

Photoluminescence of Solid Solutions $\text{GaS}_{1-x}\text{Se}_x\langle\text{Er}\rangle 0.1\text{at}\%$ ($x=0.10$) Irradiated with γ -Quanta

¹Teymur B. Taghiyev*

¹Institute of Radiation Problems, Ministry of Science and Education Republic of Azerbaijan – Azerbaijan

ARTICLE INFO

Article history:

Received: March, 12, 2023

Accepted: May, 15, 2023

Available online: June, 10, 2023

Keywords:

Radiation,
Photoluminescence,
Doping,
Energy

*Corresponding Author:

Teymur B. Taghiyev
teymur@mail.ru

ABSTRACT

The study investigated the photoluminescent properties of undoped and rare-earth element erbium-doped solid solutions $\text{GaS}_{1-x}\text{Se}_x\langle\text{Er}\rangle 0.1\text{at}\%$ irradiated with gamma-quanta. Erbium doping reduces the photoluminescence intensity in solid solutions. After irradiation $D_\gamma=300\text{-}1000\text{Gy}$, the photoluminescence intensity increases. An increase in the photoluminescence intensity in irradiated solid solutions is explained by a decrease in the concentration of centres responsible for the fast recombination channel and associated with lattice defects. At $T=77\text{K}$, due to the decay of bound Frenkel pairs, Si and Vs appear in the sulfur sublattice. The Si defects are responsible for the increase in the intensity of the green luminescence band. The redistribution of photoluminescence intensity in the $0.520 - 0.600 \mu\text{m}$ range is due to energy transfer to rare-earth centres in activated crystals. The investigated results allow us to conclude that doping with erbium leads to a series of emission lines appearing in the visible region of the spectrum.

<https://doi.org/10.53293/jasn.2023.6700.1206>, Department of Applied Sciences, University of Technology - Iraq.

© 2023 The Author(s). This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The gallium sulfide modification is yellow crystals with a melting point of 950°C [1]. Gallium sulfide single crystals are stable under standard conditions and are the predominant products in most syntheses of the corresponding gallium chalcogenides. Crystal modifications of GaS have a layered hexagonal structure. The unit cell of GaS contains -S-Ga-Ga-S- fragments from two different monolayers - they are identical in the number and types of bonds and shifted relative to each other. The GaS structures consist of a sequence of pairs of Ga-S planes. The crystal structure of GaS belongs to the space group P 63/MMC with a hexagonal lattice. Its parameters are: $a = 3.592 \text{ \AA}$, $c = 15.495 \text{ \AA}$ [2-5]. Recently, chalcogenide semiconductors activated by rare earth elements have been intensively studied. Considering this circumstance, this work presents the obtained experimental data, making it possible to develop an approach to understanding the nature of luminescence in $\text{GaS}_{1-x}\text{Se}_x\langle\text{Er}\rangle 0.1\text{at}\%$ [6, 7]. The structural and luminescence properties of chalcogenide semiconductor $\text{Ca}_x\text{Ba}_{1-x}\text{Ga}_2\text{S}_4$ solid solutions ($x=0.1\text{-}0.9$) doped with 7 at% of Eu^{2+} ions were studied at room temperature. The crystal structure of $\text{Ca}_x\text{Ba}_{1-x}\text{Ga}_2\text{S}_4$ solid solutions varies with the amount of Ca^{2+} , and phase transition from cubic to orthorhombic takes place of x value. $\text{Ca}_x\text{Ba}_{1-x}\text{Ga}_2\text{S}_4:\text{Eu}^{2+}$ solid solutions exhibit intense photoluminescence in cyan to yellow spectral region depending on x due to $5d \rightarrow 4f$ electron-dipole transitions in Eu^{2+} ions [8, 9]. The crystal structure of the layered semiconductor

