Design study: broadband mid-IR OPA

Generation of broadband mid-infrared pulses from an optical parametric amplifier

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Abstract: We report on the direct generation of broadband mid-IR pulses from an optical parametric amplifier. Several crystals with extended IR transparency, when pumped at 800 nm, display a broad phase-matching bandwidth around 1 μm, allowing for the generation of idler pulses spanning the 3-5 μm wavelength range. Using $LiIO_3$, we produce 2-μJ pulses tunable in the 3-4 μm range with bandwidth supporting 30-fs transform-limited duration.

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Motivation/applications

1. Introduction

The generation of few-optical-cycle light pulses in the mid-IR (3-6 μm) wavelength range is crucial for many applications ranging from time-resolved spectroscopy to high-field science. Such wavelength range overlaps several important vibrational transitions in molecules [1-3], as well as electronic transitions in highly correlated materials [4] (superconductors, colossal magnetoresistance materials) and intersubband transitions in quantum confined semiconductors [5]. In addition mid-IR pulses are expected to increase the cut-off energy for high harmonic generation [6].

- Time-resolved spectroscopy
  - mid-IR: many transitions in molecules, sub-bands of semiconductors
- High-field interactions
  - Ponderomotive energy scales with λ^2
  - Greater HHG cutoff

Alternative methods

Traditionally, mid-IR pulses are produced in two ways: (i) difference-frequency generation (DFG) between signal and idler of a near-IR optical parametric amplifier (OPA) [7-9], of an optical parametric oscillator [10, 11] or, more generally, between two pulses produced by different sources [12-16]; (ii) DFG between different frequency components of a single broadband pulse [17-20]. Mid-IR pulses have also been directly generated as idler pulses of an OPA, by tuning the signal as close as possible to the pump wavelength [21-25]. These OPA systems employed crystals with transparency range extended to 5-6 μm, such as $KTiOPO_4$, $LiIO_3$, $LiNbO_3$ and $KNbO_3$. Up to now, however, due to the quasi-monochromatic seeding, mid-IR OPAs have generated only relatively narrowband pulses, with transform-limited (TL) pulsewidths longer than 50 fs.

- DFG between signal, idler of another OPA
  - Pump: 800nm (1.55eV), target: 4μm (0.31 eV)
  - OPA1: sig 1.33μm (0.93 eV), idler 2μm (0.62 eV)
- DFG of parts of wide-band seed
  - Need minimum of 0.31/1.55 fractional BW: 160nm

Direct OPA requirements

- Crystal transparency (to 5-6μm)
  - KTP ($KTiOPO_4$), LiO_3, $LiNbO_3$, $KNbO_3$
- Broadband seed:
  - white light continuum in sapphire
- Broadband pump
  - Here 50fs duration
- Broadband phase matching, group velocity matching

