

EFFECT OF DOPING WITH THE D-ELEMENT Cr ON THE X-RAY CONDUCTIVITY OF A 2D TiGaS₂ SINGLE CRYSTAL

S.N. MUSTAFAEVA¹, S.M. ASADOV^{2,3}

¹*Institute of Physics of the Ministry of Science and Education of Azerbaijan, Baku*

²*Research Institute "Geotechnological Problems of Oil, Gas and Chemistry" ASOIU.
Ministry of Science and Education of Azerbaijan, Baku*

³*Institute of Catalysis and Inorganic Chemistry named after. M.F. Nagiyev Ministry of
Science and Education of Azerbaijan, Baku
E-mail: solmust@gmail.com*

The influence of chromium doping (0.5 mol.% Cr) on the X-ray dosimetric characteristics of the layered TiGaS₂<Cr> single crystal was studied. The X-ray conductivity coefficient of a TiGaS₂<Cr> single crystal at 298 K varies within $K_{\sigma} = 0.1 - 0.43 \text{ min/R}$ at an effective radiation hardness $V_a = 25-50 \text{ keV}$ with a dose rate $E = 0.75-78.05 \text{ R/min}$. The dependence of the stationary X-ray current on the X-ray dose in TiGaS₂<Cr> single crystals has a power-law character.

Keywords: TiGaS₂<Cr>, single crystal, X-ray conductivity coefficient, radiation hardness.

1. INTRODUCTION

Ionizing radiation is used in many aspects of modern life: in science, industry, power generation, and medicine [1-10]. The most important task of dosimetry is to determine the radiation dose in various environments, especially in the tissues of a living organism. Quantitative determination of the radiation dose acting on a living organism is necessary, first of all, to assess and prevent possible radiation hazards to humans. Radiobiologists must determine the maximum permissible levels of radiation from a biological hazard point of view, and dosimetrist-physicists must ensure that these levels are measured correctly. In this regard, the search for new sensitive semiconductor materials for detecting ionizing radiation is relevant.

TiGaS₂ compounds belong to the class of wide-band-gap semiconductors with a layered structure and are characterized by high sensitivity to electromagnetic radiation in both the visible and X-ray regions of the spectrum. Doping TiGaS₂ single crystals with metals makes it possible to control their physical properties. In [11–16], the effect of partial substitution of gallium by transition metals (Mn, Cr, Co) in TiGaS₂ single crystals on their *ac*-conductivity, dielectric and photoelectric properties was studied. The introduction of various impurities into these crystals makes it possible to increase their X-ray sensitivity.

The aim of the work is – to establish the patterns of influence of chromium doping of the half-filled d-orbital ([Ar] 3d⁵4s¹) on the X-ray conductivity of the photosensitive TiGaS₂ single crystal.

2. EXPERIMENTAL PART

The methods of synthesis, growth of single crystals, doping and measurement of dosimetric properties of samples were similar to that described by us earlier in works [11–16]. To obtain TiGaS₂ and homogeneous samples of TiGaS₂<Cr> (the chromium content in the crystals was 0.5 mol.%), the method of

direct synthesis of initial high-purity (≥99.999%) elements was used. Samples of TiGaS₂ and TiGaS₂<Cr> single crystals were grown by the Bridgman-Stockbarger method. The grown TiGaS₂ and TiGaS₂<Cr> single crystals were layered and easily cleaved along the basal plane of the crystals.

TiGaS₂<Cr> samples for measurements were made in a sandwich version. Silver paste was used as a contact material. The thickness of the crystals was 500–700 μm.

URS-55a type installation with a BSV-2(Cu) tube was used as an X-ray source. The intensity of the X-ray radiation was controlled by varying the current in the tube at each given value of the accelerating potential on it. The absolute values of X-ray radiation doses were measured with a DRGZ-02 crystalline X-ray dosimeter. The change in the conductivity of the studied samples under the influence of X-ray radiation was recorded in the mode of low load resistance ($R_1 \ll R_{\text{cryst}}$).

