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Optical Parametric Oscillator Modeling with Diffraction, Depletion, and Double Refraction

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Abstract

A novel, time-dependent OPO computer simulation that includes diffraction, depletion, and double refraction is used to predict output beam profiles of pulsed OPOs.

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Introduction

Advancement in the growth and fabrication of nonlinear materials along with continual improvements in the performance of solid-state lasers have led to a resurgence of interest in the development of optical parametric oscillators (OPOs). While many experimental results have been recently reported, very little attention has been given to the development of detailed models to simulate the output characteristics (such as beam quality, efficiency, and threshold) of nanosecond-pumped OPOs. Such models are necessary for understanding experiments and for developing advanced OPO designs that enhance the overall performance of these devices.

In this work, we describe a time-dependent model of pulsed OPOs that includes diffraction, depletion, and double refraction (walkoff) in the parametric amplification process. The model is used to predict output beam profiles, beam quality, and conversion efficiency of an injection-seeded KTP ring OPO. Predicted output beam profiles in the near and intermediate fields are in qualitative agreement with the experimental results reported in a companion paper.¹ Our results show that diffraction and double refraction must be included in models of pulsed OPOs to predict realistic beam profiles.

Calculational Model and Approach

The model starts with the well-known three-wave equations for optical parametric amplification with diffraction and double refraction (walkoff) in the paraxial approximation. It is restricted to propagation in uniaxial crystals and to biaxial crystals where wave propagation is in one of the principal crystal planes. The description of the propagation of the paraxial beams through the crystal follows that given by Fleck and Feit² with the inclusion of the nonlinear polarization terms. This formulation was used by Dreger and McIver to describe second harmonic generation in

uniaxial crystals.³ The wave equation for "c-waves" differs from "o-waves" by an additional walkoff term.

The temporal pulse envelope of the three waves is approximated by a step-wise function. For each "step" or time slice, the nonlinear conversion process is calculated by integrating the three-wave equations with diffraction and double refraction through the nonlinear crystal. The time step is taken to be the OPO cavity round-trip time. A weak cw signal beam is injected into the cavity as an initial condition for the generated signal.

The calculations in time proceed as follows: a time slice of the pump is taken, and the three-wave equations are integrated through the crystal generating signal and idler. The three waves are then propagated to the output mirror using the equations for free-space propagation. In the three-mirror ring version of the model, the three waves are reflected off the output mirror, propagated around the ring, inverted, and then combined with a new pump for the next time step. Another cavity round trip is then performed. This process is repeated until the pump pulse is over and the power in the three waves is negligible.

The integration of the three-wave equations through the nonlinear crystal is performed using Fourier transform techniques.⁴ The diffraction and double refraction part of the problem are analytically extracted out by transforming into spatial frequency space. The transforms are evaluated numerically using a fast-Fourier-transform algorithm. The result of this transformation is a set of coupled ordinary first-order differential equations. These equations are numerically integrated through the crystal using a fifth-order Runge-Kutta algorithm.

Analytical Results

The numerical model was used to predict the output of an injection-seeded KTP ring OPO in order to compare with experiments. The experimental arrangement is similar to that reported in Ref. [5] and is described in detail in a companion paper.¹ The OPO is pumped with a frequency-doubled, injection-seeded

Nd:YAG laser, and it is seeded with 38 mW of 784 nm light from a cw $\text{Ti:Al}_2\text{O}_3$ laser. The KTP crystal is 1 cm in length and is AR coated for the pump and signal wavelengths. The OPO is singly resonant ($R=50\%$ for the signal beam), and uses type II phase matching ($o \rightarrow e+o$, pump $\rightarrow$ signal+idler). The KTP crystal is oriented such that its ordinary polarization is perpendicular to the plane of the ring.

The model assumes a spatially Gaussian input pump beam with a $1/e^2$ diameter of 1.1 mm and 8 ns (FWHM) in duration. Figure 1 shows predicted depleted pump energy fluence (intensity integrated over time) at the output mirror for 6 mJ of incident pump energy (2.3 times above threshold). The arrow at the bottom indicates the direction the signal beam walks off in the crystal due to double refraction. The asymmetry in the depleted pump is due to walkoff. The pump is depleted more in the walkoff direction. Figure 2 is the generated signal energy fluence at a distance of 1m from the output mirror. The profile is nearly circular with some slight elongation perpendicular to the plane of the ring.

Figure 1. Predicted depleted pump energy fluence at the output mirror when pumping 2.3 times above threshold. The arrow indicates the direction the signal beam walks off in the crystal.

Figure 2. Output signal energy fluence a distance of 1m from the OPO output mirror. The OPO is pumped 2.3 times above threshold.

Figure 3 shows the signal energy fluence at the output mirror for 12 mJ of incident pump (4.6 times above threshold). Because of double refraction, the signal beam is elliptical and asymmetric in the walkoff direction (in the ring plane). This signal beam at a distance of 1m from the output mirror is shown in Figure 4. Compared to Figure 2, the signal beam generated with the higher pump energy has now developed symmetric lobes on either side of the central lobe perpendicular to the walkoff direction.

At the higher pump energy, the nonlinear drive is larger and higher angular components in the beam are able to convert. This happens preferentially in the direction perpendicular to walkoff because double refraction limits the angular acceptance of the crystal in the walkoff direction. Thus, the beam becomes elongated perpendicular to the walkoff direction. These results are in qualitative agreement with experimental observations.

Figure 3. Signal energy fluence at the OPO output mirror when pumping 4.6 times above threshold. The arrow indicates the direction of walkoff in the crystal.

Summary

In summary, we have developed a time-dependent OPO model that includes diffraction, depletion, and double refraction. Predictions of the output beam profiles of an injection-seeded KTP ring OPO are in qualitative agreement with experiments. Detailed comparisons with experiments are in progress and will be reported. Our results show that diffraction and double refraction must be included in OPO models in order to predict realistic output beam profiles from these devices.

References

1. W. J. Alford and T. D. Raymond, "Title unknown at this time," submitted to
2. J. A. Fleck, Jr., and M. D. Feit, "Beam propagation in uniaxial anisotropic media," *J. Opt. Soc. Am.*, vol. 73, pp. 920-926, July 1983.
3. M. A. Dregier and J. K. McIver, "Second-harmonic generation in nonlinear, anisotropic medium with diffraction and depletion," *J. Opt. Soc. Am. B*, vol. 7, pp. 776-784, May 1990.

4. S.-C. Sheng and A. E. Siegman, "Nonlinear-optical calculations using fast-transform methods: Second-harmonic generation with depletion and diffraction," *Phys. Rev. A*, vol. 21, pp. 599-606, February 1980.
5. C. E. Hamilton and W. R. Bosenberg, "Single-Frequency, Injection-Seeded, KTP Ring Cavity Optical Parametric Oscillator," In *Conference of Lasers and Electro-optics*, vol. 10, OSA Technical Digest Series (Optical Society of America, Washington, DC, 1992), paper CWQ3.

Figure 4. Output signal energy fluence after propagating 1m from the output mirror for the same conditions in Figure 3.

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