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The influence of a hydrocarbon environment with aliphatic and cyclic chain structures on the volt-ampere characteristic of the Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structure

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The volt-ampere characteristic of Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structures in the medium of butane gas and benzene vapors was measured in direct current mode. The molar percentage of elements in the composition of the substance $Ge_{33}As_{17}S_{35}Se_{15}$ synthesized for experiments, and the amorphous structure of the substance were determined by energy dispersive spectroscopy and X-ray diffraction scattering. The images on 2D and 3D diagrams of the influence of the butane gas and benzene vapor environment on the electrical resistance of the substance under study show that the change in the resistance value noticeably depends on the composition and type of the hydrocarbon environment.

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1. Introduction

Currently, in the context of environmental monitoring, there is a significant need to develop sensors that operate over a relatively variable temperature range. A comparative analysis of studies in this area shows that materials with a complex inorganic structure containing chalcogenic elements—sulfur (S), selenium (Se), and tellurium (Te) —exhibit an extremely high crystallization rate, high optical contrast between amorphous and crystalline phases, and high conductive properties in the crystalline phase. The conductivity, as well as the coefficients of optical refraction, extinction, and absorption, can be controlled depending on the composition, and these materials have glass transition and crystallization temperatures. This has created the basis for an increase in their areas of application [1-6]. The results of the mentioned studies show that the principle of operation of devices based on chalcogenide glasses is based on the mechanism of occurrence of various physical phenomena. On the other hand, to determine the selectivity of the obtained structures in terms of gas sensitivity, it is necessary to conduct analogous studies [7] in an environment of gas vapors and other hydrocarbons (such as benzene) that do not contain impurities.

The purpose of the presented work is to clarify the physical principles of the sensitivity of Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structures to the environment of butane gas and benzene vapors, as well as their suitability for use.

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2. Experimental details

The syntheses of $Ge_{33}As_{17}S_{35}Se_{15}$ chalcogenide glass semiconductor were performed in a rotary furnace [7]. The molar percentage of elements in the composition of the synthesized substance $Ge_{33}As_{17}S_{35}Se_{15}$ was determined by the method of energy dispersive spectroscopy. Energy dispersive X-ray analysis was performed by scanning electron microscope JEOL JSM-6610LV.

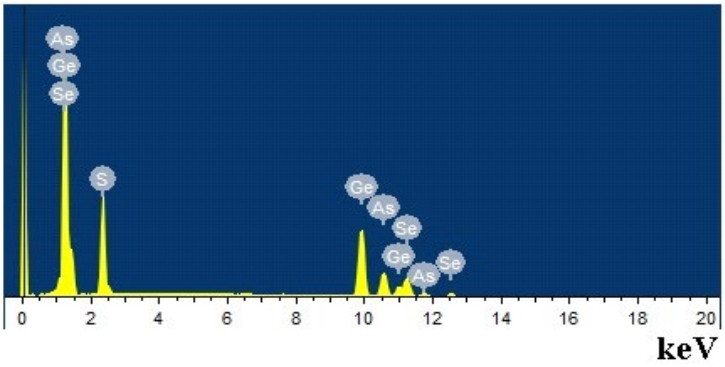

Fig. 1. Energy dispersive X-ray analysis of composition $Ge_{35.16}As_{14.84}S_{34.34}Se_{15.66}$.

The results of energy dispersive X-ray analysis show that the molar percentages of the constituent elements of the synthesized substance correspond to the composition selected for the study, with an error range of ±0.04 to ±2.24. X-ray diffraction analysis of a thin layer of the $Ge_{33}As_{17}S_{35}Se_{15}$ composition obtained by thermal evaporation in vacuum, obtained during the study, was carried out using a powder diffractometer D2 Phaser. The radiation source is the CuKa anode, operating in a voltage of 40 kV and a current of 40 mA. Its wavelength is =1,5406A^0. The volt-ampere characteristic was measured in thin amorphous sheets with a sandwich structure Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te, having a thickness of d = 2 microns, obtained by thermal evaporation in a vacuum on glass substrates. The amount of gas was determined using a MESTEK CGD02A detector.

