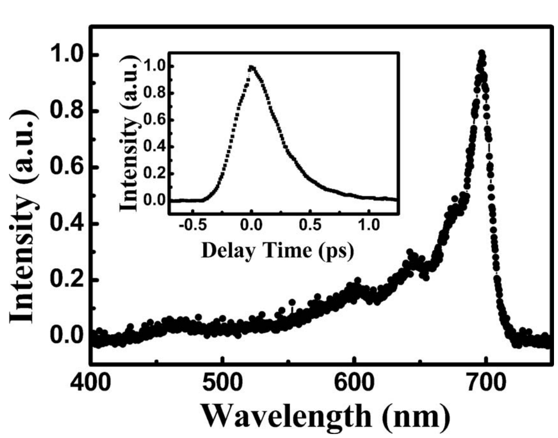

FIG. 2. Supercontinuum generated in a sapphire plate and time-resolved measurements for the supercontinuum duration using OKG with the BI glass.

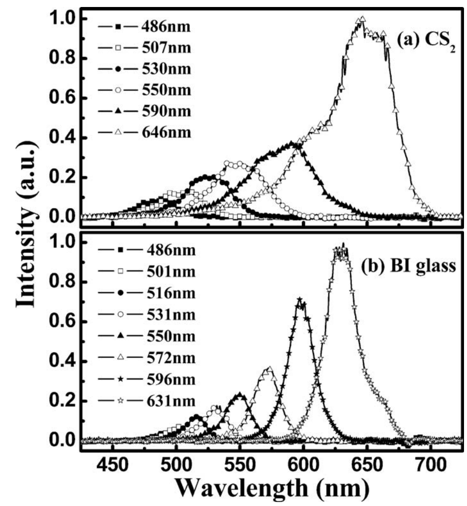

FIG. 3. Kerr gated spectra from the supercontinuum probed at different time delay. (a) CS_2 as Kerr material; (b) BI glass as Kerr material.

To compare further the difference of the gated spectra obtained using CS_2 and the BI glass, we chose four pairs of gated spectra from Fig. 3, which are shown in Fig. 4. From Fig. 4, we can see that the gated spectra bandwidth for CS_2 increases from about 100 to 150 nm with the increase in the wavelength due to the chirp characteristic of the supercontinuum, and these spectra exhibit obvious band tailing. Comparing with CS_2, the gated spectra for the BI glass show better symmetry, the bandwidths of which are narrower than 75 nm, and nearly invariant. These results show that the gated spectra obtained using ultrafast OKG of the BI glass have more superiorities.

In conclusion, we have obtained a series of Kerr gated spectra from the chirped supercontinuum using BI glass and CS_2 solution as the Kerr material, respectively. The experimental results show that the gated spectra using BI glass have narrower bandwidth and better symmetry, which could improve the time resolution and the longitudinal resolution in the 3D imaging based on OKG. In addition, this ultrafast-response and strong-signal Kerr gate can be used to capture the transient fluorescence and handle optical signals in future integrated optical systems.

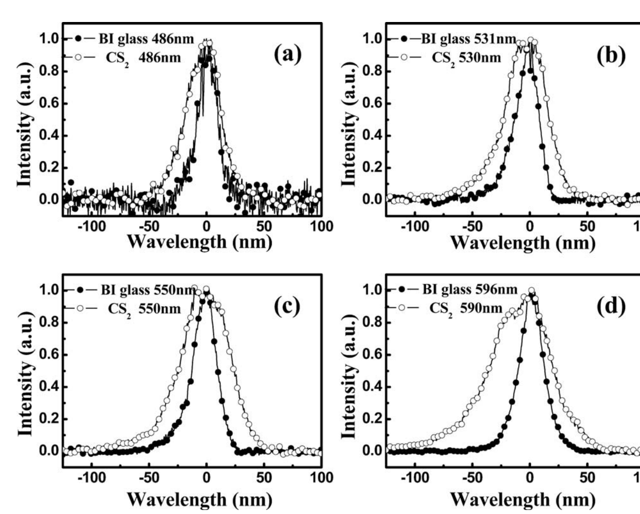

FIG. 4. Gated spectra obtained from supercontinuum using CS_2 and BI glass. The central wavelengths for the spectra of (a), (b), (c), and (d) are near 486, 530, 550, and 590 nm, respectively.

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