Prepare of nanocomposite structures through the magnetron deposition of material on the colloidal silica films and investigation of their properties

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Abstract. The paper presents a study of nanocomposite structures prepared by magnetron sputtering of titanium on a template formed during the deposition of colloidal silica particles on a metal substrate. The effect of power and spraying time on the formation of nanocomposite structures was studied. The features of the processes of growth of a metal film on an opal matrix and the Implantation of metal into its structure are revealed.

1. Introduction

The use of nanocomposite materials in micro- and nanoelectronics devices allows to discover new results, properties and regularities of physical and chemical phenomena. The area of application of nanocomposites is quite wide: nanocomposite InN (quantum dots) – semiconductor nanoelectronics devices; C, Si, Ge (3D nano-optical systems) – active systems for amplification, generation, laser control; Ga, Ti, Fe (3D – nanocomposites and nanograting, metallic photonic crystals – magnetic memory elements, reflectors).[1] In technology not only direct photonic crystal structures are applied, but also inverse photonic ones formed using the base of microsphere colloidal particles, acting as a template.

The inverse photonic crystal formation is impossible without the implantation process of functional material into template. The characteristics and properties of inverse structure change depending from the functional material used. For example, using magnetic materials as the implantation ones you can prepare porous 3-D structure with the fill factor up to 76%.

The «Luntic» (Figure 1) thin film deposition machine is for the research conduction in the field of thin film deposition by the magnetron sputtering and vacuum-evaporation technique. The thermal vacuum method of thin film’s production is based on the heating of substance in vacuum until it’s active evaporation and condensation of vaporized atoms on the surface of the substrate. The advantages of the method are the high purity of the deposited material (the process is carried out at high and ultrahigh vacuum), versatility (films of metals, alloys, semiconductors, dielectrics are applied) and relative ease of implementation [2]. One of the main disadvantages of thermal method is a droplet phase. The droplet phase is formed due to the appearance of vapors in the evaporated material, that captures macroscopic particle passing through a melted metal [3]. Also, the method is characterized by a non-adjustable deposition rate and deposition energy, variable and uncontrollable deposition energy [4].
The magnetron method consists in cathode sputtering with high-energy ions of working gas. The magnetron sputtering method is characterized by localized plasma near the cathode that allows to increase the sputtering rate significantly through the high ion current density at lower operating pressure [4].

In the process of forming nanocomposite materials, one of the main factors is the energy of the particles of the functional material. The energy determines the effectiveness of its insertion into template [5]. The film growth rate and adhesion are significantly increased when using a magnetron sputtering system, since the kinetic energy of the spraying atoms significantly exceeds the kinetic energy of the evaporated ones [3]. Based on the above factors, the method of magnetron sputtering is chosen as the method of spraying functional coatings.

![Magnetron Sputtering equipment](image)

**Figure 1.** Magnetron Sputtering equipment

An experiment of introducing titanium into template formed by sedimentation from a colloidal solution of silica was carried out with the installation of magnetron vacuum deposition [6-7].

2. **Investigation of the influence of technological deposition modes of functional material on the degree of template filling**

Possible variants for the titanium deposition on the template in the upper layer are presented in Figure 2.

![Roughness Filling](image)  ![Repetition of the surface pattern of the template](image)

**Figure 2.** Filling irregularities Top layer formation variants

The following experiment was carried out to discover features of the growth process of metallic film on the opal matrix: on the template formed on the Al2O3 aluminum substrate deposited titanium films by different thickness at different energies of the sprayed particles by the magnetron sputtering. (Fig.3) Table 1 shows the main parameters values of the titanium deposition mode. Thus, titanium with a thickness of 50 and 100 nm was deposited on a smooth test sample on a template, at each power value (700 W and 350 W).
Figure 3.- Template depth control

Table 1 – Technological mods

| Parameter name                      | Symbol | Unit of measurement | Value |
|-------------------------------------|--------|---------------------|-------|
| Vacuum chamber pressure             | P      | Pa                  | 2     |
| Argon consumption                   | Y      | cm$^3$/min          | 55    |
| Magnetron power                     | Pw     | W                   | 700   |
|                                    |        |                     | 350   |
| Current strength                    | I      | A                   | 1.43  |
|                                    |        |                     | 1.2   |
| Voltage                             | U      | B                   | 401   |
|                                    |        |                     | 292   |
| Duration                            | t      | sec                 | 60/30 |
| The distance to the substrate       | L      | mm                  | 65    |

For these four samples, spectrophotometric analysis was carried out before and after titanium deposition (Fig. 4 - 5).

Figure 4 Spectra before titanium deposition
Figure 5. Spectra after titanium deposition

The number of layers in the template structure is calculated by the formula (1) and is equal to 5. The photonic band gap of the sample without a titanium film was observed at wavelengths of 430 nm, 500 nm, 570 nm, and 650 nm. Position dates of the photonic band gap for the samples after depositing titanium are in the datasheet 2.

\[
h = \frac{\lambda_1}{2 \cdot n_{\text{eff}} \cdot \cos \theta (1 - \frac{\lambda_1}{\lambda_2})}
\]

(1)

\(n_{\text{eff}}\) - effective refractive index of the material.

| Table 2 – PBG position dates |
|-----------------------------|
| Thickness 50 nm power 350 W |
| Peak 1 | Peak 2 | Peak 3 | Peak 4 |
| 471 nm | 588 nm | 632 nm | 786 nm |
| Thickness 50 nm power 700 W |
| 436 nm | 521 nm | 663 nm | 1093 nm |
| Thickness 100 nm power 350 W |
| 450 nm | 540 nm | 617 nm | 750 nm |
| Thickness 100 nm power 700 W |
| There is no photonic band gap |

There are characteristic peaks on the reflection spectra of samples with a titanium thickness of 50 nm that is equal to 350 W power. This indicates the photonic crystal structure of the samples is unchangeable. The forth sample shows a film of 100 nm thickness formed at the 700 W power that shaped titanium blanket coating on a template and there is not found PBG.

The shift in the position of all the PBG peaks in the first three samples toward infrared waves also indicates the filling of the inter-spherical space of the template, since when titanium is introduced into the silica film, a composite structure is obtained with an eigenvalue of the refractive index, which can be determined by the formula. It proves the result reached in work [8], which is devoted to the
assessment of the uncertainty of measuring the fill factor of the opal matrix by the embedding material.

\[
    n_{\text{eff}} = \sqrt{n_{\text{op}}^2 f_{\text{op}} + n_{\text{air}}^2 f_{\text{air}} + n_{\text{imp}}^2 f_{\text{imp}}} (2)
\]

\(n_{\text{op}}\) - opal refractive index, \(f_{\text{op}}\) - opal matrix fill factor, \(n_{\text{air}}\) - air refractive index, \(f_{\text{air}}\) - matrix fill factor, \(n_{\text{imp}}\) - refractive index of the implant material, \(f_{\text{imp}}\) - matrix fill factor.

On the contrary, when spraying at a power of 700 W, titanium begins to actively deposit on the top layer and forms a blanket film on the template, due to which the material does not reach the layers located below.

3. Conclusion
The results of theoretical and experimental studies have shown that for the introduction of functional material, it is necessary to use the method of magnetron sputtering at low power (300-350 W), as it provides penetration of the material to a depth of 3-4 layers of photonic crystal structure.

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