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# Hard X–ray filter with controllable parameters

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**Abstract** – We consider the hard X–ray diffraction from reflecting atomic planes $(10\bar{1}1)$ of X–cut quartz single crystal with different thicknesses in Laue geometry influenced by the temperature gradient. It has been experimentally proved that, depending on the value of the temperature gradient, the intensity of the reflected beam can be increased by orders of magnitude. It is shown that by using the temperature gradient it is possible to separate a beam with high angular and spectral width from the white beam and move it to the direction of reflection.

Keywords: hard X-ray, filter, quartz single crystal, reflection

## 1. Introduction

The obtaining of intense sources and base elements of short wavelength hard X-ray “optics” with controllable working parameters (energy, intensity, focus length) gives an opportunity to improve the technology in medicine and to enlarge the range of X-ray diffractometry applications. Related to this, the issue of diffraction under external influences plays a special role and is actual. For example, in order to optimize the required dose of the exposure of patients needs to be separated the beam from the white spectrum of the X-rays with the necessary bandwidth, luminosity and radiation density with rage 30-250 keV energy. In order to obtain such beams the questions of diffraction under external influence occupy their special and actual place.

In the papers [1, 2], for the first time, the complete transfer of X-rays from the passing direction to the reflection one is detected for single crystals of quartz in the Laue geometry under the influence temperature gradient or ultrasonic vibrations. In [3] it was theoretically and experimentally proved that, using the temperature gradient and acoustic field, one can control the position of the focus of the reflected radiation in space and time and it is also possible to convert a spherical wave into a plane one. The transfer and control of the spectrum of the reflected hard X-rays (over 25 keV) is not experimentally investigate in these papers.

## 2. *Experimental design*

In order to obtain a band–pass filters of hard X–rays (over 25 keV) with controllable parameters, we have considered the X-ray diffraction in Laue geometry influenced by the temperature gradient. A rectangular plate of single quartz crystal ($30x30mm^2$) with the thickness 9 mm was used as a sample under investigation. The spectra of reflected and passed X-ray beams from the reflecting atomic plane $(10\bar{1}1)$ of quartz single crystal were experimentally studied with various values of the temperature gradient. The experimental scheme is shown in figure 1. The experiments were carried out with the XR-100CR spectrometer with the resolution 270 eV on Am241 17.74 keV line. The temperature gradient in the crystal was created with the help of a heater (figure 1). The heated part of the plate was parallel to the reflecting atomic planes$(10\bar{1}1)$, i.e. the temperature gradient was perpendicular to the reflecting atomic planes. The temperature gradient vector and the diffraction vector were anti-parallel. A white spectrum of X-ray was used in the test which was generated from the X-ray tube Mo BSV-29 under the voltage up to 40 kV and the anode current 10 mA. The initial beam was collimated and the angular difference was about 2 mrad. The spectrum of the reflected beam with 30 Kev energy was investigated at the observation angle equal to approximately $7^0$.

