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Surface Morphology of Y_2O_3:Eu Thin Films at Different Activator Concentrations

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Atomic force microscopy is used to study the surface morphology of thin Y_2O_3:Eu films obtained by the radio-frequency ion-plasma sputtering with an activator concentration of 1.0, 2.5, and 5 mol.%. Based on the analysis of the obtained results, an almost linear dependence of the sizes of surface structures on the value of the activator concentration and a superlinear increase in both the root-mean-square surface roughness and the average distance between grains are revealed. The obtained results are discussed.

Методою атомно-силової мікроскопії (АСМ) досліджено морфологію поверхні тонких плівок Y_2O_3:Eu, одержаних методою високочастотного (ВЧ) йонно-плазмового розпорошення, з концентрацією активатора у 1,0, 2,5 та 5 мол.%. На основі аналізи одержаних результатів встановлено практично лінійну залежність розмірів поверхневих структур від величини концентрації активатора та надлінійне зростання середньоквадратичної шерсткости поверхні та середньої віддалі між зернами. Проведено обговорення одержаних результатів.

Key words: yttrium oxide, activator, thin films, nanocrystallites.

Ключові слова: оксид Ітрію, активатор, тонкі плівки, нанокристаліти.

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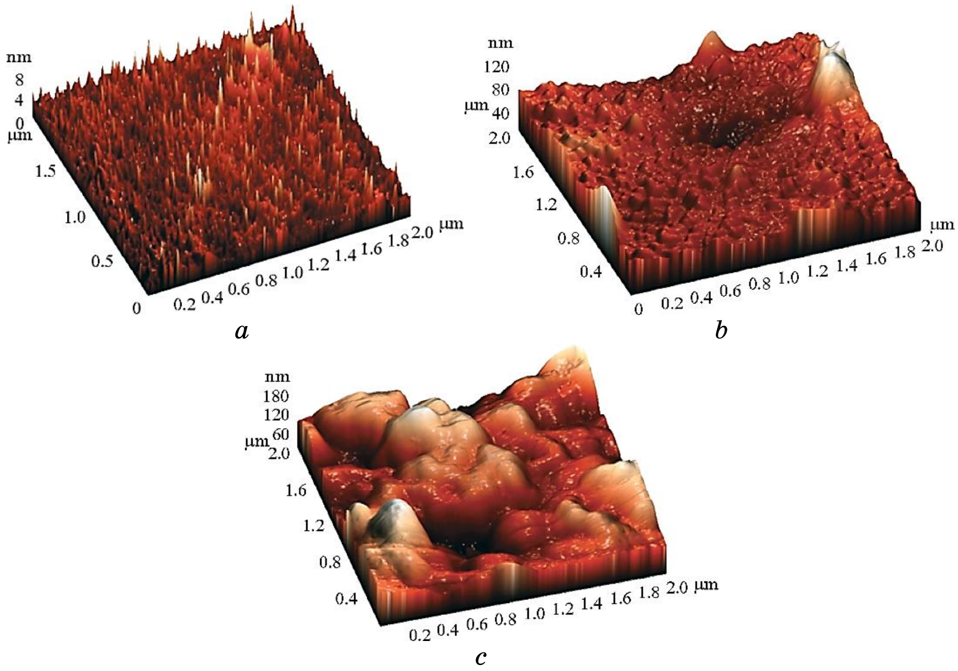
1. INTRODUCTION

Today, the wide interest of researchers in the study of metal-oxide films is due to the prospects for their practical application in instrument engineering, optoelectronics, and information display devices.

Among thin films, considerable attention is paid to the study of thin Y_2O_3 films activated by rare earth ions (REIs). In this regard, Y_2O_3:Eu^{3+}, a highly efficient phosphor emitting in the red region of the optical spectrum, is the most widely studied [1–3]. Due to the linear dependence of the glow brightness on the current density and excitation energy, the Y_2O_3:Eu phosphor is widely used as a red component of projection televisions, in the creation of flat vacuum fluorescent displays (VFDs) and field emission displays (FEDs) [4–6].

An analysis of the dimensional, morphological, and structural characteristics of thin Y_2O_3 films indicates that they are largely determined by the methods and conditions of preparation and subsequent technological methods [7–9]. This one determines the study of the surface morphology of thin Y_2O_3:Eu films obtained by RF ion-plasma sputtering, which is considered optimal for the preparation of the semiconductor and dielectric films [10].



a *b* *c*

Fig. 1. AFM image of sections of the Y_2O_3:Eu film in the topography mode at activator concentration of 1.0 mol.% (*a*), 2.5 mol.% (*b*), and 5 mol.% (*c*).

2. EXPERIMENTAL TECHNIQUE

We studied thin $Y_2O_3:Eu^{3+}$ films with a thickness of 0.2–1.0 μm obtained by RF ion-plasma sputtering on fused quartz υ-SiO_2 substrates. RF sputtering was carried out in an argon atmosphere in a system using the magnetic field of external solenoids for compression and additional ionization of the plasma column. The feedstock was Y_2O_3 'ИтО-И' brand and Eu_2O_3 'ос.ч.' brand. The activator concentration was of 1, 2.5, and 5 mol.%. After the films were deposited, they were heat-treated in air at a temperature of 950–1000°C.

