PHOTOELECTRICAL PROPERTIES OF LAMELLAR GALLIUM SULFIDE MONOCRYSTALS ARE IRRADIATED BY γ-QUANTA

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ABSTRACT

The influence of γ-quanta irradiation on photoelectrical and optical properties of lamellar GaS monocrystals at different temperatures has been investigated. It is determined that the irradiation of pure crystals at radiation dose equal to 30 krad results in the creation of shallow compensative acceptors, which are photoactive recombination centers (*r*-centers) and as a result of this both the photosensitivity and a luminescence connected with r-centers are increased. The irradiation with radiation dose more than 100 krad results in the quenching of both photosensitivity and recombination luminescence due to complex formation [V_{Ga} V_S]. It is proposed that radioactive recombination centers arising at the irradiation is conditioned by sulfur hole and interstitial gallium atoms.

Keywords: influence of γ-quanta, photoelectrical, monocrystals, recombination, luminescence.

I. INTRODUCTION

In accordance with [1-3] $A^{III}B^{IV}$ compounds are interested as prospective materials for the semiconductor detector creation of elementary particles and hard electromagnetic radiation. Higher interest to these compounds is caused by circumstance that though their strong defectiveness they have high photosensitivity in visible, infrared, roentgen and gamma-rays [3-9]. These preliminary data pointed at the possible prospective using lamellar semiconductor compounds for the development of photoelectrical devices, radiation sources and radiation detectors. In this connection the research of their photoelectrical properties at ionizing radiation is actual.

The research results of optical and photoelectrical characteristics of lamellar GaS monocrystals are irradiated by gamma-quanta with the purpose of local levels detection in the crystal forbidden-zone are given in this paper. Investigated p-GaS monocrystals were grown by Bridgman method at the Institute of Radiation Problems of Azerbaijan National Academy of Sciences. Surplus sulfur (1.5%) is used at monocrystal growing with the purpose of determination of holes filling possibility by sulfur atoms. It was experimentally determined that effective filling of holes occur at annealing temperature 500 – 700^0C. Specific resistance of the samples along and perpendicularly to *c* axis at room temperature is respectively 2·10 and $3 \cdot 10^7$ Ohm·cm. Indium is used as a material for ohmic contacts. Indium fused into GaS surface at 150^0C. Irradiation of the samples by gamma-quanta with energy 1.3 MeV is carried out using Co^{60} at 300K. The crystals are cooled by liquid nitrogen vapor during irradiation and as a result the temperature of crystals was not higher than 290K.

II. EXPERIMENTAL RESULTS

The investigations of photoconductivity and photoluminescence in the area of wavelengths 0.4 – 1.0 micrometer at the temperatures 120 and 300K have been carried out for revealing local levels in the obtained GaS monocrystals.

Spectral dependences of photoconductivity for obtained GaS monocrystals are presented in figure 1.

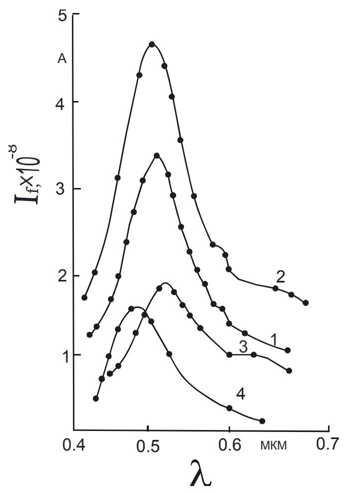

Figure1. Spectral distribution of photoconductivity for GaS monocrystals; 1,2 – radiation free; 3,4 – irradiated by gamma-quanta (30 krad): 1,3 at 300K; 2,4 at 120K

