EFFECT OF GAMMA IRRADIATION ON ELECTRICAL RESISTIVITY OF INDIUM ANTIMONIDE FILMS

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This paper presents a study of the effect of Co^{60} gamma irradiation with an energy density of at least 10^{15}–10^{17} cm^{-2} on the electrical resistivity of indium antimonide films formed by explosive thermal evaporation. The irradiation conditions are imitation of radiation exposure in Earth orbit with an absorbed dose of up to 150 kGy. The temperature dependences of electrical resistivity were obtained in the range from RT to 150 °C. It was found that with a gamma irradiation fluence of 10^{16} cm^{-2} in a narrow temperature range the resistivity increases. In the case of maximum fluence of gamma irradiation (10^{17} cm^{-2}) the resistivity decreases. It is assumed that this is due to a change in the position of the Fermi level during irradiation.

Key words: indium antimonide; films; electrical resistivity; gamma irradiation.

INTRODUCTION

The study of the radiation impact of cosmic radiation, radiation in nuclear power plants, accelerators and other sources on modern electronic components is an urgent scientific and technical task. High-energy and ionizing particles lead to structural phase transformations, generation of radiation defects, leading to many effects in semiconductor devices, for example, a change in the type of conductivity, a decrease in the mobility of charge carriers, an increase in resistance, and other changes. The consequence of such an impact can be both a decrease in performance and a functional failure, which can affect the operation of the entire electronic system. As the complexity of modern devices grows, their responses to exposure to ionizing radiation become more diverse, and new failures in operation under conditions of various types of radiation exposure are regularly observed [1].

Indium antimonide is a narrow-gap semiconductor with a high electron mobility. Changes in the structural, electrophysical properties, accumulation of defects under the influence of various types of radiation exposure, including gamma-quanta, in indium antimonide and similar semiconductor materials of the $A^{III}B^{V}$ group, are intensively studied in the world's leading scientific centers, due to the wide practical application of indium antimonide, for example, in miniature Hall transducers, including those built into electronic components of a wide class of products [2].

The formation of defects in the crystal lattice of semiconductor materials during irradiation with γ-quanta is caused by the action of secondary electrons emitted during Compton scattering, the photoelectric effect, and the formation of electron-positron pairs. At energies of gamma-quanta in the range of several MeV, Compton scattering predominates [3]. The interaction of secondary electrons with matter leads to the displacement of atoms at the nodes of the crystal lattice, which affects the final electrical and optical properties of semiconductor materials [4–7]. It is known that the irradiation of InAs/GaSb epitaxial structures with gamma rays with energies of 1.17 and 1.33 MeV and a dose of 500 Gy led to a decrease in the mobility and mean free path of charge carriers [4]. Upon irradiation of GaAs with gamma-quanta, a decrease in the mobility and concentration of charge carriers was also observed, which may be due to the appearance during irradiation of additional scattering and recombination centers in the form of radiation defects of the crystal lattice [7]. An increase in the absorbing dose of irradiation with gamma-quanta to high values of 360 kGy for photodetectors based on homoepitaxial *GaAs* films reduces their efficiency by 50% [8]. The aim of this work is to study the effect of irradiation with gamma-quanta of Co^{60} with a fluence in a wide range of 10^{15}–10^{17} cm^{-2} on the change in the electrical resistivity of samples of epitaxial films of indium antimonide on gallium arsenide substrates. Note that for modern systems of orbital spacecraft, when used under natural radiation conditions, the required radiation resistance is at least 10 kGy for 5 years and for interplanetary spaceflights, the total absorbed dose of radiation over 12 years can be 100 kGy [9].

MATERIALS AND METODS

The deposition of indium antimonide films was carried out on polished gallium arsenide plates by the method of explosive thermal evaporation of single-crystal *InSb* powder at a substrate temperature of (440.0±2.5) °C [10]. As shown by the data of [10], films deposited in the temperature range of 430–440°C have the best thermoresistive properties. After the films were deposited, their thickness was measured using a MahrMarSurf M400 profilometer. The measured film thickness was (5.00±0.05) μm. Irradiation of indium antimonide films with Co^{60} gamma-quanta with an energy of 1.17 and 1.33 MeV was carried out on the "Issledovatel" gamma-ray installation with a fluence in the range of 10^{15}–10^{17} cm^{-2} (the estimated absorbed dose is from 1.5 kGy to 150 kGy, respectively).