TlGaSe₂ is studied using neutron diffraction at room temperature and under high pressures up to 4.6 GPa. Under ambient conditions, the crystal structure of TlGaSe₂ is described by monoclinic symmetry with the space group C2/c. In the pressure range P = 0.2–0.9 GPa, TlGaSe₂ undergoes a structural phase transition without a change in symmetry. The pressure dependences of the lattice parameters and the unit-cell volume are obtained, and the bulk moduli for both phases of TlGaSe₂ are calculated [10, 11]. Photoluminescence (PL) emission and excitation spectra of ZnGa₂S₄ are recorded. The excitation maxima for these bands are respectively to photon energies 3.3eV for ZnGa₂S₄. It was determined that the ZnGa₂S₄ compound in three narrow emission lines in the visible spectral region at 430 nm, 530 nm and 675nm due to the donor-acceptor recombination [12].

2. Experimental Procedure

The effect of γ -radiation with an energy of $E=1.33$ MeV and a dose of $D_\gamma = 300, 1000$ Gy on the photoluminescence properties of solid solutions GaS_{1-x}Se_x <Er>0.1at% was investigated. The investigated solid solutions with a resistance of 10⁹ ohm at room temperature were grown by the Bridgman method. Erbium doping was carried out during the growing process. The samples were irradiated using a Co⁶⁰ installation at room temperature. The photoluminescence spectra of the studied samples were recorded on an SDL-1 spectrometer. The spectrometer consists of a double monochromator with replaceable diffraction gratings, an illuminator with a DRSh-type lamp, a capacitor, energy receivers and an amplifier-recording device. A high-pressure mercury lamp DRSH-250-3 and DRSH-500m is used to excite luminescence. The sample is placed in a holder and illuminated by a powerful monochromatic flux, which is isolated using a light filter ($\lambda=337.1$ nm) from the spectrum of a mercury lamp. The energy receiver in the spectrometer was an FEU-39A and FEU-62 photomultiplier tubes.

3. Results and Discussion

The photoluminescence spectra of solid solutions GaS_{1-x}Se_x undoped and doped with the rare-earth element erbium at 77K in the wavelength range from $\lambda= 420$ nm to 620nm were studied (Fig. 1). At nitrogen temperature in solid solutions, the maximum of the intense band is at $\lambda= 540$ nm. In addition to the main intense emission band, there is a band with a maximum at about $\lambda= 495$ nm. The maximum observed in the luminescence spectra of solid solutions is probably due to the transition of electrons from the conduction band to acceptor levels, which are $E_t=0.22$ and 0.43 eV above the top of the valence band. In erbium-activated solid solutions GaS_{1-x}Se_x, the photoluminescence intensity decreases, and narrower lines appear in the spectrum, which is related to intracenter transitions of introduced rare-earth impurities (Fig. 2.) After irradiation with γ -quanta with a dose of 300Gy (Fig. 3.), new high-intensity radiation peaks appear in the $\lambda=550-560$ nm region in solid solutions GaS_{1-x}Se_x <Er>0.1at%.

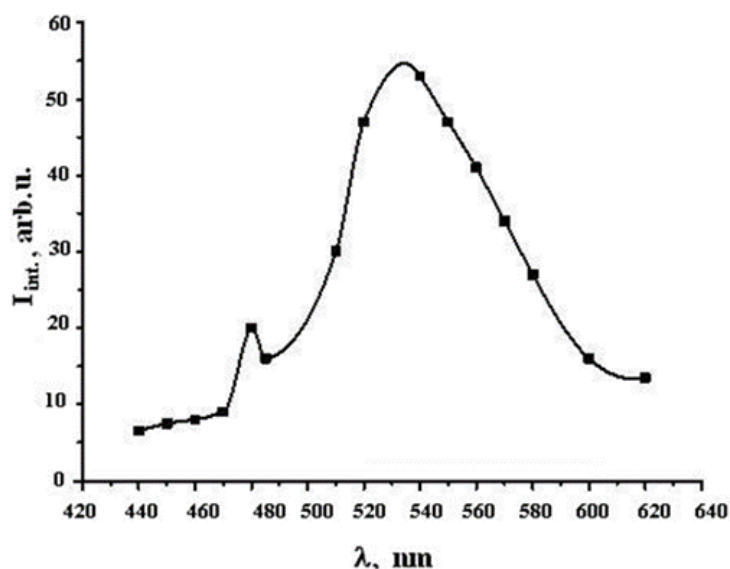


Figure 1: Photoluminescence spectra of solid solutions GaS_{1-x}Se_x 77K before irradiation.