System layout

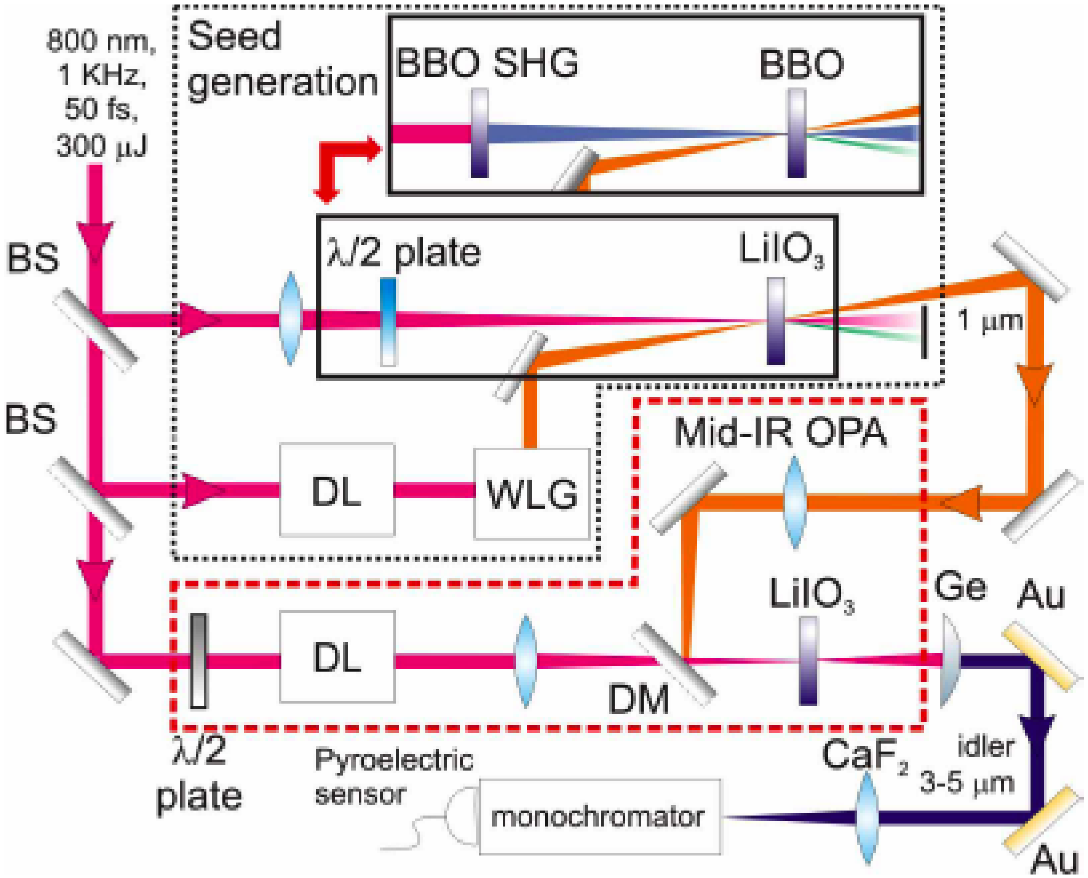

Fig. 3. Experimental setup; BS, beam splitter; DL, delay line; SHG, second-harmonic generation; WLG, white light generation; DM, dichroic mirror; Au, gold mirror. In the first stage it is possible to switch from 800-nm pumped $LiIO_3$ to 400-nm pumped BBO, substituting the λ/2 plate with a SHG crystal (BBO, 1 mm, type I, θ = 29°).

Phase matching bandwidth

- Look at group velocity mismatch

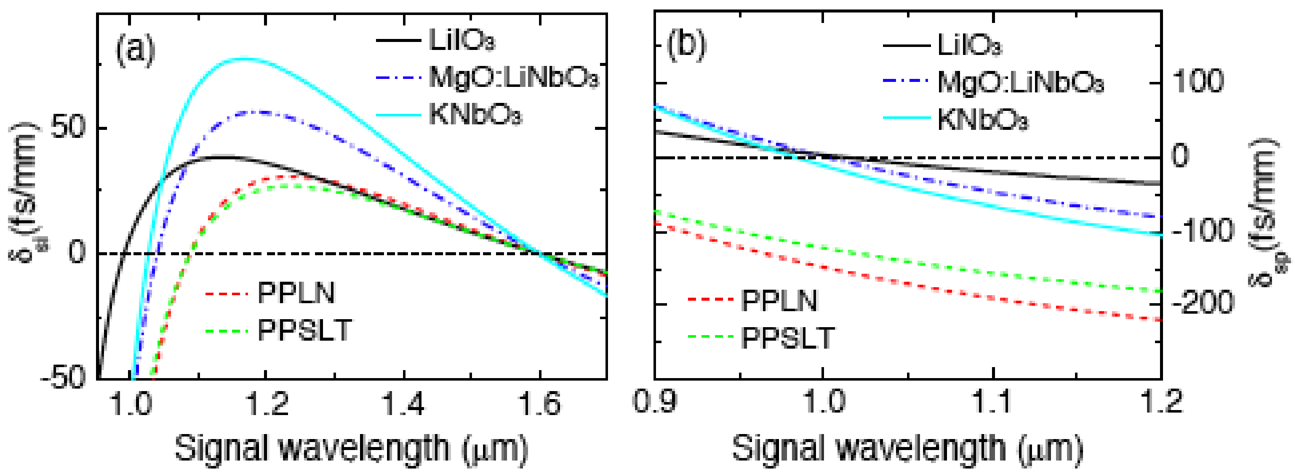

Fig. 1. (a). Calculated signal-idler group-velocity mismatch at 800 nm pump wavelength for several nonlinear optical crystals with extended mid-IR transparency. (b) Group velocity mismatch between signal and pump for the same crystals. PPLN, periodically poled lithium niobate; PPSLT, periodically poled stoichiometric lithium tantalate.

