

OPEN ACCESS

Resonant acoustic spectroscopy of the interaction of the single-mode high-power laser radiation with crystals

To cite this article: A V Konyashkin *et al* 2010 *J. Phys.: Conf. Ser.* **214** 012064

View the [article online](#) for updates and enhancements.

You may also like

- [Model of the polarization extinction ratio change due to multiple reflection of laser radiation from the faces of the terbium-gallium garnet crystal in Faraday rotator](#)
A V Seleznev, G Y Ivanov, E V Kogut et al.
- [Model of resonant acoustic spectroscopy of interaction of high power single-mode laser radiation with crystals](#)
D V Myasnikov, A V Doronkin, A V Konyashkin et al.
- [Mathematical modelling of optical radiation transport in biological tissues under the conditions of moveable integrating spheres registration](#)
T K Karpova, N V Kovalenko, G A Aloian et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

Resonant acoustic spectroscopy of the interaction of the single-mode high-power laser radiation with crystals

A. V. Konyashkin^{1,2,3}, A. V. Doronkin^{1,2}, V. A. Tyrtshnyy², D. V. Myasnikov^{1,2},
O. A. Ryabushkin^{1,2,3}

¹NTO «IRE-Polus», Vvedensky Sq.1, Fryazino, 141190, Russia

²Moscow Institute of Physics and Technology, Institutskii per. 9, Dolgoprudny, 141700, Russia

³Institute of Radio-engineering and Electronics of RAS, Vvedensky Sq.1, Fryazino, 141190, Russia

E-mail: a.konyashkin@gmail.com

Abstract. Resonant acoustic spectroscopy technique gives the opportunity to measure the crystal temperature during linear and nonlinear interaction of the laser radiation with crystals. It is based on the registration of the crystal piezoelectric or acoustical resonance frequency change caused by the interaction of the laser radiation with crystals. Piezoelectric resonance is observed by measuring the dependence of the sample electrical impedance on the external electric field frequency. It is shown that inhomogeneous crystal heating can be characterized by the equivalent crystal temperature depending on the influence laser power. Equivalent crystal temperature can be directly determined from the measured piezoelectric resonance frequency.

1. Introduction

Nonlinear-optical crystals are generally used for optical parametric generation and amplification, electro-optical and acousto-optical modulation, multi-wave mixing and frequency conversion of the laser radiation [1-2]. During every interaction of the laser radiation with crystals some part of the radiation energy converts into heat. In case of the high-power laser applications residual optical absorption in crystals can cause crystal structural defects formation and even its destruction [3, 4].

Most of the crystals applied in the nonlinear optics possess piezoelectric properties [2, 5]. It is well known that piezoelectric resonances are highly temperature-sensitive [5]. Internal crystal temperature variation results in the piezoelectric resonance frequencies change. On the base of the piezoelectric resonance frequency temperature dependence the method was proposed for the accurate determination of the weak linear optical absorption of the piezoelectric optical materials [6]. It is stated that practical application of this method is restricted by the crystal piezoelectric resonance quality factor which in turn defines the maximal allowable crystal overheating and as follows the maximal laser irradiation power. In the present work the interaction of the single-mode high-power laser radiation with crystals is investigated by means of the radiofrequency impedance spectroscopy.

2. Experiment

2.1. Crystal sample

Nonlinear optical KTiOPO_4 (KTP) crystal was taken for the detailed investigation of the high-power laser radiation interaction with crystals. KTP crystals at room temperature are orthorhombic and belong to the $mm2$ crystallographic point symmetry group, lattice constants are $a = 12.814$ Å, $b = 6.404$ Å, $c = 10.616$ Å [1, 2]. Specimen of the KTP crystal is the rectangular parallelepiped with dimensions $30 \times 3 \times 3$ mm³. Crystal c -axis and b -axis are directed along the 3 mm sides and a -axis is parallel to the 30 mm side. Main piezoelectric and elastic constants of the KTP crystal and their dependencies on temperature were reported earlier [5].

