Composite (SiO_2-Au) films for magnetophotonics

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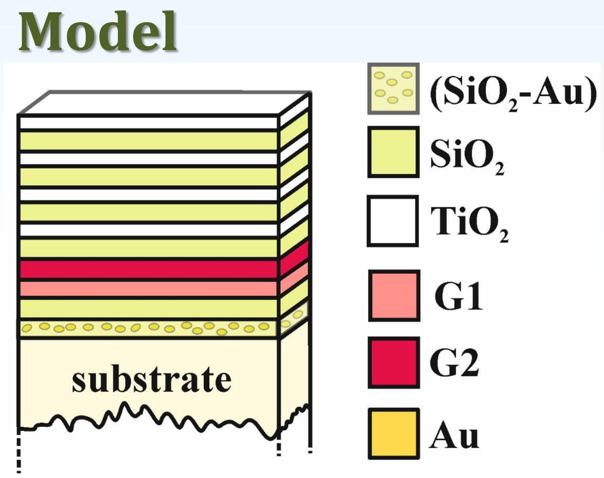
Abstract. Structural and morphological features of layers of composite (SiO_2-Au) were experimentally investigated depending on the conditions of formation. It has been demonstrated that the diameter of Au nanoparticles in a SiO_2 matrix can vary from 12 to 60 nm. The volume content of Au nanoparticles in the SiO_2 matrix in synthesized samples was f = 0.16. Taking into account the features of formation of composite and bismuth-substituted iron garnets layers, the magnetophotonic crystal "composite – SiO_2 layer – iron garnet – Bragg mirror" was proposed as the most promising from a practical point of view and implementation. Optical and magneto-optical characteristics of the magnetophotonic crystal with different numbers of layers pairs m and the center of photonic band gap λ_0 of the Bragg mirrors were considered.

Model



GGG/(SiO_2-Au)/SiO_2/G1/G2/[SiO_2/TiO_2]^m

GGG is substrate of gadolinium gallium garnet; [TiO_2/SiO_2]^m and [SiO_2/TiO_2]^m are Bragg mirrors with repetition number m; G1 is garnet of composition $Y_3Fe_5O_{12}$; G2 is garnet of composition $Bi_{2.8}Y_{0.2}Fe_5O_{12}$; ($SiO_2$-Au) is composite film and Au is a gold layer.

Simulations

- ✓ In order to simulate the optical and MO properties of MPC and numerically solve Maxwell's equations, a software algorithm was implemented using the transfer matrix method 4×4.
- ✓ All layers of the structure were preliminarily synthesized and their structural, optical and magneto-optical properties were determined.
- ✓ The dielectric constant of composite (SiO_2-Au) layer was calculated based on the Maxwell-Garnett model. The components can be calculated using the following expression:

$$\varepsilon_{\perp,\parallel} = \varepsilon_m \left(1 + \frac{f\left(\varepsilon_p - \varepsilon_m\right)}{\varepsilon_m + (1-f)(\varepsilon_p - \varepsilon_m) g_{\perp,\parallel}}\right),$$

