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Formation of nanocones on the surface of $Pb_{0.4}Sn_{0.6}Te$ films during ion-plasma treatment with argon ions with an energy of 140 eV

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Abstract. The article studies the modification of the surface of $Pb_{0.4}Sn_{0.6}Te$ epitaxial films during ion-plasma treatment in argon plasma. Lead-tin telluride films with a thickness of 2 μm were grown on BaF_2 (111) substrates by molecular beam epitaxy. Ion-plasma treatment was carried out in a dense argon plasma of a high-frequency inductive discharge at an ion energy of ~140 eV. The duration of the process is 60 and 120 s. The parameters of an ensemble of nanocones are studied, the evolution of the height of the cones, their lateral dimensions and surface density is described while maintaining the processing time.

Keywords: argon plasma, lead-tin telluride, nanostructuring

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Материалы конференции
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Формирование наноконусов на поверхности пленок $Pb_{0.4}Sn_{0.6}Te$ при ионно-плазменной обработке ионами аргона с энергией 140 эВ

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Аннотация. В статье исследована модификация поверхности эпитаксиальных пленок $Pb_{0.4}Sn_{0.6}Te$ при ионно-плазменной обработке в аргоновой плазме. Пленки теллурида свинца-олова толщиной 2 мкм были выращены на подложках BaF_2 (111) методом молекулярно-лучевой эпитаксии. Ионно-плазменная обработка проводилась в плотной аргоновой плазме ВЧ индукционного разряде при энергии ионов ~140 эВ. Продолжительность процесса составляла 60 и 120 с. Изучены параметры ансамбля наноконусов, описана эволюция высоты конусов, их поперечных размеров и поверхностной плотности при изменении времени обработки.

Ключевые слова: аргоновая плазма, теллурид свинца-олова, наноструктурирование

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Introduction

Interest in lead-tin telluride is associated with the possibility of manufacturing optoelectronic devices in the infrared region of the spectrum based on it [1]. Currently, among the methods for modifying the surface of IV–VI semiconductors, ion-plasma processing methods stand out favorably, which make it possible to control the architecture and parameters of the created micro- and nanostructures within a wide range by varying the ion energy and duration of treatment [2–6]. In particular, it was shown in [5] that during ion-plasma treatment, lead-tin telluride nanocones can grow according to a modified vapor-liquid-solid (VLS) mechanism with plasma self-formation of catalyst metal nanodroplets. The purpose of this work was to study the nanostructures that appear on the surface of $Pb_{0.4}Sn_{0.6}Te$ epitaxial films during ion-plasma treatment with an argon ion energy of 140 eV, intermediate between the previous experiments of 25 [3], 75 [4] and 200 [5] eV. The results of works [3–5] show the diversity of the architecture of the created nanostructures. Analysis of the results obtained allows us to hope that at an ion energy of 140 eV and at certain values of treatment time, we should expect the appearance of an ensemble of nanocones on the surface for all $Pb_{1-x}Sn_xTe$ compositions from lead telluride to tin telluride, which is promising for modifying the optical properties of lead-tin telluride. As part of this work, studies were carried out on $Pb_{0.4}Sn_{0.6}Te$, films, for which (in accordance with the phase diagram for the Pb-Sn alloy) metal nanodroplets will have a minimum melting point.

Materials and Methods

$Pb_{0.4}Sn_{0.6}Te$ films were grown by molecular beam epitaxy using a Riber 32 P installation (INPE, Brazil) on BaF_2 (111) substrates by the authors of [7]. Ion-plasma treatment of the samples was carried out in an argon plasma reactor of a high-frequency induction discharge (13.56 MHz, 800 W) [2]. The treatment was carried out at an ion energy of 140 eV; the treatment duration was 60 and 120 s. Surface morphology studies were carried out using scanning electron microscopy (SEM) on a Zeiss Supra-40 microscope.