3. Discussion

Fig. 2 shows the X-ray diffraction scattering spectrum of the complex composition $Ge_{33}As_{17}S_{35}Se_{15}$. The observation of the expanded X-ray diffraction scattering curve confirms that the structure of the obtained substance is predominantly amorphous. As can be seen from the X-ray diffraction scattering curve, the first sharp diffraction peak (FSDP) is observed around the value of the scattering vector Q~1$Å^{-1}$. This result corresponds to the BKDP state obtained as a result of X-ray and neutron diffraction scattering experiments conducted on various binary As_2Se_3 (As_2S_3), $GeSe_2$ and complex component chalcogenide glasses $As_xSe_yS_{1-x-y}$, $As_xSe_yTe_{1-x-y}$(x=40, y=30 at%), $As_xSe_yS_{1-x-y}$, $As_xSe_yTe_{1-x-y}$ (x=33.3, y=33.3 at%) [6,8]. The observation of the FSDP in the spectrum of the amorphous substance, characterized by a covalent bond, is associated with the presence of average order in the structure, with a size of L~33,7Å [9].

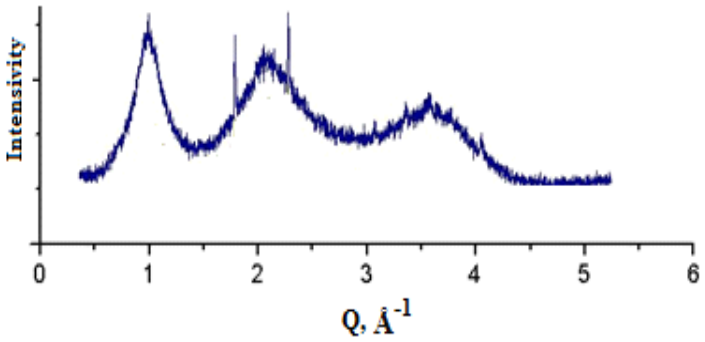

Fig. 2. The X-ray diffraction scattering spectrum of composition $Ge_{33}As_{17}S_{35}Se_{15}$.

Fig.3 shows the volt–ampere characteristic (VACh) of the Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structure in the atmosphere, as well as in butane gas and benzene vapor. As can be seen from the characteristic, an increase in the amount of butane gas and benzene vapors, which have open (aliphatic or acyclic) and closed (cyclic) chain structures, results in an increase in the resistance of the substance under study.

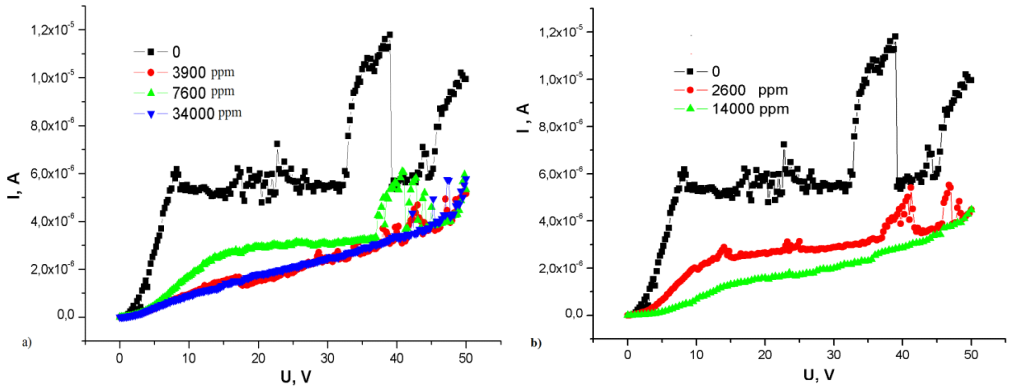

Fig. 3. Volt-ampere characteristic of the Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structure in the atmosphere, butane gas (a) and benzene vapor (b).

