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Chirped pulse Raman amplification in $Ba(NO_3)_2$ crystals

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ABSTRACT

In this study, 35.5% conversion efficiency is obtained at the first Stokes component frequency (873 nm) upon two-stage chirped pulse Raman amplification in a $Ba(NO_3)_2$ crystal by an 8 mJ, 620 ps, 800 nm pump laser. A maximum energy of 4.22 mJ with 3.82% rms stability at the first Stokes pulse can be obtained under 35 mJ pump energy. Moreover, the chirped first Stokes pulse can be compressed to 143 fs.

1. Introduction

Obtaining a powerful and slightly shifted ($\Delta\lambda < 100$ nm) center wavelength temporally synchronized with the main ultra-short ultra-intense pulse is relatively important for applications such as in two-color high-intensity laser experiments [1–3]. At present, three types of nonlinear converters are widely used for laser frequency shifting, namely, the optical parametric amplifier (OPA) [4], cascaded second-order processes [5–7] and stimulated Raman scattering (SRS) [8].

Application of the three-wave parametric process in nonlinear crystals hardly produces small $\Delta\lambda$ because of infrared radiation absorption of idler waves. Cascaded second-order processes do not involve the generation of far infrared radiation, but it requires an additional pump pulse. This additional stage complicates the optical design of the system. SRS features the advantage of allowing frequency shifts of $\sim$1000 cm^{-1} with high energy efficiency. Solid-state materials for SRS with favorable features, such as compactness and robustness, have been extensively investigated by several research groups worldwide. Among the solid-state SRS media reported thus far, $Ba(NO_3)_2$ crystals have attracted significant attention because of their high gain coefficient (16 cm/GW) in 800 nm pump lasers [9]. These crystals exhibit a strong A_g-vibrational Raman mode at 1047.3 cm^{-1} with a line width of 0.4 cm^{-1} (T_2=25 ps) [10]. Unfortunately, SRS is highly transient for pulses shorter than a few picoseconds because its vibrational dephasing times are comparatively longer than those of other methods. This phenomenon leads to considerable increases in the SRS threshold, decreases in conversion efficiency, and appearance of competing nonlinear optical processes, such as self-focusing, self-phase modulation, and generation of a spectral continuum [11,12].

A technique based on chirped pulse Raman scattering (CPRS) was developed to overcome these problems. The pulse, which is stretched by the frequency chirping process, allows decreases in laser intensity in the active Raman medium. Zhavoronkov et al. [13] demonstrated the generation of 80 μJ, 870 nm pulses by CPRS of chirped 1.5 mJ, 800 nm pulses in $Ba(NO_3)_2$ crystals, followed by recompression to $\sim$190 fs. However, using single Raman cell limits the CPRS conversion efficiency by the generation of higher Stokes and anti-Stokes frequency components and onset of other nonlinear optical processes. Several attempts have been reported to overcome these drawbacks using a two-stage generator and amplifier (chirped pulse Raman amplifier, CPRA) arrangement instead of a single Raman cell [14].

In this paper, an experimental study on CPRA in $Ba(NO_3)_2$ crystals is presented. A conversion efficiency of 35.5% can be obtained at the first Stokes component (henceforth referred to as Stokes) by pumping with the laser of an 8 mJ, $\sim$620 ps, 800 nm Ti:sapphire-based chirped pulse amplification system. To the best of our knowledge, this conversion efficiency is the highest reported thus far for single-pass long-duration (> 500 ps) CPRA based on a $Ba(NO_3)_2$ crystal. Increasing the second-stage pump pulse energy to 35 mJ allows the amplified Stokes pulse energy to reach 4.22 mJ with 3.82% rms energy stability. The amplified chirped Stokes pulse is injected into a compressor based on 1200 lines/mm diffraction gratings and compressed to 143 fs.

2. Experiment

Pump seed pulses were generated by a mode-locked Ti:sapphire oscillator. An $\sim$20 fs (full width at half-maximum, FWHM)

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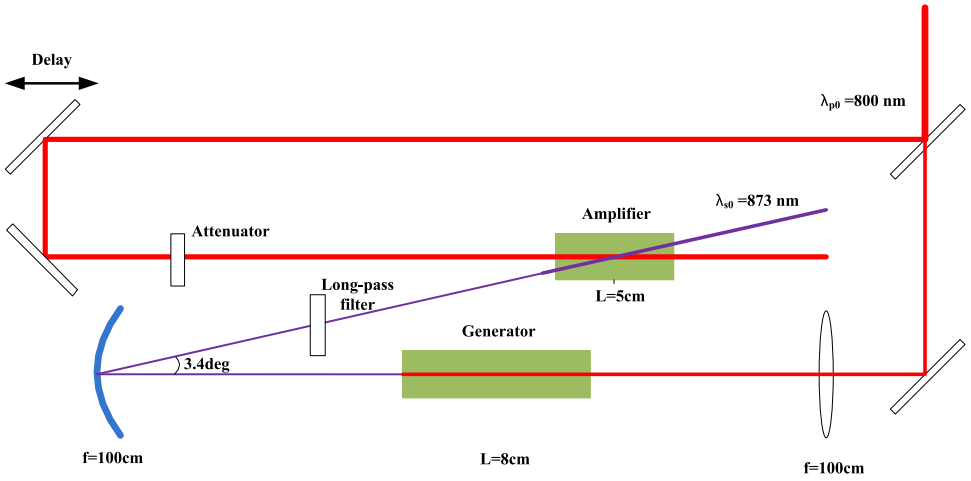

Fig. 1. Schematic diagram of the experimental setup for Raman generator and amplifier.

