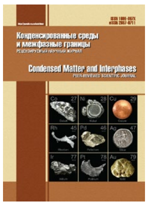

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Influence of magnetron sputtering conditions on the structure and surface morphology of $In_xGa_{1-x}As$ thin films on a GaAs (100) substrate

O. V. Devitsky[1,2] ✉, A. A. Zakharov [2], L. S. Lunin[1,2], I. A. Sysoev[2], A. S. Pashchenko[1,2], D. S. Vakalov[2], O. M. Chapura[2]

*[1]Federal Research Center Southern Scientific Center of the Russian Academy of Sciences,
41 Chekhov str., Rostov-on-Don 344006, Russian Federation*

*[2]North Caucasian Federal University,
1 Pushkina str., Stavropol 355017, Russian Federation*

Abstract

We present the results of the study of the structure and surface morphology of $In_xGa_{1-x}As$ thin films on a GaAs substrate. Thin films were obtained by magnetron sputtering from a specially formed $In_{0.45}Ga_{0.55}As$ target in an argon atmosphere.

The obtained samples of thin films were studied by Raman scattering, atomic force microscopy, scanning electron microscopy, and energy-dispersive X-ray spectroscopy. It was shown that the grains of the films obtained at a substrate temperature below 600 °C were not faceted and were formed through the coalescence of grains with a size of 30–65 nm. At a substrate temperature of 600 °C, films consisted of submicron grains with a visible faceting.

It was determined that the average grain size increased and the root-mean-square roughness of thin films decreased due to an increase in the substrate temperature. Thin films obtained at a substrate temperature of 600 °C possessed the best structural properties.

Keywords: Magnetron sputtering, Thin films, Raman scattering, Surface morphology, A^3B^5 compounds

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✉ Oleg V. Devitsky, e-mail: v2517@rambler.ru

1. Introduction

Semiconductor compounds A^3B^5 are widely used materials that are highly important in photovoltaics and optoelectronics. Today, among the most common methods for obtaining thin films and heterostructures of A^3B^5 compounds are the following: molecular beam epitaxy, metal organic chemical vapour deposition, ion-beam sputtering, and impulse laser deposition [15]. Magnetron sputtering is also used to obtain thin films of A^3B^5 compounds. Thin films of GaSb, $Al_xGa_{1-x}N$, $In_xAl_{1-x}N$, $GaAs_{1-y}N_y$, $In_xGa_{1-x}N$, and $In_xGa_{1-x}As$ on various substrates were obtained using this method [612]. $In_xGa_{1-x}As$ solid solution is widely used in modern optoelectronics [13], but the preparation of thin films using magnetron sputtering, although being highly relevant, still poses some challenges. They are mainly related to the fact that the effect of magnetron sputtering parameters on the properties of $In_xGa_{1-x}As$ thin films have not been thoroughly studied. In some works researchers either used the method of co-sputtering from high purity GaAs and In targets [14], or alternated the layers of GaAs and In, respectively. Although this method has certain advantages, it significantly complicates the process of magnetron sputtering. It is reasonable to use the targets with a set composition of the $In_xGa_{1-x}As$ solid solution the preparation of which was described in [5].

The goal of this work was to grow $In_xGa_{1-x}As$ thin films using magnetron sputtering and to study their structural properties and surface morphology.

