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THE EFFECT OF γ-IRRADIATION ON THE VOLT-AMPERE CHARACTERISTICS (VAC) OF GAS MONOCRYSTAL DOPED WITH Yb

R.S. Madatov, T.B. Tagiev, A.Sh. Khaligzadeh

Institute of Radiation Problems of ANAS
aydanxaliqzade@gmail.com

Abstract: The effect of γ-quanta on the volt-ampere characteristics of GaS layered single crystal, pure and alloyed with Yb has been studied at 300K temperature. It was obtained that, the increase in current in the ohmic region at radiation doses Φ<50 krad is due to the annihilation of the internodal additive Yb ion with V_{Ga}, and the sharp increase in current in high electric fields is due to thermoionization of local levels and as a result of dissociation of the $[V_{Ga} I_{Yb}]$ complex at radiation doses Φ>100 krad, an increase in the concentration of free charge carriers is observed.

Keywords: volt-ampere characteristics, concentration, alloy, acceptor, donor, dose.

1. Introduction

Volt-ampere characteristics (VAC) study is one of the research methods used to clarify the energy spectrum of the band gap in wide band-gap semiconductors, the characteristics of electronic processes, the interaction of local levels with free charge-carriers, as well as the characteristics of the effects associated with this interaction, the occurrence mechanism [1]. As is known from the literature [2], although some physical properties of the GaS (Yb) single crystal have been studied, their volt-ampere characteristics (VAC) and the effect of ionizing radiation on VAC have not been studied. The study of volt-ampere characteristics (VAC) allows obtaining information about the parameters of local levels present in the bandgap of semiconductor materials, such as the concentration of local levels, the cross-sectional area of the free carriers involved in the transmission of current, etc. The form of volt-ampere characteristics of semiconductor materials depends on many factors, especially the distribution of local levels in the bandgap, temperature, etc. and therefore the VAC of the crystal has sometimes a very complex structure.

2. Experimental part

The studied GaS and GaS:Yb layered single crystals were grown by the Bridgeman method. When the GaS single crystal is obtained, the amount of S in the crystal decreases because S is volatile. To overcome these shortcomings, GaS single crystals are thermally processed in S vapor. Doping of crystals was carried out during their cultivation. Itterbium Yb elements were selected as the additive atom and their content was ~ 0.1 at%. Yb is added to the GaS layered single crystal during cultivation. The grown GaSYb single crystal also had a p-type conductivity like the additive crystals and had an order of $\rho \sim 10^9$Ohm·cm. For the study, samples were scaled in the direction of the layer (001), with a smooth surface and a thickness of 200 µm. Indium was used to obtain the ohmic contact. The VAC of the prepared samples was measured at a temperature of 300 K and the electrical voltage of the sample was measured using a B7-27A voltmeter. The current generated in the crystal was recorded by a B7-30 voltmeter-electrometer amplifier.

3. Discussion of Experimental Section and Conclusions

Figure 1 shows the VAC of pure GaS (curve 1) and GaS<Yb>0.1at% single crystal at T = 300 K. As can be seen from Figure 1, in both cases the VAC of the crystal obeys the law of surface function. The dependence of the current on the voltage applied to the crystal is divided into three parts: it passes to Ohm's law in the interval U=0-2V, to quadratic region up to the interval U=2-10V, and to a sharp increase region (n>2.5) of current in $10 \leq U \leq 60$V, and into the non-trap quadratic region at the values higher than U=60V.

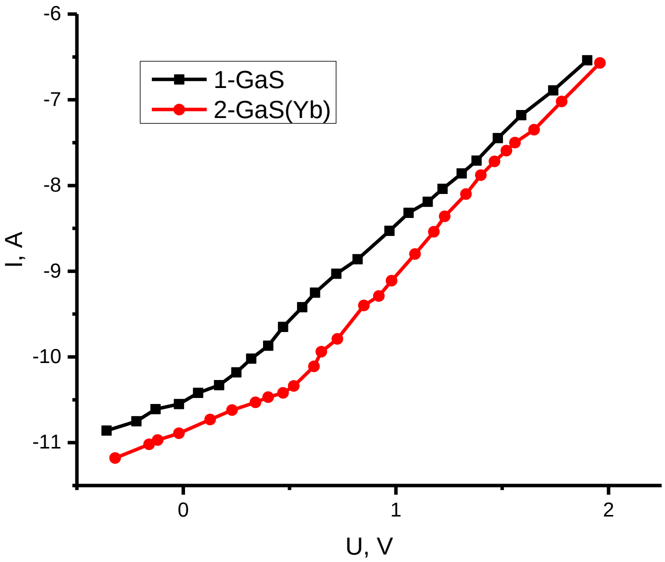

Fig. 1. Volt-ampere characteristics of GaS and GaS (Yb) single crystals (T=300K)

A comparative analysis of the curves shown in Figure 3.1 shows that when the GaS single crystal is alloyed with the Yb atom, the current decreases, the ohmic region shifts toward the high voltage region, and at the same time, the transition voltage in the non-trap quadratic region shifts toward the high voltage region.

