HAL
open science

X-ray diffraction on La3Ga5SiO14 crystal modulated by SAW near the K absorption edge of Ga

Dmitry Roshchupkin, Luc Ortega, Simone Vadilonga, Ivo Zizak, Eugenii Emelin, Olga Plotitcyna, Dominique Thiaudière, Wolfram Leitenberger, Vincenzo Formoso, Farid Fettar

To cite this version:

Dmitry Roshchupkin, Luc Ortega, Simone Vadilonga, Ivo Zizak, Eugenii Emelin, et al.. X-ray diffraction on La3Ga5SiO14 crystal modulated by SAW near the K absorption edge of Ga. Applied Physics Letters, 2020, 116 (17), pp.174101. 10.1063/5.0002388 . hal-03063771

HAL Id: hal-03063771

https://hal.science/hal-03063771

Submitted on 4 Jan 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Applied Physics Letters

X-ray diffraction on $La_3Ga_5SiO_{14}$ crystal modulated by SAW near the *K* absorption edge of Ga

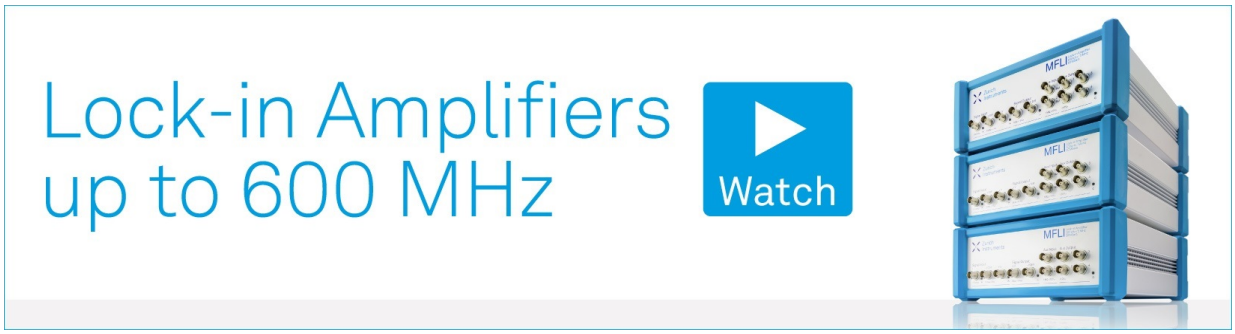
Cite as: Appl. Phys. Lett. **116**, 174101 (2020); https://doi.org/10.1063/5.0002388
Submitted: 28 January 2020 . Accepted: 17 April 2020 . Published Online: 30 April 2020

Dmitry Roshchupkin, Luc Ortega, Simone Vadilonga, Ivo Zizak, Eugenii Emelin, Olga Plotitcyna, Dominique Thiaudière, Wolfram Leitenberger, Vincenzo Formoso, and Farid Fettar

COLLECTIONS

This paper was selected as an Editor's Pick

View Online Export Citation CrossMark



© 2020 Author(s).

Applied Physics Letters ARTICLE scitation.org/journal/apl

X-ray diffraction on $La_3Ga_5SiO_{14}$ crystal modulated by SAW near the *K* absorption edge of Ga

Cite as: Appl. Phys. Lett. **116**, 174101 (2020); doi: 10.1063/5.0002388
Submitted: 28 January 2020 · Accepted: 17 April 2020 ·
Published Online: 30 April 2020

View Online Export Citation CrossMark

Dmitry Roshchupkin,[1,a)] Luc Ortega,[2] Simone Vadilonga,[3] Ivo Zizak,[4] Eugenii Emelin,[1] Olga Plotitcyna,[1] Dominique Thiaudière,[5] Wolfram Leitenberger,[6] Vincenzo Formoso,[7] and Farid Fettar[8]