A comparative analysis of the obtained results shows that as a result of the influence of hydrocarbon environment, both with aliphatic and cyclic chain structures, the current oscillations of both characteristics weaken and disappear. The gradual weakening and disappearance of oscillations is due to the effects of U^- -centers on ionization processes as a result of the accumulation of neutral gas atoms to low atomic density domains or pores [7]. To identify the presence of selectivity in the sensory properties of the structure, depending on the composition and type of hydrocarbon medium, the change in resistance under the influence of the amount of butane gas and benzene vapors at various transition voltages is depicted by 2D and 3D diagrams. Studies have shown that the principle of operation of radiation-resistant high-temperature sensors based on binary Ge_xSe_{100-x} and Ge_xS_{100-x} (x = 30,33,40) chalcogenide glasses is based on a change in the power of a fiber laser during the transition from an amorphous phase to a crystalline phase [1]. This also results in a change in optical parameters. On the other hand, Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structures obtained by thermal evaporation in vacuum on the basis of complex component chalcogenide glass ($Ge_{33}As_{17}S_{35}Se_{15}$) undergo a noticeable change in resistance in the propane-butane gas mixture environment [7].

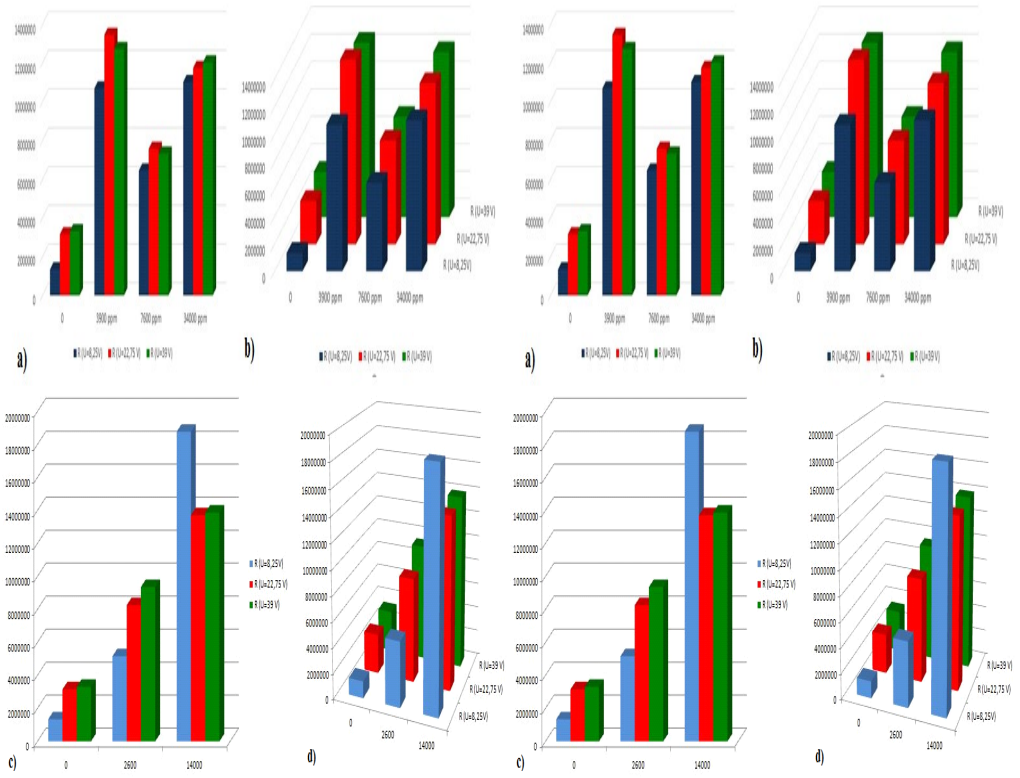

Fig. 4. Description in 2D and 3D diagrams of the effect of butane gas (a and b) and benzene vapor (c and d) on the resistance of $Ge_{33}As_{17}S_{35}Se_{15}$.