2.2. Experimental setup

Block-scheme of the experimental setup for the crystal electrical impedance measurements is shown in Fig.1. External electric field E^{rf} from the RF generator is applied to the KTP. Crystal is placed between the two quartz plates with the sputtered silver electrodes.

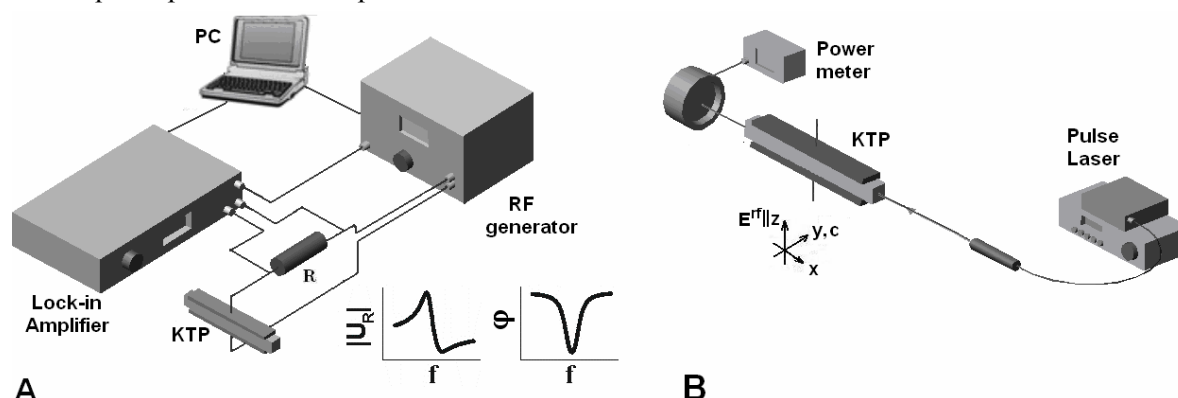


Figure 1. Block-scheme of the experimental setup: electrical part (A), optical part (B).

Crystal is placed in unclamped manner on the two thin threads in ~ 20 mkm distance away from the upper electrode. It helps to reduce uncontrollable variations of the crystal piezoelectric resonance frequency and amplitude and also to increase quality factor of the electromechanical resonator formed by the two electrodes. The KTP with electrodes is placed in the handmade thermostat with optical windows for the laser radiation passing. The small load resistor R is connected in series with the KTP crystal. For each value of the electric field frequency f the amplitude $|U_R|$ and the phase ϕ of the U_R voltage on the load resistor R are measured by the lock-in amplifier. See Fig.1 A for the typical dependence on frequency of the mentioned parameters near the crystal piezoelectric resonance. The current through the KTP is determined and the crystal complex electrical impedance $Z(f)$ is calculated. RF generator and lock-in amplifier are synchronized via the PC for providing fast data accumulation. Consecutive frequency change followed by the lock-in amplifier measured values read off can be made periodically in the automatic regime.

Ytterbium depolarized single-mode pulse fiber laser was used as the laser source with following parameters: principal scheme is Master Oscillator Power Fiber Amplifier (MOPFA), operating wavelength is 1064 nm, pulse repetition rate is 20 kHz, pulse duration is 100 ns, output average power can be varied in the 0,015 – 19 W range, pulse peak power is 10 kW. Width of the laser line is 3 nm on the -3 dB level. Laser beam diameter is 1 mm and the M^2 beam quality parameter doesn't exceed 2.

3. Results

Frequency dependencies of the KTP crystal complex electrical impedance modulus $|Z(f)|$ were measured in the 500 KHz – 3 MHz range. Typical value of the KTP crystal piezoelectric resonance

line width is about hundred hertz for the electric field E^{rf} applied along the crystal b -axis. Coefficients of the piezoelectric resonance frequency shift df_T/dT during crystal homogeneous heating without the laser radiation influence should be determined prior to investigating the laser radiation influence on the piezoelectric resonances in crystal. Piezoelectric resonances with the largest absolute values of the df_T/dT coefficient are the most sensitive to the crystal overheating induced by the laser radiation influence. KTP crystal piezoelectric resonance with one of the acoustical mode near the frequency $f_{T0} = 832.5$ kHz ($T_0 = 294$ K) was chosen.