AFFILIATIONS

[1]Institute of Microelectronics Technology and High Purity Materials Russian Academy of Sciences, 142432 Chernogolovka, Moscow District, Russia
[2]Institut Néel, F-38000 Grenoble, France
[3]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein Strasse 15, 12489 Berlin, Germany
[4]Institute for Nanometre Optics and Technology, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein Strasse 15, 12489 Berlin, Germany
[5]Synchrotron SOLEIL, L'Orme des Merisiers Saint-Aubin, BP 48 91192 Gif-sur-Yvette Cedex, France
[6]Universität Potsdam, Karl Liebknecht Str. 24-25, 14471 Potsdam, Germany
[7]Università degli Studi della Calabria-Dipartimento di Fisica, 87036 Rende, Italy
[8]CNRS/University Grenoble Alpes, F-38000 Grenoble, France

[a)]Author to whom correspondence should be addressed: rochtch@iptm.ru

ABSTRACT

The process of x-ray diffraction on the $La_3Ga_5SiO_{14}$ (LGS) crystal modulated by surface acoustic waves (SAWs) near the *K* absorption edge of Ga ($E = 10\,367$ eV) was studied. A redistribution of the diffracted x-ray intensity between the diffraction satellites occurs at the absorption edge due to the change in the x-ray penetration depth into the crystal and an effective change in the interaction of x-ray radiation with the near-surface crystal region modulated by SAW. The intensity distribution of the diffraction satellites starts to change smoothly immediately after the *K* absorption edge of Ga with a decrease in the x-ray penetration depth into the crystal.

Published under license by AIP Publishing. https://doi.org/10.1063/5.0002388

X-ray diffraction on the crystals modulated by SAWs is the optimal method for studying the process of SAW excitation and propagation in solids and allows us to measure the wavelengths, velocities, amplitudes, and attenuation of SAWs.[1–8] Today, the crystals of the lanthangallium silicate family are one of the most perspective materials for acoustoelectronics due to the high perfection of the crystal structure, the absence of the phase transitions up to the melting point, relatively high (compared to piezoquartz) piezoelectric modules, and low SAW velocities, which allow us to create miniature devices.[9–13] Note that the number of crystal cuts has a zero temperature coefficient of frequency.

Earlier, the high perfection of the crystal structure of LGS family crystals allowed us to observe the extinction of diffraction satellites connected with the small penetration depth of x-ray radiation into the crystal[14,15] and splitting of diffraction satellites due to stretching and compression of the crystal lattice in the SAW maxima and minima, respectively.[16]

The aim of the present investigation was to study the change in the process of x-ray diffraction on the LGS crystal modulated by SAWs at the *K* absorption edge of Ga.

The *Y*-cut of an LGS crystal was used to study the process of x-ray diffraction near the absorption edge of Ga. An interdigital transducer (IDT) was fabricated on the crystal surface for the SAW excitation with the wavelength of $\Lambda = 4\ \mu$m. The SAW propagation velocity in the *Y*-cut of the LGS crystal along the *X*-axis is $V = 2278$ m/s. The resonance SAW excitation frequency was $f = V/\Lambda = 569.5$ MHz.

Studies of x-ray diffraction on the LGS crystal modulated by SAWs were performed in the meridional diffraction geometry in the scheme of a double axis x-ray diffractometer, schematically shown in Fig. 1 on the DIFFABS optical beamline at the SOLEIL synchrotron radiation source and on the KMC 3 optical beamline at the BESSY II synchrotron radiation source. X-ray radiation was collimated by primary slits of 1×1 mm^2. Then, x-ray energy was selected using a

Published under license by AIP Publishing

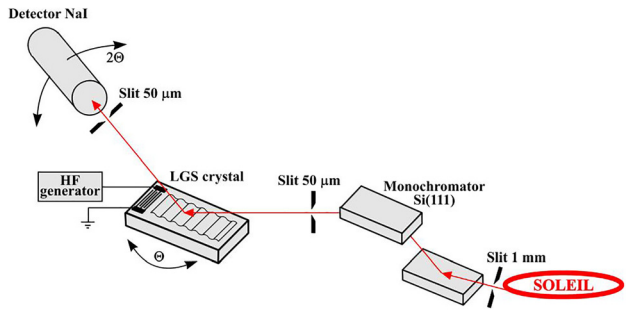


FIG. 1. Experimental setup of a double axis x-ray diffractometer.