2. Experimental

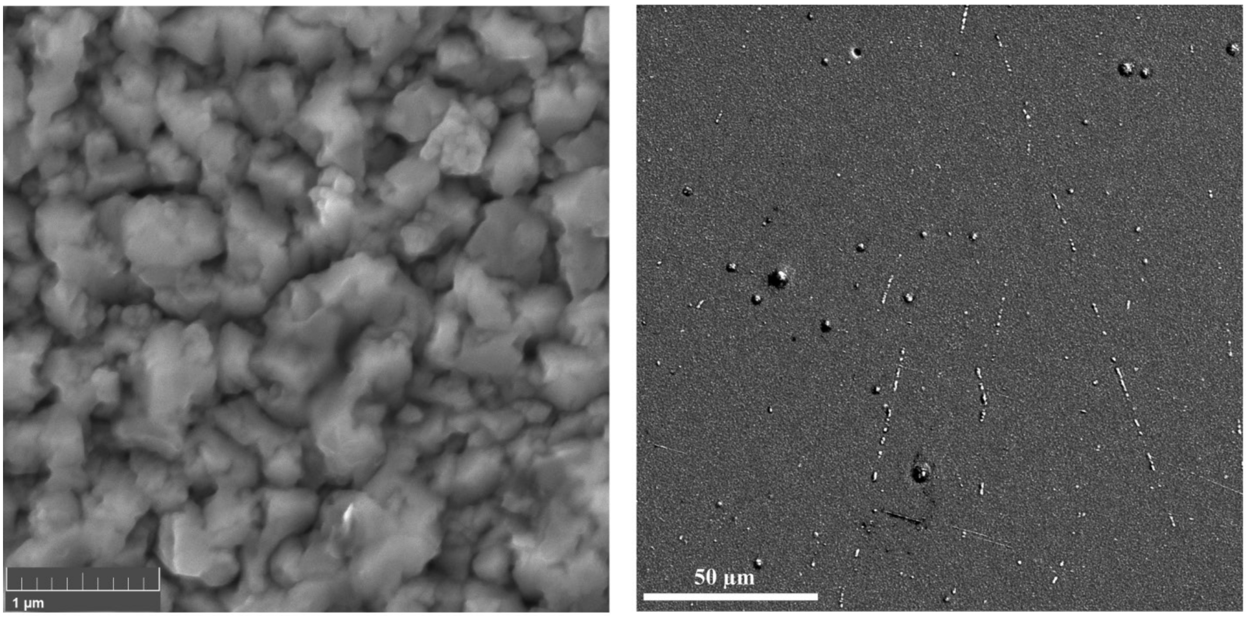
In this study, we reported the preparation of $In_xGa_{1-x}As$ thin films on GaAs (100) substrates using magnetron sputtering from a target with a calculated composition of $In_{0.45}Ga_{0.55}As$. The target was formed by sintering GaAs and InAs powders in the pure hydrogen atmosphere at a temperature of 700 °C for 120 minutes. Thin films of $In_xGa_{1-x}As$ were deposited on GaAs (100) using a PM1-60/1-02-02 IT magnetron in an argon atmosphere at a pressure of 8 Pa. The distance from the target to the substrate was 100 mm, the power of target sputtering was 1.8 W/cm^2. The duration of deposition was 60 minutes for all samples, and the temperature of the substrate varied from 400 to 600 °C. All thin film samples were 0.42 μm thick.

Micrographs of the surface and the composition were analysed using a scanning electron microscope MIRA3-LMH with a AZtecEnergy Standard/X-max20(standard) system that determines the elemental composition. The thickness of the layer was determined by micrographs of cleavages using contrast topography (SE detector). Structural properties were studied using Raman scattering on an inVia Raman Microscope (Renishaw) spectrometer with a laser wavelength of 514 nm at a room temperature. The surface morphology of thin films was studied on a Ntegra Aura atomic force microscope (AFM).