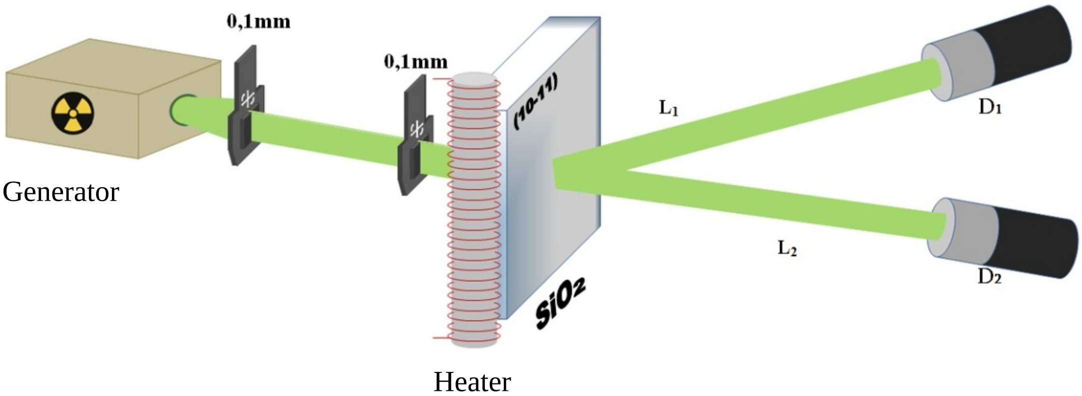


**Figure 1. Experimental scheme for the measurement of the reflected and passed X-ray beams spectra.**

In order to be sure in the effect of the “transfer” the spectra of passed and reflected X-ray radiations were measured. For the chosen orientation of the crystal the diffraction first order matches 30 keV energy. Exactly for this energy in the solid spectrum of the passed beam a flop was observed, the depth of which is determined by the value of the temperature gradient and by the energy resolution of the detector. The temperature of the heater crystal side was varied from 23 to 400 degrees, whereas the opposite side was cooled with the help of the convection. An increase in the intensity of the reflected beam in the Laue geometry by two orders of magnitude was observed compared to the uniform temperature regime of the quartz crystal with 9mm thickness. Figures 2a and 2b show the radiation spectra of the “transfer effect” depending on the temperature gradient for the quartz crystal of 9mm thickness. In the range of transfer a flop in the spectrum of the passed radiation is observed. The depth of the flop depends on the temperature and on the resolution of the detector.

Figures 2a and 2b demonstrate the spectra of the passed and reflected radiations respectively in with identical parameters which confirm the observation of the "transfer" effect.

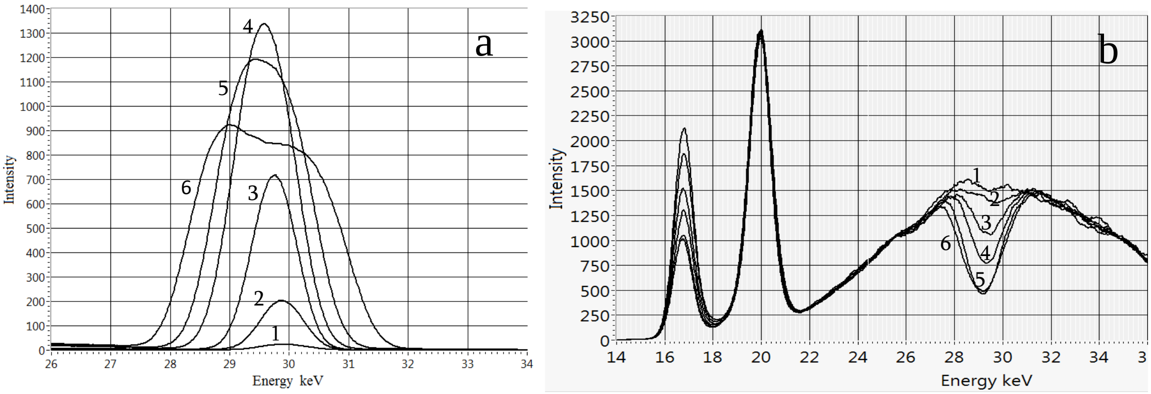


Figure 2. The spectra of the reflected (a) and passed (b) beams for different values of the temperature gradient applied to the quartz single crystal with the thickness 9mm.
1)$\Delta T/\Delta x$=0 grad/cm; 2)$\Delta T/\Delta x$=50 grad/cm; 3)$\Delta T/\Delta x$=100 grad/cm; 4)$\Delta T/\Delta x$=150 grad/cm; 5)$\Delta T/\Delta x$=200 grad/cm; 6) $\Delta T/\Delta x$= 250 grad/cm. The observation angle is $7^0$.

The spectral measurements confirm the effect of transfer from passing beam of X-ray radiation and its dependence on the temperature gradient created in the crystal. The multiple increase in the intensity is caused by the phenomenon of the full pumping of the X-ray from the passing direction to the reflecting one with a big angular width which is much bigger than the angular width of the Darwin table and depends on the thickness of the used single-crystal. The saturation and the sharp decrease of the intensity for the further increase of the temperature gradient is related to the fact that for large deformations the extinction length becomes much larger than the effective thickness of the diffraction for each monochromatic X-ray wave.

## 3. The theoretical model

Usually, the X-ray beam incident on a crystal has a divergence and spectral width and in each direction spreads a set of plane waves with different wavelengths. In the work a program is developed with the help of which it is possible to calculate the diffraction of the X-ray radiation on a single crystal with temperature gradient or acoustic influence, for a falling beam with any spectral-angular distribution. In this program, for the calculations of diffraction the incident X-ray beam is decomposed into set of plane monochromatic waves, each of which is scattered in accordance with the dynamical theory in the plane-wave approximation of the deformed crystal. Then the scattered wave integrated over the spectral and angular variables in the detector plane.