Si(111) double-crystal monochromator and was collimated by a secondary slit of $50 \times 50\ \mu m^2$. X-ray radiation at the Bragg incident angle falls on the crystal under study. The reflection from planes (100) in the Y-cut of the LGS crystal was used for studies. Diffracted x-ray radiation was recorded using a standard NaI scintillation detector. SAW propagation in the crystal leads to sinusoidal modulation of the crystal lattice and the appearance of diffraction satellites on both the sides of the Bragg peak in the rocking curve.[1,2] If the amplitude of the diffraction satellites is determined by the amplitude of the SAW, the angular divergence between the diffraction satellites is defined as

$$\delta\Theta_{mRC} = md/\Lambda, \tag{1}$$

where m is the number of diffraction satellites, d is the interplanar spacing, and Λ is the SAW wavelength.

The investigation was carried out in the x-ray energy range of 10 300 to 10 500 eV. In this range, the rocking curves of the Y-cut of the LGS crystal modulated by the SAW with an energy step of 1 eV were measured. In kinematic approximation, the depth of x-ray penetration in the LGS crystal is determined as a function of x-ray energy,

$$\mu_z^{-1}(E) = \sin\Theta_B(E)/2\mu_l(E), \tag{2}$$

where μ_l is the linear absorption coefficient and Θ_B is the Bragg incidence angle of x-ray radiation. Calculated from exp. (2), the dependence of the x-ray penetration depth in the LGS crystal for reflection (100) is shown in Fig. 2. The presence of the K-edge of Ga at $E = 10\,367$ eV causes a radical change in the absorption coefficient and x-ray penetration depth, respectively. At the K-edge, the penetration depth decreases from 3 to 1.6 μm. It should be taken into account that the SAW penetration depth into the crystal does not exceed one SAW wavelength, and the SAW amplitude in the crystal depth decreases according to the exponential law.[14,15,17,18] In this case, the efficiency of x-ray interaction with the crystal region modulated by SAWs increases at the absorption edge. As a result, this leads to the redistribution of the diffracted x-ray intensity between the diffraction satellites.

The intensities of the diffraction satellites are described by the Bessel functions of the corresponding orders in accordance with the following expression:[14,16]

$$I_m \sim \left| \int_0^\infty \exp(-\mu_z z) \cdot J_m(h \cdot q_z \cdot u(z))dz \right|^2, \tag{3}$$

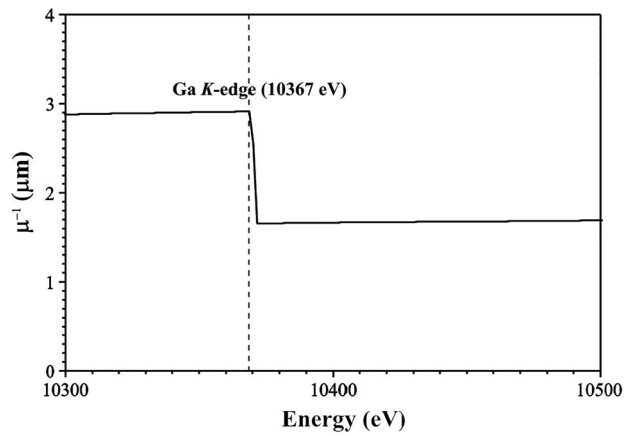


FIG. 2. X-ray penetration depth in the LGS crystal for (100) reflection vs x-ray energy.

where J_m is the Bessel function of the mth diffraction satellites, h is the SAW amplitude, $u(z)$ is the normal component of the crystal lattice displacement in crystal depth z, and q_z is the modulus of the reciprocal lattice vector. The dependences of the intensities of diffraction satellites on the SAW amplitude (amplitude of the input signal U supplied to the IDT) are shown in Fig. 3 for an x-ray energy of $E = 10\,500$ eV. If the intensity of the Bragg peak with the increasing amplitude of the input signal supplied to the IDT (increasing in the SAW amplitude) begins to decrease, the diffraction satellites appear on the rocking curve at different SAW amplitudes, begin to grow with the increasing SAW amplitude, and reach a maximum value. Thus, in our studies, the first diffraction satellite reached its maximum value with the amplitude of the input high-frequency signal supplied to the IDT $U = 20$ V.