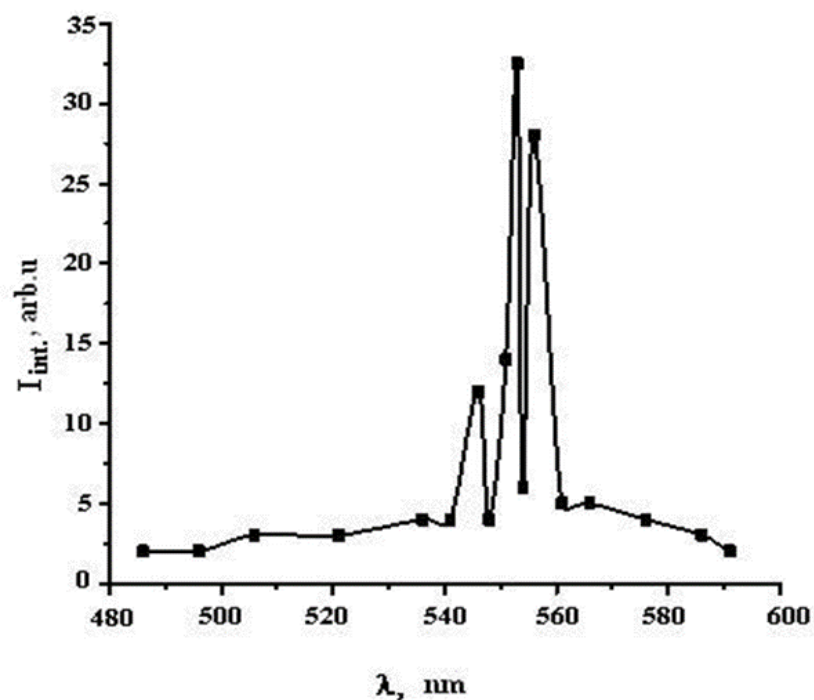


Figure 2: Photoluminescence spectra of solid solutions $\text{GaS}_{1-x}\text{Se}_x\langle\text{Er}\rangle 0.1\text{at}\%$ 77K before irradiatio

