СЕКЦИЯ 3

ВЛИЯНИЕ ИЗЛУЧЕНИЙ НА СТРУКТУРУ И СВОЙСТВА МАТЕРИАЛОВ

SECTION 3

RADIATION INFLUENCE ON THESTRUCTURE AND PROPERTIES OF MATERIALS

EFFECT OF KRYPTON IRRADIATION ON THE SURFACE MORPHOLOGY OF INDIUM ANTIMONIDE FILMS ON GALLIUM ARSENIDE SUBSTRATES

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In this work, studies have been carried out on the effect of irradiation with krypton ions with an energy of 280 keV at a dose of 10^{12} and 10^{13} cm^{-2} on the morphology of heteroepitaxial films of indium antimonide on gallium arsenide GaAs substrates by atomic force microscopy. To quantify the damage and determine the implantation profile, modeling have been carried out in the SRIM program. The studies carried out have shown that, as a result of irradiation, the formation of cone-shaped structures is observed on the surface of InSb films. The change in the surface topography is related to the angular dependence of the sputtering yield and the predominant sputtering of antimony atoms from the surface of indium antimonide heteroepitaxial films on gallium arsenide substrates.

Keywords: indium antimonide; films; vacuum deposition; ion irradiation; surface morphology.

Introduction

Heteroepitaxial InSb films on GaAs substrates can be used to manufacture a wide range of microelectronic sensors operating reliably in harsh temperature conditions down to minus 195 °C. It is known that microelectronic devices based on heteroepitaxial InSb films (e.g. Hall detectors) have a radiation hardness to gamma-quanta and electrons with absorbed dose up to 500 krad [1].

To predict changes in the performance and application of InSb-based microelectronic devices during operation under exposure conditions realized for spacecraft and nuclear facilities, it is necessary to study the effect of higher absorbed doses of radiation exposure exceeding 500 krad on the structural state and electrical properties of InSb heteroepitaxial films.

Implantation exposure on InSb single crystals plates to low-energy Ar and Ga ions (up to 5 keV) leads to changes in the morphology and elemental composition of the surface layer [2]. Under the action of ion sputtering, diffusion and segregation, micron-sized indium-enriched formations are formed on the surface, which are uniformly distributed on the plate surface.

The aim of this work is to establish the peculiarities of surface changes of InSb heteroepitaxial films on GaAs substrates irradiated with heavy krypton ions.

Materials and methods

Heteroepitaxial InSb films were synthesized by explosive thermal evaporation of single-crystal InSb powder onto semi-insulating GaAs plates [3]. The films were irradiated at room temperature with Kr ions with an energy of 280 keV and a fluence of 10^{12}-10^{13} cm^{-2} on a DC-60 linear accelerator (Institute of Nuclear Physics, Nur-Sultan, Kazakhstan). The surface morphology of the InSb films was studied by atomic force microscopy (AFM) using a Solver P47 PRO scanning probe microscope. Modeling in the SRIM program was used to quantify damage and determine the implantation profile.

Results and discussion

Figure 1 shows the distribution profiles of implanted Kr ions and the magnitude of radiation damage (in displacement per atom), simulated by the SRIM program. The maximum range of Kr ions was 350 nm with a maximum damage at a depth of 124 nm. The highest value of the damaging dose is 0.0025 dpa. The concentration of implanted Kr^+ ions does not exceed 0.0025 %. The threshold displacement energies for In and Sb elements are 6.4 and 9.2 eV, respectively [4]. The sublimation energy was used as the binding energy of In and Sb atoms on the surface: E_{In} = 2.39 eV and E_{Sb} = 2.12 eV [5].

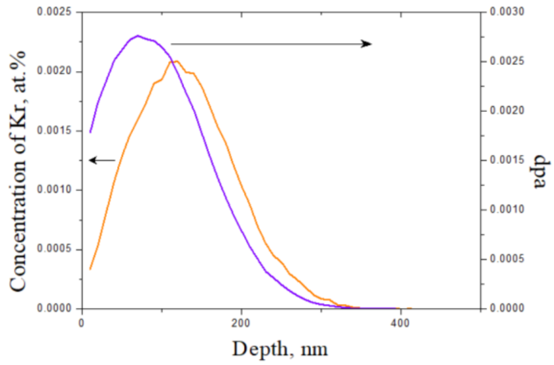


Fig. 1. Depth distribution profiles of Kr ions and damage dose in the InSb film, simulated by the SRIM program

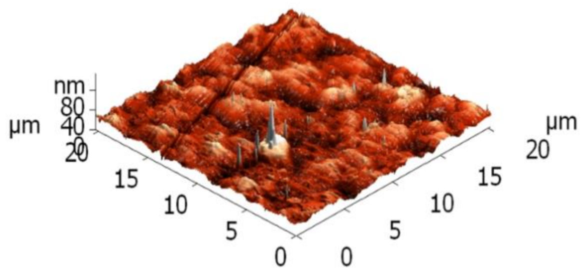
Also, as the result of the simulation, the sputtering coefficients γ_{sput} of indium and antimony atoms were estimated (Table 1). For InSb under these modeling conditions, the predominant sputtering of antimony atoms is typical.

