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The effect of laser treatment on the morphology and structure of CdSb-$Cd_{1-x}Mn_xTe$ and CdSb-$In_4(Se_3)_{1-x}$ Te_{3x} thin film heterojunctions

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ABSTRACT

Peculiarities of heteroepitaxial growth of CdSb thin films on $A^{II}B^{VI}$ and $A^{III}B^{VI}$ single crystal substrates were studied by atomic-force and scanning electron microscopy. New thin film CdSb-$Cd_{1-x}Mn_xTe$ and CdSb-$In_4(Se_3)_{1-x}Te_{3x}$ heterojunctions were obtained by high-frequency cathode sputtering of CdSb single crystal target. Laser treatment of CdSb films using millisecond YAG-laser with energy density of 0.1–4.5 J/cm^2 has been carried out in order to modify and improve their structure and phase state. Stoichiometry of composition and granular polycrystalline structure of CdSb films on $Cd_{1-x}Mn_xTe$ and $In_4(Se_3)_{1-x}Te_{3x}$ substrates have been confirmed by SEM and AFM studies. A stepwise growth processes of grains were detected under laser treatment in CdSb films. Anisotropic shape of grains in CdSb films was found depending on crystallographic orientation of In_4Se_3 substrate surface.

1. Introduction

The development of advanced thin-film technologies is closely related with the use of laser methods for modifying the morphology and structure of heterojunctions containing semiconductor thin film. Using pulsed laser treatment it is possible to control the structural state and phase composition of epitaxial films and layers and respectively to carry out the correction and optimization of their electrical parameters and characteristics [1,2]. So-called van der Waals epitaxy technology gives a possibility to obtain heterostructures with a great mismatch in lattice parameters and to create new efficient sensors, alarm systems, telecommunications devices and photodetectors on their basis [3,4].

The new thin film (CdSb as a film) heterojunctions CdSb-$Cd_{1-x}Mn_xTe$ and CdSb-$In_4(Se_3)_{1-x}Te_{3x}$ (with different values of x, including x = 0) can be promising materials for creation sensors and photoelectric devices. A number of important properties of antimonide cadmium CdSb, such as strong anisotropy, a small band gap (E_g = 0.48 eV), thermoelectric, optical and photovoltaic properties cause considerable interest in studying of CdSb as thin films and layers in film heterostructures and optical elements [5,6]. Therefore, it is important to develop effective methods for obtaining stoichiometric CdSb thin films. Great difference in the values of components vapor pressure leads to dissociation of this compound in the evaporator and predominant evaporation of more volatile components, which violates the stoichiometry of the films [7,8].

In the present work we have carried out deposition of CdSb thin films on CdTe and In_4Se_3, as well as on $Cd_{1-x}Mn_xTe$ and $In_4(Se_3)_{1-x}Te_{3x}$ In_4Se_3 single crystals, by ion-plasma RF sputtering technique, which is able to provide in optimal mode the required composition of the films [9]. This method has been used in combination with subsequent laser treatment of CdSb films in order to improve their structure and optimize the properties of film heterojunctions [10,11]. For the controlled laser correction of CdSb films properties there should be taken into account different mechanisms of interaction of radiation with the material of the film. Recrystallization processes, phase transformation and strong redistribution of impurities in the films, evaporation of adsorbed atoms and volatile components, such as Cd in the case of CdSb [12] take place under the action of pulsed laser radiation of different intensity. High speed heating and cooling of CdSb films in the area of laser treatment can lead to the formation and hardening of acceptor-type defects [13], and additionally modify electrical properties of studied thin film heterojunctions.