3. RESULTS AND ITS DISCUSSION

Below are the results of studying the X-ray dosimetric properties of TiGaS₂<Cr> single crystals. All measurements were carried out at $T = 298 \text{ K}$.

The studied TiGaS₂<Cr> single crystals exhibited high sensitivity to X-ray radiation. The X-ray conductivity coefficient (K_{σ}), which characterizes the X-ray sensitivity of the crystals under study, was determined as the relative change in conductivity due to X-ray irradiation per unit dose:

$$K_{\sigma} = (\sigma_E - \sigma_0) / \sigma_0 \cdot E,$$

where σ_0 – is dark conductivity, σ_E – is the conductivity under the influence of X-ray irradiation at dose rate E (R/min).

X-ray dosimetry measurements were carried out on TiGaS₂<Cr> samples manufactured in a sandwich version. The values of the characteristic coefficients of TiGaS₂<Cr> were determined for different values of

the accelerating potential (V_a) on the tube and corresponding doses of X-ray radiation.

Figure shows the dependences $K_\sigma(E)$ for $TiGaS_2<Cr>$, and Table shows for comparison the

values K_σ for $TiGaS_2$ at $T = 298$ K and an external applied voltage $F = 80$ V/cm from the Ohmic section of the current-voltage characteristic.

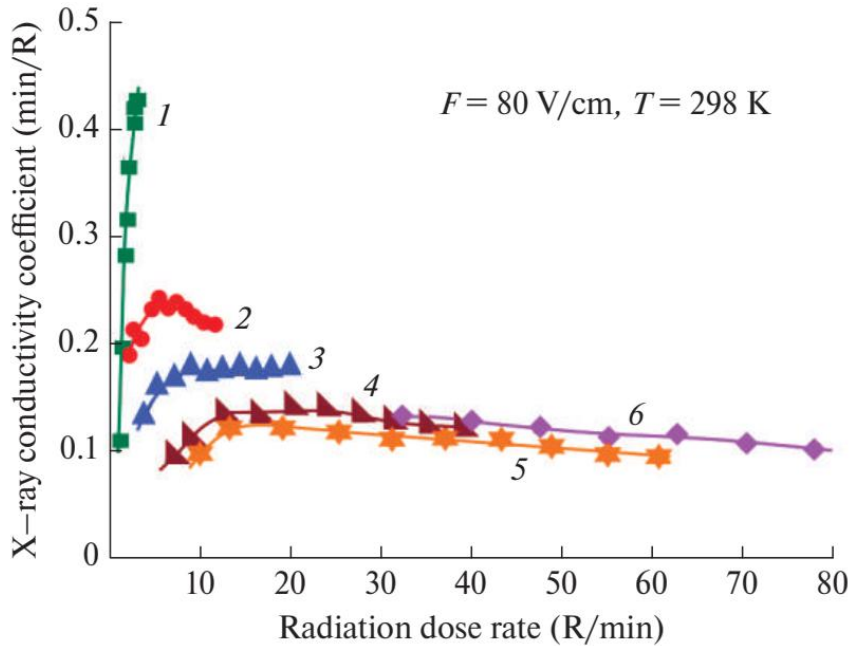


Figure. Dependences of the X-ray conductivity coefficient on the irradiation dose rate for a $TiGa_{0.995}Cr_{0.005}S_2$ single crystal at various accelerating voltages on the tube V_a , keV: 1–25; 2–30; 3–35; 4–40; 5–45; 6–50.

As can be seen from Figure and Table, the X-ray sensitivity of a $TiGaS_2$ single crystal varies in the range 0.025 – 0.174 min/R, and in $TiGa_{0.995}Cr_{0.005}S_2$ $K_\sigma = 0.1 – 0.43$ min/R, i.e. the X-ray conductivity coefficient of a $TiGaS_2<Cr>$ single crystal is significantly higher than that of a $TiGaS_2$ single crystal. Analysis of the obtained experimental results showed that K_σ both $TiGaS_2$ and $TiGa_{0.995}Cr_{0.005}S_2$ decrease with increasing accelerating voltage.

