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How to select nonlinear crystals and model their performance using SNLO software

A. V. Smith

Sandia National Laboratories, MS 1423, Albuquerque, NM 87185

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ABSTRACT

SNLO is public domain software developed at Sandia Nat. Labs. It is intended to assist in the selection of the best nonlinear crystal for a particular application, and in predicting its performance. This paper briefly describes its functions and how to use them.

1. INTRODUCTION

The advent of powerful desktop computers has made it possible to automate calculations of the linear and nonlinear properties of crystals, and to perform detailed simulations of nonlinear mixing processes in crystals. The purpose of SNLO is to make these calculations available to the public in a free, user-friendly, windows-based, package, with the hope that this will advance the state of the art in applications such as optical parametric oscillators/amplifiers (OPO/OPA), optical parametric generation (OPG), frequency doublers, etc. There are two types of functions included in SNLO. The first set help in computing the crystal properties such as phase-matching angles, effective nonlinear coefficients, group velocity, and birefringence. The second set help model the performance of nonlinear crystals in various applications. The capabilities of each are presented below in the form of answers to the "How do I:" question.

2. CRYSTAL PROPERTY CALCULATIONS

How do I:

1.1 Select an angle-tuned crystal

The function QMIX is the best starting place. When you select a crystal the viewing area will display its properties including transmission range (as a plot if the information is available), references for Sellmeier data, nonlinear coefficients, damage thresholds, etc. Enter the wavelengths for your mixing process and push 'Run' to get further information specific to all possible phase matched processes. Note that for biaxial crystal only the principal planes are allowed in QMIX. If you are curious about a biaxial crystal's properties outside the principal planes, you can explore them using BMIX. Note that more information on crystal properties is available in the papers listed in the bibliography 'Crystals.pdf' included with SNLO. It references over 500 papers relating to nonlinear optical crystals.

1.2 Select a quasiphase-matched crystal

The function QPM helps you find the right quasiphase matched poling period for any of the popular quasiphase matchable crystals. It also shows the temperature and pump wavelength tuning properties of the crystal. You can chose the polarizations for you processes as well, although the zzz polarization is usually the one of practical interest.

1.3 Select an angle-tuned OPO crystal

The function Opoangles displays a plot of the signal/idler wavelength versus crystal angle for a given pump wavelength. It also computed the nonlinear coefficient and the parametric gain versus angle. Comparing gain across the wavelength range of interest and between different crystals and phase matching types gives a good indication of relative OPO performance. Note that this function computes noncollinear phase matching. Click on the 'pump tilt' edit box for a diagram of the noncollinear angles. The signal is assumed to remain aligned to the cavity of an OPO, the pump is tilted by a fixed angle relative to the signal while the crystal and idler tilt by variable amounts to achieve phase match.

1.4 Compute crystal properties

The function Ref. Ind. can be used to compute refractive indices, group velocities, group velocity dispersions, and birefringent walk off for a given propagation angle, temperature, and wavelength. This is useful if you want to make your own calculations of phase matching, group velocity matching, etc.

3. NONLINEAR MIXING MODELS

How do I:

2.1 Model single-pass mixing

The functions with 'mix' in their title are for single pass mixing, as opposed to mixing in an optical cavity. The functions with the 'PW' prefix model plane-wave mixing, those with the '2D' prefix include Gaussian spatial profiles with diffraction and birefringent walk off. The functions with suffix 'LP' ignore group velocity effects and can be used for ns and longer pulses or for cw beams. Functions with suffix 'SP' incorporate group velocity effects and are useful for ps and fs pulses. Suffix 'BB' indicates that the pulses are long but broad band so there is temporal structure on a time scale short enough to require inclusion of group velocity effects. The function Focus is included to help decide the wavefront curvature at the crystal entrance face. Generally for mixing low power beams you want to focus into the crystal with a confocal length comparable to the crystal length. The models of SNLO are based on split-step propagation methods. They are state-of-the-art in technique, and are all-numerical to cover the widest possible range of applications. I have carefully validated them against analytical expressions and against each other.

2.2 Model mixing in a cavity (OPO, frequency doubling, etc.)

The functions with 'OPO' in their title are for mixing in a cavity. Note that they will model not only OPO's but also any mixing process in a cavity such as frequency doubling in a build-up cavity. The functions with the 'PW' prefix model plane-wave mixing with planar cavity mirrors, that with the '2D' prefix includes Gaussian spatial profiles with diffraction and birefringent walk off and can accommodate curved cavity mirrors. The functions with suffix 'LP' ignore group velocity effects and can be used for ns and longer pulses or for cw beams. The function with suffix 'SP' incorporates group velocity effects and is intended to model synchronously-pumped OPO's pumped by ps or fs pulses. The suffix 'BB' indicates that the pulses are of long duration but have a broad bandwidth so there is temporal structure on a time scale short enough to require inclusion of group velocity effects. Generally for mixing of low power beams you want to use a stable cavity with focusing mirrors. The cavity can be designed using the Cavity function which will also help you find the wavefront curvature of the input beams at the input mirror, and the cavity round-trip phase which must be known to achieve exact resonance in the cavity. The models of SNLO are based on split-step propagation methods. They are state-of-the-art in technique, and are all-numerical to cover the widest possible range of applications. I have carefully validated them against analytical expressions and against each other.

2.3 Model OPG (optical parametric generation)

The function PW-mix-BB can be used to model OPG in the plane-wave approximation. You must specify the correct signal and idler energies, bandwidths, and mode spacings to simulate start-up quantum noise. The mode spacing should be the inverse of the signal/idler pulse length. For example, if you have a 1 ps pump pulse, you could use 5 ps signal and idler pulses (to allow for temporal walk off) and a signal/idler mode spacing of 100 GHz. The bandwidth should be set to several times the OPO acceptance bandwidth, and the pulse energy of the signal and idler should be set so there is one photon per mode, ie energy = $h\nu \times \text{bandwidth} \div (\text{mode spacing})$. Because the gain is very high for OPG, the number of z integration steps must be quite large. I suggest you start with 100 steps and double it until the results converge. Each run will use different start up noise, so convergence does not mean identical results here. A good test is to look at both the irradiance and spectra plots and make sure they are both similar to the previous run with fewer integration steps.

4. SNLO DOWNLOAD

SNLO is a free download at web site <http://www.sandia.gov/imrl/XWEB1128/xxxtal.htm>

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