It is necessary to note that initial GaS samples have photoconductivity maxima near fundamental absorption edge at λ = 0.51 micrometer. In addition, it is observed intensive impurity peaks with maxima at λ = 0.61 and λ = 0.70 micrometers (fig.1, curve 1). These maxima correspond to optical transition from acceptor level to conduction band. Activation energy of the levels is equal to 0.50 and 0.74 eV respectively. It is coincide with a value given in [3,4]. Photocurrent increases approximately in 30-40% after the irradiation of the samples by gamma-quanta with dose equals to 30 krad. At this maximum intensity at 0.61 micrometer decreases and with increasing irradiation dose gradually decrease and disappear at dose is equal to 100 krad (fig. 1, curves 2,3,4). The peak in spectral region 0.74 eV displaced to the short waves and appeared at λ = 0.82 micrometers. It is seen from the figure 1 that further irradiation decreases the photoconductivity of GaS in all investigated spectral region (curves 3,4). It points to the generation of large quantity of recombination centers with big capture cross-section for electrons.

The temperature dependences of photocurrent in the initial and irradiated GaS samples at λ = 0.51 micrometers are given in fig.2.

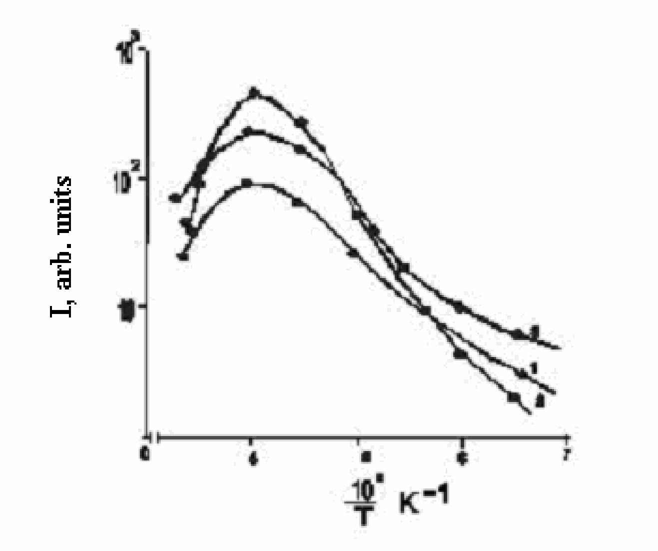

Figure 2. Temperature dependences of photocurrent (λ_{max} = 0.51 micrometers) monocrystals GaS; 1 – before irradiation; 2 - 30 krad; 3 – 100 krad

The samples are irradiated by gamma-quanta with the doses equal to 30 and 100 krad. As it is seen the irradiation does not influence to the temperature dependence of photocurrent in GaS samples. It is observed temperature quenching of photocurrent at the temperature higher then 170K. Such sensitivity changing connected mainly with intrinsic defect levels rearrangement into the forbidden zone and changing in hole filling ratio of sensitivity centers in GaS. Photoluminescence spectra of the investigated samples at 77K are given in fig.3. Helium-cadmium laser (λ = 0.3716 micrometers) has been used for excitation. Intensive exciton emission bands with λ_1 = 0.48 micrometers are observed in both GaS crystals irradiated by low doses and unirradiated samples. Wide structureless band having considerably more intensity with maxima at λ_1 = 0.48, λ_2 = 0.52 and λ_3 = 0.66 micrometers is raised after the irradiation of samples with 30 krad dose. Observed maximum λ_3 = 0.66 micrometers disappears at high level of irradiation (curve 3, 100 krad) and the dependence behavior gets initial view as before irradiation. The dependence of irradiation intensity and photosensitivity from irradiation dose is shown at fig.4. It is seen that at low irradiation doses up to 30 krad it is observed heightened intensity band, and further increasing irradiation dose result in the intensity decreasing. The photoconductivity dependence of irradiated samples has the same behavior.

