Temperature variation in the process
of terahertz wave generation by intense laser pulses

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To reach satisfactory energy efficiency of the optical-to-terahertz frequency conversion, femtosecond and nanosecond pulsed periodic lasers are used. This considerably affects the lattice temperature and can lead to the dramatic decrease in conversion efficiency.

Nevertheless, the calculations done during the development of a conversion method are often based on the parameters of the non-linear medium taken without an account for its heating up by focused laser radiation. This can result in unpredicted effects.

We have developed a method for the account for non-linear medium heating based on first-principle analytical study of thermo-optical processes that take place in nonlinear-optical crystal structures under periodic femtosecond or nanosecond pumping. The developed approach will allow the experimentalists evaluate the temperature and thermo-optical anomalies just inside a pumped volume in every particular case.

It is generally considered that the refractive index of a crystal is uniquely defined by the crystal temperature and its stress-strain state. In case of short laser pulses, the situation is more complicated: 1) for times less than the highest relaxation time of photo-excited carriers and phonon subsystem, the concept of crystal temperature cannot be defined. In this time interval, even if the dielectric constant can be correctly defined at each moment, the computation of the refraction coefficient is a kinetics-type problem; 2) if the time interval exceeds the relaxation time, but is shorter than the sound propagation time, it is necessary to take into account the temperature waves; 3) if the time interval exceeds the sound propagation time, the standard parabolic equation for temperature is quite correct. We demonstrate that with a short pump pulse and a high pulse repetition frequency, the parabolic equation gives the correct results.

We have developed analytical and numerical methods for calculating the temperature for pulsed-periodic pumping. Numerical methods are not considered here. For the established periodic regime, an analytical solution for a specific experimental scheme can be obtained using known solutions from existing reference materials, replacing the time dependence.

In experiments for measuring *dn/dT* in some cases it is not this value that is directly determined, but the temperature coefficient of the optical path length change *ds/dT*, which describes the thermally induced distortion of a beam during its passing through a sample. Transversal inhomogeneity of crystal heating will lead to variation in change of optical path length for radiation propagating at different distances from the pumping beam optical axis. In turn, this will result in inclination, spherical deformation ("thermooptical lens" effect) or more complicated distortion of optical pumping wave front. Spatially inhomogeneous depolarization of radiation is also possible

Some concrete results (LiNbO₃ crystals) [1].
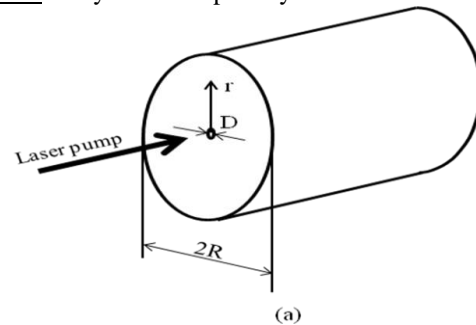Case A. A cylinder-shaped crystal with radius 0.5 cm,

Fig.1a

much smaller than its doubled length (**Fig.1(a)**). Pumping radiation with Gaussian profile of diameter 100 μm propagates along the cylinder axis. On the crystal surface the heat exchange with air at 300 K
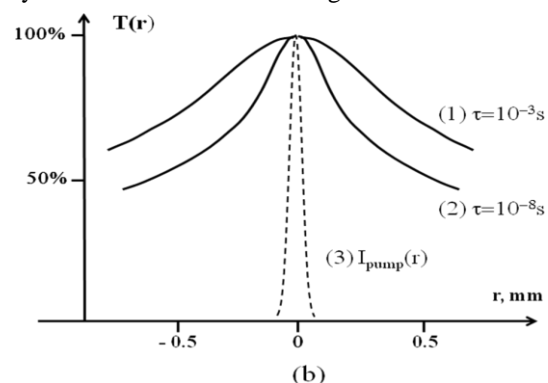

Fig.1(b)

temperature takes place according to Newton's law. The heat exchange coefficient is taken 8 W/m²K. The graph of the corresponding dependence on the transversal coordinate *r* is shown in **Fig.1(b)**. With an increase in the repetition period of the pump pulses from 10^{-8} seconds to 10^{-3} seconds, the width of the profile of the temperature distribution increases approximately twice.

Case B. Cherenkov geometry, **Fig.2a**. A specially line-focused laser beam generally propagates as near as possible to one of the side facets of the 8 mm slab-shaped crystal equipped with a special prismatic massive Si-coupler. Here a pump laser beam (average power 8 W) propagates at the distance of 0.5 mm from the working side surface.

Case B1. The non-working surface of crystal is thermally insulated, the temperature of the Si-prism is 100 *K*, the repetition time frequency of the laser pulses is 3 kHz. In **Fig.2b (a) and (b),** the result of the numerical calculations of the temperature and *dT/dr* dependence on the distance *r* is shown; the scaled pump intensity profile is shown also there. The value of d^2T/dr^2 on the axis is 7 K/mm^2.

