Journal of Radiation Researches, vol.6, No.2, 2019, Baku
The effect of γ-irradiation on the electrophysical properties of GaS monocrystal doped with Yb and Sm

pp. 60-64

PACS: 71.23.Cq

THE EFFECT OF γ-IRRADIATION ON THE ELECTROPHYSICAL PROPERTIES OF GaS MONOCRYSTAL DOPED WITH Yb AND Sm

A.Sh. Khaligzadeh

Institute of Radiation Problems of ANAS

Abstract: The effect of γ-quanta on the electrical conductivity of GaS layered single crystal, pure and alloyed with 0.1at% Yb and Sm has been studied at a temperature range of 100-300K. It has been established that the electrical conductivity of crystals decreases due to the formation of acceptor- and donor-type levels corresponding to 1.56 and 0.16 eV activation energy as a result of insertion of the dopant atom Yb into the GaS matrix. Although the inclusion of the dopant atom Sm partially reduces the conductivity of the GaS crystal (~0.24 eV) at 100–300K, its conductivity is of a metallic character at 100-190K and it is semiconductor in the high-temperature regions.

***Keywords*:** electrical conductivity, activation energy, acceptor, donor, dose.

1. Introduction

The fact that GaS monocrystal, which is included to $A^{III}B^{VI}$ group compounds, has wide band gap, high sensitivity in the UV region of spectrum, resistance to radiation, anisatropy of chemical bonds increases its ability to control and apply its fundamental properties [1-4]. One of the characteristic features of layered crystals is that they have covalent bonds within the layer and weak van der Waals bonds between the layers. The control features of the above-mentioned bonds by doping and ionizing radiation allow for the purposefully control of the physical properties of layered crystals. Despite the widespread study of the electrical [5], optical and photoelectric [6] properties of the layered GaS monocrystal, the influence mechanism of structural defects on the flux mechanism of crystals remains unstudied. Thus, in the study [7], partially-disordered system model has been applied to the layered crystals during the study of the influence of metal and dopant atoms of REE on the conductivity of layered crystals. It has been shown that it is possible to control properties of layered crystals through controlling the height of potential barrier between the regions by the influence of dopant atoms. Other studies [8] provide information on the control of conductivity of GaS monocrystals depending on the radiation dose of gamma quanta. These data provide information on the formation mechanism of radiation defects in pure crystals. Analysis of [9] shows that defining the influence mechanism of defect-dopant interaction in layer and intralayered regions is one of the fundamental issues to give a control mechanism of the physical properties of defective (~10^{17} cm^{-3}) layered crystals. In order to address this issue, it is important to study the regularities and characteristics of change of physical properties of layered crystals depending on the nature and concentration of the defect and dopant atoms. For this purpose, the work is devoted to the elucidation of the mechanism of interaction of structural – dopant - radiation defects in the GaS monocrystal.

2. Experimental part

The studied monocrystals GaS, GaS(Yb) and GaS(Sm) have been grown by Bridgman method. Yb and Sm are added to GaS layered monocrystal during a growth. As S is volatile, its amount in the crystal decreases during the acquisition of GaS monocrystal. To overcome these deficiencies, the GaS monocrystal has been thermally processed in the steam of S. The doping of crystals was carried out during their cultivation. Itterbium Yb and Sm elements were chosen as dopant atoms and their amount was ~1.0 at%. The grown GaS(Yb) and GaS(Sm) monocrystals also have p-type conductivity and were $\rho \sim 10^9$ Ohm·cm, as pure crystals. For the study, samples with 200 μm thickness, which are sacaled in the direction (001) of layer, have mirror surface, have been prepared. The indium has been used to obtain ohmic contact. The electrical properties of the prepared samples were measured at a temperature range of 100-190 K and the electric tension was measured using a B7-27A voltmeter. The current formed in crystal is recorded by means of a B7-30 voltmeter-electrometer amplifier.

3. Discussion of Experimental Section and Conclusions

Figure 1 presents the temperature dependence of the electrical conductivity of the GaS monocrystal, pure (1) and doped with Yb (2) and Sm (3) dopant atoms.

It is seen from σ-f(1/T) dependence that monocrystal has semiconductor properties and from linear parts of curve that the activation energies defined from low-temperature and high-temperature regions were 0.08 and 1.52 eV respectively (Figure 1, curve 1). As can be seen from the graph, the electrical conductivity of the pure GaS monocrystal partially increases with the increase in temperature at the temperature range of T=100-220K, but it sharply increases with the increase in temperature at a temperature range of T=220-300K. This shows that there are shallow and deep energy levels, of which concentrations in the band gap of the pure GaS monocrystals differ sharply. As shown in curve 2, the conductivity of the GaS(Yb) crystal drops sharply in the 100-300K range as a result of the introduction of the Yb atom, and two levels with different natures are observed in the σ-f(1/T) curve, of which activation energies are 1.56 and 0.16 eV, respectively. It can be seen from the first curve in Figure 1 that the conductivity decreases with increasing temperature in the range of T=180-210K, but there is a sharp increase in the conductivity in GaS (Yb) crystal at T> 210K, as in pure crystals.

