

# Influence of temperature gradient on diffracted X-ray spectrum in quartz crystal

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**Abstract.** In this work characteristics of hard X-ray (with energy higher than 30 keV) were investigated. In the experiment we measured spectra of X-ray reflected by a quartz mono-crystal in Laue geometry under influence of the temperature gradient. The measurements were made by the spectrometer BDER-KI-11K with 300 eV resolution on the 17.74 keV spectral line of Am241 and the spectrometer XR-100CR with 270 eV resolution on the same spectral line. An existence of temperature gradient leads to increasing of the diffracted beam intensity. The intensity was measured dependently on the temperature of one of the edge of the crystal.

## 1. Introduction

Designing of new methods of monochromatic hard X-ray beams producing with tuned parameters such as angular distribution and monochromaticity is stimulated by requirements of new, more sensitive and universal methods for providing of investigations in different fields of science and engineering. It is well known that an existence of acoustic field or temperature gradient in crystal monochromators allows to control parameters of diffracted X-ray in space and time [1, 2]. In the works [3, 4] the first time it was observed a phenomenon of full X-ray transfer from the direction of propagation to the reflection direction in mono-crystal of quartz under the influence of temperature gradient or ultrasonic waves. In the works [5] a sharp decreasing of X-ray absorbing coefficient under the temperature gradient perpendicular to atomic reflective planes was observed in Laue geometry. In the work [6] a high-resolution diffractometer based on the proposed techniques was made. In the work [7] it was experimentally shown that under the influence of high-temperature gradient an angular width of full X-ray transfer increases proportionally to a crystal width. For designing of X-ray optic elements with controlled parameters which are based on proposed techniques it is very important to know what deformation exactly is in the crystal influenced by temperature gradient or acoustic waves (see, for instance, works [8, 9]). The results of investigation of reflected X-ray intensity depending on the temperature gradient value are presented in our work.

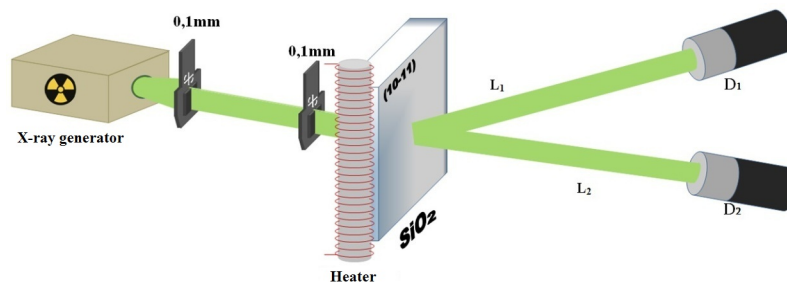
## 2. Experimental setup

As investigated samples there were used rectangular plates of quartz mono-crystal with 6, 8, 9 mm thickness. One of the crystal edges was heated up. This edge of the plates was parallel to atomic reflective planes of the crystal ( $10\bar{1}1$ ), i.e a temperature gradient was applied



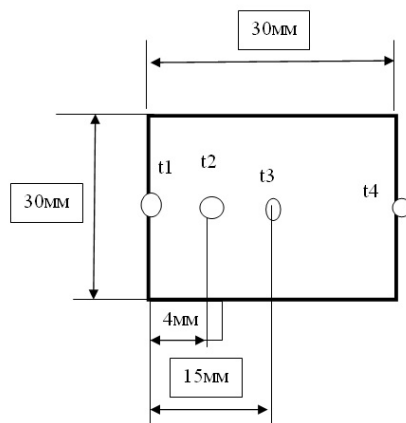
perpendicularly to the reflective planes. The temperature gradient vector and the diffraction vector were anti-parallel to each other. In the experiment a continuous X-ray spectrum was used. This spectrum was generated by the X-ray tube Mo BSV-29 with 45 kV voltage and 10 mA current.

A dependence of reflected X-ray intensity on a temperature gradient was experimentally investigated. The dependence was investigated with 25, 30, 35 keV energies of the X-ray. The schematic of the experiment is shown in figure 1. In the figure  $L_1 = L_2 = 25$  cm, distance between the last slit and the crystal is 8 cm, angles of observation are  $\theta = 6^\circ \div 8^\circ$ . Angular divergence of the beam was less than 2 mrad.

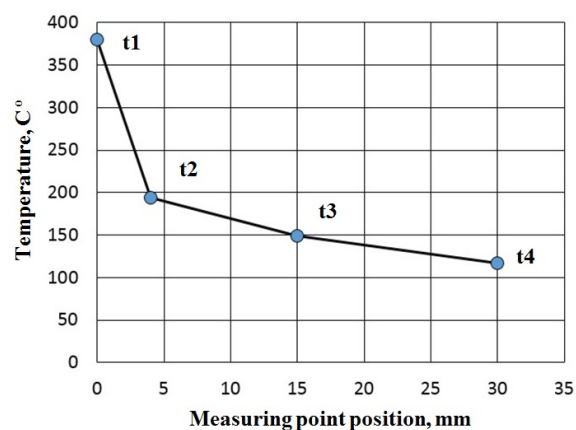


**Figure 1.** The schematic of the experiment.

The temperature of the crystal was measured in four points, these points are shown in figure 2 ( $t_1 = 0$  mm,  $t_2 = 4$  mm,  $t_3 = 15$  mm,  $t_4 = 30$  mm). The crystal was heated up from the side of  $t_1$  point. The beam was passing through the crystal between the points  $t_2$  and  $t_3$ . One of the temperature distributions is shown in figure 3.