Results and Discussion

The initial samples had a smooth surface with the presence of dislocation pits. During plasma treatment of $Pb_{0.4}Sn_{0.6}Te$ films in argon plasma with an energy of 140 eV, the formation of ensembles of cone-shaped structures shown in Fig. 1 was observed. 1. After processing for 60 s, the cones were ~70 nm high with quasi-spherical caps at the top. The physical nature of the formation of metal caps is described in [4, 5]. It is important to note that the formation of such nanocones under similar conditions of processing $Pb_{1-x}Sn_xTe$ films with $0.6 < x < 0.6$ was not observed. As the processing time increased to 120 s, the height of the structures increased to ~80 nm. In this case, the lateral dimensions of the bases of the nanocones were ~60 nm for 60 s and ~65 nm for 120 s. The surface density of the structures after 60 s of treatment was ~8·109 cm^{-2}; with an increase in treatment time to 120 s, the density decreased to ~$7\cdot10^9$ cm^{-2}.

Figure 2 shows the quantitative characteristics of the parameters of nanocones, including the dimensions of the heights with a cap, the diameters of the caps, and the lateral dimensions at the surface. From an examination of the histograms it follows that the sizes of the structures change insignificantly. On average, the heights and diameters of the caps increase by 20%, while the dimensions of the structures at the base of the cones practically do not change. At the same time (Fig. 1), there is an increase in the lateral dimensions of the cones under the cap. Based on the geometric dimensions of the caps and the parameters of truncated cones, the volumes of cone ensembles were determined for processing times of 60 and 120 s. The results of these calculations showed that the volume of material

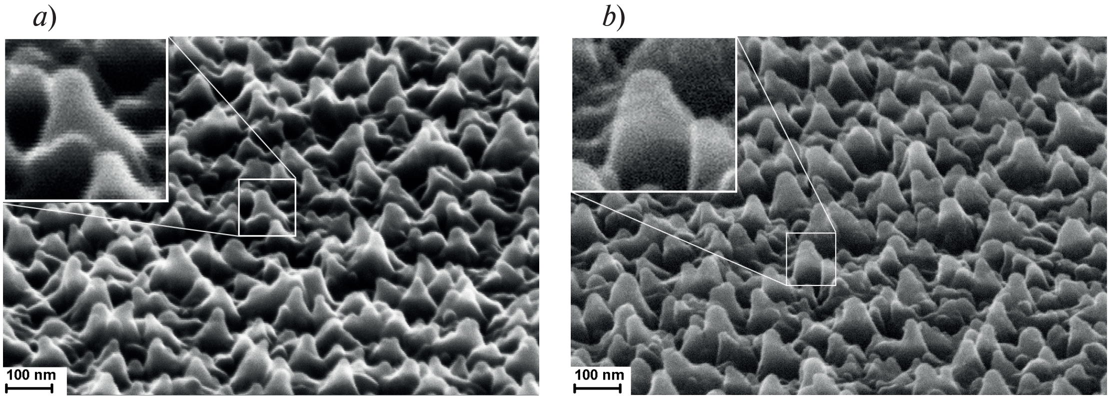

Fig. 1 Modification of the surface of the $Pb_{0.4}Sn_{0.6}Te$ film after treatment in argon plasma with an ion energy of 140 eV for 60 (*a*) and 120 (*b*) s. View at an angle of 70°

