Armenian Journal of Physics, 2015, vol. 8, issue 2, pp. 73-78 FOCUSING OF HARD X-RAYS IN A QUARTZ CRYSTAL UNDER EXTERNAL TEMPERATURE GRADIENT S. H. Khlopuzyan

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Abstract – In order to obtain monochromators and lenses with controlled parameters in the hard X-ray range (above 30 keV), we have considered the X-ray diffraction in Laue geometry influenced by the temperature gradient. It is shown that with the help of the temperature gradient impact it is possible to separate a beam with high angular and spectral width from a white beam, transfer it in the direction of reflection and focus it, i.e., control the parameters of the beam in a large range.

Keywords: X-ray, diffraction, temperature gradient

The creation of new, more sensitive and universal methods for research in various fields of science and technology, such as the definition of real structures of perfect crystals, imaging of biological objects, elements of micro and nano electronics, etc., is an actual problem. One of the essential factors for the solution of this problem is to get alternative monochromatic beams of gamma rays - without harmonics – that will have controllable parameters, such as angular divergence and intensity, in space and time. One of such methods is the diffractometry of reflection of the order of angstrom waves formed in the presence of external stimulation. In these works the authors show that the presence of external acoustic fields or temperature gradients can sharply change the cross of the process of scattering in a given example and thus can become a handle to control the parameters of the defragmented X-rays in space and time.

In turn, this phenomenon opens new possibilities for the formation of beams with given parameters, thus widespread use of X-ray diffraction science and technology. For example, in works [1,2] the phenomenon of the full pumping of X-rays from the direction of the reflection in the direction of quartz crystal in Laue geometry under the influence of temperature gradient or ultrasonic vibrations was firstly discovered. In work [3] it was experimentally shown that the angular width of the fully pumped radiation depends on the thickness of the investigated sample and is directly proportional to it.

Khlopuzyan // Armenian Journal of Physics, 2015, vol. 8, issue 2

In [4] it was possible to observe a decrease in the absorption coefficient of X-rays to its minimum value at a certain value of the temperature gradient in the Laue geometry under the influence of temperature gradient perpendicular to the reflecting atomic planes. The works [5, 6] experimentally and theoretically demonstrate that with the help of the acoustic field and temperature gradient the focus position of the reflected radiation can be controlled in space and time, as well as transform a spherical wave into a plane wave. The question of the transfer and control of the focus of the reflected hard X-rays (above 30 keV) is not experimentally examined in these works. Nonetheless, in this context, the obtaining of intense monochromators and lenses with controlled parameters have high perspectives for medicinal [7] and astronomical purposes [8].

In order to obtain monochromators and lenses with controlled parameters in the hard X-ray range (over 30 keV), we have considered the X-ray diffraction in Laue geometry influenced by the temperature gradient. Rectangular plates of single quartz crystal ($30x30 \text{ mm}^2$) with a thicknesses of 6 mm and 9mm were used as testing samples. The heated facets of the planes were parallel to reflecting atomic planes ($10\overline{1}1$), i.e. the temperature gradient was applied perpendicular to those planes. In the sample the temperature gradient was created with the help of a nichrome spiral (figure 1) with the resistance of 0.3 Ohm. The spiral was placed so that the temperature gradient was perpendicular to reflecting atomic planes ($10\overline{1}1$) and the vectors of temperature gradient and diffraction were antiparallel. The dependences of the intensity of reflected X-rays with the energies of 30 keV, 40 keV and 50 keV from reflecting atomic planes ($10\overline{1}1$) on the value of temperature gradient were experimentally studied. Cross-section photos of the reflected beam with the energy of 30 keV were taken at three different distances (4 cm, 35 cm and 110 cm). The experimental design is shown in Fig.1.

Figure 2 presents the dependences of intensities of the reflected beams on the current flowing through the spiral for the energies of 30 and 40 keV. In the experiment we used the continuous X-ray spectrum generated by the Mo BSV-29 X-ray tube. For the reflection energy of 30 keV, the BSV-29 with a molybdenum anode was generated at 35 keV voltage, with the anode current of 10 mA. When the reflection energy was set 40keV, the voltage was 45 keV and the anode current was 10 mA. As one can see in Fig. 2, the intensities of the reflected beams increase more than 60 times when the energy is 30 keV and more than 45 times when the energy is 40 keV. The manifold increase of intensity is caused by the complete transfer of X-rays from the direction of passing to the direction of reflection with great angular width. This angular width is much greater than the Darwin width and depends on the thickness of a single crystal.