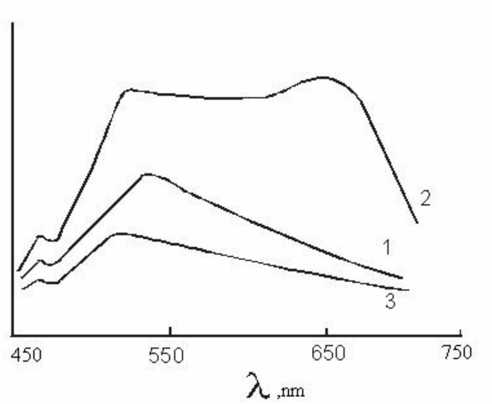

Figure 3. Photoluminescence spectra of monocrystals GaS; 1 – before irradiation; 2 - 30 krad; 3 – 100 krad

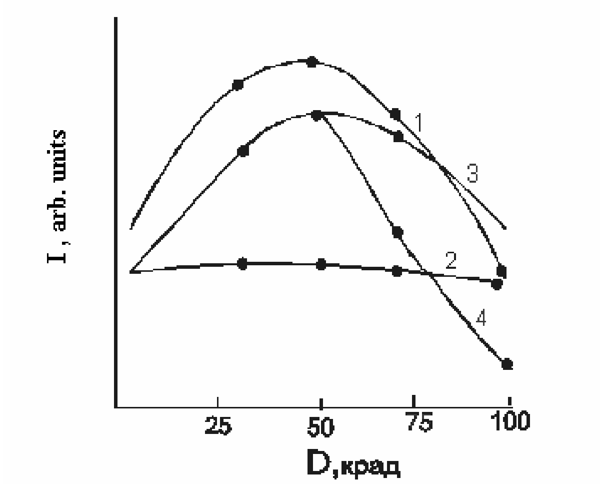

Figure4. Photosensitivity dose depen-dences (1) and intensity of photolu-minescence (2-4) monocrystals GaS: 2. λ = 0.48 micrometers; 3. λ = 0.53 micrometers; 4. λ = 0.66 micrometers

III.DISCUSSION OF THE OBTAINED RESULTS

The researches of stationary characteristics of photoconductivity and photoluminescence allow to determine a recombination model in GaS monocrystlas including after gamma-irradiation influence. The observation of such phenomena as radiation photo and luminescence of the crystals as well as thermal quenchering of photocurrent can be explained within the framework of three-level recombination diagram containing low – r, fast – s and capture levels – t for majority charge carriers. It is known [11] that in the thermodynamical state of equilibrium for implementation of high photoconductivity the levels of *r* and *s* should be completely filled by the holes.

At this the electron concentration N_{r0} should correspond to the following conditions:

$N_{ro} << P_{ro} = N_r, N_{so} << N_r$, where N_r and P_{ro}, N_s are the concentrations of r and s centers respectively. Majority charge carriers for GaS are holes and the condition $N_a > N_d$ is carried out. The lighting of samples leads to the optical recharging of local levels and as a result the filling of these levels significantly differs from dark value.

