The Effect of Er Dopant Atoms on the Photoelectric Properties of Monocrystal GaS

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Abstract— Monocrystal GaS is a wideband, photosensitive semiconductor material in visible and ultraviolet regions of the spectrum. To expand the possibilities of application of this crystal, Er atoms were used as dopant atoms. In layered semiconductor crystals, a covalent-ionic bond between the atoms on the surface and a relatively weak Van der Waals bond exist between the layers. Therefore, it is possible to intercalate impurity atoms with different ionic radii into these crystals. The mentioned properties can also be attributed to the p-GaS crystal, which is one of the $A^{III}B^{VI}$ type semiconductors. Studies have shown that Er atoms, a rare earth metal, also affect the photoconductivity spectrum of the p-GaS layered monocrystal. The maximum of the photoconductivity spectrum of GaS and GaS:Er layered monocrystals coincides with the edge of the fundamental absorption region and is equal to hν=2,45 eV. The width of the bandgap at room temperature was E_g=2,4 eV. The photosensitivity region of the layered monocrystals covered the wavelength interval of 450÷630 nm, the main maximum was observed in λ=486 nm, and additional maxima were recorded at wavelengths of λ=463 nm and λ=543 nm. With increasing temperature, the photocurrent increases, λ_{max} shifts towards the long-wave region.

Keywords— layered monocrystal, rare earth metal, photoconductivity, intercalation, exciton

I. INTRODUCTION

The GaS compound is a wide gap semiconductor material and crystallizes in the hexagonal syngony in the P63/mm space group, with elementary lattice parameters of a=0,3578 nm, c=1,547 nm [1, 2]. Since there is a weak Van der Waals bond between atomic planes in the direction of the "c" crystallinity axis, it is possible to mechanically separate the crystal into layers in a direction perpendicular to the "c" axis and obtain a GaS-based 2D structure. At room temperature, the bandgap of a GaS layered crystal is 2,53 eV and the edge of the fundamental optical absorption region is formed by oblique electron transitions [3]. Theoretical calculations of the energy structure of the conduction band of GaS crystals have shown that three extrema (minima) are located in the center of the Brullien zone. Two of these minima are located 8 meV and one is located 22 meV from the bottom of the conduction band [4]. The non-equilibrium electrons located in these subbands can perform a transition and recombination with energies of 2,53 eV; 2,61 eV and 2,75 eV. For this reason, the GaS crystal is promising for the production of light-emitting diodes that emit radiation in the blue-green range of the spectrum.

GaS monocrystal is a wide-bandgap semiconductor material (E_g=2,5 eV at T=300 K) that is photosensitive in the visible and ultraviolet regions of the spectrum [1]. One of the methods to expand the applicability of this crystal is to use various dopant atoms. In recent decades, rare earth metals have been used as dopant atoms [2].

Since the 60s of the last century, the use of rare earth metals in solid state electronics, especially in lasers, has sharply increased the interest in them. However, rapid oxidation of some lanthanides and the inability to obtain them with high purity caused certain technological difficulties. Another problem with lanthanides is that their ionic radii are ~50% larger than some traditional semiconductor elements such as Ge and Si, and they form complex compounds with chalcogens [3].

Regarding the electronic configuration some of the rare earth metals are characterized by incomplete filling of the inner *4f* electron shell [5]. Therefore, these elements are used in the preparation of strong magnets because they have a large magnetic moment. The rare earth metals have been little used in electrophysics due to the low mobility of charge carriers ($10 \div 10^2$ $cm^2/V\cdot sec$). Another characteristic of rare earth metals is that they form nanoscale atomic clusters in various crystal matrices. Depending on the purity and type of the matrix these clusters and nanostructures become centers of radiative recombination of different wavelengths. As mentioned, the GaS layered monocrystal has a large bandgap. This allows it to be used in laser technology and in the preparation of luminophores in quantum systems for various purposes by doping it with rare earth metals [6].

Unlike bulk crystals, the presence of weak molecular bonds (Van der Waals bonds) in layered semiconductor crystals allows rare earth elements to intercalate between the layers. Therefore, the influence of rare earth elements on the electrophysical, photoelectric and optical properties of layered monocrystals and their modification has led to the creation of numerous structures and electronic devices.

II. EXPERIMENTAL PART

The mentioned factors can also be attributed to the p-GaS crystal, which is one of the representatives of the $A^{III}B^{VI}$ type semiconductors. Unlike other crystals, layered crystals have a strong anisotropy. The monocrystalline GaS compound is obtained by Bridgman method. During the process, the speed of passage of the quartz ampoule containing polycrystalline GaS material through the two band boundaries was 2 mm/h.. To prove the anisotropy of the p-GaS crystal, its resistivity was measured in different directions. The results of the studies showed that the resistivity in the c-axis direction was $3 \cdot 10^7$ Ohm·cm, but along the surface it was $2 \cdot 10^9$ Ohm·cm.