Calibration measurements of the piezoelectric resonance frequency shift $\Delta f_T = f_T - f_{T0}$ during crystal homogeneous heating without the laser radiation influence revealed that its df_T/dT coefficient linearly depends on temperature. For the selected resonance measured coefficient value is $df_T/dT = -53 \pm 0.5$ Hz/K.

It is well known that the influence of the single-mode high-power laser radiation of the beam diameter less than the crystal aperture leads to the inhomogeneous crystal heating. Crystal piezoelectric resonance frequency shift $\Delta f_P = f_P - f_{P0}$ ($P_0 = 0$) due to the laser radiation influence is determined in the whole laser power range after reaching of the thermal equilibrium state. For the selected KTP crystal acoustical mode and the experimental heat transfer conditions of the crystal with the ambient air the measured piezoelectric resonance frequency shift linearly depends on the time-averaged laser power P with the incline $df_P/dP = -15.5 \pm 0.5$ Hz/W.

Comparison was made of the KTP piezoelectric resonance line form change due to the homogeneous crystal heating with case of the inhomogeneous heating induced by the laser radiation influence. From the measured complex voltage U_R values the current through the KTP crystal can be determined and the its complex electrical impedance $Z(f)$ can be calculated. Then the KTP crystal electrical impedance real part $Re(Z(f))$ was approximated by the Lorentz function (1).

$$Re(Z(f)) = R_0 + \frac{2A_p}{\pi} \left(\frac{\Delta w}{4(f - f_c)^2 + \Delta w^2} \right) \quad (1)$$

Typical examples of the Lorentz function (1) approximation of the crystal electrical impedance real part $Re(Z(f))$ made for the case of the crystal inhomogeneous heating are shown on the Fig.2 A.

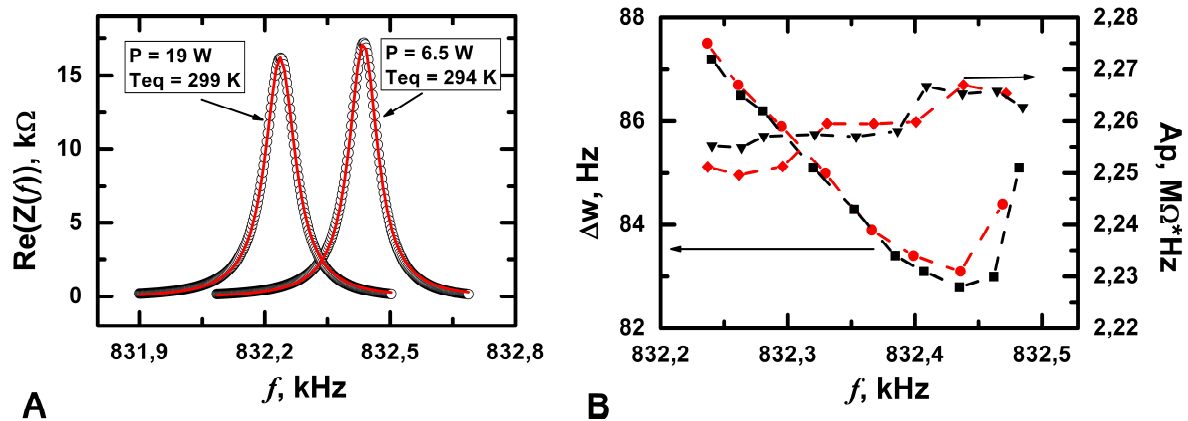


Figure 2. (A) Crystal electrical impedance real part $Re(Z(f))$ frequency dependencies during inhomogeneous heating (P - laser radiation power) approximated by the Lorentz function (1). (B) Line width Δw and parameter A_p of the KTP crystal electrical impedance real part $Re(Z(f))$ for the different crystal temperatures during homogeneous heating without the laser radiation influence ($\blacksquare - \Delta w$, $\blacktriangledown - A_p$), for the different average laser powers P ($\bullet - \Delta w$; $\blacklozenge - A_p$); f_c – the frequency value of the Lorentz peak position (1).

The piezoelectric resonance positions during the homogeneous heating as well as during the laser radiation influence can be characterized by the frequency f_c . Line width Δw and A_p parameter obtained from the Lorentz function (1) approximation of the measured KTP crystal complex electrical

impedance real part $\text{Re}(Z(f))$ are shown on the Fig. 2 B. Here the f_c values are set as the Fig. 2 B plot X-axis values.

4. Discussion and Conclusions

Piezoelectric resonance line form changes due to the laser radiation influence and due to the homogeneous crystal heating occur in the same way. For this laser power range (from 0 to 19 W) and for the natural heat conduction conditions of the crystal surfaces with surrounding air such similar line form behavior enables us to characterize inhomogeneous crystal heating during the interaction with the laser radiation by the equivalent crystal temperature $T_{\text{eq}}(P)$. Equivalent crystal temperature change (ΔT_{eq}) with the laser power P is directly determined from the measured piezoelectric resonance frequency shift Δf_p and the temperature coefficient df/dT priority measured in the conditions of the homogeneous crystal heating without the laser radiation influence from (2).

$$\Delta T_{\text{eq}} = \Delta f_p / (df / dT) \quad (2)$$

Spatial distribution of the crystal temperature T_c during interaction with the laser radiation of the time-average laser power P in this case is determined by the equation (3). The value of the temperature inhomogeneity $|\Delta T(x, y, z, P)|$ in (3) satisfies the following condition $|\Delta T(x, y, z, P)| \ll T_{\text{eq}}(P)$.

$$T_c(x, y, z, P) = T_{\text{eq}}(P) + \Delta T(x, y, z, P) \quad (3)$$

The represented method of the resonant acoustic spectroscopy enables to characterize the inhomogeneous crystal heating caused by the interaction with the high-power laser radiation by the equivalent crystal temperature. The conception of the equivalent crystal temperature gave the opportunity to unite classical mechanical and thermodynamical approaches for the investigation of the high-power laser radiation interaction with crystals. Change of the T_{eq} is directly determined from the measured piezoelectric resonance frequency shift. Equivalent crystals temperature is the fundamental factor for the quantitative determination of the true inhomogeneous crystal temperature. Also crystal linear and nonlinear-optical absorption coefficients can be determined for the versatile high-power laser application processes including laser frequency generation and conversion processes [7].

References

- [1] V. G. Dmitriev and L. V. Tarasov // "Applied Nonlinear Optics", Fizmatlit, Moscow (in Russian) (2004).
- [2] M. C. Gupta and J. Ballato // "Handbook of Photonics, 2nd edition", CRC Press by Taylor & Francis Group, New York, Part III Ch. 5-6 (2007).
- [3] M. W. Roger // "Laser-induced damage of optical materials", Institute of Physics publishing, Bristol and Philadelphia, P. 192-207 (2003).
- [4] H. Yoshida, H. Fujita, M. Nakatsuka // "Dependences of laser-induced bulk Damage threshold and crack patterns in several nonlinear crystals on irradiation direction", Jap. J. Appl. Phys. Vol. 45, № 2a, P. 766-769 (2006).
- [5] David K. T. Chu, J. D. Bierlein, R. G. Hunsberger // "Piezoelectric and acoustical properties of potassium titanyl phosphate (KTP) and its Isomorphs", IEEE Transaction on Ultrasonics, Ferroelectrics, and Frequency Control, Vol. 39, № 6, P. 683-687 (1992).
- [6] F. Bezancon, J. Mangin, P. Stimer, M. Maglione // "Accurate determination of weak optical absorption of piezoelectric crystals used as capacitive massive bolometers", IEEE Journal of Quantum Electronics, Vol. 37, № 11, P. 1396-1400 (2001).
- [7] O. A. Ryabushkin, D. V. Myasnikov, A. V. Konyashkin // "A model of acoustic-resonance spectroscopy of nonlinear-optical interaction of single-mode laser radiation with crystals", Proc. EOS Annual Meeting 2008, Paris France, 29th Sept. – 2nd Oct., TOM (Topic Of the Meeting) 6 – Nonlinear Optics, P.810 (2008).