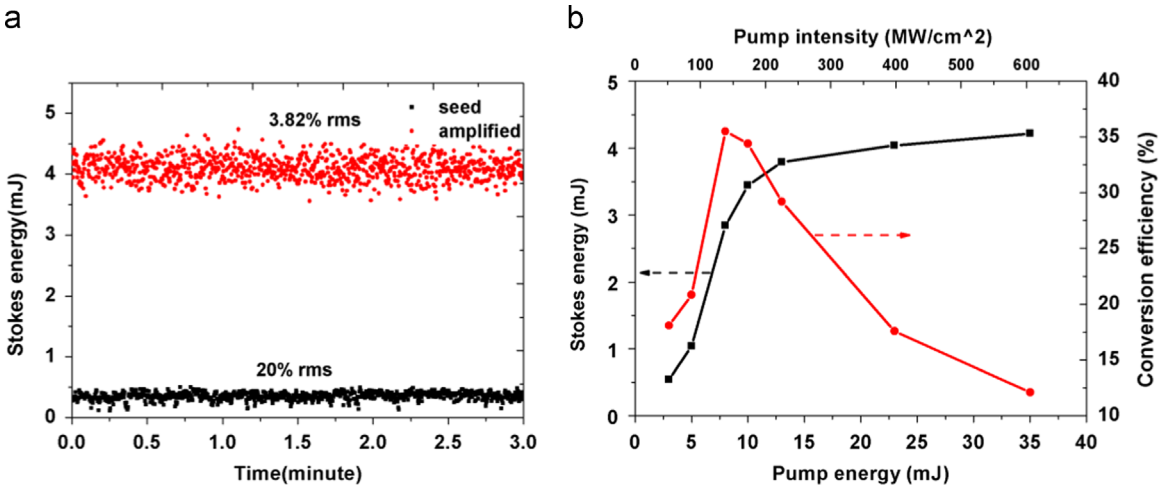

Fig. 2. (a) Energy stability of the Stokes pulse in the generator stage (black scattering) and the amplifier stage (red scattering). (b) Dependence of amplifier stage Stokes pulse energy on pump pulse energy. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

transform-limited pulse from the Ti:sapphire oscillator is injected into an Offner-type pulse stretcher consisting of a 1480 lines/mm diffraction grating providing a 14 ps/nm stretching factor. The stretched pulse is injected into a regenerative six-pass multi-pass amplifier and amplified to ~42 mJ working at 10 Hz. The pump pulse is then split into two pulses with an intensity ratio of 3:7. The weaker portion of the pulse (~7 mJ) is focused with an $f=100$ cm lens, and the $Ba(NO_3)_2$ crystal is located 40 cm before the focus to generate a Stokes seed pulse. The spot diameter of the $Ba(NO_3)_2$ crystal is approximately 2 mm.

The $Ba(NO_3)_2$ crystal, which was purchased from MolTech GmbH, was 8 cm long with a 1 cm × 1 cm cross section and 700–900 nm anti-reflecting (AR) coating. The remaining pump pulse (~35 mJ) is passed through a delay line to synchronize its arrival with the second-stage Stokes seed pulse. The unfocused pump pulse enters the second $Ba(NO_3)_2$ crystal with 5 cm length at normal incidence, and the pump pulse energy can be adjusted by an attenuator before the crystal. The spot diameter is approximately 4 mm (full width at $1/e^2$ maximum). Collimated Stokes seed pulses pass through an 850 nm cut-wavelength long-pass filter to remove the residual pump component and propagate through the $Ba(NO_3)_2$ crystal with the same beam diameter at a small angle (3.5°) to the pump path. The amplified Stokes pulse is then sent to the mismatched grating compressor. The 1200 lines/mm compressor gratings are separated at approximately 121.3 cm with an optimized angle of 41.9°. Fig. 1 shows the details of Raman generator and amplifier.

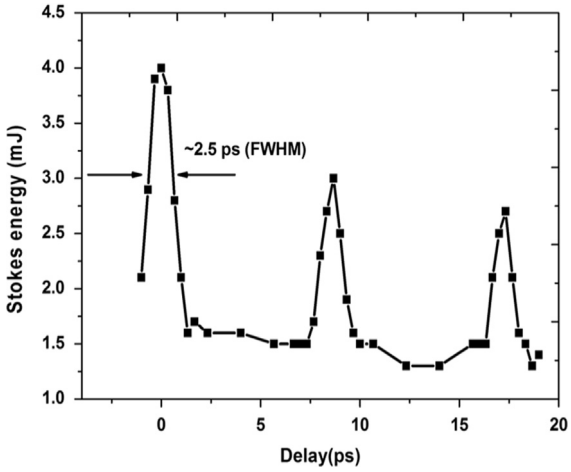

Fig. 3. Amplifier-stage Stokes pulse energy as a function of the delay between Stokes seed and pump pulses.