3. Results and discussion

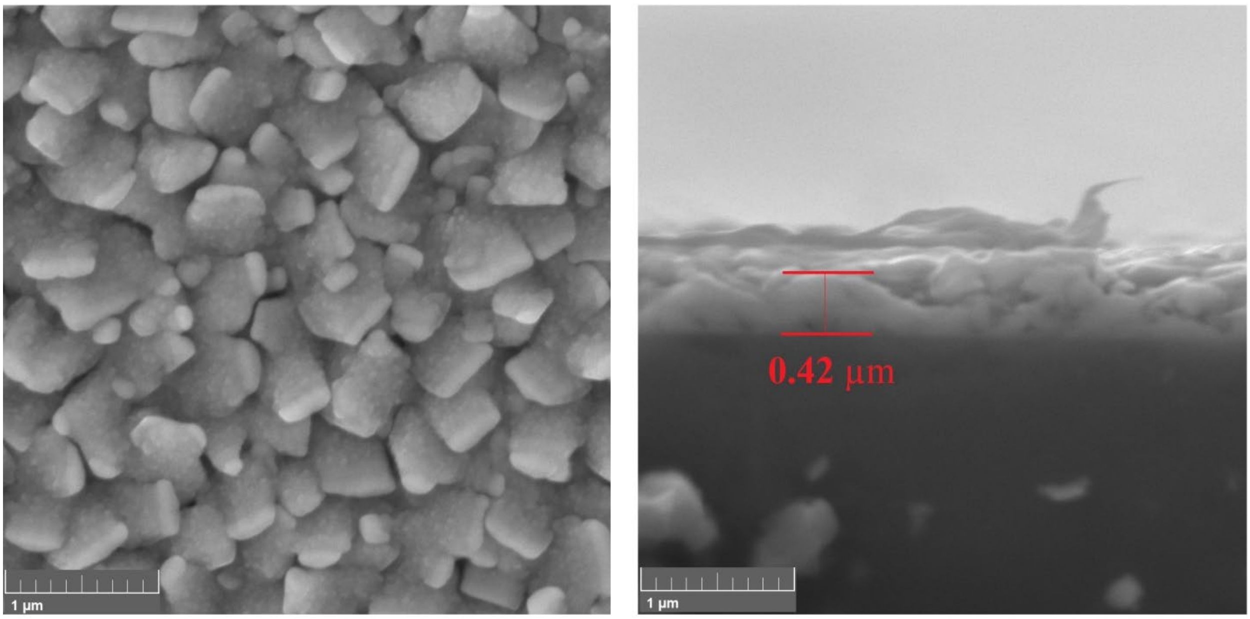
Figs. 1 and 2 show SEM images of the surface of $In_xGa_{1-x}As$ thin films on GaAs grown at a temperature of the substrate 400 and 600 °C. The presented images show that the surface of both films consists of grains that become faceted when the substrate temperature increases up to 600 °C. There were also microdrops on the surface of all samples of thin films (Fig. 1b). The size of the microdrops was not more than 2 μm, and their density was approximately 0.06 μm^{-2} for thin films obtained at 400 °C. There were almost no microdrops on thin films obtained at 500 and 600 °C. According to the presented results, a non-classical mechanism of crystal growth was observed for thin films obtained at 400 °C, which means that oriented attachment of small crystal grains occurred in the surface of a larger grain [15–16]. The surface of the films was very rough, and there were grains with the size of 260 μm that were not faceted and had interfaces that were not clearly visible. When the substrate temperature increased up to 500 °C, there were a greater number of larger grains (up to 320 μm) with a poorly visible faceting. There were a great number of homogeneous multifaceted grains on the surface of a film grown at 600 °C. These grains were no more than 560 μm in size. It is obvious that the structural properties of films increase with the growth of the size of grains.

Energy dispersive analysis showed that the composition of the films grown at 400 and 500 °C is similar to that of $In_{0.32}Ga_{0.68}As$, while



a b

Fig. 1. SEM image of the surface of a thin $In_xGa_{1-x}As$ film on a GaAs substrate grown by magnetron sputtering at a temperature of 400 °C in the secondary electron detection mode at 10 kV, 64 kV (a), and 20 kV (b)