For the purpose of comparison of the reflected and passed radiations with the experimental results, the calculations are done with the help of this program when the X-ray beam with white spectrum falls on the quartz crystal. In the calculations the diffraction in the Laue geometry is considered for reflecting atomic planes $(10\bar{1}1)$ of quartz single-crystal with 9 mm thickness when the crystal is in the Bregg condition for the photon energy 30keV.

It was assumed, that in the presence of the temperature gradient [5] in the scattering plane XOZ, at a certain distance from the heating face of the crystal, the shift function $Ux$ can be written as

$$U_x = \frac{t^2 - (t-2z)^2}{8R},$$

where t is the thikness of the crystall, R is the curvature radius of reflecting atomic planes.

The results of the calculations are given in the figure 3. As is seen, the calculations confirm the existence of the multiple increase of the intensity which is caused by the phenomenon of full pumping of the X-ray from passing direction (figure 3b) to the reflecting direction (figure 3a) with a big angular width. In the experimental results the flop in the spectrum of the passed beam near the Bregg angle does not reach zero value which is related to the resolution of the spectrometer.

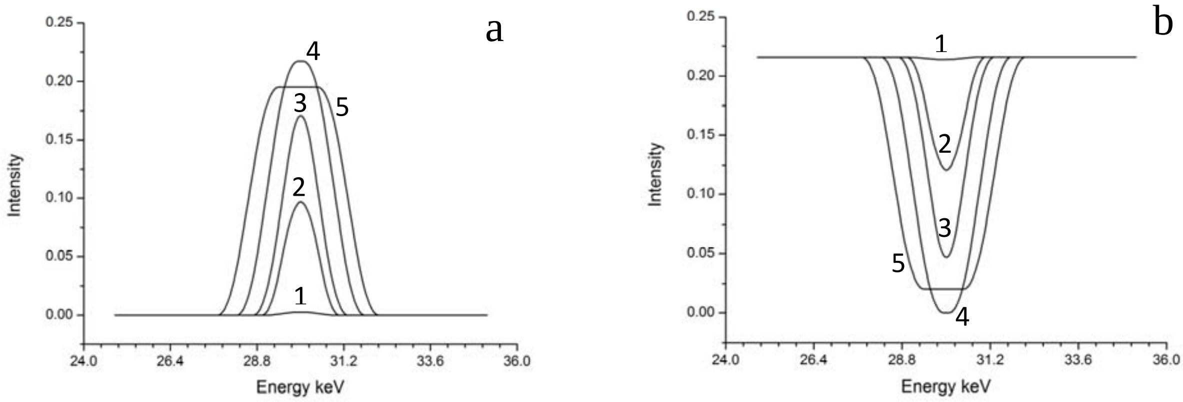


Figure 3. The spectra of the reflected (a) and passed (b) beams for different values of the curvature for the reflecting atomic planes of the quartz single crystall with the thickness 9mm.
1)1/R=0 $cm^{-1}$; 2)1/R=0.0005 $cm^{-1}$; 3) 1/R=0.001 $cm^{-1}$; 4) 1/R=0.002 $cm^{-1}$; 5) 1/R=0.003 $cm^{-1}$;

## 4. Conclusion

Thus, we have obtained a multiple increase in the intensity of the reflected hard X-rays, the full pumping of X-rays from the passing direction to the reflecting one with big spectral width, its dependence on the thickness of the used single crystal and on the applied temperature gradient. It is shown that by using quartz monochromator in the Laue geometry with external temperature gradient it is possible to create a linear filter in the region of hard X-ray radiation with controllable parameters.

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## References

1. Mkrtchyan A.R., Navasardyan M.A., Mirzoyan V.K. // Pis’ma v ZhTF. T. 8. № 11. p. 677 (1982).
2. Mkrtchyan A.R., Navasardyan M.A., Gabrelyan R.G. at al.. // Pis’ma v ZhTF. T 9, . № 11, p. 1181, (1983).
3. Mkrtchyan A.R., Navasardian M.A., Gabrielyan R.G., Kocharian L.A., Kuzmin R.N. // Solid State Communications. V. 59. № 3. p. 147−149, 1986.
4. Mkrtchyan A.R., A.S. Bagdasaryan, S.H. Khlopuzyan, V.R. Kocharyan. // Nelineinyi mir (Nonlinear World)., T. 13, № 4, p.47, 2015
5. V.R. Kocharyan, R.Sh. Aleksanyan, K.G. Truni. Journal of Contemporary Physics (Armenian Academy of Sciences), Vol. 45, No.4, pp. 190–194, 2010.