Controllable harmonic generation by couplings of horizontal- and vertical- polarized components

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For quasi-phase-matching (QPM) technique, much research has been done for purpose of obtaining efficient frequency conversion where the largest nonlinear coefficient (corresponding to $ee \to e$ process) is used. However, these crystals do have other considerable nonlinear coefficients. In these cases, QPM parametric interactions such as $oo \to e$, $oe \to o$ and $eo \to e$ process can be realized efficiently. From the viewpoint of coupling, the conventional harmonic generation with largest nonlinear coefficient should be treated as a particular case, the coupling of second-order parametric interactions based on different nonlinear second-order processes could be considered as a more general situation.

We concentrate on the cascading third harmonic generation (THG) with domain engineered micro-structures. To investigate the QPM nonlinear interactions by coupling of non-$ee \to e$ processes, we select cascaded $o_1e_1 \to o_2$ (SHG) and $o_1o_2 \to e_3$ (SFG) processes for THG as an example. $o_1e_1 \to o_2$ process generates y-polarized second harmonic (SH) using both ordinary and extraordinary components of the fundamental, while $o_1o_2 \to e_3$ process utilizes the remaining ordinary fundamental and the produced SH to generate z-polarized third harmonic (TH). In this way, not only SHG is coupled with SFG process but also the polarization has a strong coupling with the ratio of nonlinear coefficients, resulting in more flexibility in dynamic tuning of the harmonic conversion.

It is noted that the coupled equations have a symmetrical form. We concentrate on the relationship between the maximum TH conversion efficiency $\eta_{3e\max}$ and the ratio of coupling coefficients *t*, as well as the angle between the incident fundamental polarization and the z-axis of the crystal θ. The conversion efficiencies can be solved analytically.

$$\eta_{3e\max} = \frac{3t^2\cos^2\theta\left(1-\sqrt{\tan^2\theta(t^{-2}-1)+1}\right)^2}{(1-t^2)^2} \quad \text{and} \quad \eta_{3e\max} = \frac{12t^2\cos^2\theta}{(1+t^2)^2}$$

The two solutions are valid in different domains, which are separated by a continuous boundary. Generally, the coupled wave equations in nonlinear optics are difficult to solve analytically, especially for the multiple parametric processes. It's surprising to get such complete analytical results in current configuration.