Generation of Tunable, 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 crystals, sub-30-fs signal pulses tunable across the whole spectral range of 1150-1600 nm with energies exceeding 80-µJ are generated.

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Generation of tunable, high energy, ultrashort light pulses in the near-IR has many applications, in particular in nonlinear optics and time-resolved spectroscopy. Nonlinear frequency down-conversion based on resonator-free, traveling-wave optical parametric generation and/or amplification (OPG/OPA) is a well established method for this, relying on amplified Ti:sapphire laser systems as pump sources near 800 nm. Thus, for instance, signal tunability from 1100 nm up to degeneracy (1600 nm) was demonstrated with one of the very early OPG/OPA systems based on 3 BBO type-II stages [1]. This system was pumped by 150 fs, 750 µJ pulses from a Ti:sapphire regenerative amplifier at 1 kHz and the maximum signal energy (~100 µJ) and minimum pulse duration (60 fs) were obtained near 1300 nm. The parametric amplification itself leads to temporal shortening of the generated signal/idler pulses due to the gain narrowing effect [2], however, the limit to the achievable pulse duration is set basically by the parametric gain bandwidth of the crystals used and not by the pump pulse duration [3]. Thus, shorter signal pulses could be obtained using shorter pump pulses near 800 nm only in combination with shorter crystal lengths [4] or type-I interaction in BBO [5], however, the signal pulse energy was only of the order of 8 µJ in the former case and no tunability could be shown in the latter case. The efficiency of an OPA can be improved by using relatively long pump pulses and chirped pulse amplification when seeding by white light continuum (WLC), while sub-50 fs output pulses can be still obtained by subsequent compression, as demonstrated in the case of 400 nm pumping of BBO in a noncollinear propagation geometry [6], however, the output energy reached in this case was only a few microjoules for the 1100-1600 nm spectral range because of the limited pump energy. Recently, we realized several efficient femtosecond OPG/OPA configurations based on the nonlinear crystal bismuth triborate, BiB_3O_6 (BIBO), which covers a very similar spectral range in the near-IR but exhibits higher effective nonlinearity than BBO, see [7] for a review. Most relevant to the present study is the demonstration of sub-30 fs pulses in the near-IR with a BIBO OPA at energy levels up to 200 µJ [8]. However, as with BBO, the ultra-broad gain bandwidth of type-I BIBO used in both stages of the WLC-seeded OPA, confined the tuning range to the vicinity of 1300 nm, far from the degeneracy point [8].

In this work, we report on generation and compression of high energy, sub 30 fs pulses tunable across the whole spectral range of 1150-1600 nm by taking advantage of the broadband tunability of a type II BIBO crystal in the first stage and the large gain bandwidth of a type I BIBO crystal under 800 nm pump pulses in the second stage. Pumping by 45 fs pulses with 750 µJ in the second stage, signal pulses as short as 22 fs and maximum energies of 80 µJ are obtained.

The OPA is pumped by the fundamental of a Ti:sapphire amplifier system at 800 nm. The laser provides ~45 fs pulses with an energy up to 2.8 mJ at 1 kHz repetition rate. The crystal applied in the first stage is a 1.5-mm-long BIBO cut at $\theta = 42°$ for type-II ($o \rightarrow e+o$) PM inside the optical *xz* plane and the second stage crystal is a 3-mm-long BIBO cut at $\theta = 11.4°$ for type-I ($e \rightarrow o+o$) PM inside the same plane. Both crystals are uncoated. In this experiment we applied 1 mJ of the energy of laser pulses to pump the OPA. For generation of WLC less than 20 µJ of the pulse energy is focused onto a 3-mm-thick YAG plate using a lens with f = 50 mm. About 230 µJ of the fundamental pulse energy is focused on the first BIBO using an f = 400 mm lens. The type II BIBO crystal, applied in the first stage, ensures tuning at almost constant but large enough bandwidth while the type I BIBO crystal, applied in the second stage, provides the amplification of the first stage signal pulses while maintaining their spectral width. The continuous tuning of the amplified signal pulses from the second stage can be seen in Fig. 1(a). The spectral width of the pulses at full width half maximum (FWHM) ranging from 90 to 130 nm across the tuning range supports sub

30 fs pulses across the whole signal tuning range. 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. Near transform-limited pulses with about 25 fs duration for λ<1250 nm and pulses as short as 22 fs in the vicinity of 1300 nm could be obtained. Figure 1(b) shows the retrieved temporal intensity and phase profiles from a SHG-FROG measurement for a typical compressed signal pulse near 1300 nm (FROG error 0.01). The retrieved pulse duration of 22 fs (FWHM) corresponds to a time-bandwidth product of 0.39. Across the tuning range of 1150<λ<1400 nm, from 55 to 80 μJ pulse energy is produced in the second stage, corresponding to a maximum internal conversion efficiency of 20% in this stage. For 1400<λ<1500 nm the pulses have negligible chirp content and without using any compression they are close to transform limited with slightly less than 30 fs pulse duration and the time-bandwidth product is about 0.5. The energy of the signal pulses from 70 μJ at 1400 nm decreases to 40 μJ at 1500 nm. Approaching degeneracy the spectral filtering (separation) of the signal pulse after the second stage is not ideal and with some portion of the idler, the chirp shows more complex behavior and the pulses broaden to about 50 fs. This could be compensated by negative chirping of the pump pulses which resulted in reduction of the signal pulse duration to about 30 fs without compression. These pulses with a time-bandwidth product of <0.5 are also close to the transform-limit. The pulse energy in this spectral region shows the same trend, diminishing towards longer wavelengths, with 25 μJ at degeneracy. This reduction of the pulse energy with increasing wavelength is a result of the weak WLC content at longer wavelengths.

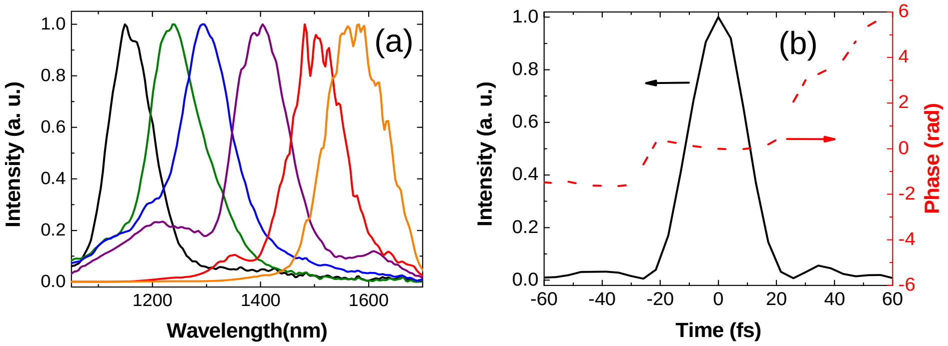

Fig. 1. (a) Spectra of the amplified signal pulses across the tuning range and (b) Retrieved intensity and phase as a function of time for the 22 fs compressed signal pulse with a time-bandwidth product of 0.39.

In conclusion, we have demonstrated a two-stage, WLC seeded OPA capable of producing sub 30 fs signal pulses tunable across the spectral range of 1150-1600 nm. The OPA benefits from using two BIBO crystals based on type-II and type-I collinear phase matching in the two stages for producing near-IR signal pulses at 1 kHz repetition-rate with duration as short as 22 fs under pumping by 45 fs pulses. The continuous tuning, short temporal width and near-transform-limited characteristics of the pulses are attractive for a wide range of applications in nonlinear optics and spectroscopy. By applying higher pump pulse energies, further energy scaling of the system should be possible.

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