

# Broadband parametric chirped pulse amplification at 1.5 $\mu\text{m}$

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**Abstract:** We present the design and performance of an OPCPA system operating at 1550 nm. The pump laser and the broadband phase matching in RTP and KTA are discussed in detail.

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## 1. Motivation

In the past, high-energy ultra-fast lasers have been mainly limited to wavelengths, accessible with Ti:Sapphire as an amplification medium [1]. Recently, the optical parametric chirped pulse amplification (OPCPA) has been demonstrated by several groups as an alternative technique [2,3,4,5,6]. Amplification was focused on 1.05  $\mu\text{m}$  and 0.8  $\mu\text{m}$  due to their accessibility with hybrid amplification in Nd:Glass and Ti:Sapphire. This approach eliminates several disadvantages of conventional regenerative amplifiers. Most importantly, it eliminates pre-pulses and improves the pulse contrast of the compressed pulse by dramatically reducing the spontaneous emission.

The extension to wavelengths beyond 1.05 $\mu\text{m}$  is attractive for several reasons. Atmospheric transmission windows and an “eye-safe” operation due to a reduced Maximum Permissible Exposure (MPE) requirement favor operation at 1.55  $\mu\text{m}$ . The combination of short-pulse Erbium-doped fiber lasers and OPCPA technology provides a unique route to high energy short pulses at 1.55  $\mu\text{m}$ . We present a 1.55  $\mu\text{m}$  laser system, based on the OPCPA technology in conjunction with an Erbium-doped fiber oscillator with bandwidths in excess of 50 nm and energies on the mJ level.

## 2. Theory

The OPCPA theory has been described elsewhere by several authors. To realize the OPCPA at certain wavelengths, the choice of nonlinear crystals is very important. The choice of nonlinear crystals is limited for two reasons. First, they have to support a high gain, large bandwidth amplification. Second, due to the high energy process, they have to support high transmission for pump, signal and idler.

OPCPA demonstrated at 1.05  $\mu\text{m}$  utilizes the second harmonic output of an Nd:YAG or Nd:YLF laser with several nonlinear crystals, such as BBO, LBO and KDP. The second harmonic favors a degenerated parametric process that possesses a large bandwidth and high gain in a type-I configuration. Amplification away from degeneracy is achieved by introducing a small non-collinear angle between pump and signal. This technique has been demonstrated for 800 nm in a hybrid amplification scheme [4].

Extending this technique to longer wavelengths is challenging due to a lower parametric gain and the availability of pump wavelengths that support a degenerated process.

Under perfect phase-matching conditions, the parametric gain is given by:

$$G_I = 1 + \sinh^2 \left[ \frac{4 \pi d_{\text{eff}} \sqrt{I_p}}{\sqrt{2 \epsilon_0 n_p n_s n_i} c_0 \lambda_s \lambda_i} L \right]. \quad (1)$$

It can be seen that the gain is considerably less for longer wavelengths under the same pumping conditions and that the parametric gain is the highest for degenerated mixing. For a parametric amplification at 1.55  $\mu\text{m}$  with a 1.06  $\mu\text{m}$  pump, a survey showed that RTP (Rubidium Titanyl Phosphate) is the only crystals that support a large bandwidth in a collinear geometry. However, it still absorbs the idler at 3.35  $\mu\text{m}$  (see Figure 1).

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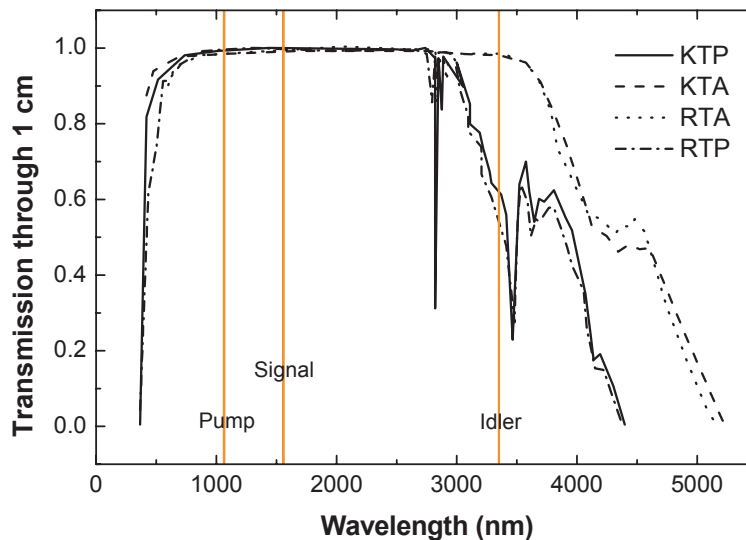


Fig. 1. KTA and RTA are transparent for the idler wavelength.

Potassium Titanyl Arsenate (KTA) and Rubidium Titanyl Arsenate (RTA) on the other hand, show good transmission in the infrared up to 3.5  $\mu\text{m}$  and nonlinear properties similar to KTP. In order to generate a large bandwidth, these crystals have to be phase matched in a non-collinear setup.