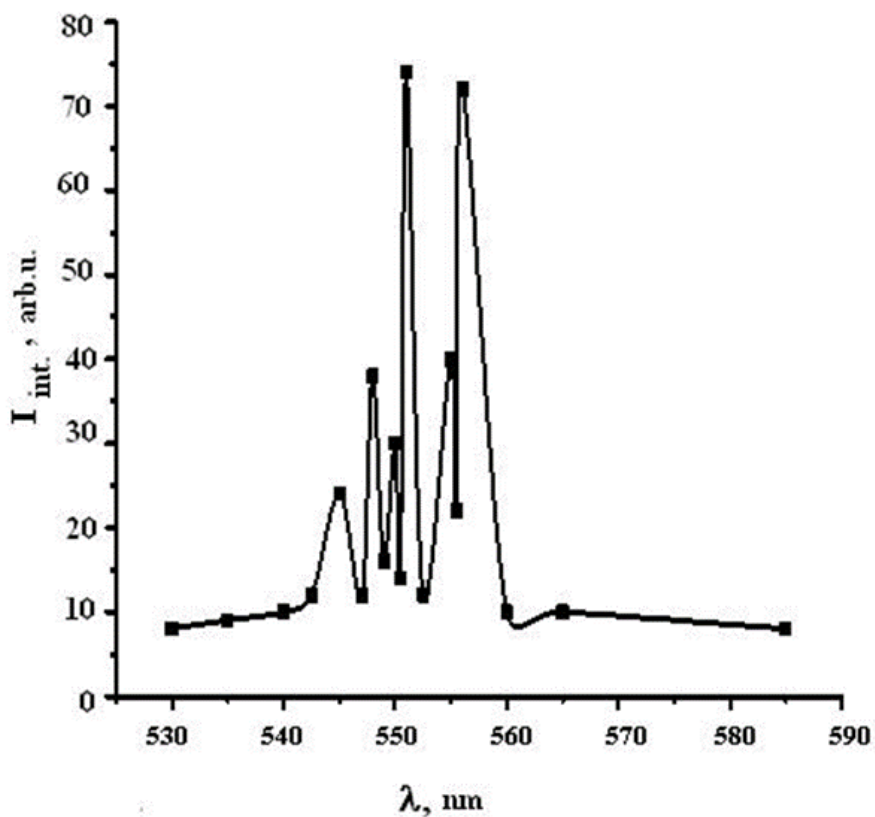


Figure 3: Photoluminescence spectra of solid solutions $\text{GaS}_{1-x}\text{Se}_x\langle\text{Er}\rangle 0.1\text{at}\%$ at 77K after irradiation $D_\gamma = 300$ Gy.

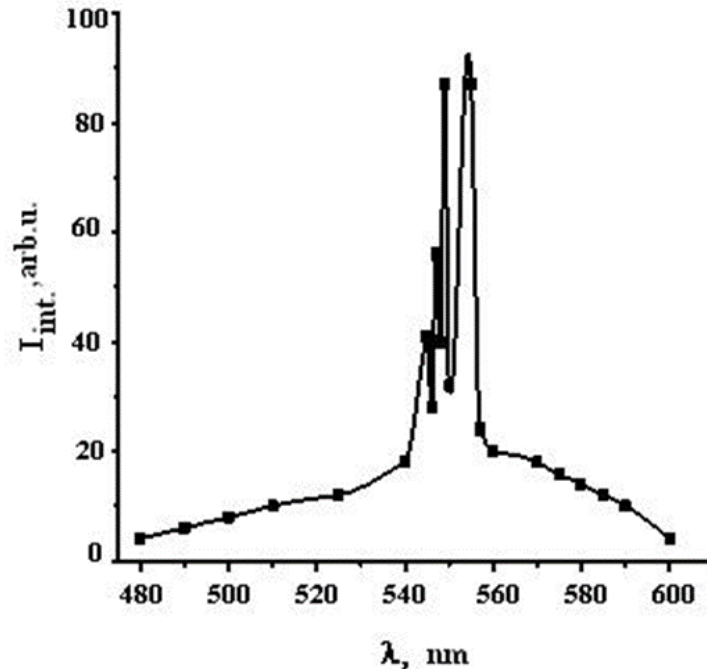


Figure 4: Photoluminescence spectra of solid solutions $\text{GaS}_{1-x}\text{Se}_x < \text{Er} > 0.1\text{at}\%$ at 77K after irradiation $D_\gamma = 1000$ Gy.

Irradiation with a dose of $D=1000$ Gy (Fig. 4) increases the line intensity in the range of $\lambda=550-560$ nm. The increase in the green luminescence intensity can be explained by the decay of bound Frenkel pairs in the sulfur sublattice, which, together with the separated pairs, are formed upon gamma irradiation of the samples. The appearance of new lines and a change in the relative line intensities known for the studied samples are interpreted as a consequence of the migration of defects arising from the displacement of sulfur atoms and their binding to rare-earth ions. At $T=77\text{K}$, free S_i and V_s arise in the sulfur sublattice due to the decay of bound Frenkel pairs. S_i defects are responsible for increasing the intensity of the green luminescence band. The redistribution of the photoluminescence intensity in the range of $\lambda= 520 - 600$ nm is due to energy transfer to the rare-earth centres in the activated crystals. The observed number of bands in the spectrum and their narrowness give reason to believe that Er^{+3} ions occupy mainly one position in the studied samples, forming the main erbium centre. Along with the main Er^{+3} - centre, complexes consisting of Er^{+3} ions, intrinsic crystal defects, or uncontrolled impurities can form in the studied samples. This is evidenced by the results of a study of photoluminescence, which allowed several erbium centres. Several erbium centres in these crystals are associated with substituting impurity ions for various regular positions in the crystal lattice and multiple mechanisms for compensating for the excess charge.

4. Conclusions

The investigated results allow us to conclude that doping with erbium leads to a series of emission lines appearing in the visible region of the spectrum. The detected luminescence bands of solid solutions $\text{GaS}_{1-x}\text{Se}_x < \text{Er} > 0.1\text{at}\%$ result from intra-center transitions in the Er^{+3} ion. After irradiation with γ -quanta, free S_i and V_s appear in the sulfur sublattice due to the decay of bound Frenkel pairs. S_i defects are responsible for an increase in the intensity of the green luminescence band. The observed number of bands in the spectrum and their narrowness give grounds to believe that Er^{+3} ions occupy predominantly one position in $\text{GaS}_{1-x}\text{Se}_x$, forming an erbium centre.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

- [1] M.P. Pardo, "Diagramme de phases gallium-soufre et etudes structurales des phases solides," *Journal Solid State Chemistry*, vol. 102, p. 423–433, 1993.
- [2] A. Kuhn, "Charge-density analysis of GaS" *Physical Review B*, vol. 25, p. 4081–4088, 1982.
- [3] R.S. Madatov, T.B. Taghiyev, S.A. Abushev, Sh. P. Shekili, A.R. Mobili, et al., "Optical and photoelectric properties of layered single crystals irradiated with γ -quanta," *Neorganichesue materiali*, vol.14, p. 396-399, 2008.
- [4] A.Sh. Abdinov, N.M. Mehdiyev, R.F. Babayeva, R.M. Rzayev, R.M. Ismayilov, et al., "Photoluminescence of indium and gallium selenide single crystals doped with dysprosium," *News of Azerbaijan National Academy of Sciences, series of physical-mathematical and technical sciences*, vol.5, p. 143-147, 2003.
- [5] B.G. Taghiyev, O.B. Taghiyev, S.A. Abushev, G.Y. Eyyubov, et al., "Electrical and photoelectric properties of GaS: Er, Yb single crystals," *Physics*, vol.8, p. 85-88, 2007.
- [6] E.I. Yarembash, A.A. Eliseev, et al., "Rare earth chalcogenide," *M. Nauka*, p. 260, 1975.
- [7] A.M. Gurvich, "Introduction to the physical chemistry of crystal phosphors," *M.Mir*, p. 221, 1979.
- [8] B.G.Tagiyev, O.B. Tagiyeva, A.I. Mammadov, Vu Xuan Quang, T.G. Naghiyev, S.H. Jabarov, et al., "Structural and luminescence properties of $\text{Ca}_x\text{Ba}_{1-x}\text{Ga}_2\text{S}_4:\text{Eu}^{2+}$ chalcogenide semiconductor solid solutions," *Physica B: Condensed Matter*, 478, p.58-62, 2015.
- [9] D T Khan, N T Dang, S H Jabarov, et al., "Study on luminescent properties of Tb^{3+} and Sm^{3+} co-doped CaSiO_3 phosphors for white light emitting diodes," *Material Research Express*, 7016507, 2020.
- [10] S.H. Jabarov, T.G. Mammadov, et al., "Structural phase transition in TlGaSe_2 under high pressure," *Journal of Surface Investigation. X-ray, Synchrotron and Neutron Techniques*, vol.9, p.35–40, 2015.
- [11] S.H. Jabarov, et al., "High pressure Raman study of layered semiconductor TlGaSe_2 ," *Materials Science-Poland*, 36(2), p.203-208, 2018.
- [12] S.G. Asadullayeva, T.G. Naghiyev, G.A. Gafarova, et al., "Room temperature photoluminescence study of undoped ZnGa_2S_4 compound," *Advanced Physical Research*, vol.1, p.81-85, 2019.