Model: gain and output spectra

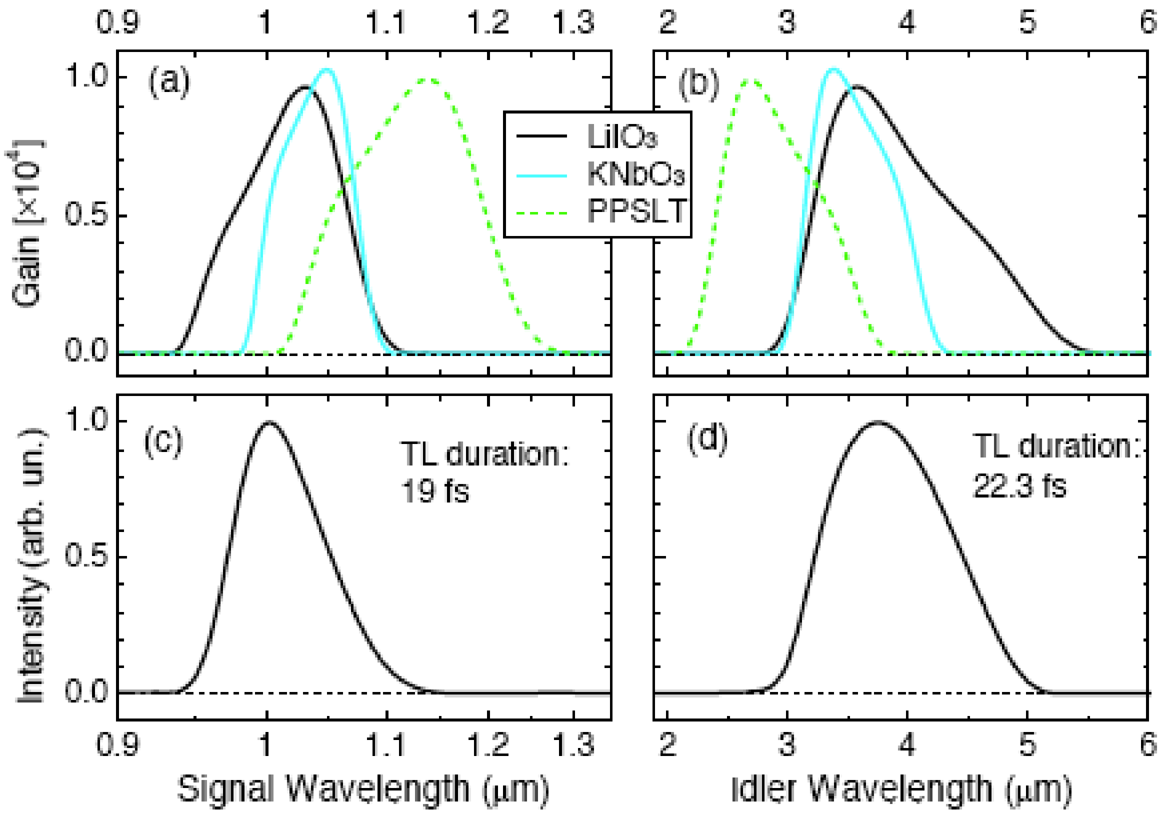

Fig. 2. (a,b). Calculated frequency dependence of the parametric gain for 2-mm-thick 800-nm pumped $LiIO_3$, $KNbO_3$ and PPSLT crystals, assuming phase-matching at zero GVM point; (c,d) complete simulation of signal and idler bandwidths for $LiIO_3$ according to the model described in the text.

Measured spectra

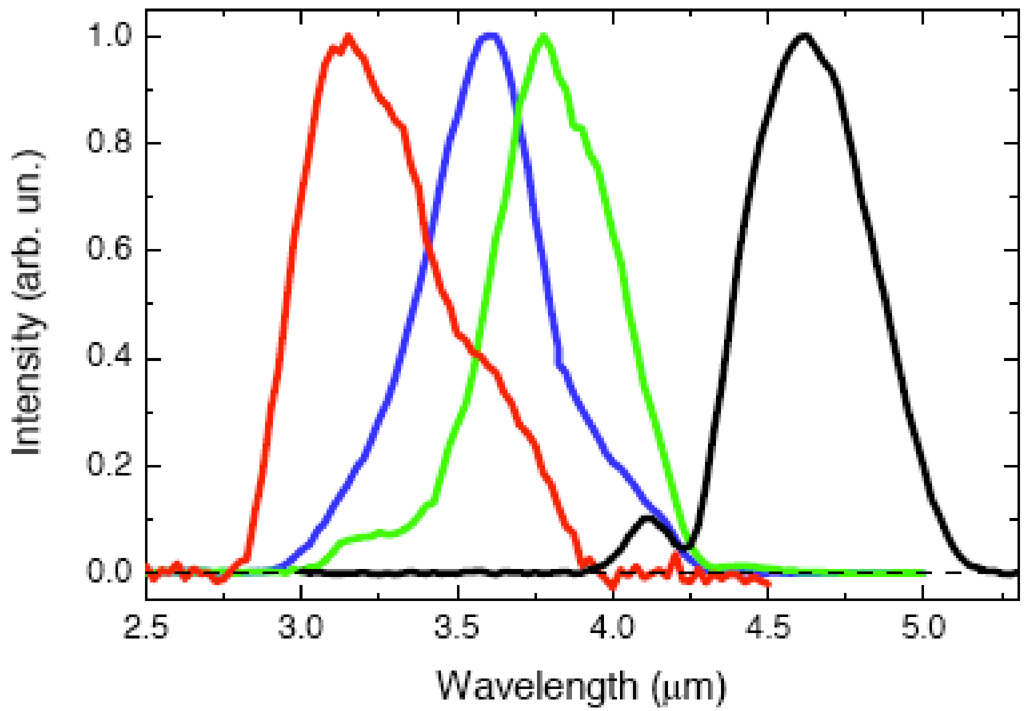

Fig. 4. Idler spectra from the second stage.