The results of x-ray diffraction on the Y-cut of an LGS crystal modulated by the SAW with the wavelength of $\Lambda = 4\ \mu$m in the x-ray energy range of 10 300 to 10 500 eV are shown in Fig. 4. The studies

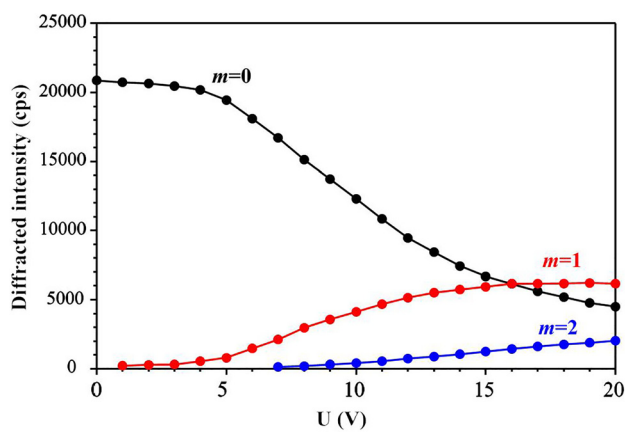


FIG. 3. Intensities of the diffraction satellites ($m = 0,\ 1,\ 2$) vs amplitude of the input signal supplied to the IDT U [circles—experimental data; solid line—calculations from exp. (3)]. X-ray energy $E = 10\,500$ eV; Y-cut of an LGS crystal; $\Lambda = 4\ \mu$m; reflection (100); $\Theta_B = 4.919°$.

Published under license by AIP Publishing

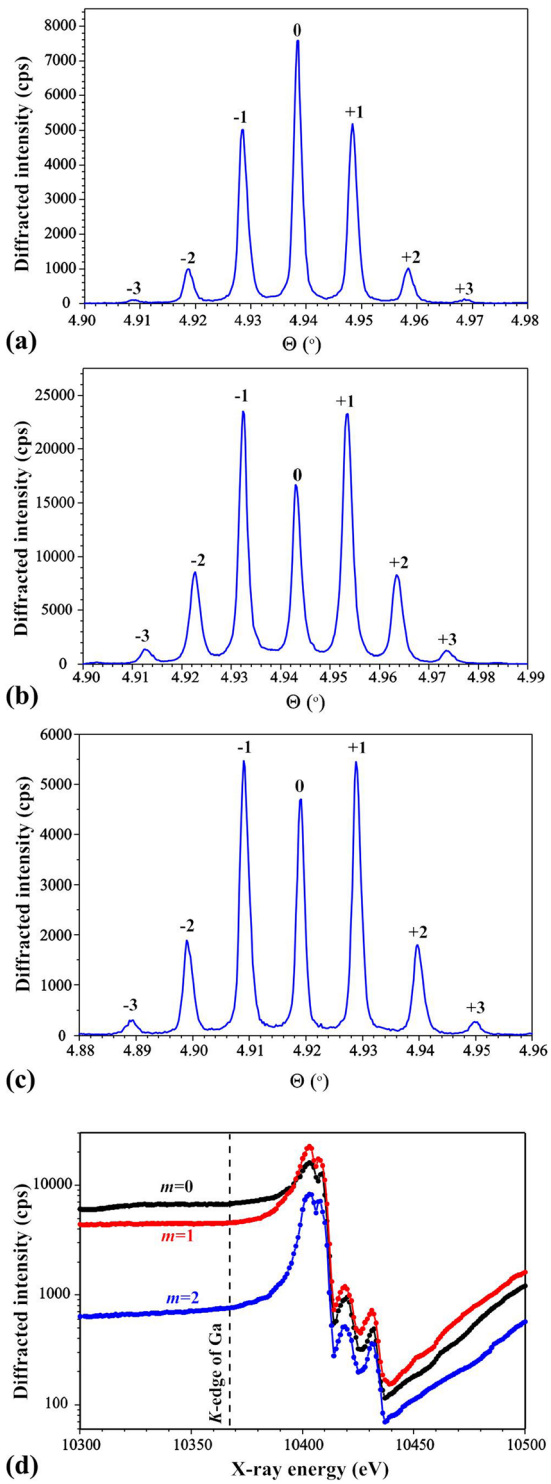


FIG. 4. X-ray diffraction on the *Y*-cut of an LGS crystal modulated by SAWs: (a)–(c) rocking curve measured at x-ray energies of 10 300 eV, 10 400 eV, and 10 500 eV, respectively; (d) intensities of the diffraction satellites ($m = 0, \quad 1, \quad 2$) vs x-ray energy. $\Lambda = 4\ \mu$m; reflection (100).