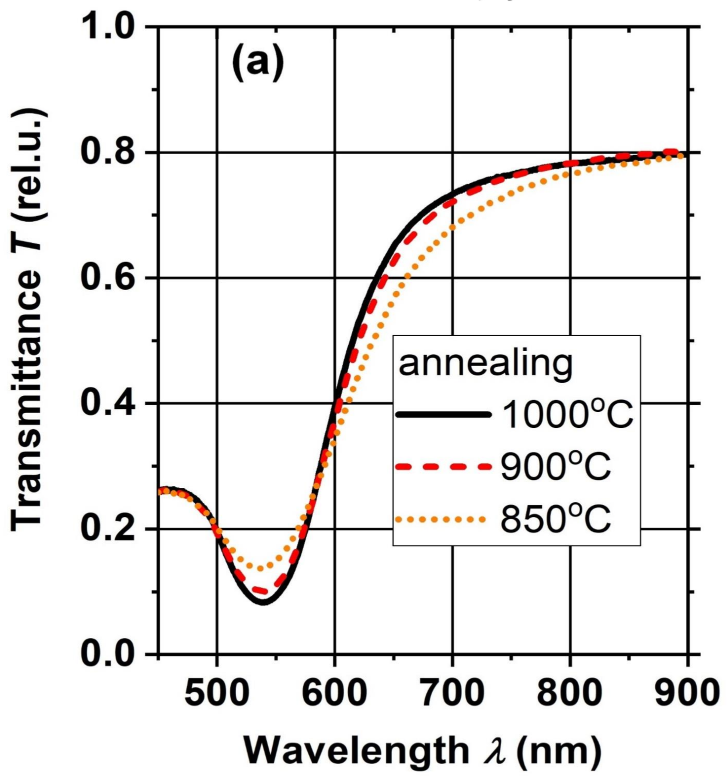
where ε_m and ε_p are dielectric constants of metal inclusions and dielectric matrix, respectively; f is volume fraction of inclusions; $g_{\perp,\parallel}$ are geometric factors that take into account the effect of nanoparticles shape on the induced dipole moment of nanoparticles. We assumed that $g_\perp = g_\parallel = 1/3$: the nanoparticles have a spherical shape.