The X-ray current characteristics of $TiGa_{0.995}Cr_{0.005}S_2$ single crystals have also been studied, from which it follows that the dependence of the steady-state X-ray current on the X-ray dose is power-law in nature:

$$\Delta I_{E,0} = I_E - I_0 \sim E^\alpha.$$

The obtained results have demonstrated that doped by chromium $TiGaS_2$ single crystals are characterized by a high X-ray sensitivity and can be used in the design of uncooled (operable at room temperature) X-ray detectors. Such miniature X-ray detectors can find wide application in space technology, in the development of oil wells, as well as in medicine for clinical examination and diagnosis of internal organs of living organisms.

X-ray conductivity coefficients of a $TiGaS_2$ single crystal ($F = 80$ V/cm; $T = 300$ K)

Table

E, R/min	$K_\sigma, 10^{-2}$ min/R	V_a , keV	E, R/min	$K_\sigma, 10^{-2}$ min/R	V_a , keV
0.75	9.33	25	7.0	3.57	40
1.26	10.28		8.89	4.38	
1.47	12.91		12.6	4.53	
1.68	14.88		16.38	4.21	
1.82	15.92		20.09	4.33	
2.03	16.24		23.8	4.08	
2.24	17.40		27.58	3.96	
2.38	17.24		31.29	3.82	
2.59	16.59		35.07	3.40	
2.73	16.48		38.78	3.32	
1.75	6.30	30	10.00	3.90	45
2.73	6.95		13.37	3.52	

3.64	7.96		19.32	3.36	
4.62	7.57		25.34	3.28	
5.53	8.14		31.29	3.16	
6.44	7.92		37.24	3.10	
7.42	7.69		43.26	2.97	
8.33	7.33		49.21	2.82	
9.31	6.98		55.23	2.70	
10.22	7.14		61.18	2.57	
3.75	5.06		13.05	3.45	
5.18	5.99		17.01	3.47	
7.0	6.14		24.64	3.21	
8.82	6.24		32.27	3.07	
10.64	5.92	35	39.9	3.04	50
12.46	5.70		47.53	2.92	
14.28	5.39		55.16	2.89	
16.1	5.03		62.79	2.80	
17.92	4.86		70.42	2.65	
19.74	4.71		78.05	2.52	

4. CONCLUSION

Thus, the results of studying the X-ray dosimetric properties of TlGaS₂<Cr> single crystals showed that partial replacement of gallium with chromium leads to an increase in the X-ray conductivity coefficient. In addition, the X-ray dosimetric characteristics of TlGaS₂<Cr> single crystals, compared to TlGaS₂, were

more stable and well reproducible, which is very important for the use of these crystals as active elements of uncooled X-ray detectors.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

