The Influence Of Irradiation On Electrophysical And Optical Properties Of Pb\textsubscript{1-x}Mn\textsubscript{x}Te(Se) Thin Films

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Abstract: - In the given paper the influence of accelerated electrons on photoelectrical, electrophysical and optical properties of Pb\textsubscript{1-x}Mn\textsubscript{x}Se (x=0.01) and Pb\textsubscript{1-x}Mn\textsubscript{x}Te (x=0.04) epitaxial films, grown on freshly broken faces of BaF\textsubscript{2}, have been investigated. It was established that the samples became more photosensitive after irradiation.

Key-Words: - semimagnetic semiconductor, epitaxial films, photosensitive, accelerated electrons, photoelectrical, electrophysical, optical

1 Introduction

At present, significant development of semiconducting infrared (IR) devices' market is observed. This tendency, first of all, is associated with the application of new materials in IR technology devices. Achievements of semiconducting material science, observed in recent years, have played an important role in the accelerated development of modern technology and instrument engineering. The research and establishment of scientific basis of new perspective materials' technology are one of the major tasks of semiconducting material science [1].

In connection with wide application of the indicated semiconductors A\textsuperscript{IV}B\textsuperscript{VI} in optoelectronic devices these materials are of large scientific interest and draw the investigators attention. They are used in manufacturing of different infrared (IR) engineering instruments [2]. There have been developed a number of methods for obtaining structural-perfect uniform epitaxial films of these materials with predetermined thickness, composition and concentration of charge carriers [3].

There is a little number of works devoted to preparation, study and application of Pb\textsubscript{1-x}Mn\textsubscript{x}Te(Se,S) epitaxial films, however we didn’t find any publications devoted to the influence of irradiation on photoelectrical, electrophysical and optical properties of Pb\textsubscript{1-x}Mn\textsubscript{x}Te(Se,S) thin films.

The crystalline structure and physical properties of these films are much determined by substrates parameters. It is desirable that the maximum possible coincidence of parameters of lattice, coefficients of substrate thermal expansion and film to be sputtered. The use as substrates of monocrystalline plates of the indicated compounds or solid solutions allows achieving the full coincidence of all parameters. On the other hand, the epitaxial films and structures obtained on insulating dielectric substrates are of great practical interest.

Development of new types of optoelectronic devices operating in IR region of the spectrum and resistant against effect of ionizing radiation of a various type is the important task facing by a modern science and engineering. So the characteristics of many materials nowadays using in engineering become considerably worse under the effect of radiation as a result of transformations occurring in them.

From this point of view A\textsuperscript{IV}B\textsuperscript{VI} type compounds and solid solutions on their basis are of special interest. So, in these solid solutions as a result of introduction of Mn ions in a lattice of lead chalcogenides a lattice constant decreases though it is unsignificant. In results the band gap is increase and in structures made on the basis of these substances an opportunity to control their properties by magnetic field and temperature occurs and it is possible to use them for manufacturing radiation-proof optoelectronic devices.
2 EXPERIMENTS AND DISCUSSION

2.1 Pb$_{1-x}$Mn$_x$Te thin films

In this section the peculiarities of increase of epitaxial films Pb$_{1-x}$Mn$_x$Te (x=0.04) grown on freshly broken faces of BaF$_2$ and on polished plates (100) by the method of molecular beams condensation have been considered. The choice of BaF$_2$ as a substrate is due to that it has cubic structure of CaF$_2$ type with the parameter of elementary unit 6.19Å, it is transparent within spectral range 3÷12mcm, dielectric, has good mechanical strength and chemically inert.

There have been studied epitaxial films Pb$_{1-x}$Mn$_x$Te on BaF$_2$ substrates obtained by the method of molecular-radiation epitaxy [4,5]. Films thickness was about 0.5÷1mcm.

The measurements were carried out on structures formed by two silver contacts obtained by sputtering in a vacuum. The width of clearance between contacts was 0.5÷1.0 cm at clearance size from 16 to 64mcm.

Both capacitance and ohmic components of structure conductivity could be measured by standard scheme.

The epitaxial films are grown by the method of molecular beams condensation in a vacuum 10$^4$Pa. Presynthesized alloys Pb$_{1-x}$Mn$_x$Te (x=0.04) of appropriate chemical composition served as a source of molecular beams.

With the aim of preparing films of more perfect structure and with required values of electrophysical parameters the additional compensating source of Te vapours has been used during growth. The researched showed that epitaxial growth occurs at substrate temperature T$_n$=473÷523K. The films with more perfect structure (W$_{1/2}$=90÷100), thickness 0.5÷1mcm are obtained at condensation rates 8÷9Å/sec and T$_n$=613 653 K.

The starting samples were irradiated at room temperature in linear amplifier of electrons ELU-6 (E=5MeV, $\Phi=5\cdot10^{17}$ cm$^{-2}$). For each sample prior and after irradiation the temperature dependence of specific resistance has been studied (Fig 1).

At all samples studied at first decreases slowly and then increases at temperature 77K. The more significant changes being characteristic for samples with the least starting concentration of electrons. The nature of dependences $\rho(1/T)$ of the samples with high starting concentration of electrons doesn’t change. Within temperature region close to room one, the activation section appears connected with own ionization of charge carriers.