2D and 3D diagrams of the influence of butane gas (a and b) and benzene vapor (c and d) on the electrical resistance of chalcogenide glass $Ge_{33}As_{17}S_{35}Se_{15}$ show that the change in the value of the resistance depends at a noticeable level on the composition and type of hydrocarbon. The results obtained show that, compared with butane with an open chain structure, the benzene vapor environment with a closed chain structure has a more preferable effect on increasing the resistance of the substance. This result is associated with the differentiation of the diametrical and length dimensions of benzene and butane molecules (d=6A^0; L=5,7A^0 və d=4,9A^0; L=7,78A^0), the type of bond, adhesion and length. Thus, it was found that the Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structure has a selective sensitivity depending on the type of environment.

4. Conclusion

Volt-Ampere characteristics of Al-$Ge_{33}As_{17}S_{35}Se_{15}$-Te sandwich structures in butane gas and benzene vapor environments have been studied by constant current method and it has been shown that current oscillations of volt-ampere characteristics weaken and disappear as a result of influence of hydrocarbon environment (with aliphatic and cyclic chain structures). The reason for the gradual weakening and disappearance of oscillations is due to the accumulation of gas atoms in low atomic density domains or pores and, as a result, the influence of U^- -centers on ionization and recombination processes. The preferable effect of the benzene vapor environment with a closed chain structure on increasing the resistance of the substance compared to butane gas with an open chain structure is associated with the difference in the diametrical and length dimensions of their molecules, also the type of bond, bond angle, adhesion and length.

Acknowledgements

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References

[1] Bahareh Badamchi, Al-Amin Ahmed Simon, Maria Mitkova, Harish Subbaraman, Sensors 21(5) (2021), 1616; https://doi.org/10.3390/s21051616

[2] Burr, G.W., Brightsky, M.J., Sebastian, A., Cheng, H.Y., Wu, J.Y., Kim, S., Sosa, N.E., Papandreou, N., Lung, H.L., Pozidis, H., et al. R IEEE J. Etcas 6(2016), 146-162; https://doi.org/10.1109/JETCAS.2016.2547718

[3] Abdollahramezani, S., Hemmatyar, O., Taghinejad, H., Krasnok, A., Kiarashinejad, Y., Zandehshahvar, M., Alù, A., Adibi, A., Nanophotonics 9(2020), 1189-1241; https://doi.org/10.1515/nanoph-2020-0039

[4] Ahmed Simon, A.A., Jones, L., Sakaguchi, Y., Kunold, H., van Rooyen, I., Mitkova, M. Phys. Status Solidi (b) (2020), 2000429; https://doi.org/10.1002/pssb.202000429

[5] Simon, A.A.A., Badamchi, B., Subbaraman, H., Sakaguchi, Y., Mitkova, M. J. Mater. Sci. Mater. Electron. 31(2020), 11211-11226; https://doi.org/10.1007/s10854-020-03669-0

[6] Tanaka, K., Shimakawa, K. Amorphous, Chalcogenide Semiconductors and Related Materials, Springer Science & Business Media, New York, USA, 2011; https://doi.org/10.1007/978-1-4419-9510-0

[7] S.İ. Mehdiyeva, R.İ. Ələkbərov, S.M. Məmmədov, H.İ. Məmmədova, B.H. İbrahimov, M.V. Kazımov, V.N. Poladova, Azerbaijan Journal of Physics, XXX N1(2024) p. 23-27

[8] R.I. Alekberov, S.I. Mekhtiyeva, A.I. Isayev, M. Fabian. J. Non - Crystalline Solids, 470(15) 2017, p.152-159; https://doi.org/10.1016/j.jnoncrysol.2017.05.015

[9] S.İ. Mehdiyeva, R.İ. Ələkbərov, S.M. Məmmədov, Azerbaijan Journal of Physics, XXVII N4(2021) p. 7-10