The complex researches at different temperatures were carried out in order to determine the cause of photoconductivity changing in the irradiated p-type GaS samples. It is determined that at low irradiation doses (up to 20 krad) the photosensitivity in the field of self-photoconductivity and the intensity of bands with maxima in wavelength λ_f = 0.62 micrometers (fig.1, curve 2) and λ_I = 0.48 micrometers (fig.3, curve 1) are not practically changed and it is an evidence of low speed photosensitivity of radiation defects injection. Increasing photosensitivity λ_{max} = 0.51 micrometers and decreasing λ_f = 0.62 micrometers occur with increasing gamma irradiation dose up to 30 krad. This fact is explained by the increasing of low recombination centers in the composition of which V_s is included, and the decreasing of V_{Ga} concentration. It is difficult on the basis of the obtained results to give a conclusion about the nature of *r*-centers, but it is possible to suppose that complex defects with sulfur and gallium vacancies are responsible for these centers. In fact, decreasing impurity maximum (0.62 micrometers) testifies to the decreasing of V_{Ga} concentration, it seems due to interaction with Ga_i [5]. The researches results of photoluminescent spectra for irradiated GaS crystals (fig. 3, curves 2,3) shown the creation of radiation defects. It is seen from fig.3 that in the excitation spectrum of luminescence for irradiated sample (30 krad) additional high intensity maximums with λ_2 = 0.53 micrometers and λ_3 = 0.66 micrometers are formed in addition to exciton band (λ_1 = 0.48 micrometers). It is necessary to note that short-wave peak with λ_1 = 0.48 micrometers is conditioned by radioactive recombination of free electrons and its energetic position coincide with energetic position for exciton peak n=1 in absorption spectrum [2,6]. It is known [12] that boundary energy of electrons required for sulfur atoms displacement into the interstitial site is in two times less than energy required for gallium atoms displacement. Therefore, we can suppose that the acceptor centers (interstitial sulfur atoms S_i) are responsible for band of 0.53 micrometers. At this, irradiation occurs at the recombination of free electrons with holes are captured by the acceptor centers S_i. The displacement of luminescence maximum (0.53 micrometers) to short-wave part of spectrum and the decreasing of its intensity with increasing irradiation dose (fig. 3, curve 3) can be explained by shielding action to the lighting centers of charged holes, which are Ga_i [7] and removal of S_i to different sinks, which could be V_s, defect cluster, dislocations and etc. It is note that the complex with Ga_i^+ atoms is responsible for luminescence band 0.66 micrometers. Decreasing of the luminescence band (0.66 micrometers) intensity in the irradiated GaS crystals (at 100 krad) is connected with complex dissociation as a result of that Ga_i^+ atoms annihilator with V_{Ga} are formed. It is seen from fig. 2 (curve 1) that TGF is observed in initial crystals at the temperature range T>200 K due to the development of thermal generation of electrons form r-levels into C-zone and its further capture at s-levels. At temperature decreasing below 200K the photocurrent decreases and it shows the localization of holes at t-levels and corresponding electrons at r-recombination levels. As a result of N_r=N_t formation accordingly to [11], the decreasing of both the holes lifetime and photocurrent is happen. It is seen from fig. 2 (curves 2,3) that the irradiation does not influence on the behavior of photocurrent temperature dependence and it is observed TGF at the temperature above 240K.It means that irradiation by gamma-quanta leads to the radiation sensitization in the temperature range above 170K. Such change of sensitivity is connected with the change of hole filling degree of sensitivity centers in GaS as well as GaSe and GaTe [10]. Irradiation by gamma-quanta creates shallow-lying capture levels with ionization energy 0.23 eV. These levels compensate deep levels. The parameters of sensitizing r-centers of recombination and trapping were determined: the values of capture cross-section for electron and hole are equal to $S_{nr}=2\cdot10^{-14}$ and $S_{pr}=5\cdot10^{-19}$ cm^{-2} respectively, the concentration of these centers is equal to $2\cdot10^{-14}$ cm^{-3}, and energetic state of trapping levels for holes is E_{vt}=0.23 and 0.40 eV and their concentration is $N_t=7\cdot10^{14}$ - $2\cdot10^{15}$ cm^{-3}. all of these facts show that irradiation by gamma-quanta with low dose leads to the formation of radioactive recombination centers in which the band of 0.53 micrometers is determined by donor center with participation of S vacancy, and the band of 0.66 micrometers is determined by interstitial Ga atoms. The irradiation by high doses (above 100 krad) leads to the photosensitivity quenching and recombination luminescence recombination due to the formation of bivancies [V_{Ga} , V_S].

IV.CONCLUSION

Thus, the irradiation by gamma-quanta of pure crystals leads to the formation of shallow acceptor capture levels with energy 0.23 eV. These levels compensate deep donors, which are sensitizing recombination centers (r-centers). It leads to the increasing of photosensitivity and strengthening luminescence that is connected with r-centers. Obtained experimental results in the irradiated GaS crystals are explained satisfactory within existing model [11].

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