Fig.1. Temperature dependence of specific resistance of electrons irradiated ($\Phi=5\cdot10^{17}$ cm$^2$) sample 1. Before irradiation, 2. after irradiation.

At the same time the experimental data, obtained [6,7] in the course of study of p-type crystals, don’t allow to predict with enough reliability the nature of n-type alloys parameters change in irradiation depending on ratio of rates of generation of defects of donor and acceptor nature. The irradiation of n-type crystal can lead to both n-p-conversion of conductivity type (dN$_d$/d$\Phi$<dN$_a$/d$\Phi$) and to the increase of electrons concentration in conductivity zone up to the stabilization of Fermi level at energy level of donor type defect (dN$_d$/d$\Phi$>dN$_a$/d$\Phi$). Besides, the points on energy position of radiation level of donor type and nature of rebuilding of energy spectrum of irradiated alloys in variation of tin content in alloy remain uncertain.

Therefore the general task of the present work was the study of effect of deep electrons irradiation on electrophysical properties of unalloyed monocrystals n-Pb$_{1-x}$Mn$_x$Te (x=0.04) for determination of parameters charge carriers energy spectrum for these material, elucidation of nature of their properties change and in particular, possibility
for achievement the limiting characteristics of materials as a result of irradiation.

On the basis of developed regime there have been obtained high ohmic epitaxial films Pb$_{1-x}$Mn$_x$Te of n and p-type conductivity with concentration $n$, $\rho(77K) = 4 \cdot 10^{15} \div 1.5 \cdot 10^{16}$ cm$^{-3}$ and charge carriers mobility $\mu(77K) = 2.5 \div 3 \cdot 10^{4}$ cm$^2$/V·sec.

The films with different types of conductivity have been obtained by changing temperature of basic Pb$_{1-x}$Mn$_x$Te and compensating source of Te. It has been established that under the above mentioned conditions the epitaxial films are photosensitive at the temperature of liquid nitrogen (77K) (Fig.2). As is seen from Fig.2 the maximum of spectrum of films Pb$_{1-x}$Mn$_x$Te (x=0.04) photoconductivity is shifted towards the shorter wakes in comparison with similar spectra for the other compositions of the given solid solution (0≤x≤0.04) carried out in [8], that is explained by increasing width by increasing of energy gap of the studied samples. From Fig.2 is seen that after irradiation, the samples become more sensitive.

2.2 Pb$_{1-x}$Mn$_x$Se thin films

In this section have been studied the crystal structure and surface morphology of epitaxial films of Pb$_{1-x}$Mn$_x$Se (x=0.01) solid solutions, which grow on BaF$_2$ substrates.

Crystal perfection of the films has been studied by electron diffraction, X-ray diffraction methods, and its surface morphology by the method of atomic-force microscope.

The epitaxial films Pb$_{1-x}$Mn$_x$Se have been received by molecular beam condensation (MBC) method in vacuum 10$^{-4}$ Pa. As a source it has been used pre-synthesized Pb$_{1-x}$Mn$_x$Se (x=0.01) solid solutions with different chemical composition. Lattice constants of solid solutions have been calculated from X-ray diffraction curves and reflection electron diffraction, received from the films. As a substrate it has been used natural layers of BaF$_2$ monocrystals, cut of accordingly on its plane (111).

The researches show that, at temperature 663÷673K and condensation rate $\nu_k = 8 \div 10$ Å/s during growth process of BaF$_2$ substrates by using additional compensating source Se, epitaxial films of solid solutions Pb$_{1-x}$Mn$_x$Se (x=0.01) with high crystal perfection ($W_{1/2} = 90 \div 100^\circ$) and surface, lattice constant $a= 6.11 \div 6.05$ Å, thickness 0.5÷1 mkm are obtained (Fig. 3.a, b).

Fig.2 Spectrum of photoconductivity of Pb$_{1-x}$Mn$_x$Te (x=0.04) films at temperature 77K. 1. before irradiation, 2. after irradiation.

Fig.3 Electron diffraction (a) and X-ray diffraction (b) of epitaxial films Pb$_{1-x}$Mn$_x$Se

Lattice constants $a= 6.11 \div 6.05$ Å reaffirms that, the studied films consist of solid solutions with different chemical composition.
Surface morphology of obtained epitaxial films has been studied by atomic-force microscope (AFM). On the basis of the researches it has been determined that, the obtained epitaxial films grow similarly along the whole surface parallel to substrate. At the same time as a result of the research it has been determined three-dimensional topography of the sample, studied by atomic-force microscope, and its surface roughness (Fig.4).

![Surface morphology of obtained epitaxial films](image)

3 Conclusion
In the presented work the influence of electron rays on photoelectrical, electrophysical and optical properties of Pb$_{1-x}$Mn$_x$Se (x=0.01) and Pb$_{1-x}$Mn$_x$Te (x=0.04) epitaxial films have been studied. The resistance of the researched sample has been measured before and after irradiation. It has been determined that, after irradiation the samples’ resistance at nitrogen temperature first gradually decreased, then sharply increased. This change is mostly observed in the samples of electrons with low concentration. This result wasn’t achieved in the samples with high concentration. On the basis of the researches it has been determined that, by changing of Mn quantity in epitaxial films, maximum of photosensitivity slips towards short waves. It results with increase of Mn composition and width of the band gap. It has been defined from the experiments that, after irradiation the samples become more sensitive to light.

References: