X-ray diffraction analysis of the surface acoustic wave propagation in langatate crystal

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Abstract X-ray diffraction on a langatate crystal (La$_3$Ga$_5$Ta$_{0.5}$O$_{14}$, LGT) modulated by a $\lambda = 12 \mu$m Rayleigh surface acoustic wave (SAW) was studied in a double axis X-ray diffractometer scheme at the BESSY synchrotron radiation source. SAW propagation in the crystal causes sinusoidal modulation of the crystal lattice and the appearance of diffraction satellites on the rocking curves, with their number, angular positions, and intensities depending on the wavelength and amplitude of acoustic vibrations of the crystal lattice. Strong absorption of X-ray radiation in LGT enables the observation of the diffraction spectra extinction at certain SAW amplitudes. X-ray diffraction spectra analysis makes it possible to determine SAW amplitudes and wavelengths, to measure the power flow angles, and investigate the diffraction divergence in acoustic beam in LGT.

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1 Introduction

Development of telecommunication systems based on acoustoelectronic devices and operating with digital signals in a real time mode (mobile phones, radio, pages, TV, GPS, etc.) requires the application of new piezoelectric materials. Well-known piezoelectric crystals of quartz, LiNbO$_3$, and LiTaO$_3$ do not meet the requirements of new telecommunication standards. The appearance of piezoelectric crystals of langasite family, which combine the best acoustic properties of LiNbO$_3$ (high value of electromechanical coupling coefficient) and quartz (zero temperature coefficient of frequency), permits to design miniature acoustoelectronic devices with unique properties [1–4].

Another aspect stimulating progress in acoustoelectronics is the development of methods which would enable the investigation of excitation and propagation of surface and bulk acoustic waves in crystals. Of greatest interest among these methods are scanning electron microscopy (SEM), X-ray topography, and high-resolution X-ray diffractometry, which allow visualization of acoustic wave excitation and propagation in the real time mode. SEM in the mode of secondary electron recording can make it possible to visualize surface and bulk, traveling and standing acoustic waves, to study diffraction phenomena in acoustic beams and acoustic wave interaction with crystal structure defects, and to measure acoustic wavelengths and power flow angles [5–10]. However, the SEM method affords only qualitative analysis of acoustic wave propagation and only in piezoelectric materials. Unlike SEM, X-ray diffractometry and topography provide quantitative analysis of acoustic wave field propagation because X-ray radiation is sensitive to sinusoidal crystal lattice modulation caused by acoustic wave propagation. So X-ray methods can be used to study excitation and propagation of acoustic waves both in piezoelec-
tric and nonpiezoelectric crystals. X-ray topography, like SEM, permits one to visualize acoustic wave fields in the real time mode, to study the interaction of acoustic waves with crystal structure defects, and to measure acoustic wavelengths and amplitudes [11–16]. Visualization of acoustic wave field is based on X-ray focusing by X-ray minima that can be regarded as concave focusing mirror, and the distance at which acoustic wave images are observed is determined by the acoustic wavelength and amplitude [11, 15]. The period of an observed image corresponds to the acoustic wavelength. High-resolution X-ray diffractometry together with the analysis of diffraction spectra of acoustically modulated crystals makes it possible to determine amplitudes and wavelengths of acoustic vibrations both in the crystal depth and along the direction of acoustic wave propagation [17–20].

The aim of this work is to study the Bragg diffraction of X-ray on the Y- and X-cuts of an LGT crystal modulated by a SAW. SAW propagation in the crystal causes sinusoidal modulation of the crystal lattice, which acts as an ultrasonic grating. Since the SAW velocity is $10^5$ times slower than that of X-ray photons, the ultrasonic superlattice is stationary for X-ray. The presence of an ultrasonic superlattice in the crystal gives rise to diffraction satellites on a rocking curve. The number of diffraction satellites increases with an amplitude of acoustic vibrations of the crystal lattice, and the angular divergence between diffraction satellites depends on an SAW wavelength.

2 Experimental setup

Diffraction of X-ray radiation on the Y- and X-cuts of the LGT crystal modulated by an SAW was studied in a double axis X-ray diffractometer scheme at the optics beamline KMC2 at the BESSY synchrotron radiation source (Fig. 1). The angular resolution of the double axis diffractometer was 0.5 arcsec, which is sufficient to resolve diffraction satellites on the rocking curve.

X-ray energy of $E = 12$ keV (X-ray wavelength $\lambda = 1.07$ Å) was selected by a double Si(111) monochromator. Primary and secondary slits with horizontal and vertical gaps of $1 \times 1$ and $0.1 \times 0.1$ mm, respectively, were used to collimate the X-ray radiation. A Cyberstar NaI scintillation detector was used to measure the diffracted X-ray intensity.

3 SAW device

LGT is a piezoelectric crystal of space group symmetry 32. The crystal lattice is similar to that of quartz with the parameters $a = 8.235$ Å and $b = 5.128$ Å [21]. The crystal we have studied was grown along the {001} axis by the Czochralski technique at “FOMOS Materials Co.”

The Y-cut ((100) atomic planes parallel to the crystal surface) and X-cut ((110) atomic planes parallel to the crystal surface) of the LGT were used in experiments. An interdigital transducer (IDT) was fabricated on the crystal surface by photolithography techniques for Rayleigh SAW excitation. IDT consists of 20 pairs of electrodes of a 6 µm period, which corresponds to SAW wavelength $\Lambda = 12$ µm. The SAW amplitude on the crystal surface can be varied linearly from 0 to several angstroms by varying the amplitude of the high-frequency electrical signal supplied to the IDT. In the Y-cut of an LGT, at the resonance excitation frequency $f = 186.8$ MHz, the SAW wavelength was $\Lambda = 12$ µm, and the propagation velocity was $V = 2242$ m/s; in the X-cut of an LGT, at the resonance excitation frequency $f = 189.0$ MHz, the SAW wavelength was $\Lambda = 12$ µm, and the propagation velocity was $V = 2268$ m/s. The SAW propagation in the Y- and X-cuts differs essentially. In the Y-cut, the direction of acoustic energy flow coincides with the SAW wave vector, whereas in the X-cut, the data on the direction differ substantially from each other, which makes the examination of SAW propagation in the X-cut more complicated.