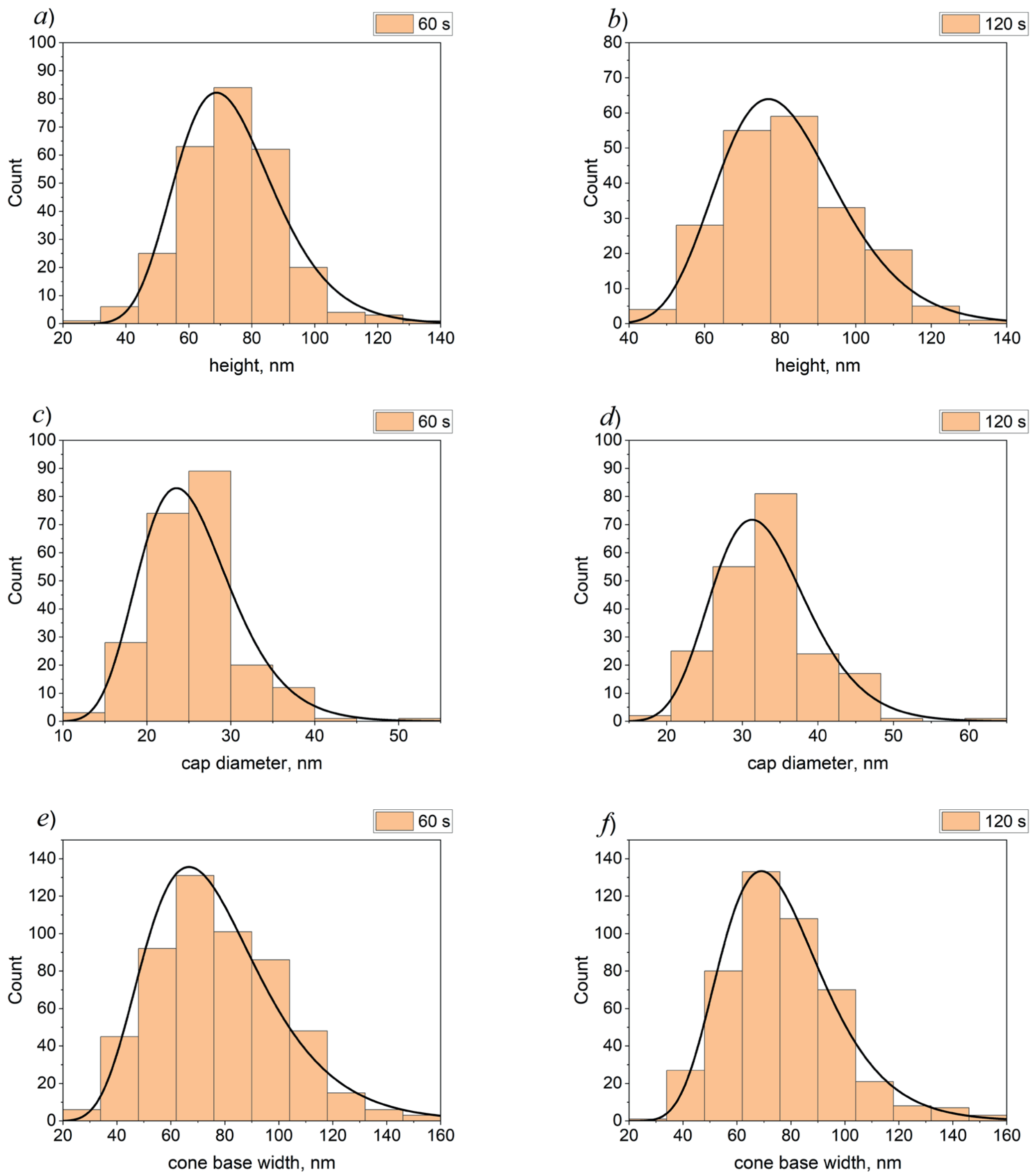

Fig. 2 Histograms of the distribution of heights of cone-shaped structures after treatment for 60 (*a*) and 120 (*b*) s. Histograms of size distribution for cap diameter (*c*, *d*) and lateral dimensions at the base on the cones (*e*, *f*) for treatment 60 (*c*, *e*) and 120 (*d*, *f*) s

increases by approximately 1.7 times, which correlates with the total volume of sputtering material during plasma treatment. The material is redeposited onto the walls of the cones from saturated steam, forming a thickening with a slight increase in the height of the cones.

Conclusion

For $Pb_{0.4}Sn_{0.6}Te$ films, the growth of nanocones was demonstrated during treatment with argon ions with an energy of 140 eV for 60 and 120 s. The results of the work made it possible to establish new experimental patterns in the model of the formation of ensembles of nanocones according to the “vapor-liquid-solid” mechanism with a parallel process of ion sputtering. It is shown that a homogeneous ensemble of truncated cones (similar to the structures obtained in previous experiments [3–5]) of lead-tin telluride with a metal cap on the top, when the processing time changes from 60 to 120 s, slightly increases in height and does not change its lateral dimensions on the surface. Changes occur in the upper part of the nanocones, where there is an increase in the lateral dimensions of the cones under the quasi-spherical caps.

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