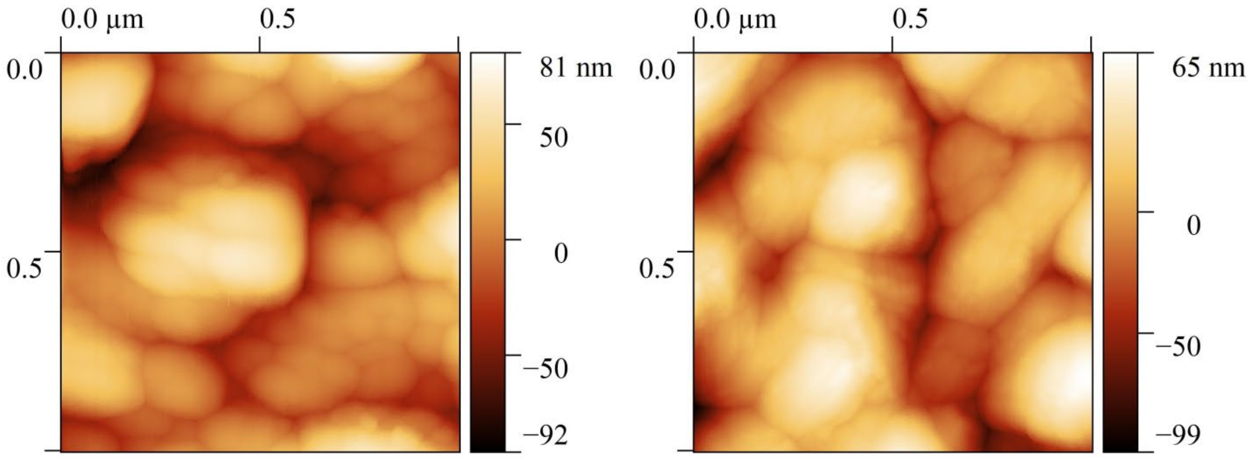
a b

Fig. 2. SEM image of the surface (a) and cleavage (b) of a thin $In_xGa_{1-x}As$ film on a GaAs substrate grown by magnetron sputtering at a temperature of 600 °C

the composition of the film grown at 600 °C had a greater content of indium, $In_{0.43}Ga_{0.57}As$. This can probably be explained by the fact that the content of indium in a thin film decreased due to the segregation of indium at a lower temperature of a substrate.

To study the surface of thin films more thoroughly, we performed an AFM study of the surface morphology (Fig. 3) and determined root-mean-square roughness (RMS) of the surface. It was shown that when the substrate temperatures increased from 400 to 600 °C, RMS of thin films decreased from 32.62 to 26.75 µm, respectively.

The effect of the substrate temperature on the structural properties of $In_xGa_{1-x}As$ thin films was also studied by Raman spectra (Fig. 4). Two



a *b*

Fig. 3. AFM images of $In_xGa_{1-x}As$ thin films on a GaAs substrate grown by magnetron sputtering at 400 °C (a) and 600 °C (b)

high-intensity transverse (TO) phonon modes related to InAs and GaAs can be identified on the spectra in the frequency intervals of 219–223 cm^{-1} and 245–257 cm^{-1} respectively. It should be noted that in case of the film grown at 400 °C, we observed a longitudinal (LO) optical mode of InAs on the spectra located at the frequency of 223 cm^{-1} as well as a low_intensity GaAs (LO) mode of 287 cm^{-1}. The region in the range of 110–130 cm^{-1} can be associated with the presence of microdrops on the surface of films. According to the rules of selection, both LO and TO phonon modes must be allowed on Raman spectra for a perfect crystal [17]. The thin films grown at 500 and 600 °C obviously have the most perfect structure as InAs (TO) and GaAs (TO) modes are dominant in their spectra. A displacement in the position of an InAs (TO) phonon mode regarding the position of the frequency of an InAs (TO) mode for the voluminous InAs [14] (221 cm^{-1}) for 2 cm^{-1} was observed only for the films grown at 400 and 500 °C, which is typical for thin films with a decreased content of In [1821].

4. Conclusions

Thus, we grew $In_xGa_{1-x}As$ thin films on a GaAs substrate using magnetron sputtering. Using scanning electron microscopy and energy dispersion analysis, it was shown that $In_xGa_{1-x}As$ thin films obtained at the substrate temperature of 600 °C had the most similar composition to that of a sputtered target. The comparison of SEM images of the surface of $In_xGa_{1-x}As$ thin films on GaAs showed that the substrate temperature had a great effect on the surface morphology and structure of a film. The results of the study of Raman scattering spectra showed that $In_xGa_{1-x}As$ thin films obtained at the substrate temperature of 600 °C had the best structural properties. The presented experimental data showed that magnetron sputtering is a promising method that can be used for growing $In_xGa_{1-x}As$ thin films on GaAs.

