Tutorial 6

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PH 421: Photonics
Due: 12:30 Thursday, October 19, 2023

Problem 6.1. Symmetry of linear permittivity tensor
Prove that the linear permittivity tensor must be symmetric.

Problem 6.2. A beautiful technology for OPO tuning

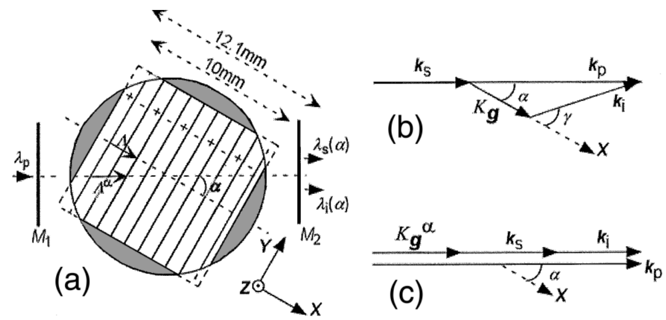

Figure 1: Schematic of the tunable OPO. The plus and minus signs denote the polarization directions of the ferroelectric domains. The gray areas are unpoled. x, y, and z are the crystallographic axes, and z is the polarization direction for all fields. The grating vector is K_g, L is the period of the grating, and $k_{p,s,i}$ are the interacting wave vectors. M_1 and M_2 are cavity mirrors. Crystal rotation angle is α and the idler angle as shown is γ. **Idler is assumed to be non-resonant.**

An optical parametric oscillator is an attractive source for industrial and research applications on account of its wide wavelength tunability. One way to tune the output wavelength is by tuning the wavelength of the pump itself. Another approach is fixing the pump wavelength, but tuning the crystal to modify the phase matching. In class, we mostly focused on birefringence phase matching. However, as we discussed, such an approach suffers from the problem of beam walk-off and usually offers a limited phase matching range. In this exercise, we will explore whether the principles of quasi-phase matching (periodic modulation of the $\chi^{(2)}$ tensor) can enable a continuous tuning of the OPO wavelength.

The geometry of the OPO is shown in Fig. 1. Variation of the output wavelengths was obtained by rotation of the cylinder around its revolution axis, which was orthogonal to the cavity axis and to the plane containing the QPM grating vector, K_g.

(a) *Phase matching approach 1:* Write down the phase matching condition by conserving the momentum (wave-vector) parallel to the grating. Your final expression should only have variables $k_p, k_s, k_i, \alpha, \gamma$.

(b) *Phase matching approach 2:* Write down the phase matching condition by assuming all three wave-vectors k_p, k_s, k_i are horizontal (essentially $|\gamma| \approx |\alpha|$). Effective grating vector component in the horizontal direction may be used. Your final expression should contain only the following variables: $n_z(\lambda_p), n_z(\lambda_s), n_z(\lambda_i), \lambda_p$, $\lambda_s, \lambda_i, \alpha, \Lambda$.

(c) *OPO tuning curve:* Using your results in parts (a) and (b), plot the complete tuning curve (that is, a plot where λ_s, λ_i (say between 1500nm to 4000nm) are on the $y-$axis (in nm) and rotation angle α (between 0 and 90 degrees) on the $x-$axis (in degrees). Note that you will need to plot two tuning curves corresponding to each of the two phase matching conditions you derived in parts (a) and (b). Pump wavelength maybe be assumed to be fixed at $\lambda_p = 1.064\mu$m (from an Nd:YAG laser) and $\Lambda = 35\mu$m. The refractive index of the material is given by a Sellmeier Equation:

$$n_z^2 = A + \frac{B}{1 - C/\lambda^2} + \frac{D}{1 - E/\lambda^2} - F\lambda^2 \tag{1}$$

where $A = 2.12725; B = 1.18431; C = 5.14852 \times 10^{-2}\mu m^2; D = 0.6603; E = 100.00507\mu m^2; F = 9.68956 \times 10^{-3}\mu m^{-2}$; where λ is given in microns. For this problem, you do not need to worry about the discreteness of the allowed modes since the cavity maybe assumed to be quite large.

(d) *Threshold intensity:* Plot the threshold intensity of this OPO as a function of the signal wavelength for the entire tuning range. The parameters are given below: cavity length $L_c = 13.5$mm, mirror reflectivity for signal $R_s = 0.95$ and $d_{\text{eff}} = 5.8$ pm/V. Expected x axis range is 1500nm to 2500nm.

Note: Python code in the form of a Jupyter notebook needs to be attached for parts (c) and (d) to receive credit.

Problem 6.3. Talking numbers: intensity dependent refractive index

For fused silica, $n_2 = 3 \times 10^{-20}\text{m}^2/\text{W}$. A laser beam of intensity $1\,\text{GWcm}^{-2}$ is incident on it. Find the change in the refractive index.