The structure and phase composition of the obtained films were studied by x-ray diffraction analysis (Shimadzu XDR-600). X-ray diffraction studies showed the presence of a polycrystalline structure with a predominant orientation in the (222) plane. The shape of the obtained diffraction patterns is practically similar to the diffraction patterns of pure Y_2O_3 films, which we presented in [11]. All diffraction maxima are identified according to the selection rules and belong to the space group $T_h^7 = I_a^3$ that indicates the cubic structure of the obtained films.

The surface morphology of thin films was studied using a 'Solver P47 PRO' atomic force microscope (AFM). The 'Image Analysis 2' software package was used to calculate the surface morphology parameters. The topography of the samples was quantitatively characterized by the root-mean-square roughness R_q determined from AFM data for areas of the same size (2000×2000 nm). The same scans were used to analyse grain sizes and their surface concentration.

3. RESULTS AND DISCUSSION

Characteristic micrographs of the surface of Y_2O_3:Eu films with different activator concentrations are shown in Fig. 1.The characteristic parameters of these thin Y_2O_3:Eu films are given in Table. As can be seen from the results obtained, the concentration of the activator has a significant effect on the size of crystalline grains and

TABLE. Surface morphology parameters of thin Y_2O_3:Eu films.

Parameter	Activator (Eu^{3+}) concentration		
	1.0 mol.%	2.5 mol.%	5.0 mol.%
The average grain diameter d, nm	15.7	63.1	196.0
Mean square roughness R_q, nm	0.7	5.7	34.1
The average distance between grains D, nm	29	84	257
Grain concentration N, μm^{-2}	65	35	13

the surface roughness of films.

The results obtained show that, with an increase in the concentration of the Eu^{3+} activator in thin Y_2O_3 films, a superlinear increase in the root-mean-square (RMS) roughness of film surface is observed (Fig. 2).

According to [12], the value of R_q may depend on the size of the scanning area. However, in our case, the root-mean-square roughness is much smaller than the linear size of the scanning zone (2000×2000 nm), and, therefore, according to [13], the value of R_q saturates, and it practically does not change.

With an increase in the activator concentration in thin Y_2O_3:Eu films, the sizes of crystalline grains, which form the film, increase, while their surface concentration (the number of grains on the sur-

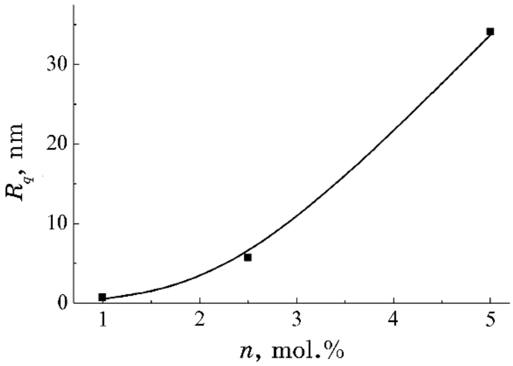


Fig. 2. RMS surface roughness of thin Y_2O_3:Eu films as a function of activator concentration.

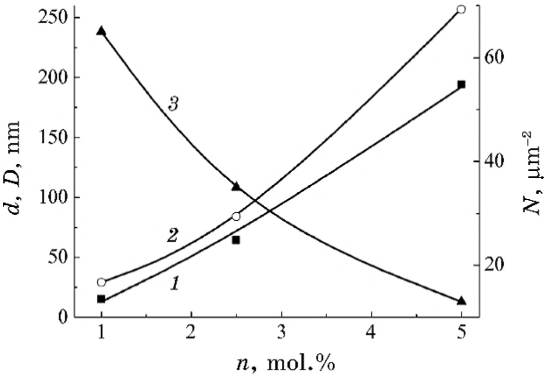


Fig. 3. Average grain size (*1*), average distance between grains (*2*), and surface concentration of grains (*3*) depending on the activator concentration in thin Y_2O_3:Eu films.

face per unit area) decreases (Fig. 3). In this case, within the studied concentration range, the sizes of crystalline grains increase almost linearly with an increase in the concentration of the activator.

Based on the results of [14], to calculate the average distance D between grains on a flat surface, we use the relation

$$D = 0.5N^{-1/2}, \tag{1}$$

where N is the concentration of grains.

As can be seen from Fig. 3, as the grain concentration decreases, the value of D increases. In this case, the average distance between grains always exceeds their size. According to Fig. 3, the growth of D in a given range of activator concentrations is characterized by a linear dependence.

A fairly rapid decrease in the grain concentration N and, simultaneously, a rapid increase in grain size indicate the presence of certain processes caused by an increase in the concentration of the activator. Among them, the most probable ones are the transition of the surface into a nanostructured state (recrystallization and crystallization of the surface layer) and the simultaneous removal of small globules located between large grains.

4. CONCLUSIONS

It has been established that, during RF ion-plasma sputtering of thin Y_2O_3:Eu films with an activator concentration in the range of 1.0–5.0 mol.%, polycrystalline films consisting of nanometre grains are formed. AFM studies of the surface morphology of films obtained by the AFM method revealed an almost linear dependence of the sizes of surface structures on the concentration of the activator in the studied concentration range. At the same time, a superlinear increase in both the root-mean-square surface roughness and the average distance between grains is observed with increasing concentration of the activator.

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