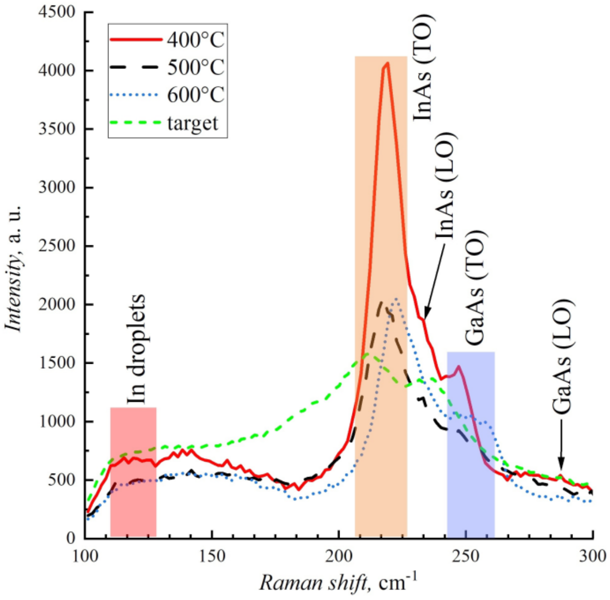


Fig. 4. Raman spectra of an $In_{0.45}Ga_{0.55}As$ target and $In_xGa_{1-x}As$ thin films on GaAs grown at different substrate temperatures

Author contributions

Oleg Devitsky – the idea of experiments, text writing, final conclusions. Alexey Zakharov –

conducting research. Igor Sysoev – scientific leadership, research concept. Leonid Lunin – scientific leadership, review writing, and text editing. Alexander Pashchenko – review writing, text editing, final conclusions. Dmitry Vakalov – conducting research. Oleg Chapura – conducting research.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Information about the authors

Oleg V. Devitsky, Cand. Sci. (Tech.), Senior Researcher, Laboratory of Physics and Technology of Semiconductor Nanoheterostructures for Microwave Electronics and Photonics, Federal Research Centre Southern Scientific Centre of the Russian Academy of Sciences *(Rostov-on-Don,* Russian Federation); Senior Researcher, Scientific and Educational Centre for Photovoltaics and Nanotechnology, North Caucasian Federal University *(Stavropol,* Russian Federation).

https://orcid.org/0000-0003-3153-696X
v2517@rambler.ru

Alexey A. Zakharov, Junior Researcher, Scientific and Educational Centre for Photovoltaics and Nanotechnology, North Caucasian Federal University *(Stavropol,* Russian Federation).

https://orcid.org/0000-0003-0379-9383

v2517@rambler.ru

Igor A. Sysoev, Dr. Sci. (Tech.), Director, Scientific and Educational Centre for Photovoltaics and Nanotechnology, North Caucasian Federal University *(Stavropol,* Russian Federation).

https://orcid.org/0000-0001-5415-0782
v2517@rambler.ru

Leonid S. Lunin, Dr. Sci. (Phys.–Math.), Chief Researcher, Laboratory of Physics and Technology of Semiconductor Nanoheterostructures for Microwave Electronics and Photonics, Federal Research Centre Southern Scientific Centre of the Russian Academy of Sciences *(Rostov-on-Don,* Russian Federation; Chief Researcher, Scientific and Educational Center for Photovoltaics and Nanotechnology, North Caucasian Federal University *(Stavropol,* Russian Federation).

https://orcid.org/0000-0002-5534-9694
lunin_ls@mail.ru

Alexander S. Pashchenko, Cand. Sci. (Phys.–Math.), Senior Researcher, Head of the Laboratory of Physics and Technology of Semiconductor Nanoheterostructures for Microwave Electronics and Photonics, Federal Research Center Southern Scientific Center of the Russian Academy of Sciences *(Rostov-on-Don,* Russian Federation; Senior Researcher, Scientific and Educational Center for Photovoltaics and Nanotechnology, North Caucasian Federal University *(Stavropol,* Russian Federation).

https://orcid.org/0000-0002-7976-9597
as.pashchenko@gmail.com

Dmitry S. Vakalov, Cand. Sci. (Phys.–Math.), Head of the Research Laboratory of Physicochemical Methods of Analysis, Scientific-laboratory Complex of Clean Rooms, Faculty of Physics and Technology, North Caucasian Federal University *(Stavropol,* Russian Federation).

https://orcid.org/0000-0001-6788-3811
megadims@gmail.com

Oleg M. Chapura, Engineer of the Department of Physical Electronics, Physics and Technology Faculty, North Caucasian Federal University, *(Stavropol,* Russian Federation).

https://orcid.org/0000-0002-6691-0010
chapurol-7@mail.ru

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