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Formation of Ordered Zinc Nanosystems under Near Equilibrium Condensation Using Alumina Membranes as Templates for Deposition

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A new technological approach has been proposed to the process of obtaining ordered zinc nanosystems using alumina membranes and device-based on DC magnetron sputter with system of the tubes that allows the formation of narrowly directed atoms fluxes. The regularities of zinc condensates structure formation inside the pores in the alumina membrane depending on the technological conditions such as condensation temperature, magnetron discharge power and working gas pressure has been investigated. It was found that the system of ordered islands formed inside the pores in membrane at temperatures about 35 to 70 °C and deposition time from 3 to 10 minutes.

Keywords: Ordered nanosystem, Zinc, Alumina membrane, Magnetron sputtering, Near-equilibrium condensation.

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1. INTRODUCTION

Ordered arrays of nanostructures are currently of great interest due to their unique physical properties and applications in the field of electronics, optoelectronics, ultra-thin display devices, sensing, high density storage [1-2]. There are several technologies for producing ordered nanostructure arrays: lithographic methods [3], self-assembly processes [4] scanning probe techniques [5]. It should be noted that these methods do not allow the combination of small sizes of structural elements and high layer porosity. In contrast to the listed above technologies, we have proposed the most universal approach to transfer material in vapor state i.e., unbalanced magnetron sputtering. This technology allows to form extremely low steady-state vapor fluxes, which is a condition for making nanosystems near thermodynamic equilibrium. The aim of this work was to obtain ordered zinc nanoislands inside the pore in alumina membranes by combining concepts about near-equilibrium condensation and using alumina membranes as templates for deposition.

2. EXPERIMENTAL PROCEDURE

Zinc condensates have been formed using DC magnetron spattering near thermodynamic equilibrium in ultra-pure argon atmosphere, which additionally purified from chemically active gases using titanium sputtering (the partial pressure of reactive gases was about 10^{8}) [6]. A small value of chemical potential difference for particles in the vapor and condensed state can be used as criteria for approximation of thermodynamic equilibrium, which is given by [7]:

$$\Delta\mu \cong k_b T\left(P-P_0\right)/P_0 = k_b T\xi \qquad (1)$$

here T – the growth surface temperature; $\xi = \left(P-P_0\right)/P_0$ – relative supersaturation; $\Delta P = \left(P-P_0\right)$ is a deviation of the depositing flux pressure P from equilibrium values P_0 which is determined by

$$P_0 = A\left(T\right)\exp\left(-\frac{E_d}{k_b T}\right) \qquad (2)$$

where E_d – is the adatoms desorption energy; $A\left(T\right)=\exp\left(\alpha+\beta T+\gamma/T\right)$ – is a temperature depended with constants α, β and γ characteristic for a particular material.

The growth surface temperature increases due to the influence of the plasma. As a result, according to the relations (1) and (2), the value is reduced and the system is close to equilibrium conditions. Features condensation of matter and mass transfer processes near the growth surface, and the corresponding mathematical model we have been reviewed in our works [8-9]. Significant role in approaching the thermodynamic equilibrium has increases of the growth surface temperature and reduced for desorption energy to effective value.

It is known that, for magnetron sputtering the direction of the velocity distribution of sputtered atoms is of cosine character. Atoms approaching to the Al_2O_3 pores have a wide range of directions. This can lead to overgrowth of input parts of pores and, therefore, preventing formation of ordered zinc structures. To solve this problem we have developed a new technological approach [10] that allows the formation of narrowly directed atoms fluxes along the pores in membrane. The main element of the develop device is a tightly packed arrays of tubes which have a diameter of 2 mm (fig.1). Axes of these tubes are oriented perpendicular to the surface of the membrane. The main functional feature of this device is that through the tubes 6 are only those atoms direction of which is oriented parallel to the axis of the tubes.

Besides formation of parallel flux of ion sputtered

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atoms by using the device shown in Fig. 1 has been solved another important issue. The condensation on the top of the membrane surface can prevent the penetration of sputtered atoms into the pores of alumina membrane. To minimize undesired condensation, the surface of membrane was heated up to a temperature T_1. At the same time, area of the membrane that directly contacts with the substrate surface should have a significantly lower temperature T_2. The temperature gradient $T_1 > T_2$ is realized by cooling the substrate 8 with the cooler 10 and synchronous heating of the alumina membrane surface be the heating 4.

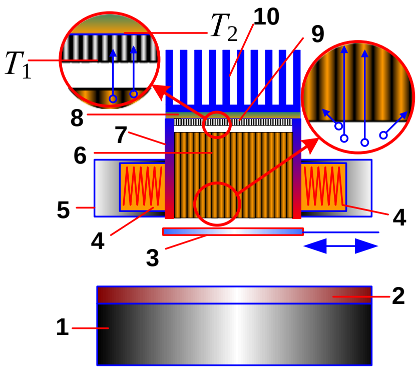

Fig. 1 – Sputtering device (1 – unbalanced magnetron sputter; 2 – zinc target; 3 – shield; 4 – heater; 5 – heating frame; 6 – system of tubes; 7 – copper cylinder; 8 – substrate; 9 – alumina membrane; 10 – cooler) [10].

For ordered zinc nanosystems formation alumina membranes with different pore diameter have been used (50, 70 and 95 nm). Based on previous exper-?ments, the optimal values of magnetron discharge power (13 W) and working gas pressure (1.5 Pa) were identified.

3. RESULTS AND DISCUSSION

We performed a series of experiments, which helped us to set regularities of zinc structure formation on the surface and inside the pores of alumina membrane.

It was found that at temperatures from 35-70 °C and deposition time from 3-10 minutes inside the pores of the membrane, a system of ordered islands with well-defined edges has been formed (Fig. 2).

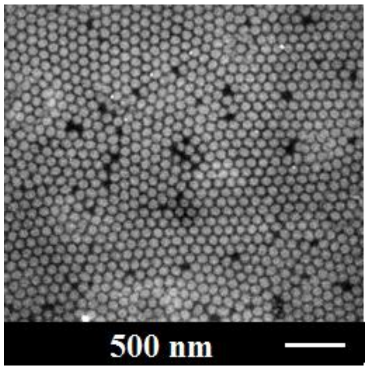

Fig. 2 – Ordered Zn nanosystems formed inside the pores of alumina membrane

Sputtering coefficient greatly depends on the target temperature, which is heated with increasing power level. Thus, at relatively high power (23-30 W) level, thick porous layer of zinc have been formed on the membrane surface (Fig. 3), which eliminates the efficient formation of islands.

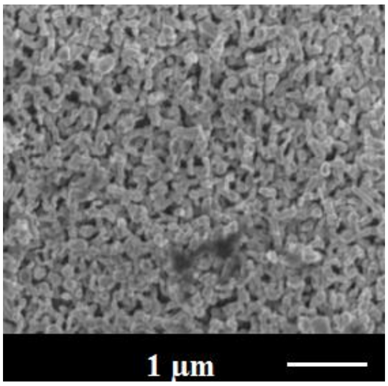

Fig. 3 – Porous Zn structure on the alumina membrane surface

4. CONCLUSIONS

In this work, a new technological approach has been proposed which allows obtaining ordered zinc nanosystems in the form of islands. The condensation of zinc vapor inside the pore of alumina membranes has been achived by using system of the tubes that allows the formation of narrowly directed atoms fluxes and by realization of condition for the chemical potential deference $\Delta\mu(T_2) > \Delta\mu(T_2) \approx 0$.

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