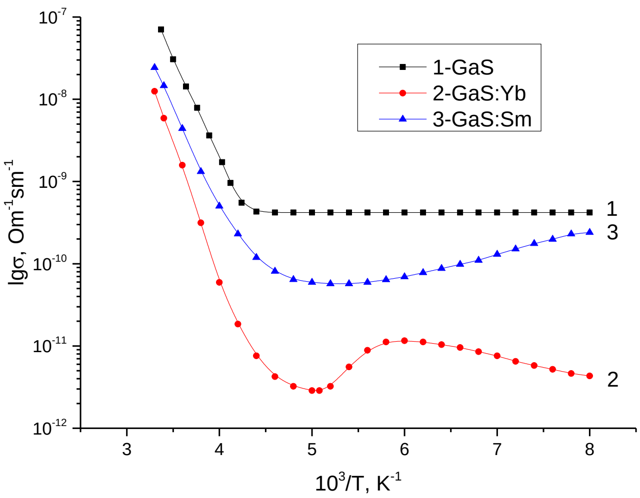

Fig. 1. The temperature dependence of the electrical conductivity of the GaS, GaS(Yb) and GaS(Sm)

Figure 1, graph 3 shows that the electrical conductivity in Sm-doped GaS crystal decreases in the temperature range of 100-200K as that in Yb-doped crystal and this dependence is of a metallic character, but it increases at the temperatures of T>200 K. The conductivity of the GaS(Sm) crystal sharply increases with increasing temperature in the range of 200-300K, as of the pure crystal and activation energy of the level was E=1.50eV.

Figure 2 shows the temperature dependence of the electrical conductivity of GaS; GaS(Yb) and GaS(Sm) monocrystals irradiated with different dose γ-quanta. The influence of gamma quanta on pure crystals has been extensively studied in the works [5,6,8]. It has been shown that the conductivity of the GaS crystal decreases at 20-50krad radiation doses and the decrease is due to the donor nature of the radiation defects. But at higher radiation doses, as acceptor-type defects prevail due to dissociation of complexes, there is observed an increase in the conductivity (curves 1; 2 and 3). Those results we obtained were compared with the results observed in doped crystals. Figure 2, graph 4 shows that the conductivity of the GaS(Yb) crystal irradiated with a dose D=20krad increases at a temperature range of 100-300 K compared to the non-irradiated crystal, and the activation energy of new level corresponds to~ 0.08 eV. The region of the sharp decrease in the conductivity observed in the temperature range of 180–250 K is shifted towards higher temperatures, and there is a sharp increase at T> 250 K. At a radiation dose of 50krad (curve 6), there is observed an increase in the conductivity of GaS (Yb) crystal in the specified temperature range compared to the 4th dependence and no sharp decrease in the conductivity. During the irradiation at D= 100krad dose (curve 8), there is a decrease in the conductivity in the temperature range of 100-300K in σ~f(1/T) dependence compared to non-irradiated GaS(Yb) crystal (curve 2).