To study the photoelectric properties of a layered monocrystal GaS, an optical device based on an MDR-2 monochromator was used. To conduct the experiment in a wide temperature range (100K÷300K), the sample was placed in an IVS-68 platinum sensor cryostat. Indium was used as the ohmic contact and Er- a rare earth element was used as dopand.

III. Conclusion

As can be seen from the photoconductivity spectra of GaS and GaS:Er layered monocrystals, the maximum of the photoconductivity spectrum coincides with the value hν=2,4eV which is close to the edge of the fundamental absorption region. From optical measurements it was determined that the the width of the bandgap was E_g=2,4eV at room temperature [7].

Figure 1 shows the photoconductivity spectra of a GaS:Er monocrystal at different voltages. As can be seen from the graph, the photosensitivity region of the crystal covers the wavelength range of 450÷630 nm. The main maximum is recorded at the wavelength of λ=486 nm, and the additional maxima are recorded at λ=463 nm and λ=543 nm. It is observed that the photocurrent increases as the voltage between the electrodes increases.

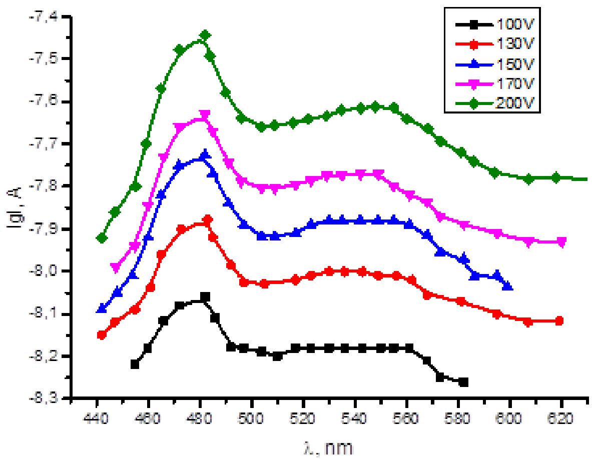

Figure 1. Photoconductivity spectrum of GaS:Er,Yb monocrystal at different voltages.

In the sample as the temperature increases, the photocurrent increases and the maximum shifts towards the long-wavelength region. Based on the results of the studies, we have determined that the maximum corresponding to 460 nm is due to the photoactive decay of the exciton [8]. At a temperature of 300 K the maximum corresponding to 503 nm is due to the photoactive decay of the oblique excitons.

Figure 2 describes the change in the photoconductivity spectrum of a GaS:Er monocrystal at different temperatures.

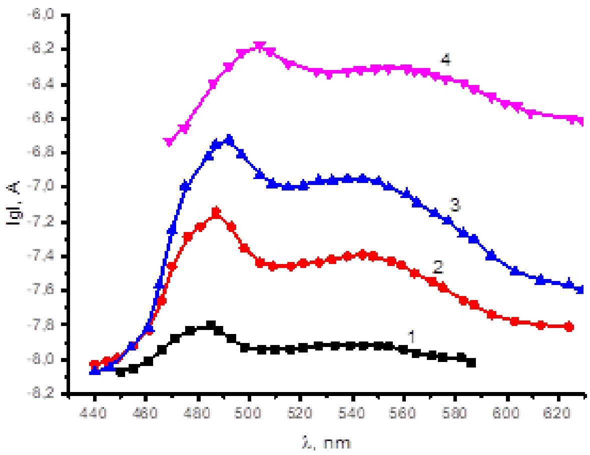

Figure 2. Photoconductivity spectrum of GaS:Er,Yb monocrystal. 1−T=100K; 2−T=200K; 3−T=300K (U=150V).

It should be noted that this maximum was also observed in the samples in which the GaS crystal was doped with transition elements (Fe, Mn) and Yb [9-16]. The percentage of Er dopants added to the GaS crystal corresponding to the maximum at 543 nm increases in the range of 0.01÷0.1 atm%.

Further increase in dopants leads to a decrease in the photosensitivity of the GaS:Er crystal.

The mentioned facts suggest that Er impurities create rapid recombination centers in the crystal at a certain temperature. A further increase in temperature results in the extinction of the photocurrent.

Thus, the following results are obtained by the effect of Er impurity atoms on the photoelectric properties of GaS monocrystal:

–the maximum in the spectrum corresponding to 460 nm is due to the photoactive decay of the exciton;

–the maximum corresponding to 503 nm at a temperature of 300K arises as a result of the photoactive decay of the oblique excitons;

–Er dopands create rapid recombination centers in the crystal at a certain temperature;

–further increase in the concentration of impurities and temperature leads to a weakening and extinction of the photocurrent.

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