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A NONCRITICALLY PHASE MATCHED FEMTOSECOND
OPTICAL PARAMETRIC OSCILLATOR NEAR 3 MICRONS

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Abstract

An optical parametric oscillator designed for the 3 μ m spectral region is described. Pulses shorter than 100 fs are produced. Alignment is simple and conversion efficiency is good.

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Introduction

Optical Parametric Oscillators (OPOs) pumped synchronously by Ti:sapphire lasers permit ultrafast pulse generation in the infrared region. Operation in the wavelength region between 1 and 2 μm has been characterized for femtosecond pulses using angle tuned KTP crystals (Ref. 1,2). However, femtosecond OPOs have not been reported at wavelengths significantly longer than 2 μm . While KTP can be type II phase matched for 3 μm generation at $\theta=42^\circ$, $\phi=0^\circ$ degrees with a 800 nm pump, the walkoff, angular tolerances, and effective gain make operation significantly more difficult than at the previously reported wavelengths. Noncritical phase matching avoids these problems at the expense of limiting the tuning range. Picosecond duration pulses have been generated using noncritically phase matched KTP over the range of 2.28 to 2.87 μm (Ref. 3).

We report an OPO that produces pulses an order of magnitude shorter than previously available in this spectral region, with good stability and high average powers. Alignment is simple due to the collinear interacting beams.

KTP and its isomorphs are hard, nonhygroscopic crystals with good IR transparency and high nonlinear coefficients. The requirement for generating an idler beam at long wavelength, coupled with the need to operate at pump wavelengths where the Ti:sapphire laser is efficient, limit the choice to the isomorphs with the most birefringence, KTP and KTA. A plot of the signal and idler wavelengths is given in Figure 1, for the two noncritical orientations, both in the XY plane. $\theta=90^\circ$ and $\phi=0^\circ$ degrees for the x-cut crystal. For the y-cut crystal $\phi=90^\circ$ degrees. To summarize, KTA is slightly more birefringent than KTP, and the longest wavelengths can be reached for the y-cut crystals.

In the region of 3 μm , absorption of water vapor in the air and in coatings make it difficult to obtain low losses. Fortunately, for a singly resonant OPO, it is necessary to minimize losses only for one wave, and the signal wave is chosen.

Results

The Ti:sapphire pump laser pulse width is 71 fs, at a center wavelength of 800 nm. Power is 1.15 W uncorrected for reflection losses at the pump dichroic. The KTP crystal is 1mm thick, with a single layer MgF_2 coating centered at 1.06 μm .

Figure 1. Calculated wavelengths produced by an OPO with noncritical phase matching. The open circles are used for the idler wave (left axis) and the filled circles for the signal wave (right axis). This figure was produced using Sellmeier coefficients from K. Cheng.

A linear cavity with prism dispersion compensation is used for the OPO (Figure 2). The idler wave is extracted through a dichroic fold mirror and is collimated by an off axis paraboloidal mirror. The transmission of the OPO output coupler for the signal wave is either 3.6 or 9% at the center of the signal band, with a steep increase to longer wavelength.

Figure 1. Layout of the linear OPO cavity. The fold mirrors are short wave pass dichroic for the pump and long wave pass dichroic for the 3micron beam.

The OPO can be operated with net positive or negative dispersion by translating a cavity prism. With no prisms or with net positive dispersion the spectrum has a characteristic double peak similar to that reported in ref. 2. Under negative dispersion conditions, the signal wave is nearly transform limited. With the 9% output coupler, 185 mW is extracted in the signal beam and 100 mW is in the idler beam, without correction for losses in the

dichroic mirror for the idler wave. An additional 40 mW of the signal wave is available at the idler wave dichroic. With the 3.6% output coupler, the signal wave power decreases to 115 mW, and the idler wave shows an insignificant increase. Power is similar in the regimes of positive and negative dispersion.

The threshold pump power is 0.75 W and 0.54 W for the two output couplers. Pump depletion is 51% and 58% for the high and low transmission output couplers, respectively. The signal pulse has a FWHM of 92 fs for the above conditions. By adjusting the prisms for less negative dispersion the pulse width dropped to 62 fs FWHM at about 80 mW in the idler beam. Spectra corresponding to the longer and the shorter pulse are given in Figure 3.

Figure 3. Signal spectra taken with different amounts of negative dispersion in the cavity. The narrow spectrum has an autocorrelation of 92 fs FWHM; the broad spectrum is 62 fs.

For shorter duration pump pulses and near zero dispersion in the cavity the signal pulse width is as short as 30 fs. A smooth, single-peaked spectrum is necessary to servolock the cavity. An error signal is produced by dispersing the signal beam across a dual detector, which drives a piezoelectric translator, maintaining the length with the required fractional micron accuracy (ref. 4).

An idler spectrum, obtained with 825nm pumping (Figure 4), contains sharp absorption features due to water vapor in air, and has sufficient bandwidth to permit a pulse width of less than 80 fs. Vigorous purging of the laser system, detectors, and connecting path with dry nitrogen is required to minimize these features. A cross correlation of the idler wave with residual pump pulses in LiIO_3 (Figure 5) shows a FWHM of 180 fs (uncorrected for pulse shape). None of the beams were externally compensated for chirp. Pulse width was limited by optics at the longer wavelengths. It should be possible to obtain idler waves nearly as short as the best signal wave pulse width of 30 fs.

Figure 4. Idler wave spectrum. The sharp features are due to water vapor.

Figure 5. Cross correlation of idler and pump beam after passage through the OPO. The uncorrected width is 180 fs.

As noted previously (ref. 1,2), bright visible beams collinear with the pump and signal wave are generated by non-phase-matched processes in the nonlinear crystal at the second harmonics of the Ti:sapphire laser and signal wave, along with sum frequencies of the Ti:sapphire laser with both the signal and idler wavelengths.

The maximum length of the KTP crystal is determined by its dispersion (ref. 3). The dispersion at $\theta=90$ is higher than at smaller angles used for angle tuning. A thinner crystal is likely to improve performance and reduce the pulse width while having sufficient gain to be convenient.

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