The VAC observed in Figure 1 is explained on the basis of the theory of current injection in solids [3,4] and it was found that in GaS(Yb) semiconductor crystals with additives, the $I \sim U^n$-dependence corresponds to the theory of current, which is limited with volume-charge region. Based on this theory, the concentrations of free charge carriers in GaS and GaS(Yb) crystals were determined based on the value of the transition voltage from the ohmic part to the quadratic part for both cases from Figure 1 and were $n_0 \sim 2.8 \cdot 10^{10}$ cm^{-3} and $4.7 \cdot 10^{7}$cm^{-3}, respectively. The concentration of traps was calculated based on the value ($C=5 \cdot 10^{-10}$) of the capacitance of the sample at U=0 input voltage and in the transition state of traps to the full state and was $N_t = CU_{ttd}/g \cdot v$ = $3.681 \cdot 10^{16}$ cm^{-3} for GaS crystal and N_{to}= $3.4 \cdot 10^{17}$cm^{-3} for GaS(Yb). A comparison of the parameters calculated from Figure 1 shows that partial compensation of the acceptor-type structural defect occurs as a result of the inclusion of the Yb atom and as a result, a decrease in the concentration of free carriers and traps in the crystal is observed. This indicates that at low voltages and low temperatures, the traps of the charge carriers injected from the electrode cannot fill the traps, and the conduction is due to the thermal ionization of shallow levels.

Figure 2 shows the volt-ampere characteristics of GaS and GaS (Yb) single crystals at different doses at room temperature, and the results before irradiation are given in curves 1 and 2 to compare the graphs.

Figure 2 shows that as can be seen from the graph, the VAC of the GaS(Yb) crystal irradiated with γ-quanta is observed with the regularity before irradiation, but the value of the voltage corresponding to ohmic, quadratic (J-V^2), a sharp increase in current (J-V^3) and finally, non-trap regions corresponding to ≥60V shift to the high voltage region.

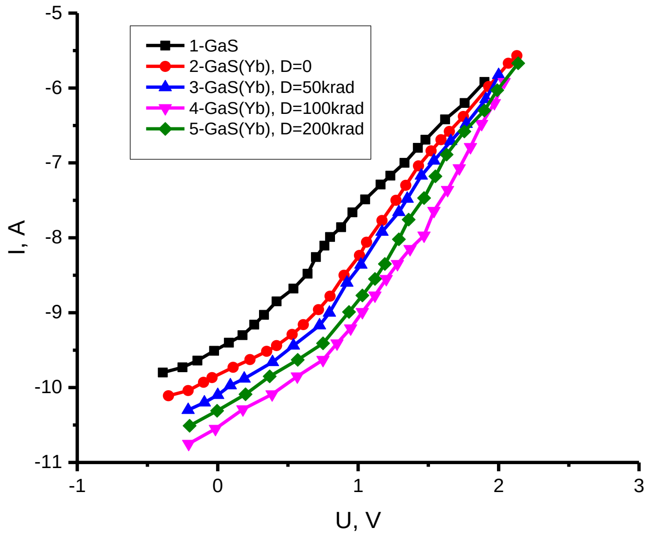

Fig. 2. Volt-ampere characteristics of GaS and GaS(Yb) single crystals at different doses (T=300K)

When the GaS (Yb) crystal is irradiated with a dose of D = 50krad (curve 3), the value of the current passing through the sample decreases compared to the non-irradiated sample, but the nature of the curve does not change. In this case, the value of the transition voltage from the ohmic region to the quadratic region increases. Based on the U_k-transition voltage value and the formula given in [5], the concentrations of free charge carriers and traps were calculated and were $3.61\cdot10^7$ cm^{-3} and $N_{tor} = 3.3\cdot10^{17}$ cm^{-3}, respectively. A comparison of the parameters shows that the decrease in current in the irradiated GaS (Yb) crystal at a dose of 50 krad is due to a decrease in the concentration of free charge carriers. Curve 4 shows that when irradiating GaS(Yb) single crystal with a dose of D=100 krad, the value of the current passing through the sample decreases again, and the non-trap quadratic region is not observed in the subsequent increase in voltage (U≥100V). Such a change in current may be due to the formation of deep levels that collect the charge carriers involved in the conduction. When irradiating a GaS(Yb) crystal with a dose of D=200 krad, the value of current increases in the whole voltage region ($U=8*10^{-1}\div10^2$), and after U≥60V, a non-trap quadratic region is observed.