Case B2. The same as Case B1, but the temperature of the Si-prism is 300 *K*, the repetition time frequency of the laser pulses is 80 MHz, non-working

surface experiences heat with air. **Fig.2c (a) and (b)** presents the spatial dependences of the temperature and *dT/dr*. The value of d^2T/dr^2 is 33 K/mm^2. d^2T/dr^2 on the axis of the laser beam is 7 K/mm^2.

Case B3. The same as in Case B2, but the non-working lateral surface contacts with a metallic cold loop. In **Fig.2d** the result of the numerical calculation of the temperature dependence on the distance *r* is shown. The value of d^2T/dr^2 is 18 K/mm^2.

References

1. *Kitaeva, G.Kh.., Moiseenko, E.V., Shepelev, A.V.* Temperature variation induced by the pulsed-periodic laser pumping under terahertz wave generation // Las. Phys. Lett. 2017, V.4, No.9, P.095401.
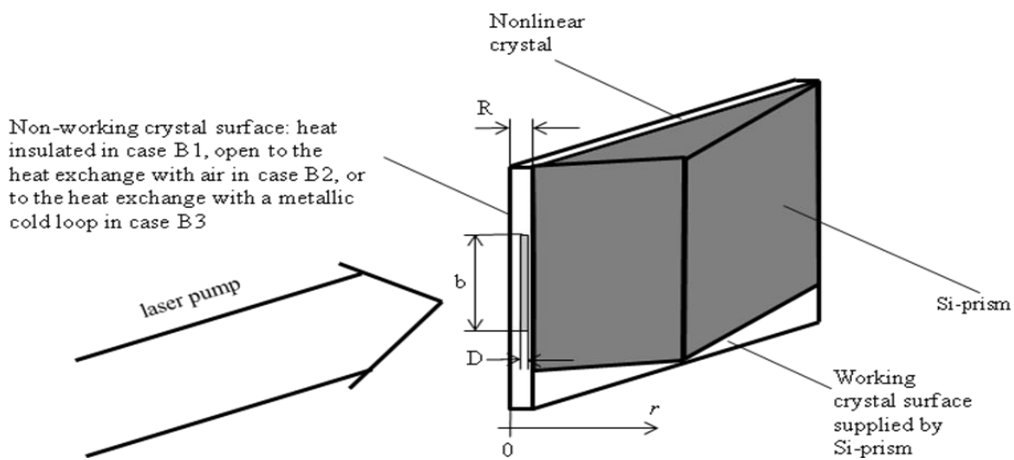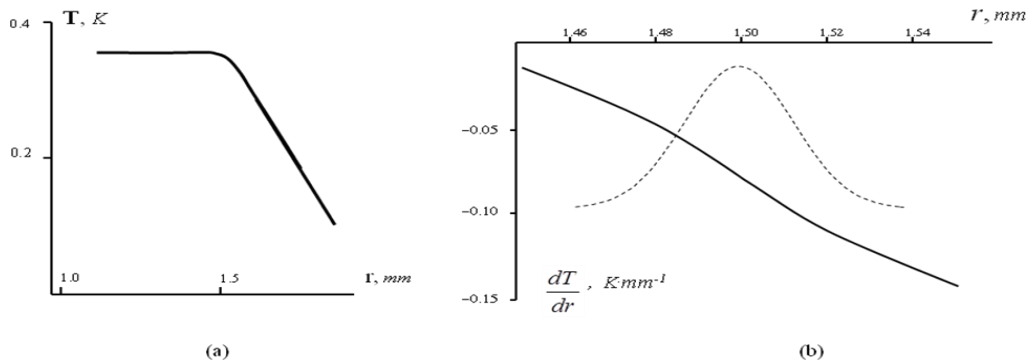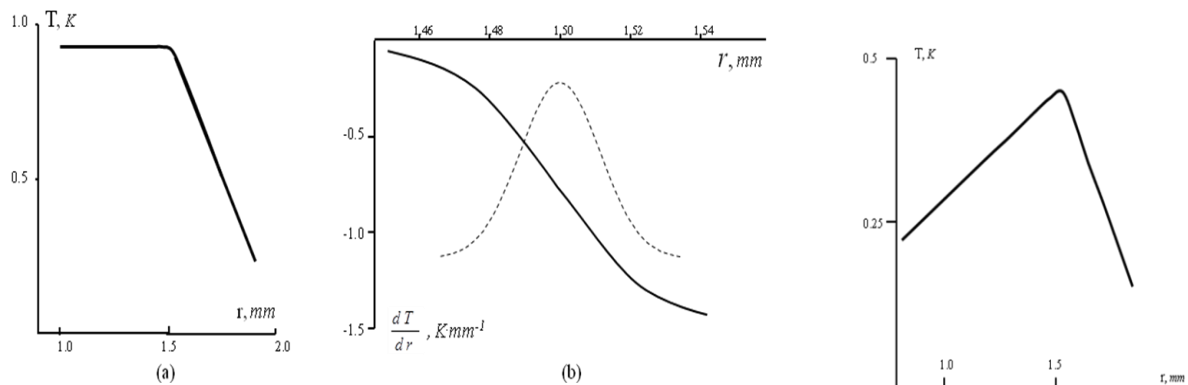

Fig.2a

Fig.2b

Fig.2c

Fig.2d