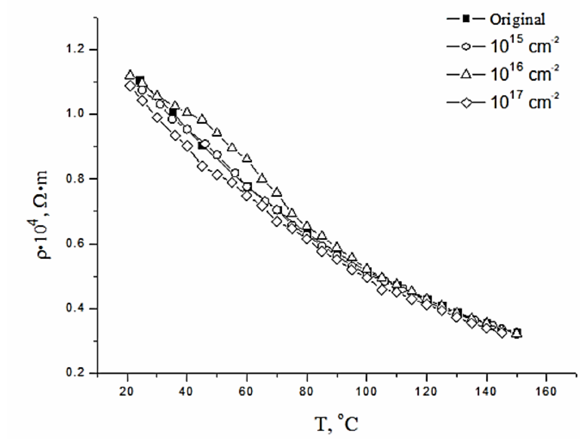
Measurements of the electrical resistivity of indium antimonide films were carried out in the temperature range from RT to 150 °C. The estimated error in measuring the electrical resistivity does not exceed 2%.

RESULTS AND DISCUSSION

To determine the radiation resistance of the obtained films, the temperature dependence of the electrical resistivity was measured. Figure shows the electrical resistivity of indium antimonide films for both irradiated and non-irradiated samples in the temperature range from RT to 150 °C.

It can be seen from the obtained data that the resistivity of indium antimonide films increases with the growth of the gamma-quantum fluence up to 10^{16} cm^{-2} (absorbing dose of 15 kGy), then at the maximum fluence of 10^{17} cm^{-2} (absorbing dose of 150 kGy) the resistivity of the films decreases relative to the initial values. The change in observed resistivity is more pronounced in 30–75 °C range. It was also observed that at lower dose of 10^{15} cm^{-2} (absorbing dose of 1.5 kGy) resistivity was not affected significantly.

In the general case, the film resistance is an integral characteristic determined by several parameters. One of these parameters is the concentration of charge carriers, which depends on the concentration and nature of radiation defects in the film. According to the amphoteric defect model, the type of dominant defects is determined by the position of the Fermi level E_F relative to the position of the level in the E_{FS} standard [11]. When $E_F < E_{FS}$, the formation energy of charged donor defects decreases, so the formation of intrinsic donor-type defects becomes energetically favorable. In undoped InSb, antimony vacancies (V_{Sb}) act as an acceptor and indium vacancies (V_{In}) act as a donor, so the results show that in the studied range at a fluence of 10^{16} cm^{-2}, more indium vacancies V_{In} are introduced than antimony vacancies V_{Sb}. In this case, it should be taken into account that the position of the Fermi level during irradiation is unstable and becomes stable when a certain concentration of defects is reached [11]. Therefore, during irradiation, defective complexes of both donor and acceptor types can be formed, corresponding to a decrease in resistivity at the maximum irradiation fluence (10^{17} cm^{-2}).



The dependence of the electrical resistivity of indium antimonide films on temperature before and after irradiation with gamma-quanta with a fluence in the range of 10^{15}–10^{17} cm^{-2}

Unlike perfect single crystals, indium antimonide films have structural features in the form of crystallites, intercrystallite boundaries, the presence of internal stresses, a transitional defective layer between the substrate and the film, etc. These structural features of the films can be effective sinks for radiation defects caused by various ionizing effects (secondary electrons caused by photoemission, the Compton effect, etc.) upon irradiation with gamma rays. Moreover, the annihilation of radiation defects can also occur at room temperature [7, 12]. It is also reported that the annealing of defect states occurs at a temperature of 160–230°C [13].

Thus, the recombination of generated defects on the structural features of indium antimonide films significantly limits the change in the electrical resistivity of irradiated films at maximum absorbing doses of gamma rays to 150 kGy.

CONCLUSIONS

As a result of the study, it was found that when irradiated with gamma-quanta, the resistivity of indium antimonide films increases with an increase in the fluence of gamma-quanta up to 10^{16} cm^{-2}, then at a maximum irradiation fluence of 10^{17} cm^{-2}, the resistivity of the films decreases relative to the initial values. The observed change in resistivity is more pronounced in 30–75 °C range. It is assumed that this is due to a change in the position of the Fermi level during irradiation, as a result of which the formation of intrinsic defects of the donor (at a fluence of 10^{16} cm^{-2}) or acceptor type (at a fluence of 10^{17} cm^{-2}) is energetically favorable. Further, with an increase in temperature to 150 °C, the values of resistivity, depending on the fluence of gamma-quanta, change within the error. This behavior may be due to the annealing of defect states. It was also observed that at a lower dose (at a flux density of 10^{15} cm^{-2}) the resistivity did not change significantly due to recombination processes of radiation defects caused by ionizing effects.

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