Acoustic “pumping effect” for quartz monochromators

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Abstract. There are investigations of dependences scattered at quartz crystals X-ray in Bragg direction of intensity on amplitude and frequency external alternating electromagnetic field, which initiates acoustic waves in crystal, in spectral mode.

Nowadays the X-rays are widely used for different applied problems of science, technology and medicine. Today X-ray tubes are used as a prevalent source of X-ray. However in some applications, such as medical roentgenology, the standard methods of diagnostics using X-ray tubes run into certain difficulties, caused by radiation of white spectrum by X-ray tubes. Some difficulties can be obviated by using monochromatic X-ray radiation.

The monochromatic X-ray source on the basis of compact electron accelerator is of great interest nowadays. One of the common methods to generate monochromatic X-ray is monochromatization of bremsstrahlung. In the other method the Compton effect is used. The both methods have specific disadvantages. The first case is characterized by low efficiency, because a considerable part of initial X-ray beam is lost due to partial reflection and absorption of radiation by a monochromator. In the second case the installation has low frequency.

In this report it is offered to use a “pumping effect” [1] to improve the parameters of monochromatic X-ray beam on the basis monochromatization of bremsstrahlung. This effect appears in the crystals with ordered deformation. Deformation can be obtained with using constant electrical fields, elastic stresses, temperature gradient, acoustic wave fields etc. For example, in case of using acoustic field the effect appears when a frequency of the excited wave coincides with the resonant frequency determined by:

\[ f_n = \frac{nv}{2l}, \]  

where \( l \) is crystal thickness, \( v \) is sound velocity, \( n \) is odd integer number.

Using the optical elements with “pumping effect” allows adjusting the intensity of monochromatic X-rays source based on diffraction and implement dynamic control and transportation of X-ray beams with minimal loss in the optical elements. Besides, it is possible to control the intensity and form of diffracted beam in time and space with a controlled external influence.

In the papers [2–4] the authors demonstrated the possibility to control the intensity of the diffracted beam in case of application of the acoustic wave field and non-uniform temperature field at the piezoelectric crystal monochromator. Theoretical explanation of “pumping effect” and independent experimental results of investigations of acoustic wave field influence on the process of X-rays coherent scatter at the integral mode are presented in the paper [5].

The purpose of this report is the investigation of “pumping effect” in a spectral mode.
The experimental setup is shown in figure 1. X-ray tube RAP 160-5 was used as a source of X-rays. All measurements were performed with the same parameters of the tube, the voltage and average current were 48 kV and 1 mA, respectively. X-ray tube was placed in lead with 5 cm wall.

The X-cut quartz crystals with different thickness (0.3 and 0.9 mm) were used in the experiment. Aluminium coating was applied on crystal surface for more effective stimulation of acoustic fields in crystal.

Radiation from X-ray tube was formed by 3 mm collimator, which was placed at the distance 90 mm from exit window and after that scattered by quartz crystal, then fixed in the goniometer at the distance of 215 mm from collimator.

Goniometer has three translational and three rotational freedom degrees with accuracy of orientation not worse than 0.5 mm and 10 µrad, respectively. It is possible to install the crystal at the Bragg angle for any families of reflecting atomic planes, so that a detector located in the horizontal plane could register only beams propagating in this plane. The reflection from atomic planes oriented perpendicular to the large surface of the sample (1011) with interplanar distance \( d = 3.3429 \, \text{Å} \) is studied.

Radiation was registered at the symmetric Laue geometry at distance from crystal monochromator equal to 300 mm by semiconductor detector BDER-KI-11K with resolution about 280 eV at the 5.6 keV line. A round lead lengthy collimator with 2 mm diameter and 50 mm length was placed in front of the detector.

Crystal was oriented for the position to satisfy the maximum of rocking curve according to techniques from paper [5].

The theoretical values of resonant frequency were calculated by formula (1) and it is equal to 3.16 and 9.50 MHz for thickness 0.9 and 0.3 mm accordingly. Also frequency was determined by scanning in around theoretical value (figure 2) and after fitting were determined real values of \( f_1 \) (table 1).

| Crystal thickness (mm) | Resonant frequency (MHz) |
|------------------------|--------------------------|
|                        | Theoretical | Experimental |
| 0.90±0.02              | 3.16         | 3.18±0.01    |
| 0.30±0.02              | 9.50         | 9.43±0.03    |
Dependencies of diffracted beam intensity on the frequency of electromagnetic field affect on the monochromator for crystal thickness equal to 0.3 (a) and 0.9 (b) mm.

Dependencies of diffracted beam intensity on voltage value on crystal are presented in figure 3. Data are shown relative to the mean level of diffracted beam intensity without excitation. The initial parts of these dependencies are linear. The length of a linear part depends on crystal’s thickness and equals to 40 V for 0.9 mm and 12.5 V for 0.3 mm.

Radiation spectra for cases of oriented and disoriented crystal are shown in figure 4. At the oriented case is changing only the diffracted beam intensity when deformation field turn on, and spectral line is lost when crystal is disoriented, as it was expected.

**Figure 2.** Dependencies of diffracted beam intensity on the frequency of electromagnetic field affect on the monochromator for crystal thickness equal to 0.3 (a) and 0.9 (b) mm.

**Figure 3.** Dependencies of diffracted beam intensity on amplitude of the voltage for crystals thickness equal to 0.3 (a) and 0.9 (b) mm. Line is mean level of diffracted beam intensity without excitation.

**Figure 4.** Radiation spectra for cases of oriented and disoriented crystal with acoustic wave field (a) and without (b). Thickness of crystal is 0.3 mm.
Spectra in the maximum of rocking curve for different orientation angle for cases of excited and unexcited crystal are presented in figure 5. The Bragg angle was equal to 4.4° and 5.5° that corresponds to energy 24.3 and 19.3 keV. Value of amplitude was equal to 12 and 40 V for crystals with thickness of 0.3 and 0.9 mm accordingly.

According to the experimental results the intensity of X-ray beam into diffraction direction was increased 5.3 and 4.7 times for thickness equal to 0.3 and 0.9 mm, correspondingly. The Width of energy line is determined by experiment conditions and width of detector instrument line.

As figure 5 shows, with the change of orientation angle the energy line changes, and when turning on the external deformation field the intensity of a diffracted beam increases, as it was expected, that allows to speak about prospectivity of using “pumping effect” when creating brighter sources of monochromatic X-ray radiation with controlled parameters of radiation on the basis of bremsstrahlung monochromatisation.

The presented experiments demonstrated an efficiency of the pumping effect. With the help of external influences on the crystal monochromator increasing and tunability of the diffracted X-ray beam intensity are shown. The enhancement of intensity of 5 times under acoustic pumping has been observed. The obtained results suggest the possibility of creating a fast tunable adaptive X-ray optics.

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