The equivalent temperature model in process of nonlinear conversion of laser radiation

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In laser optics nonlinear frequency conversion proved to be one of the most important branch. Thanks to development of nonlinear optics one can obtain new powerful laser sources in different spectral ranges. The usage of nonlinear-optical frequency conversion is rather broad. It spreads from medical applications and biophotonics to inertial confinement fusion and precise micromachining. Stability and uniformity of crystal temperature is fundamental demand for efficient nonlinear frequency conversion in terms of critical phase matching. However if we for example consider second harmonic generation process than in practice taking into account optical absorption α at both pump wavelength λ_1 and converted laser radiation λ_2 wavelength it is almost impossible to achieve such conditions. One can observe high temperature gradient in radiation propagation direction not only due to absorption coefficient difference (in most cases $\alpha(\lambda_2) > \alpha(\lambda_1)$) but also due to nonlinear conversion. Because of the last one the pump power P_1 decreases and second harmonic power P_2 increases along the crystal. Yet, to the present day the problem of measuring and maintaining nonuniform temperature distribution inside nonlinear-optical crystal in terms of laser frequency conversion has not been solved.

In this paper we present theoretical model of crystal temperature calculation in terms of nonuniform heating by laser radiation. Also we compare the true thermodynamic temperature $T_{cr}(x,y,z,P_1,P_2)$ with measurable parameter $\Delta\Theta_{eq}$ – the equivalent temperature of nonlinear-optical crystal heated by laser radiation that we have recently introduced in laser physics [1-3]. Thanks to the fact that all nonlinear-optical crystals are piezoelectric materials one can excite and detect acoustic vibrations in direct manner. This feature allowed us to introduce the concept of equivalent temperature. In work [2] the temperature distribution in crystal was calculated according to 2-dimension model of distribution of laser radiation propagating through the crystal. Still longitudinal gradient of the crystal temperature wasn't taken into account. However in processes of frequency conversion of laser radiation there is always longitudinal temperature nonuniformity in crystal. In many practical applications longitudinal temperature gradient can be considerably high and thus phase matching conditions along the crystal length may be violated. This effect exhibits dramatically in so-called periodically poled nonlinear optical crystals such as periodically poled lithium niobate (PPLN) and periodically poled potassium titanyl phosphate (PPKTP). Longitudinal temperature gradient in periodically poled crystals is very essential in terms of conversion phase matching because it has strong influence on nonlinear conversion efficiency. Three-dimensional heat conduction equation with the heat sources is well-known and can be written in form: $\kappa\nabla^2 \mathrm{T}(x,y,z) = \alpha(\lambda_1)P_1(x,y,z) + \alpha(\lambda_2)P_2(x,y,z)$. Here κ is heat conduction coefficient. Also we have to write boundary conditions in terms of convective heat transfer between crystal and air: $\kappa \left.\frac{\partial \mathrm{T}(x,y,z)}{\partial n}\right|_{\partial V} = h^T(\mathrm{T}_{air} - \mathrm{T}_{cr})\big|_{\partial V}$. Here h^T is heat transfer coefficient, T_{cr} and T_{air} are crystal and air temperature at the interface respectively, n is normal vector to the crystal surface. Experimental values of optical absorption coefficients $\alpha(\lambda_1)$ and $\alpha(\lambda_2)$ and heat transfer coefficient h^T are obtained by measuring kinetics of the crystal equivalent temperature when crystal is irradiated by λ_1 wavelength, λ_2 wavelength, and by the sum of λ_1 and λ_2 [3]. After calculating temperature distribution $\mathrm{T}(x,y,z, P_1,P_2)$ in crystal the problem of calculating piezoelectric resonance modes of nonlinear-optical crystal with nonuniform temperature distribution is solved. In order to solve this considerably complicated problem variation principle is used as in [1, 2]. Experimental verification of the proposed three-dimensional model of the crystal heating is performed by measuring the dependence of the equivalent temperature on pump laser power P_1 and converted laser power P_2.

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