Focusing of Hard X-Rays || Armenian Journal of Physics, 2015, vol. 8, issue 2

Fig. 2. The dependence of intensity of reflected X-rays on the current flowing through the spiral. The dots represent the dependence for 30 keV and the triangles show the dependence for 40 keV.

There is an explanation to the sharp decrease of intensity with the simultaneous increase in the current applied to the spiral: at high strains, the extinction length becomes much larger than the effective area (thickness) of diffraction for each of the waves taking part in the diffraction. Since the extinction length is greater for 40 keV than for 30 keV, the saturation is achieved at a lower value of the current on the spiral.

Figure 3 shows the spectrums of reflected and transmitted X-rays from the reflecting atomic planes ($10\overline{1}1$) single quartz crystal with a thickness of 9 mm at 30 keV reflection energy for different values of the temperature gradient.

Spectra were taken with a spectrometer XR-100CR with a resolution of 270 eV on the line Am241 17,74 keV. As can be seen from the spectrum of the reflected X-rays (Fig. 3), with an increase of the temperature gradient values occurs multiple increase of intensity, broadening of the spectrum (due to the curvature of the reflecting atomic planes) and spectral shift to the direction of low-energy (due to an increase of inter-planar distance of reflecting atomic planes).



Fig. 3. Spectra of the reflecting (a) and passing (b) X-rays for different values of the current applied to the spiral: 1) I=0, 2) I=10A, 3) I=0, 4) I=15A, 5) I=20A, 6) I=25A.

The characteristics of the pumping effect in the spectrum of the transmitted radiation as a function of the temperature gradient were simultaneously investigated (Fig. 3b). In the continuous spectrum of the transmitted beam a failure was observed, the depth of which was determined by the temperature gradient and the energy resolution of the detector.

The phenomenon of focusing the reflected beam under the influence of temperature gradient was studied for the energy of 40 keV. For this purpose photographs of the front section of the beam were

taken at distances L_1 , L_2 and L_3 from the sample while exposed to the temperature gradient and without it. The photos show that without temperature gradient, the front sections of the reflected beam gradually get smaller as the distance from the sample increases, i.e. the focal distance is farther from L_3 . In the presence of temperature gradient, the integral intensity of the reflected beam increases, while the front sections of the reflected beams at these distances change in different ways. At the distance L_1 , the front section of the beam remains virtually unchanged with an increase in the value of the temperature gradient. At the distances L_2 and L_3 the section shrinks. Then, after reaching a certain value of the temperature gradient at the distance L_1 , the section expands. It reaches its minimal value at the distance L_3 with the minimal value of the temperature gradient.



Fig. 4. Dependence of the focal length of the reflected beam for the family of reflecting atomic planes of a single quartz crystal $(10\overline{1}1)$ on the intensity of the current applied to the spiral.

As part of the experiment, the front sections of the reflected beam ΔL_1 and ΔL_3 were measured at the distances L_1 and L_3 from the scattering single crystal for different values of the temperature gradient. Using the results of the experiment, one can calculate the position of the focus L_f of the reflected beam in the following way:

$$L_f = \frac{L_3 \Delta L_1 + L_1 \Delta L_3}{\Delta L_3 + \Delta L_1}$$

Figure 4 demonstrates the dependence of the focal length of the reflected beam for the family of reflecting atomic planes of a single quartz crystal $(10\overline{1}1)$ on the intensity of the current applied to the spiral. It can be seen that when the electric current on the spiral increases, the focus moves closer to the crystal. The photos of the front section of the reflected beam show that the focal spot narrows in the diffraction plane.

Thus we have experimentally shown that if the X-ray energies are 30 keV and 40 keV for reflecting atomic planes $(10\overline{1}1)$ of an X-cut single quartz crystal the intensity of the reflected beam can be increased in orders depending on the value of the temperature gradient. It is shown that with the help of the temperature gradient impact it is possible to separate a beam with high angular and spectral width from the white beam, throw it in the direction of reflection and focus it, that is, control the parameters of the beam in a large range.

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