Laser Frequency Conversion with Pulse Compression in Solid Solution Crystals[1]

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Abstract – A theoretical model designed to deal with optical frequency conversion in a solid solution nonlinear crystal is adapted to solid solution crystals with a gradual longitudinal or transverse variation of composition ratio. Using the quasi-geometrical optics method, new diffraction-free coupling equations are developed to describe second harmonic, combination frequency and optical parametric generations. Conversion reductions and optimizations of generated powers by absorption, transverse modulation and walk-off effect are studied in detail. It was developed that intended longitudinal and transverse modulations of composition ratio in mixed crystals are useful for design of parametric frequency converters with predetermined spectral bandwidth or pulse compression. More over, realization of parametric generation at non-critical spectral conditions (extreme wide spectral bandwidth) itself let us somebody to compress generated pulses upon sub-picosecond and femtosecond pulse pump. The model finally was exemplified by applying to AgGa1-xInxSe2 and other solid solution nonlinear crystals.

1. Introduction

In nonlinear optics, transparency range, dispersion of refractive indices, effective quadratic susceptibility coefficient, damage threshold and thermal properties of nonlinear crystals are mostly concerned by laser specialists due to their direct links to frequency conversion efficiency. Up to now, researchers have been motivated by these parameters to synthesize desirable crystals in different application. A multitude of nonlinear crystals has been grown as frequency converters. However, none of them can meet various demands on designs of parametric mixers today when new frequencies, high power lasers, ultrashort intense pulses, etc. are getting more and more importance in lab and engineering. On the other hand, it has been found that a solid solution of two existing parent crystals turns out to be an effective way to tailor the dispersion of refractive index, effective quadratic susceptibility coefficient and even term “birefringent engineering” was introduced in practice.

It is a well-known fact that the mixed crystals grown by standard crystal growth techniques will inevitably bring composition ratio variations. Distribution of the heating temperature in the crystal volume in a crystallization process directly account for that. In [1], a method and an algorithm to estimate influence of gradual variation of composition variations of solid solution crystals on frequency conversion is presented.

In this paper, we develop an algorithm to estimate and carry out estimations of composition variations of the solid solution nonlinear crystals that allow some bodies to wider phase matching bandwidth and/or to compress femtosecond pulses during frequency conversion.

2. Modeling

Equation (34a) for tuning function $\left|F_0\left(\tau_{cl},\bar{\delta}\right)\right|^2$ from [1], which is proportional to power P3 of frequency converted emission, was used as a basic equation.

$$\left|F_0\left(\tau_{cl},\bar{\delta}\right)\right|^2=\frac{1}{4}\left[C\left(\tau_{cl}-\bar{\delta}\right)+C\left(\tau_{cl}+\bar{\delta}\right)\right]^2+ \\ +\frac{1}{4}\left[S\left(\tau_{cl}-\bar{\delta}\right)+S\left(\tau_{cl}+\bar{\delta}\right)\right]^2. \qquad (1)$$

To evaluate the width of this function we analyzed a limit case: $\tau_{cl}\to\infty$ with $\bar{\delta}\sim\mp\tau_{cl}$. Thus, equation (1) becomes

$$\left|F_0\left(\tau_{cl}\pm\bar{\delta}\right)\right|^2\to\frac{1}{4}\left[C\left(\tau_{cl}\pm\bar{\delta}\right)+0.5\right]^2+ \\ +\frac{1}{4}\left[S\left(\tau_{cl}\pm\bar{\delta}\right)+0.5\right]^2. \qquad (2)$$

Equation (2) reaches its half maximum value at $\bar{\delta}=\tau_{cl}-\bar{\delta}_0$ and at $\bar{\delta}=\bar{\delta}_0-\tau_{cl}$ with $\bar{\delta}_0\equiv 0.5290237...$, respectively. Then the full width half maximum can be estimated by $\Delta\bar{\delta}=2\left(\tau_{cl}-\bar{\delta}_0\right)$. Neglecting the variation of Ω with wavelength, this analysis gives rise to a tolerable wave vector mismatch

$$\Delta k_b\cong\pi\Delta\bar{\delta}\Omega=\pi\Omega\left(\Omega L-2\bar{\delta}_0\right). \qquad (3)$$

In accordance with (3), a gradual index crystal can be used for the frequency conversion of wideband lasers by a suitably designed composition variation.

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[1] The work was supported by joint grant of RFBR (07 02 92001 HHC_a) and NSCT (96WFA0600007). One of the authors (G.L.) also gratefully acknowledges the Russian Science Support Foundation and Presidium SB RAS.

Further more, pulse compression can be realized for chirped ultrashort pulses in a frequency conversion process. The principle of compressing frequency converted light therein is similar to that in the model of periodically polarized ferroelectric crystals, with a longitudinally nonuniform period of alternating domains [2]. Thus, different frequency components of a chirped pulse (each of them is located at a different time within the pulse) will be phase matched at different positions with different birefringence in the gradual index medium. The wide bandwidth of the longitudinal gradual index crystal becomes a modulation tool to compress short pulses. However, it cannot provide new light frequencies. So, the shortest pulse duration it can produce is just that of transform-limited pulses. Our investigation shows that for a Gaussian ultrashort pulse it duration can be shortened $\sqrt{2}$ times.

If the index variations are oriented transversely for large aperture crystals, then a tunable phase matching can be carried out by the transverse location of incident pumping beams.

3. Conclusion

The wideband filtering property of the gradual index crystals make them excellent frequency converters of wideband lasers and ultrashort pulse lasers with pump pulse compression.

References

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