Generating Efficient Femtosecond Mid-infrared Pulse by Single Near-infrared Pump Wavelength in Bulk Nonlinear Crystal Without Phase-matching

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Abstract: We experimentally demonstrate efficient mid-infrared pulse generation by dispersive wave radiation in bulk lithium niobate crystal. Femtosecond mid-IR pulses centering from 2.8-2.92 μm are generated using the single pump wavelengths from 1.25-1.45 μm.

OCIS codes: (320.7110) Ultrafast nonlinear optics; (190.4400) Nonlinear optics, materials

1. Introduction

Femtosecond laser pulses in the mid-infrared (MIR) range are highly important for the study of molecular vibrational modes and lots of other topics. To obtain such pulses, nonlinear optical parametric processes are normally exploited to convert the Near-infrared (NIR) wavelengths. The most commonly used processes are optical parametric amplification (OPA) [1], optical parametric oscillation (OPO) [2], and difference frequency generation (DFG) [3]. These processes are with decent conversion efficiency and good wavelength tunability, but require critical phase-matching condition, either two synchronized pump wavelengths or one pump wavelength but synchronous pumping scheme. Four-wave mixing (FWM) in $\chi^{(3)}$ media for MIR pulse generation has also been reported [4], which involves two synchronized pump wavelengths as well, and bears rather low conversion efficiency.

An ultrafast MIR generation technique with a single NIR non-synchronous pumping wavelength and without critical phase-matching condition will be therefore highly intriguing. Recently, some of the authors proposed such a novel and simple MIR pulse generation method, which is related with MIR dispersive wave radiation through phase-mismatched quadratic interactions [5, 6]. The formation of efficient MIR dispersive waves was predicted with the energy coupled from the NIR solitons. In this abstract, we demonstrate the first experimental results based on this concept. Femtosecond MIR pulses from 2.8 to 2.92 μm are achieved through a 10-mm-long bulk lithium niobate (LN) crystal with single pump wavelengths ranging from 1.25 to 1.45 μm and a simple one-pass pumping scheme. The NIR to MIR conversion efficiency as high as 4% was obtained.

2. Experimental setup and results

The MIR generation setup is very simple, consisting of only the pump laser, silver mirror telescope, and quadratic nonlinear crystal. The pump laser is a 1 kHz commercial OPA system. We tuned the OPA wavelength from 1.25 to 1.45 μm. The pulse duration of the NIR pump is around 50 fs. A 10-mm-long, 5% MgO-doped Y-cut congruent LN ($\theta = \pi/2$, $|\phi| = \pi/2$) is used. The pump beam is projected to the LN with normal incident angle and 0.6 mm spot size. Because we exploit noncritical cascaded SHG interaction with huge phase-mismatching, the MIR generation is rather unsensitive to crystal angle adjustment. We observed significant spectrum broadening when gradually increased the pump intensity, which is related with soliton effect under normal dispersion regime and the ultra-broadband self-defocusing nonlinearity [7]. Fig.1(a,b)show the measured supercontinuum spectra for 1.3 and 1.4 μm pump cases.

Both measured supercontinua show significant dispersive wave radiation beyond 2.6 μm. To isolate the MIR dispersive wave radiation, we applied a piece of long pass filter with 2.4 μm cut-on. The evolution of the isolated MIR radiation spectra under various pump intensities are shown in fig.1(c,d). The isolated MIR dispersive wave spectra under various NIR pump wavelengths are illustrated as well in Fig.2(a). When the pump wavelength increases, the MIR pulses central wavelength slightly decreases (from 2.92 to 2.8 μm). This trend agrees well with theory prediction: shorter pump wavelength leads to longer dispersive wave wavelength. MIR pulses with central wavelength beyond 3 μm are possible if pump laser below 1.25 μm with decent power was availabe.

