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MB3

Phase-Matched Self-Doubling Optical Parametric Oscillator

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Frequency conversion using synchronously pumped optical parametric oscillators (OPO) extend the wavelength range of ultrafast laser systems [1]. Further wavelength extension can be obtained by frequency doubling one of the OPO beams with the use of another crystal inside the cavity [2].

We report a self-doubling OPO where a single nonlinear crystal is employed for both parametric generation and frequency doubling. Our self-doubling OPO is based on a KTP ($KTiOPO_4$) crystal that is pumped by a Ti:Sapphire laser operating at a wavelength of 739 nm. The KTP crystal is cut such that the signal wavelength of the OPO is at 1064 nm, corresponding to an idler wavelength of 2420 nm. The OPO cavity resonates only the signal wavelength. The signal beam is also phase-matched for second harmonic generation (SHG) at the same crystal orientation. With proper polarization rotation, an output beam at a wavelength of 532 nm can be obtained. To our knowledge, this is the first demonstration of optical parametric oscillation and phase-matched frequency doubling within a single crystal.

We use an 8 mm long KTP crystal cut for doubling 1064 nm in a type-II phase-matching geometry ($\theta = 90°, \phi = 23°$). The crystal has antireflection coatings for the fundamental and second-harmonic wavelengths. The second-harmonic output is an extraordinary wave polarized in the horizontal (y-axis) direction. In parametric generation, the pump at 739 nm and the signal at 1064 nm are both horizontally polarized, and the idler at 2420 nm is vertically (z-axis) polarized.

A mode-locked Ti:Sapphire laser (Coherent, Mira 900F) with approximately 100 fs long pulses at a repetition rate of 76 MHz provides the pump beam to the OPO at a wavelength of 739 nm. We constructed a ring cavity consisting of four mirrors that are high reflectors at 1064 nm as shown in Figure 1. M1 and M2 are 25 cm radius concave, M3 is a 3 m radius concave, and M4 is a flat mirror. The KTP crystal is positioned at the intracavity focus between M1 and M2. The pump beam is focused with a lens (L) of focal length 15 cm and enters into the cavity through M1. For efficient frequency doubling, a half-wave retarder at 1064 nm is placed inside the OPO cavity which couples some of the horizontally polarized signal beam to the vertical. The length of the cavity is adjusted by moving M4 in order to synchronize the intracavity signal pulses with the pump pulses. The frequency doubled beam at 532 nm exits the cavity through M2. In addition, there is a weak 1064 nm beam

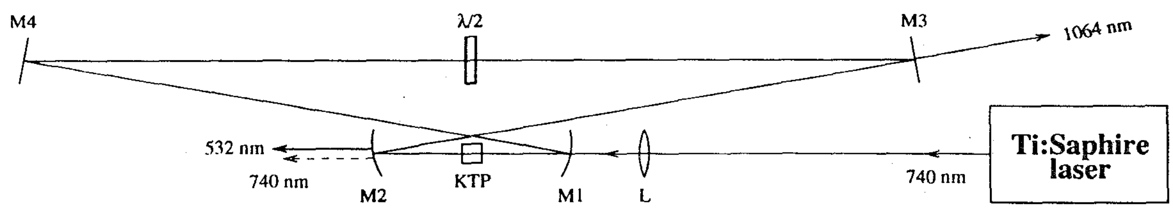

Figure 1: Self-doubling OPO setup.

coming out through M3, as this mirror has a slightly lower reflectance compared to the other cavity mirrors. This output is used to probe the signal beam for measurements.

When the half-wave retarder is not in the cavity, there is no (or very little) frequency doubling. This results in an undercoupled OPO cavity for the signal beam. We measured the threshold for this OPO to be 60 mW. At a pump power of 500 mW, the pump beam is depleted by more than 50%, showing strong conversion. In the case of frequency doubling with the retarder in place, the threshold of the OPO becomes 170 mW. At a pump power of 440 mW, 25 mW of 532 nm is obtained, corresponding to 6% conversion efficiency to the green. Figure 2 shows the pump depletion with the retarder in the cavity. Depletion is seen to be as high as before, indicating strong conversion to the signal wavelength. The autocorrelation width of the green pulses are measured to be 18 ps. This pulse broadening is due to group velocity mismatch in the crystal and the retarder.

We expect significant improvement on these initial results by optimizing the cavity mode, crystal length, and using prisms to compensate for the group velocity mismatch. To this end, we designed a self-doubling OPO which uses a non-critically phase-matched KTP crystal. In this OPO, when the pump beam is at 744 nm, the OPO signal is at 1080 nm, and the doubled signal is at 540 nm. It is possible to tune this self-doubling OPO by changing the wavelength of the pump beam together with the crystal angles. Varying θ from 90° to 75° ($\phi = 0°$) and the pump wavelength from 744 nm to 750 nm, it is possible to generate frequency doubled output between 540 nm and 564 nm. Changing ϕ from 0° to 30° ($\theta = 90°$) and the pump wavelength from 745 nm to 739 nm, one can get 540 nm to 529 nm frequency doubled output.

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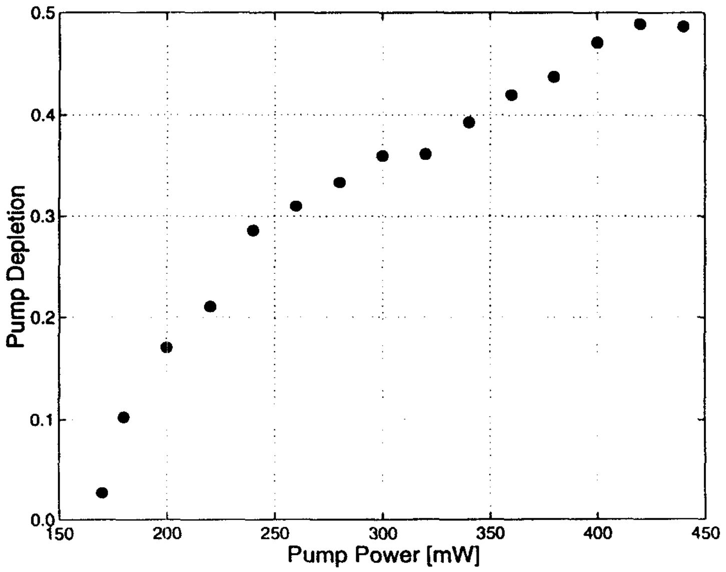

Figure 2: Pump depletion as a funcion of pump power.

[1] Special issue on Optical Parametric Oscillators and Amplifiers, *J. Opt. Soc. Am. B*, vol. 10, No. 11, pp. 1656–2243, 1993.

[2] P.E. Powers, R.J. Ellingson, W.S. Pelouch, and C.L.Tang, *J. Opt. Soc. Am. B*, vol. 10, pp. 2162–2167, 1993.