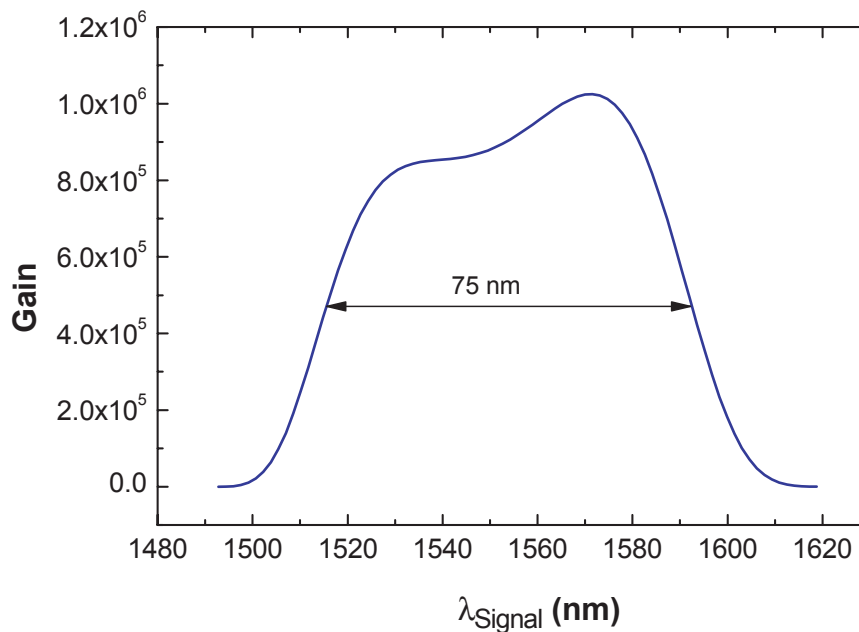


Fig. 2. KTA can support a bandwidth of 75 nm for a gain of  $10^6$ .

Analysis shows (see Figure 2) that a 3deg non-collinear angle can support amplification with 75 nm bandwidth for a gain of  $10^6$ . The non-collinear angle partially compensates for the spatial walk-off and ensures good beam overlap, even for long crystals.

### 3. System Description

#### 3.1. Oscillator and Stretcher

The oscillator is an Er-doped fiber ring laser [7]. The oscillator generates over 50 nm mode-locked bandwidth of pulses at 1.55  $\mu\text{m}$ . The repetition rate is 50 MHz and the output power 40 mW. The pulses enter an all-reflective

stretcher with a bandpass of 70 nm and a dispersion of 26 ps/nm. Upon exit, the pulses will be temporally stretched to 0.9 ns FWHM.

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### 3.3. Pump Laser

The Optical Parametric Chirped Pulse Amplification (OPCPA) puts stringent requirements on the pump laser. Due to the large chirp of the signal and the broad bandwidth, any temporal modulation of the pump pulse will be imprinted on the signal. This calls for a single-longitudinal mode pump pulse with low temporal jitter and pulse-shaping capability. Any spatial modulation on the pump pulse limits the focusability of the signal beam. Finally, the pump laser has to be exceptionally stable, both in pulse-to-pulse and long-term operation.

These requirements led to a unique pump laser design that is suitable for generating OPCPA pump pulses. Our laser generates pulses in excess of 20 mJ with a pulse-to-pulse stability better than 0.5% RMS and a temporal jitter of less than 200 ps. Further amplification can increase the energy to the Joule level.

### 3.4. OPA Stage

In our setup we utilize oeo phase matching in the XZ plane of KTA and for comparison RTP. Amplification is achieved in a setup comprising two crystals, as shown in Figure 3. The crystal axis of the second crystal is opposite to that of the first one, to compensate for residual walk-off effects. The energy output will be in excess of 1 mJ.

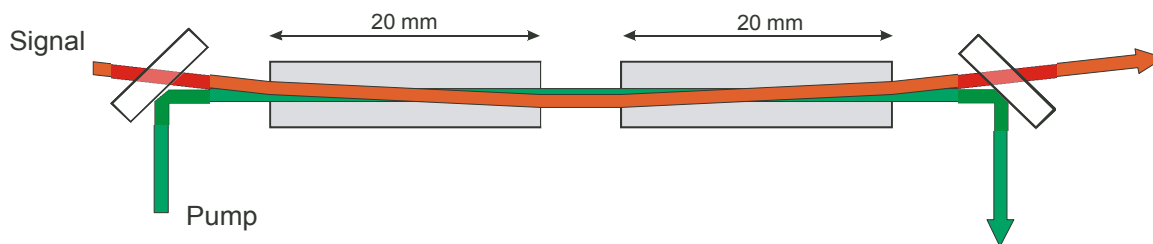


Fig. 3. Setup for the parametric amplifier.

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