A home-made SHG intensity autocorrelator was built with a 0.4-mm-thick $AgGaS_2$ crystal to measure the isolated MIR pulses. A typical result for the 1.3 μm pump case is shown in fig. 2(b). The pulse duration is 153 fs assuming a Gaussian shape. The measured pulse durations are between 150 to 200 fs under other pump wavelengths, indicating

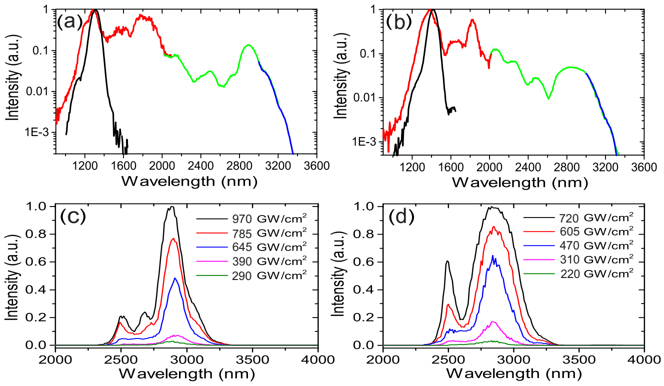

Fig. 1. (a) 1.3 μm pump laser spectrum (black curve) and output spectrum with the pump intensity 970 GW/cm^2(red curve by InGaAs CCD spectrometer, green and blue curves by monochromator based MIR spectrometer with different order sorting long pass filters. (b) 1.4 μm case with the pump intensity 720 GW/cm^2. (c) long pass filter isolated MIR spectra under various pump intensities at 1.3 μm. (d) 1.4 μm case.

that all the MIR pulses are quite chirped. Much shorter pulses are possible after simply removing the linear chirps. Some of the MIR spectra could support pulse duration below 3 optical cycles.

The output MIR average power is 8 mW with 198 mW pump power at 1.3 μm, corresponding to a NIR to MIR conversion efficiency of nearly 4%. The conversion efficiency by 1.35 and 1.4 μm pump are about 4%, and nearly 3% for the 1.25 and 1.45 μm pump. Regardless the simplicity of the setup, the efficiency level is already comparable with the traditional DFG process under critical phase-matching condition.

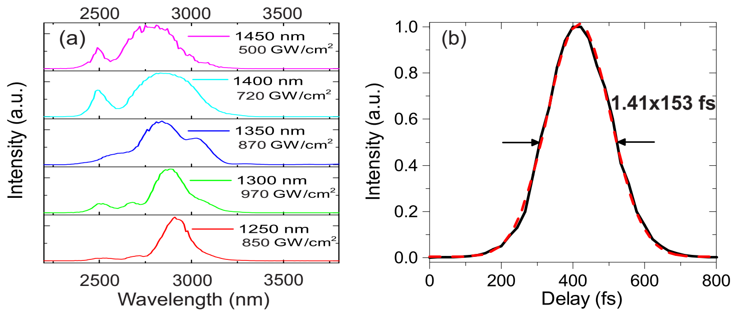

Fig. 2. (a) MIR spectra under various NIR pump wavelengths. (b) intensity autocorrelation trace for the MIR pulse under 1.3 μm pump.

3. Conclusion and outlook

In conclusion, we experimentally demonstrate a novel and simple way to generate ultrafast MIR pulses. Femtosecond MIR pulses from 2.8 to 2.92 μm are obtained through a 10-mm-long bulk LN crystal with single NIR pump wavelengths. The corresponding NIR to MIR conversion efficiency reaches 4%. This MIR generation technique does not require phase-matching condition, two synchronized pump wavelengths, or synchronous pumping scheme; this brings great simplicity compared with traditional techniques. The NIR to MIR conversion efficiency from the initial experiment is already comparable with traditional phase-matching techniques despite the great simplicity. We hope this work could pave the way for a new kind of practical ultrashort MIR source. It is also worth to note that there are plenty of nonlinear crystals which could be applied with this technique and realize different MIR coverage.

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