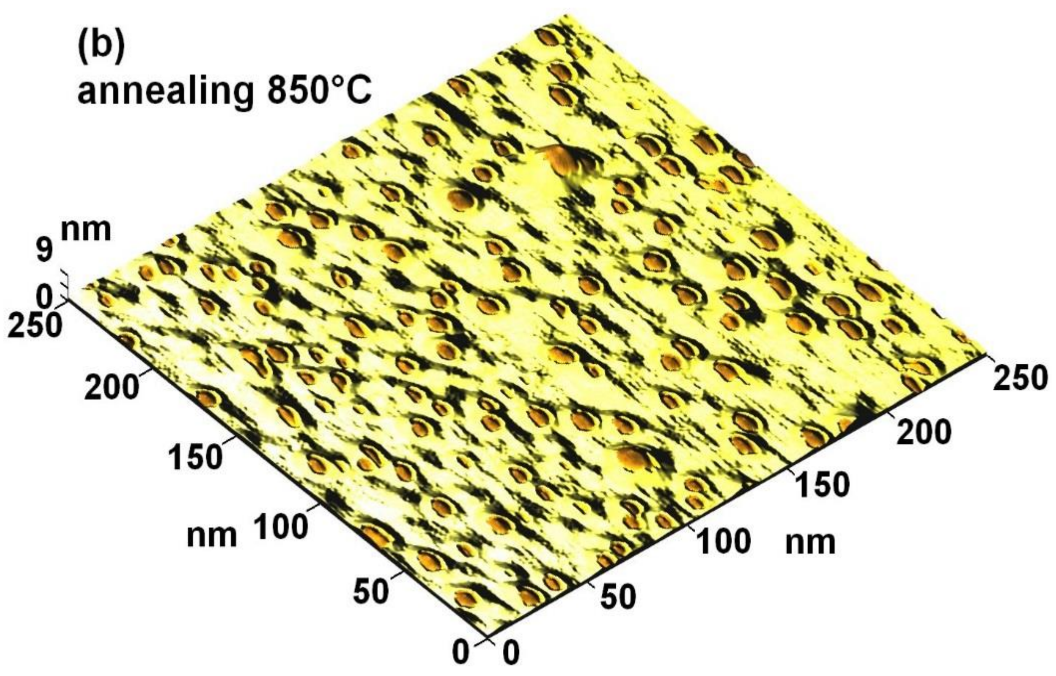
Experimental technique

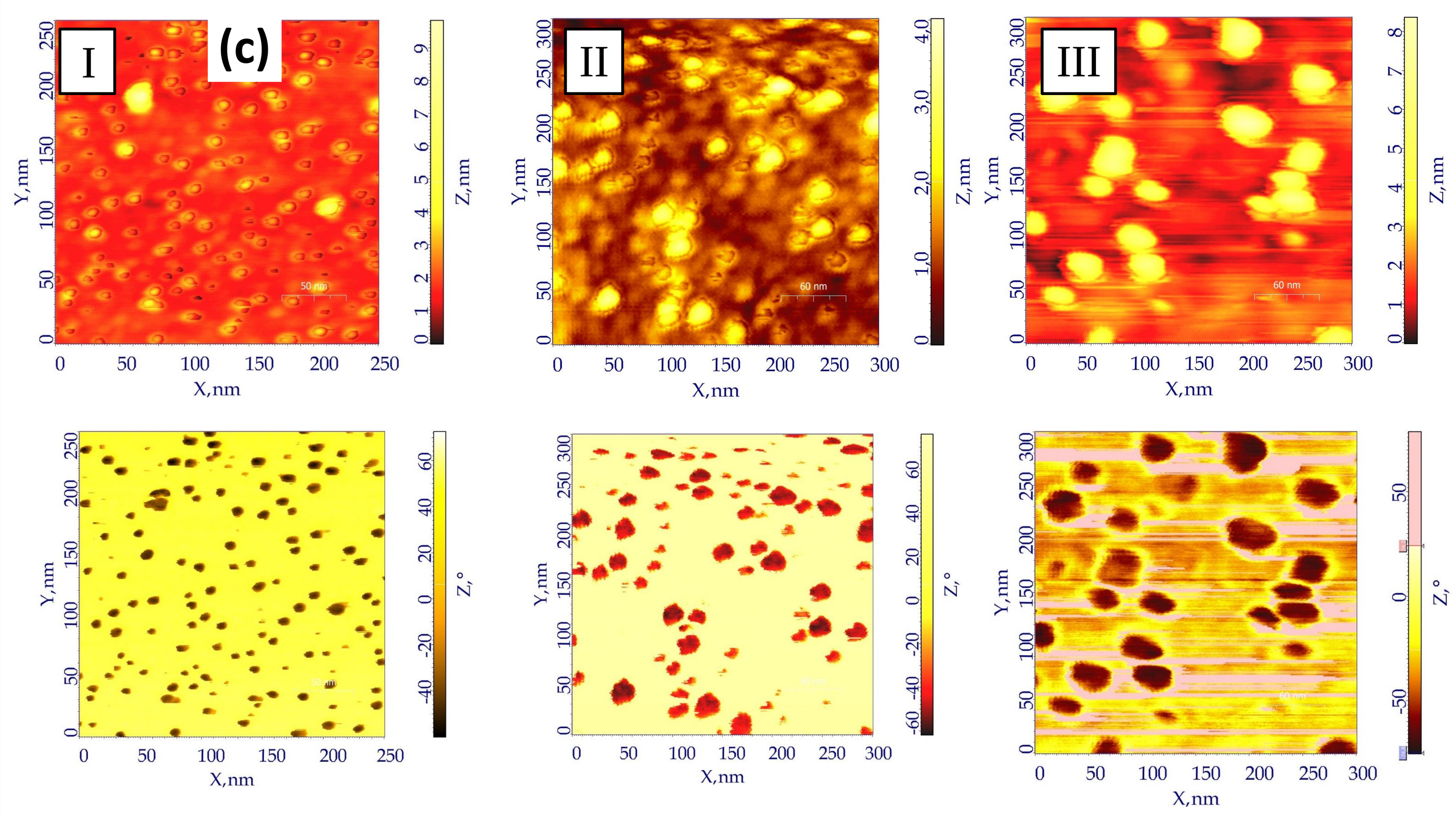
- ✓ For the synthesis of composite (SiO_2-Au), the technology of simultaneous sputtering of Au plates and SiO_2 targets was used. To form nanoparticles with lateral dimensions from 10 to 50 nm, the deposited layers were annealed. The sample was sequentially annealed for 30 min at different temperatures from 700°C to 1000°C. Reactive ion beam sputtering was implamented at a URM 3-279.014 setup with ion-beam Kholodok-1 source.
- ✓ G1 and G2 iron garnet films were synthesized using high-frequency magnetron sputtering at MVU TM MAGNA 09. In order to form the garnet phase, each layer was annealed at the optimum temperature Ta and duration τa: Ta = 800°C and τa = 5 min for layer G1 and Ta = 670°C and τa = 25 min for layer G2. Bragg mirror layers were deposited by high-frequency magnetron sputtering at Elim TM 5.
- ✓ Atomic force microscopy methods (intermittent contact and phase contrast imaging modes) were used to characterize the microstructure. The measurements were carried out by cantilevers of HA_HR ETALON using the INTEGRA scanning probe microscope (NT-MDT, Russia).