Table 1. The sputtering yield of In and Sb atoms upon irradiation with Kr ions with an energy of 280 keV

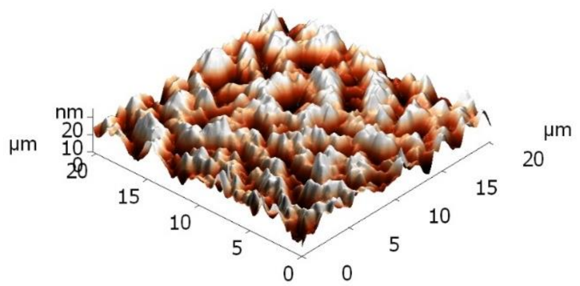
Element	In	Sb
γ_{sput}, atom/ion	4.30	4.70

Figure 2 shows AFM images of the surface of the original film (fig. 2a) and films irradiated with Kr ions with an energy of 280 keV and doses of 10^{12} cm^{-2} and 10^{13} cm^{-2} (fig. 2b, 2c).

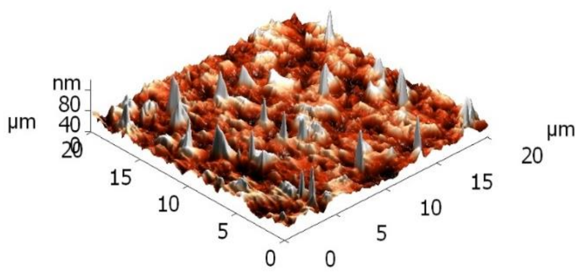
From the data obtained, it can be seen that when irradiated with a dose of 10^{12} cm^{-2}, a significant change in the surface morphology is observed. In this case, the main process responsible for the formation of the surface is sputtering [6, 7]. Figure 2c shows that the InSb film irradiated with a dose of 10^{13} cm^{-2} tends to form cone-shaped protrusions. The formation of such structures is associated with different sputtering rates of In and Sb. In particular, the predominant sputtering of antimony leads to a violation of the stoichiometric composition of the film surface, due to which indium atoms segregate into droplets, which serve as a seed for further cone growth.



(a)



(b)



(c)

Fig. 2. AFM images of surface of InSb films irradiated with Kr ions with an energy 280 keV: a - initial; b - 10^{12} cm^{-2}; c - 10^{13} cm^{-2}

The cone growth rate depends on two factors: the angular dependence of the spray output and the presence of surface stresses. To describe the influence of the first factor, it is necessary to consider the erosion rate equation, which determines the evolution of the surface profile z (x, t) [6]:

$$-\frac{\partial m}{\partial t} = \frac{JY(\theta)cos\theta}{N} = v(\theta), \quad (1)$$

where v(θ) – is the erosion rate, Y(θ) – is the sputtering yield, J – is the ion flux, N – is the surface atomic density.

Provided that the surface is isotropic in directions lying in the plane of the surface, the erosion rate can be divided into two components: perpendicular υ_z and lateral υ_r, which are determined by the following expressions:

$$v_r = \frac{J}{N}\frac{dY}{d\theta}cos^2\theta, \quad (2)$$

$$\frac{\partial z(r,t)}{\partial t} = v_z = \frac{J}{N}\left(\frac{dY}{d\theta}sin\theta cos\theta - Y(\theta)\right), \quad (3)$$

An analysis of equations (2) and (3) showed that the stationary surface configurations are a plane perpendicular to the direction of the incident ions and faceted surfaces. The angle between the edges and the surface is determined by the angle that corresponds to the maximum spray output Y(θ). Since the ion beam does not fall at a right angle relative to the lateral surface of the cone, surface stresses are formed on the slopes, stimulating the diffusion of atoms to the top of the cone, where stresses are practically or completely absent [8].

Conclusion

InSb heteroepitaxial films on GaAs substrates were synthesized by explosive thermal evaporation. Studies of the surface relief of heteroepitaxial InSb films after irradiation with krypton ions with an energy of 280 keV using atomic force microscopy showed that the formation of cone-shaped structures is characteristic of the surface of InSb films. The change in the surface morphology is related to the angular dependence of the sputtering yield and the predominant sputtering of antimony, as evidenced by the calculated sputtering coefficients using the SRIM program (4.30 atom/ion for In and 4.70 atom/ion for Sb).

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