2. Materials and methods

High-frequency cathode sputtering was used for the first time for obtaining a number of CdSb-$Cd_{1-x}Mn_xTe$ and CdSb-$In_4(Se_3)_{1-x}Te_{3x}$ heterojunctions. The use of $A^{II}B^{VI}$ and $A^{III}B^{VI}$ solid solution crystals as the substrates gives a possibility to obtain heterojunctions with different band gap alignment depending on the

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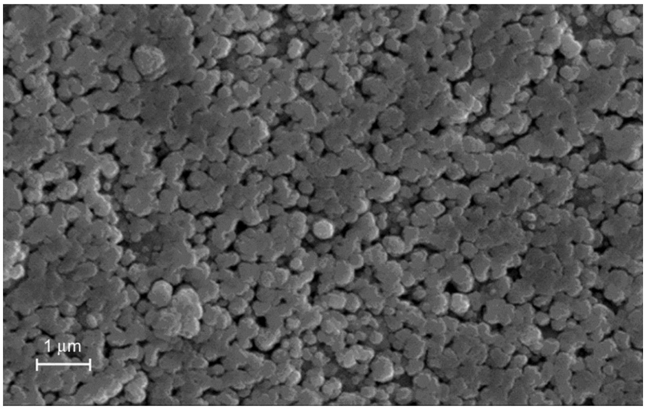

Fig. 1. SEM image of CdSb film on $In_4(Se_3)_{0.94}(Te_3)_{0.06}$ single crystal substrate.

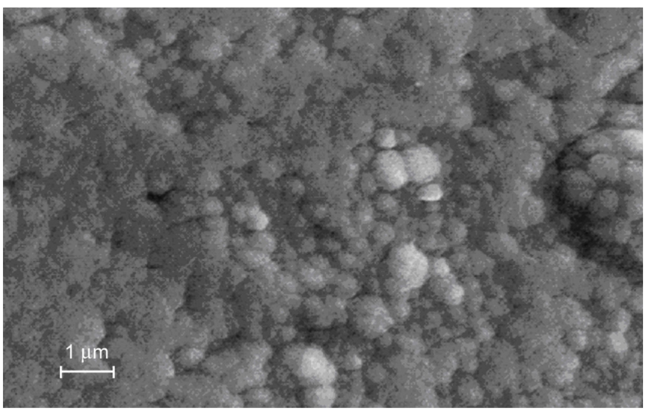

Fig. 2. SEM-image of CdSb film on $In_4(Se_3)_{0.94}(Te_3)_{0.06}$ single crystal substrate after laser treatment with energy density of 0.4 J/cm^2.

Table 1
Composition of CdSb films deposited on In_4Se_3 substrate in some local areas of the film.

	Cd	Sb	∑
Area number	(at.%)	(at.%)	(at.%)
1	51.28	48.72	100.0
2	47.42	52.58	100.0
3	50.17	49.83	100.0