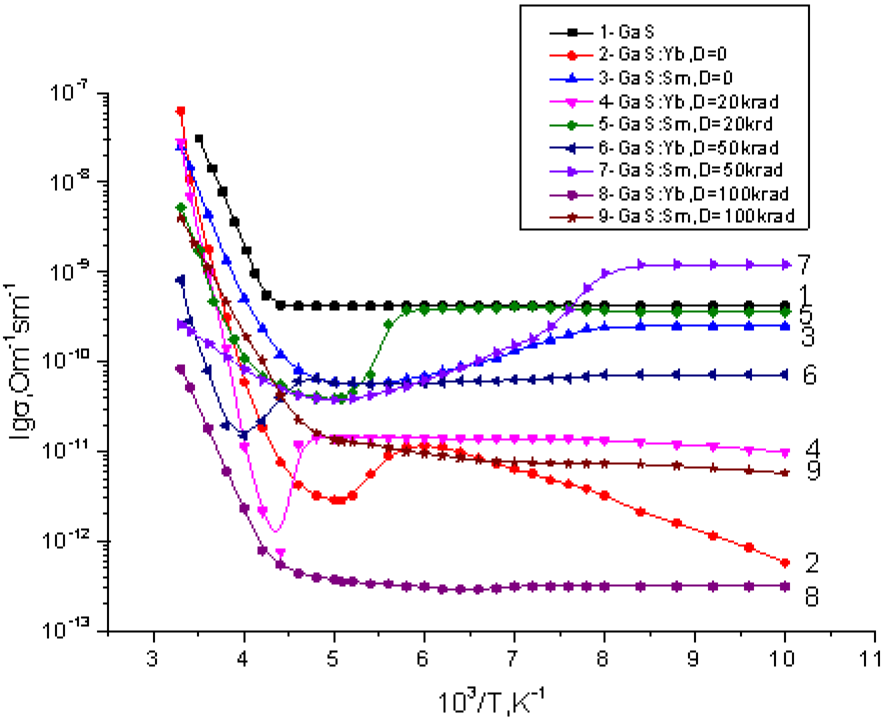

Fig. 2. The temperature dependence of the electrical conductivity of the GaS, GaS(Yb) and GaS(Sm) irradiated with different dose γ-quanta

But when irradiating the GaS (Sm) monocrystal at a dose of D=20krad, the electrical conductivity increases at the investigated temperature range (T=100-300K) compared to the non-irradiated crystal (curve 5), and the metallic character of the conductivity decreases in the range of 100-200 K and the conductivity relatively decreases at 200-250 K. There is an increase in the conductivity at T>250K, and the activation energy of the level becomes E=0.70 eV. Although at

D=100krad radiation dose (7 curves), the conductivity relatively increases (compared to curve 5) in the range of 125–300K and there is a relative increase in the conductivity in the range of 100–125K compared to the pure GaS crystal (curve 1).

As a result of the studies, it was found that as the Yb and Sm dopant atoms in the GaS monocrystal are replaced by V_{Ga} and Yb_{Ga} (Sm_{Ga}) in the main matrix, there is observed partial compensation of the initial acceptor-type levels. This results in a decrease of the crystal conductivity and the obtained result is in complete agreement with the results obtained in [] studies. From defect-dopant-defect (radiation) interaction during the irradiation with γ-quanta, simple defects (Frenkel pair) are generated in anion and cation sublattice according to the given model and the conductivity changes depending on the irradiation dose, as there is observed the formation mechanism of V_{Ga} + Yb = Yb_{Ga} substitution and [V_{Ga} I_{Yb}] complex due to their interaction with dopant atoms. It has been found that donor type levels are generated while the doping of the GaS monocrystal with Yb and Sm, which reduces the value of the electrical conductivity by compensating the major charge carriers. The formation of Yb (Sm)-S bonds as a result of defect-dopant interaction at high irradiation doses may result in an increase in the conductivity. It is needed to carry out the additional research for further improve the mechanism on the basis of the obtained results.

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ВЛИЯНИЕ γ-ИЗЛУЧЕНИЯ НА ЭЛЕКТРИЧЕСКИЕ СВОЙСТВА ЛЕГИРОВАННЫХ Yb И Sm В МОНОКРИСТАЛЛАХ GaS

А.Ш. Халигзаде

Резюме: Влияние γ-излучений на электропроводимость слоистого монокристалла легированных Yb и Sm 0,1 ат% GaS изучали в интервале температур 100-300К. Установлено, что в результате легирования GaS энергии активации кристаллов, уменьшаются из-за образования уровней акцепторного и донорного типа, соответствующих энергии активации 1.56 и 0,16 эВ. Легирование атома Sm уменьшает электропроводимость кристалла GaS в интервале 100–300К по сравнении исходных кристалла, но его электропроводимость в интервале температур 100–190К является металлической, а в области высоких температур - полупроводниковой.

Ключевые слова: электропроводность, энергия активации, акцептор, донор, доза.

Yb VƏ Sm İLƏ AŞQARLANMIŞ GaS MONOKRİSTALININ ELEKTROFİZİKİ XASSƏLƏRİNƏ γ-ŞÜALANMANIN TƏSİRİ

A.Ş. Xalıqzadə

Xülasə: Aşqarsız və 0,1at% Yb və Sm ilə aşqarlanmış GaS laylı monokristalının elektrikkeçiriciliyinə γ-kvantların təsiri 100-300K temperatur intervalında öyrənilmişdir. Müəyyən edilmişdir ki, Yb aşqar atomunun GaS matrisasına daxil edilməsi nəticəsində aktivləşmə enerjiləri 1.56 və 0,16 eV uyğun olan akseptor və donor tipli səviyyələrin yaranması səbəbindən kristalların elektrikkeçiriciliyi azalır. Sm aşqar atomunun daxil edilməsi isə, GaS kristalının (~ 0,24 eV) keçiriciliyini 100-300 K intervalında qismən azaltsa da, 100-190K temperatur intervalında onun keçiriciliyi metallik, yüksək temperatur oblastında isə, yarımkeçirici xarakterə malik olur.

Açar sözlər: elektrik keçiriciliyi, aktivləşmə enerjisi, akseptor, donor, doza.