were carried out with the amplitude of the input signal supplied to the IDT $U = 20$ V. Figure 4 shows the rocking curve measured before (a) and after the *K* absorption edge of Ga (b)–(c). A strong absorption begins at the absorption edge in accordance with Fig. 2, and a substantial decrease in the x-ray penetration depth into the crystal occurs from 3 to 1.6 μm. The efficiency of x-ray interaction with the near-surface region modulated by SAWs increases after the absorption edge due to a decrease in the x-ray penetration depth. This leads to a redistribution of the diffracted intensities between the diffraction satellites. It can be seen from the rocking curves that before the *K*-edge of Ga, the intensity of the zero diffraction satellite exceeds the intensities of the first diffraction satellites because x-ray radiation diffracts on both the SAW modulated near-surface region and the deeper nonmodulated region [Fig. 4(a)]. After the absorption edge, the first diffraction satellite slowly increases with respect to the zero diffraction satellite as the x-ray penetration depth decreases [Fig. 4(b)], reaches its maximum with the minimum x-ray penetration depth, and then starts to decrease gradually with the subsequent increase in the x-ray penetration depth [Fig. 4(c)]. In the case of a SAW wavelength of $\Lambda = 4\ \mu$m and an x-ray penetration depth of 1.6 μm after the absorption edge, the diffraction process corresponds to the kinematic diffraction since, in this case, x-ray radiation diffracts only on the near-surface region modulated by the SAW (the SAW penetration depth exceeds the x-ray penetration depth).[14,15] The angular divergence between diffraction satellites on the rocking curve is independent of x-ray energy and is $\delta\Theta_{mRC} = 0.011°$, which corresponds to the calculated value from expression (1). It should be noted that the number of diffraction satellites on the rocking curve does not change.

Dependences of the diffraction satellite intensities vs X-ray energy in the range of 10 300 to 10 500 eV are shown in Fig. 4(d). It is clearly seen that the redistribution of the diffracted x-ray intensities between the diffraction satellites begins at the *K*-edge of Ga. The intensity of the zero diffraction order exceeds the intensities of the first diffraction satellites before the absorption edge. The intensities of the first diffraction satellites exceed the intensity of the zero diffraction order after the *K*-edge of Ga due to a decrease in the x-ray penetration depth into the crystal, and x-ray radiation diffracts only on the SAW modulated near-surface region. Thus, at the absorption edge, there is a redistribution of diffracted x-ray intensity between diffraction satellites due to the decrease in the x-ray penetration depth.

It should also be noted that after the Ga absorption edge, when the depth of x-ray penetration decreases, the intensity of diffracted x-ray radiation increases. Previously, this phenomenon was observed when studying x-ray diffraction on GaAs crystals.[19] The present study with the energy step of 1 eV allowed us to observe the oscillations of the diffracted x-ray intensity after the *K* absorption edge of Ga [Fig. 4(d)]. There are four oscillations that are related to the structure of Ga atoms, which have four electron shells. The presence of these oscillations does not affect the process of x-ray diffraction on the *Y*-cut of the LGS crystal modulated by SAWs. Usually, the structure of atoms and chemical bonds are studied using EXAFS spectroscopy,[20,21] but it turns out that this can also be observed in the process of x-ray Bragg diffraction at the absorption edge.

These studies were carried out at the BESSY II and SOLEIL synchrotron radiation sources and showed the same results. Investigations of the x-ray diffraction process on the LGS crystal modulated by SAWs demonstrated a change in the distribution of the diffracted x-ray

Published under license by AIP Publishing

intensities between the diffraction satellites in the rocking curve near the K absorption edge of Ga due to the change in the x-ray penetration depth into the crystal and an effective change in the interaction of X-ray radiation with the near-surface crystal region modulated by SAWs.