Analysis of the experimental results shows that the concentration of specific charge carriers decreases as a result of partial compensation of initial acceptor-type defects in the crystal by the inclusion of Yb additive atom in the p-GaS layered single crystal and the Yb-additive atom creates a donor-type energy level. During gamma-quanta irradiation, a defect formation process occurs in the Ga and S lattices, and this dn/dΦ - defect formation rate depends on the bond energy of the component and the radiation dose. Therefore, the concentration of radiation defects formed in the Ga and S sublattice differs from each other. Therefore, at low doses of radiation, the concentration of specific charge carriers decreases due to the predominance of donor-type defects in GaS crystals, and at high doses of radiation, on the contrary, it increases [6]. The inclusion of the additive Yb atom also reduces the conductivity of the crystal, as shown in Figure 3.1, and this is due to the partial compensation of the acceptor-type level. Based on the above considerations and the experimental facts we have obtained, it can be said that the process of defect formation in the GaS(Yb) crystal under the influence of gamma quanta occurs according to the mechanism observed in layered GaS and GaSe crystals. The ionization process occurs as a result of the excitation of the electron shell of the atom by gamma-quanta. The Compton formed as a result of ionization slides the ion at the nodes of the electron lattice into the lattice space, as a result, vacancy + inter-nodal atomic pair is formed. The interaction of the vacancy - inter-nodal atom depends on the bond energy. Depending on this value of energy, the annihilation of the resulting pairs or complex formation occurs. On the basis of these considerations, the following can be said based on the results obtained during the analysis of VAC in irradiated GaS(Yb) crystals:

- The increase in current in the ohmic region at radiation doses $\Phi<50$ krad is due to the annihilation of the internodal additive Yb ion with V_{Ga}, and the sharp increase in current in high electric fields is due to thermoionization of local levels;
- As a result of dissociation of the $[V_{Ga}\ I_{Yb}]$ complex at radiation doses $\Phi>100$ krad, an increase in the concentration of free charge carriers (relative to the pre-irradiation concentration) is observed, the VAC of the crystal shifts to a low voltage region.

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ВЛИЯНИЕ γ-ИЗЛУЧЕНИЯ НА ВОЛЬТ-АМПЕРНЫЕ ХАРАКТЕРИСТИКИ ЛЕГИРОВАННЫХ Yb МОНОКРИСТАЛЛА GaS

Р.С. Мадатов, Т.Б. Тагиев, А.Ш. Халигзаде

Резюме: Исследовалось влияние γ-квантов на вольт-амперные характеристики чистого и легированного Yb слоистого монокристалла GaS при 300K. Установлено, что увеличение тока в омической области при дозах облучения D<50 крад связано с аннигиляцией межузельного примесного иона Yb с V_{Ga} , а резкое увеличение тока в сильных электрических полях- за счет термоионизации локальных уровней. Диссоциация комплекса [V_{Ga} I_{Yb}] при дозах облучения D>100 крад, наблюдается увеличение концентрации свободных носителей.

Ключевые слова: вольт-амперная характеристика, концентрация, акцептор, донор, доза.

Yb İLƏ AŞQARLANMIŞ GaS MONOKRİSTALININ VOLT-AMPER XARAKTERİSTİKASINA γ-ŞÜALANMANIN TƏSİRİ

R.S. Mədətov, T.B. Tağıyev, A.Ş. Xalıqzadə

Xülasə: γ-kvantların aşqarsız və Yb aşqarlanmış GaS laylı monokristalının volt-amper xarakteristikasına təsiri 300K temperaturda öyrənilmişdir. Müəyyən edilmişdir ki, D< 50 krad şüalanma dozalarında omik oblastda cərəyanın artması düyünlərarası aşqar Yb ionunun V_{Ga} ilə anniqlyasiyası , yüksək elektrik sahələrdə cərəyanın kəskin artması isə lokal səviyyələrin termoionlaşması hesabına baş verir. D> 100 krad şüalanma dozalarında isə [V_{Ga} I_{Yb}] kompleksinin dissosasiyası nəticəsində sərbəst yükdaşıyıcıların konsentrasiyasının artması müşahidə olunur.

Açar sözlər: volt-amper xarakteristikası , konsentrasiya , akseptor, donor, doza.