Generation of High Energy, Ultrashort Pulses in the near-IR with an OPA System Based on BIBO

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Abstract: Using a two stage, white-light seeded, collinear, femtosecond optical parametric amplifier based on BIBO crystal, sub-30-fs signal pulses with energies exceeding 200-μJ, corresponding to 5-fold pulse shortening and ~30% internal conversion efficiency, are generated.

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High energy, ultrashort pulses in the near-IR are of special interest for a variety of applications in nonlinear optics and time-domain spectroscopy. Generation of pulses as short as 14.5 fs at 1.5 μm and with energies of about 12 μJ (signal+idler) using β-BaB_2O_4 (BBO) crystal has been reported [1]. Also 200 μJ, 15 fs phase-stable pulses at 1.5 μm were produced by difference-frequency generation of a hollow-fiber broadened supercontinuum followed by two-stage BBO-based optical parametric amplification pumped by 50 fs pulses Beside the complex set up, because of the need to generate broadband supercontinuum in this work the use of short pump pulses not much longer than 50 fs will be necessary [2]. Recently a relatively new nonlinear crystal, bismuth triborate, BiB_3O_6 (BIBO) has attracted a lot of attention because of its efficient performance for light conversion applications in the visible and near-IR spectral regions [3-6]. The unique property of BIBO for having ultra broadband spectral acceptance in the near-IR for type I ($e\rightarrow o+o$) phase-matching (PM) inside *xz* optical plane under pumping at wavelengths near 800 nm has been recently the subject of a number of experiments including a mode-locked Ti:Sapphire laser pumped femtosecond BIBO optical parametric oscillator [7], ultra broadband parametric generation [8] and ultra broadband parametric amplification of white-light continuum (WLC) in the near-IR [9].

Here we report on efficient generation and compression of high energy pulses near 1300 nm by taking advantage of the large gain bandwidth of BIBO when pumped by near 800 nm pulses [8]. In a two-stage WLC seeded optical parametric amplifier (OPA) under pumping by 150 fs pulses, signal pulses as short as 25 fs with energies exceeding 200 μJ are generated.

The OPA is pumped by the fundamental of a regenerative/multipass Ti:sapphire amplifier. The laser provides up to 12 W of average power at 807 nm in ~150 fs pulses at 1 kHz repetition rate. The crystals applied in both stages are 3-mm-long, uncoated BIBO cut at (θ=11.4°) for type I ($e\rightarrow o+o$) phase-matching inside the optical *xz* plane. The WLC is generated in a 2-mm sapphire plate using few μJ of the fundamental pulse energy.

Less than 250 μJ of the fundamental energy is applied to the first stage OPA crystal at this stage for 1150 nm<λ<1300 nm, well-defined spectra with 30-100 nm FWHM, increasing with wavelength, and pulse energies exceeding 5 μJ are achieved. Starting from 70 fs at shorter wavelengths, the signal pulses become shorter down to 40 fs with increasing the wavelength, which can be expected because of the better group velocity matching [7]. At longer wavelengths λ>1300 nm the signal behavior changes, a broad spectrum with little tunability only around ~1400 nm is selected by the crystal. At this wavelength the negligible group velocity dispersion (GVD) of BIBO (≈33 fs^2/mm) results in near transform-limited signal pulses with a duration as short as ~18 fs without using any compression.

About 1.6 mJ of the pump pulse energy is sent to the second OPA stage. The amplified signal pulses in the second stage nearly follow the behavior of the seed pulses from the first stage: For wavelengths shorter than 1200 nm where still the interaction is not in the ultra broadband regime and the spectral acceptance bandwidth is limited, signal pulses with well-defined spectra and spectral bandwidths of about 30 nm (FWHM) are generated. For signal wavelengths in the range of 1200 nm<λ<1300 nm, the spectral acceptance bandwidth starts growing rapidly and the spectral bandwidths are about 80-120 nm which supports sub-30 fs transform-limited pulses. Across the tuning range of 1150 nm<λ<1300 nm, more than 400 μJ (signal+idler) pulse energy is produced in the second stage corresponding to an internal conversion efficiency of 30% in this stage. In order to compress the signal pulses we applied a prism pair compressor in a double-pass configuration consisting of two Brewster-angled prisms of SF11 with a separation of 50-70 cm, depending on the wavelength. The characterization of the generated signal and idler pulses was performed using the second harmonic generation frequency resolved optical gating (SHG FROG) technique Figure 1(a) shows the retrieved temporal intensity and phase profiles, respectively, for a typical compressed signal pulse near 1300 nm (FROG error 0.009). The SHG was performed using a 25-μm-thick BBO crystal cut at $\theta = 44^\circ$ for type I (o+o→e) PM. The retrieved pulse duration of 25 fs (FWHM) with a time-bandwidth product of 0.31 is close to the transform limit which is evident from the almost constant phase in time.

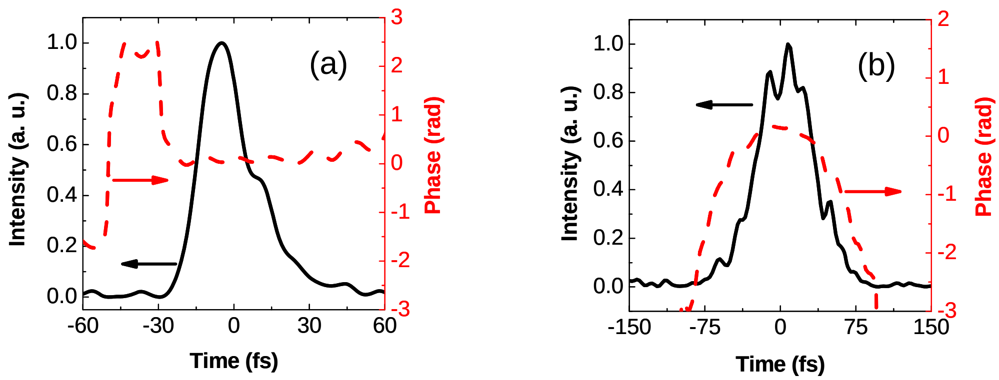

Fig. 1. Typical FROG measurements of the amplified pulses with a FROG error of < 0.01 (128×128 pixels). Retrieved intensity and phase as a function of time for the (a) 25 fs compressed signal pulse with a time-bandwidth product of 0.31 and (b) 55 fs uncompressed idler pulse with a time-bandwidth product of 0.5.

We also characterized the idler pulses generated in the second stage in the spectral range characterized by high output energy. A typical SHG FROG measurement at ~ 2300 nm is shown in Fig. 1(b) presenting an idler pulse with a duration of 55 fs and a spectral width of 160 nm which corresponds to a time-bandwidth product of 0.5. The idler pulses carry negative chirp content and cannot be further compressed by the available prism pair compressors.

In conclusion, we have demonstrated a two-stage, WLC seeded OPA capable of producing sub-30 fs pulses near 1300 nm. Using two BIBO crystals based on type I collinear phase matching, the OPA showing an order of magnitude energy-scaling generates near-IR signal pulses at 1 kHz repetition-rate with an energy exceeding 200 μJ and duration as short as 25 fs under pumping by 150 fs pulses, presenting significant pulse shortening. The short temporal width and near-transform-limited characteristics of the pulses combined with high output energies can make this device an attractive tool for a wide range of applications in nonlinear optics and spectroscopy. Further energy scaling of the system by applying higher pump pulse energies with increasing the number of the amplification stages and also performing the pulse compression by the use of a more sophisticated compressor like a deformable-mirror-based set up should result in shorter pulses with higher energy across the near-IR and extension of the signal tuning range.

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