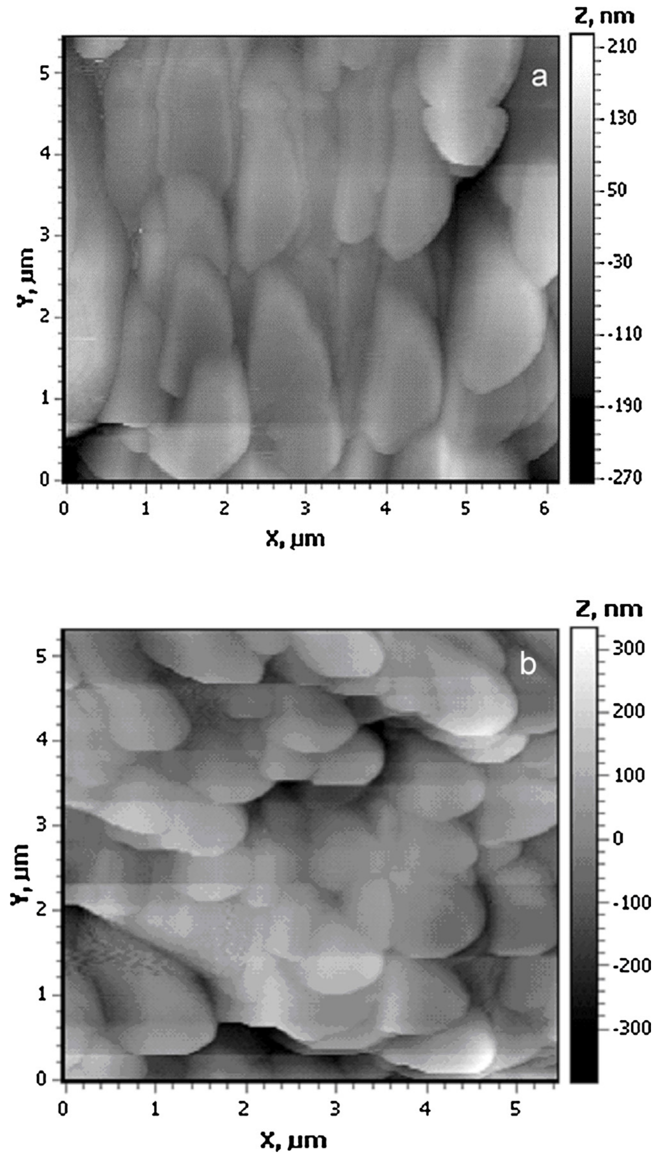

Fig. 3. AFM-images of CdSb films on In_4Se_3 single crystal substrates grown in the direction [010] (a) and in the direction [001] (b) after laser treatment with the energy density of 0.4 J/cm^2.

composition of solid solution. Film-forming CdSb compound has strongly different partial vapor pressure of Cd and Sb components and decomposes at deposition in vacuum. Therefore, it is important to set technological modes of RF cathode sputtering, which provide congruent evaporation of Cd and Sb components and enable obtaining stoichiometric CdSb thin films.

Initial CdSb crystals were grown by the Czochralski method. The concentration of carriers in undoped CdSb crystals, which were used as the cathode targets, was of (2–5)·10^{15} cm^{-3} at 77 K. Deposition of CdSb thin films has been carried out similarly to the procedure described in [10]. The process was carried in an atmosphere of Ar at RF power of 10–30 W with the deposition rate of 2–5 Å/s, substrate temperatures was of 343–443 K. The thickness of CdSb films was within 0.8–1.3 μm.

In_4Se_3 and In_4Te_3 single crystals grown by the Czochralski method using the Peltier effect were used as the substrates for obtaining CdSb-$In_4(Se_3)_{1-x}Te_{3x}$ (x = 0.06–0.08) film heterojunctions. Carrier concentration in *n*-In_4Se_3 substrates was of 4·10^{15} cm^{-3} in p-type $In_4(Se_3)_{0.94}(Te_3)_{0.06}$ crystals was of 6.3·10^{16} cm^{-3} at room temperature. Substrates of 0.5 mm thickness were obtained by cleavage of layered crystals in the direction of (100) cleavage plane.

CdTe and $Cd_{1-x}Mn_xTe$ (x = 0.15, 0.25) single crystals grown by Bridgman method were used as the substrates for obtaining CdSb-$Cd_{1-x}Mn_xTe$ film heterojunctions. n-Type single crystals had conductivity of 3.2·10^{-3} Ohm^{-1} cm^{-1} (x = 0.15) and 1.1·10^{-2} Ohm^{-1} cm^{-1} (x = 0.25) respectively. The substrates of the crystals were polished mechanically and etched by chemical etchants.

Morphology, structure and composition of CdSb thin films before and after laser treatment were studied by SEM and electron probe microanalysis method on Zeiss EVO 50 microscope at 20 kW voltage and also by AFM microscopy on NT-206 set. The AFM measurements were carried out in contact mode using CSC38/AL BS probe manufactured by MikroMasch. The radius of the probe was of 8 nm; the number of points in the scan matrix – 256 × 256; load on the probe was of 10–12 units.

In order to modify and improve the structure and phase state of CdSb thin films deposited on different crystalline substrates, they were irradiated by out of focus laser beam using a diaphragm with

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