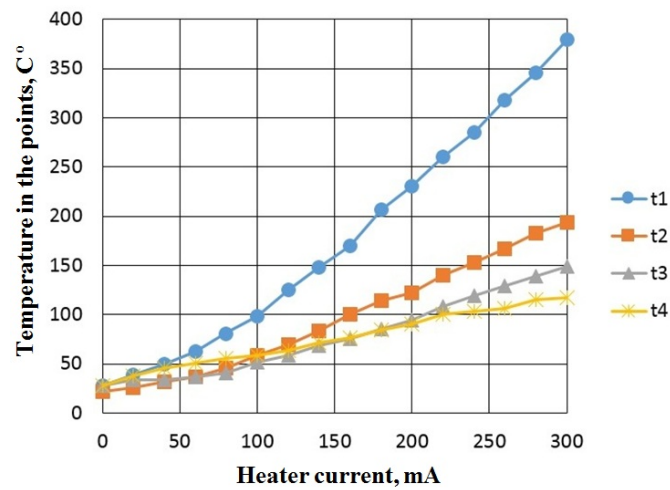


**Figure 2.** The schematic of the temperature measuring points location.



**Figure 3.** The temperature distribution.

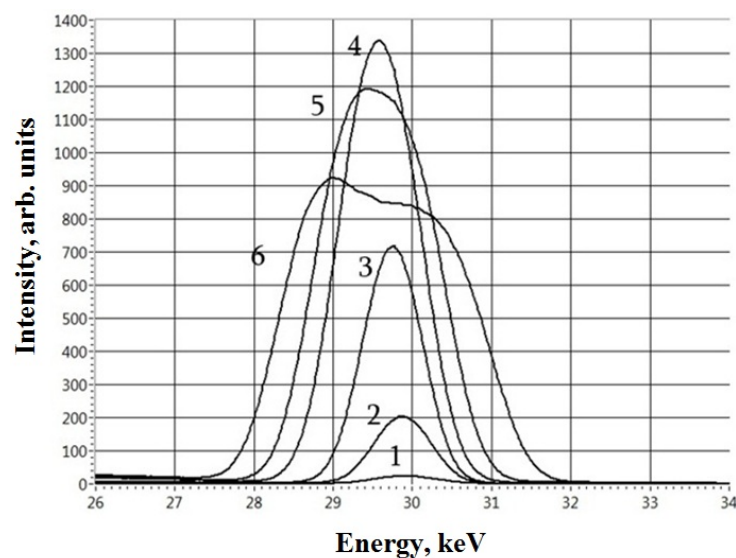
In figure 4 a dependence of temperature in the points on the heater current for 6 mm thickness quartz crystal is shown. Maximal temperature in the point  $t_1$  was  $380^{\circ}$ , further heating leads to destroying of the crystal.



**Figure 4.** Dependence of temperature in the points on the heater current.

### 3. Results

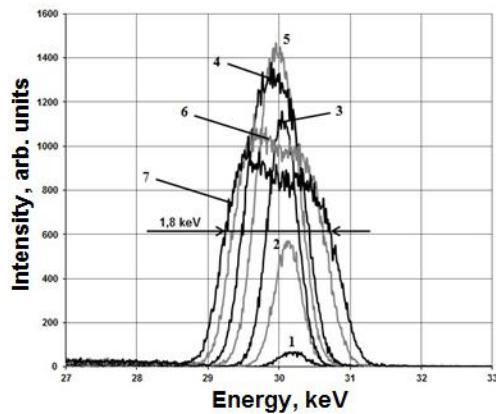
In figure 5 there are shown spectra of diffracted in 9 mm thickness crystal X-ray for different temperature gradients. As one can see from the figure that there take place a multiple increasing of the diffracted X-ray intensity, a widening of the spectrum and a misplacing of maximum in low energy region within the increasing of temperature gradient. The widening of spectrum is caused by a bending of the crystal atomic reflective planes and the misplacing of maximum is a result of increasing of distances between the reflective planes.



**Figure 5.** The spectra of diffracted in 9 mm thickness crystal X-ray for different temperature gradient:

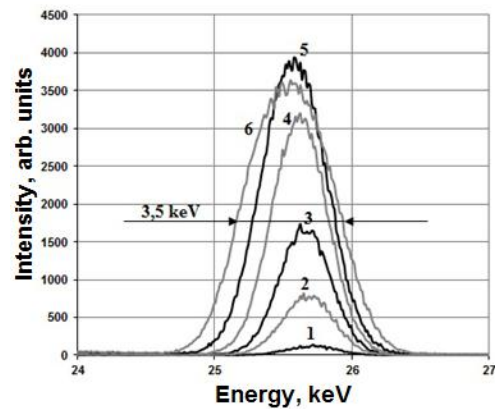
- 1)  $\Delta T/\Delta x = 0 \text{ C}^\circ/\text{cm}$ ; 2)  $\Delta T/\Delta x = 10 \text{ C}^\circ/\text{cm}$ ;
- 3)  $\Delta T/\Delta x = 100 \text{ C}^\circ/\text{cm}$ ; 4)  $\Delta T/\Delta x = 150 \text{ C}^\circ/\text{cm}$ ;
- 5)  $\Delta T/\Delta x = 200 \text{ C}^\circ/\text{cm}$ ; 6)  $\Delta T/\Delta x = 250 \text{ C}^\circ/\text{cm}$ .

In figures 6, 7 the same as in figure 5 spectra are shown but for the 8 mm and 6 mm thickness crystals respectively. As one can see from figures 5 - 7 the beam spectral line is widening within increasing of the crystal thickness.



**Figure 6.** 8 mm crystal:

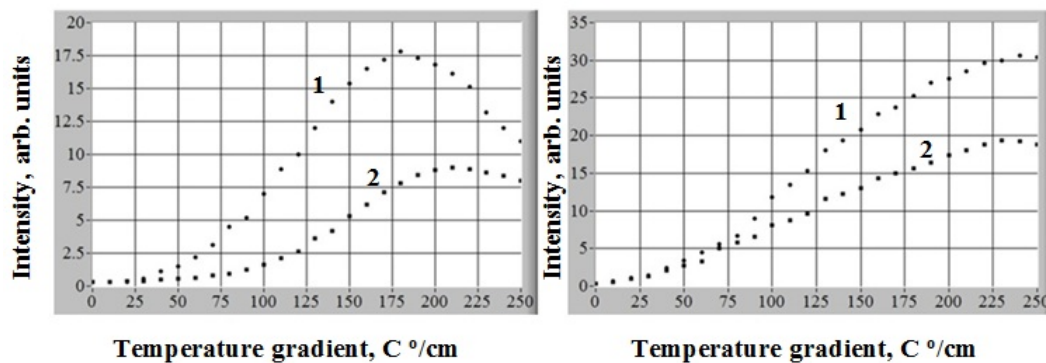
- 1)  $\Delta T/\Delta x = 0\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 2)  $\Delta T/\Delta x = 10\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 3)  $\Delta T/\Delta x = 100\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 4)  $\Delta T/\Delta x = 150\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 5)  $\Delta T/\Delta x = 200\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 6)  $\Delta T/\Delta x = 250\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 7)  $\Delta T/\Delta x = 300\text{ }^{\circ}\text{C}/\text{cm}$ .



**Figure 7.** 6 mm crystal:

- 1)  $\Delta T/\Delta x = 0\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 2)  $\Delta T/\Delta x = 10\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 3)  $\Delta T/\Delta x = 100\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 4)  $\Delta T/\Delta x = 150\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 5)  $\Delta T/\Delta x = 200\text{ }^{\circ}\text{C}/\text{cm}$ ;
- 6)  $\Delta T/\Delta x = 250\text{ }^{\circ}\text{C}/\text{cm}$ .

There are shown the dependencies of diffracted X-ray intensity on the value of temperature gradient for energies 30 keV and 40 keV in figure 8. The Left figure is for 6 mm thickness crystal and the right one is for 9 mm thickness crystal.



**Figure 8.** The dependencies of diffracted X-ray radiation intensity on the value of temperature gradient. 1 - the dependence for 30 keV energy; 2 - the dependence for 40 keV energy. Left figure - 6 mm thickness crystal; Right figure - 9 mm thickness figure.

One can see from the left figure that it takes place increasing of intensity more than in 60 times for 30 keV energy and more than in 45 times for 40 keV energy. For 9 mm thickness of the crystal (right figure) the intensity increases more than in 100 times for 30 keV energy and about 80 times for 40 keV energy.

The multiple increasing of X-ray radiation intensity is caused by the phenomenon of full X-ray radiation transfer from the propagation direction to the reflection direction.

The saturation and the decreasing of reflected X-ray intensity within the increasing of temperature gradient is a result of that within large deformations of the crystal a length of extinction becomes many times larger than effective region of diffraction for every radiation mode which takes part in the diffraction. It means that since the length of extinction for 40 keV energy photons is larger than for 30 keV photons so in the last case the saturation takes part within smaller temperature gradient.

Thus, it is experimentally demonstrated that the intensity of diffracted X-ray can increase on the order of 2 when there is the temperature gradient in the crystal. Also it is shown that within the temperature gradient increasing the intensity of reflected beam increases and the spectral line width within the maximal intensity are determined by the crystal thickness. Further increasing of temperature gradient leads to increasing of the spectral line width and decreasing of the intensity.

## References

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