This work was done according to the state task of Ministry of Science and Higher Education of the Russian Federation (No. 075-00920-20-00). We thank the Helmholtz-Zentrum Berlin für Materialien und Energie GmbH and SOLEIL for the allocation of synchrotron radiation beam times.

REFERENCES

[1]E. Zolotoyabko, D. Shilo, W. Sauer, E. Pernot, and J. Baruchel, Appl. Phys. Lett. **73**, 2278 (1998).
[2]R. Tucoulou, F. de Bergevin, O. Mathon, and D. Roshchupkin, Phys. Rev. B **64**, 134108 (2001).
[3]J.-D. Nicolas, T. Reusch, M. Osterhoff, M. Sprung, F. J. R. Schülein, H. J. Krenner, A. Wixforth, and T. Saldit, J. Appl. Crystallogr. **47**, 1596 (2014).
[4]T. Reusch, F. Schülein, C. Bömer, M. Osterhoff, A. Beerlink, H. J. Krenner, A. Wixforth, and T. Salditt, AIP Adv. **3**, 072127 (2013).
[5]R. Tucoulou, R. Pascal, M. Brunel, O. Mathon, D. V. Roshchupkin, I. A. Schelokov, E. Cattan, and D. Remiens, J. Appl. Crystallogr. **33**, 1019–1022 (2000).
[6]I. A. Schelokov, D. V. Roshchupkin, D. V. Irzhak, and R. Tucoulou, J. Appl. Crystallogr. **37**, 52–61 (2004).
[7]R. Tucoulou, O. Mathon, C. Ferrero, V. Mocella, D. V. Roshchupkin, and R. E. Kumon, J. Appl. Phys. **97**, 113505–113505 (2005).
[8]V. I. Punegov, Y. I. Nesterets, and D. V. Roshchupkin, J. Appl. Crystallogr. **43**, 520–530 (2010).
[9]R. Singh, S. K. R. S. Sankaranarayanan, and V. R. Bhethanabotla, Appl. Phys Lett. **94**, 263503 (2009).
[10]H. Fritze and H. L. Tuller, Appl. Phys. Lett. **78**, 976–977 (2001).
[11]K. Shinekumar and S. Dutta, J. Electron. Mater. **44**, 613–622 (2015).
[12]T. Sahaa, N. Guo, and N. Ramakrishnan, Sens. Actuators, A **252**, 16–25 (2016).
[13]S. Sakharov, D. Roshchupkin, E. Emelin, D. Irzhak, O. Buzanov, and A. Zabelin, Procedia Eng. **25**, 1020–1023 (2011).
[14]D. V. Roshchupkin, D. V. Irzhak, R. Tucoulou, and O. A. Buzanov, J. Appl. Phys. **94**, 6692 (2003).
[15]D. V. Roshchupkin, A. I. Erko, L. Ortega, and D. V. Irzhak, Appl. Phys. A **94**, 477–484 (2009).
[16]D. Irzhak and D. Roshchupkin, J. Appl. Phys. **115**, 244903 (2014).
[17]*Surface Acoustic Wave Devices and Their Signal Processing Applications*, edited by C. Campbell (Academic Press, San Diego, 1989), pp. 1–484.
[18]E. Dieulesaint and D. Royer, *Ondes Elastique Dans Les Solides* (Masson, Paris, 1974), pp. 1–308.
[19]S. Zhou, Z. Zhao, T. Fukamachi, R. Negishi, M. Yoshizawa, and T. Nakajima, Physica B **228**, 390 (1996).
[20]M. Katsikini, F. Pinakidou, E. C. Paloura, J. Arvanitidis, S. Ves1, U. Reinholz, E. Papadomanolaki, and E. Iliopoulos, J. Phys.: Conf. Ser. **712**, 012126 (2016).
[21]G. Vlaica and L. Olivi, Croat. Chem. Acta **77**, 427–433 (2004).

Published under license by AIP Publishing