- [1] A. Meghzifene, D.R. Dance, D. McLean, H.-M. Kramer. Dosimetry in diagnostic radiology. European Journal of Radiology. 2010. Vol. 76. P.11–14. <https://doi.org/10.1016/j.ejrad.2010.06.032>
- [2] E.B. Podgoršak, Fundamentals of radiation dosimetry. In: Radiation physics for medical physicists. Springer, Cham. 2016. P. 643–670. https://doi.org/10.1007/978-3-319-25382-4_15
- [3] D. Richter, D. Mittelstra, S. Kreuzer, R. Pintaske, K. Dornich, M. Fuchs. A new fully integrated X-ray irradiator system for dosimetric research. Applied Radiation and Isotopes. 2016. Vol. 112. P. 122–130. <https://doi.org/10.1016/j.apradiso.2016.03.022>
- [4] D. Alamoudi, A. Lohstroh, H. Albarakaty. The effect of dose enhancement near metal interfaces on synthetic diamond based X-ray dosimeters. Radiation Physics and Chemistry. 2017.S0969806X1730289X. <https://doi.org/10.1016/j.radphyschem.2017.03.010>
- [5] S.M. Asadov, S.N. Mustafaeva, D.T. Guseinov. Dependence of the X-Ray Dosimetric Parameters of AgGaS_{2x}Se_{2-2x} Single Crystals on Their Composition. Technical Physics. 2018. Vol. 63, No. 4. P. 546–550. <https://doi.org/10.1134/S1063784218040047>
- [6] W.B. Li, A. Belchior, M. Beuve et al. Intercomparison of dose enhancement ratio and secondary electron spectra for gold nanoparticles irradiated by x-rays calculated using multiple Monte Carlo simulation codes. Phys Med. 2020. Vol. 69. P. 147–163. <https://doi.org/10.1016/j.ejmp.2019.12.011>
- [7] E.G. Yukihara, S.W.S. McKeever, C.E. Andersen et al. Luminescence dosimetry. Nat. Rev. Methods Primers. 2022. Vol. 2. No. 26. <https://doi.org/10.1038/s43586-022-00102-0>
- [8] V. Chopra, Y.R. Parauha, D. Poelman, S.J. Dhoble. Radiation Dosimetry Phosphors. Chapter 2 - Principle, mechanism, and models of radiation dosimetry. 2022. P. 27-45. <https://doi.org/10.1016/B978-0-323-85471-9.00012-9>
- [9] E. Aboelezz, B.W. Pogue. Review of nanomaterial advances for ionizing radiation dosimetry. Appl. Phys. Rev. 2023. Vol. 10. P. 021312. <https://doi.org/10.1063/5.0134982>
- [10] M.D. Salman, Y.M. Radzi, A.A. Rahman et al. Advancements and applications of dosimetry techniques in modern medical radiation therapy: a comprehensive review. J Radioanal Nucl Chem. 2024. Vol. 333, P. 3713–3737. <https://doi.org/10.1007/s10967-024-09517-3>
- [11] S.N. Mustafaeva. Dielectric properties of TlGa_{1-x}Mn_xS₂ single crystals (0 ≤ x ≤ 0.03). Inorganic Materials. 2006. Vol. 42. No. 5. P. 530–533.
- [12] S.N. Mustafaeva. High-frequency dielectric measurements of doped single crystal TlGaS₂<Cr>. Journal of Radioelectronics. 2008. No. 8. P. 1–8.

- [13] *S.N. Mustafaeva*. Dispersion of dielectric coefficients and *ac*-conductivity of $\text{TlGa}_{1-x}\text{Co}_x\text{S}_2$ single crystals in the radio frequency range. *Journal of Radioelectronics*. 2009. No. 4. P. 1-10.
- [14] *S.N. Mustafaeva*. Photoelectric and X-ray dosimetric properties of $\text{TlGa}_{0.97}\text{Mn}_{0.03}\text{S}_2$ single crystals. *Inorganic Materials*. 2009. Vol. 45. No. 6. P. 659–662.
- [15] *S.N. Mustafaeva*. Parameters of localized states in TlMX_2 (M=In, Ga; X=S, Se) single crystals doped by transition metals. Book of Abstracts. 16th International Conference on Ternary and Multinary Compounds (ICTMC-16). Technical University Berlin, Germany. Sept. 15-19, 2008. ID:23
- [16] *S.N. Mustafaeva, M.M. Asadov, S.S. Guseinova, A.I. Dzhabarov, V.F. Lukichev*. Electronic, dielectric properties and charge transfer in a $\text{TlGaS}_2:\text{Nd}^{3+}$ single crystal at direct and alternating current. *Physics of the Solid State*. 2022. Vol. 64. No. 4. P. 426–433. <https://doi.org/10.21883/PSS.2022.04.53497>. 251