(SiO_2-Au) – Films properties

Optical spectra (a) and topology (b, c) of (SiO_2-Au) films annealed at different temperatures and time: I – 850°C 30 min; II – (850°C 30 min + 900°C 30 min); III – (850°C 30 min + 900°C 30 min + 1000°C 30 min). f=0.16.



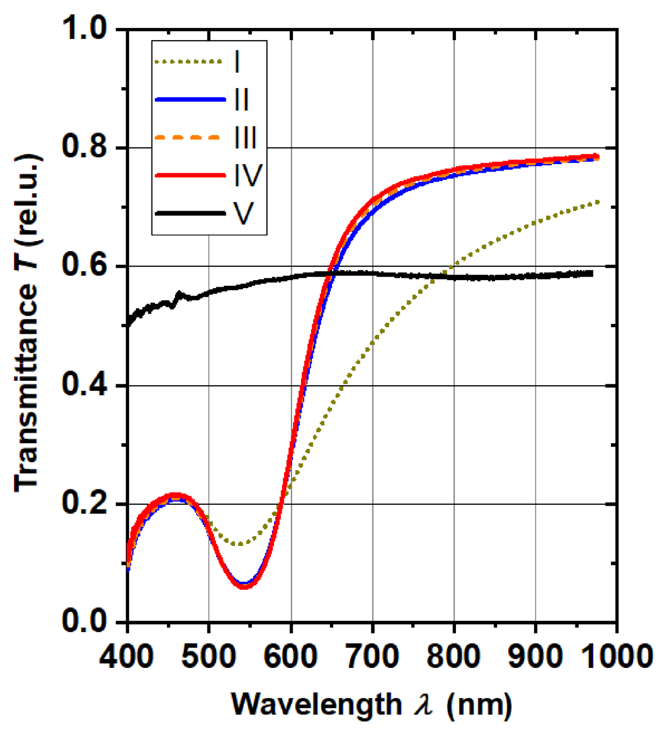


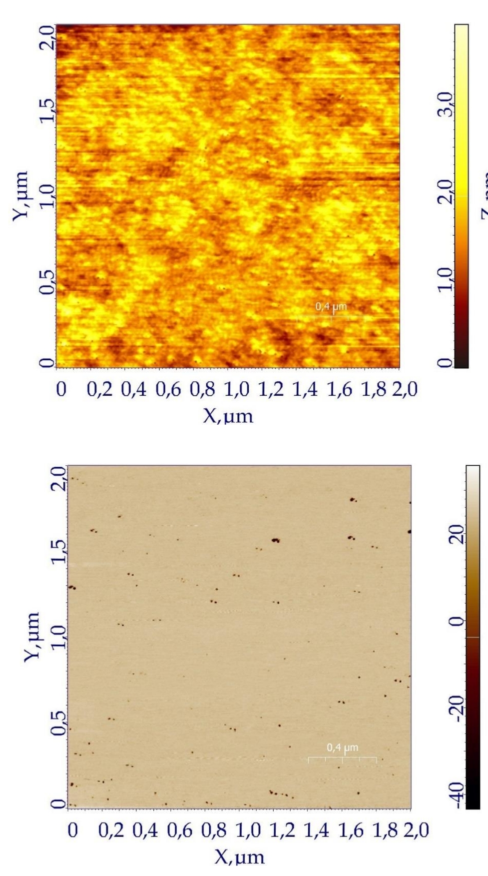


Atomic force microscopy (AFM-) images: top – morphology; bottom – phase contrast

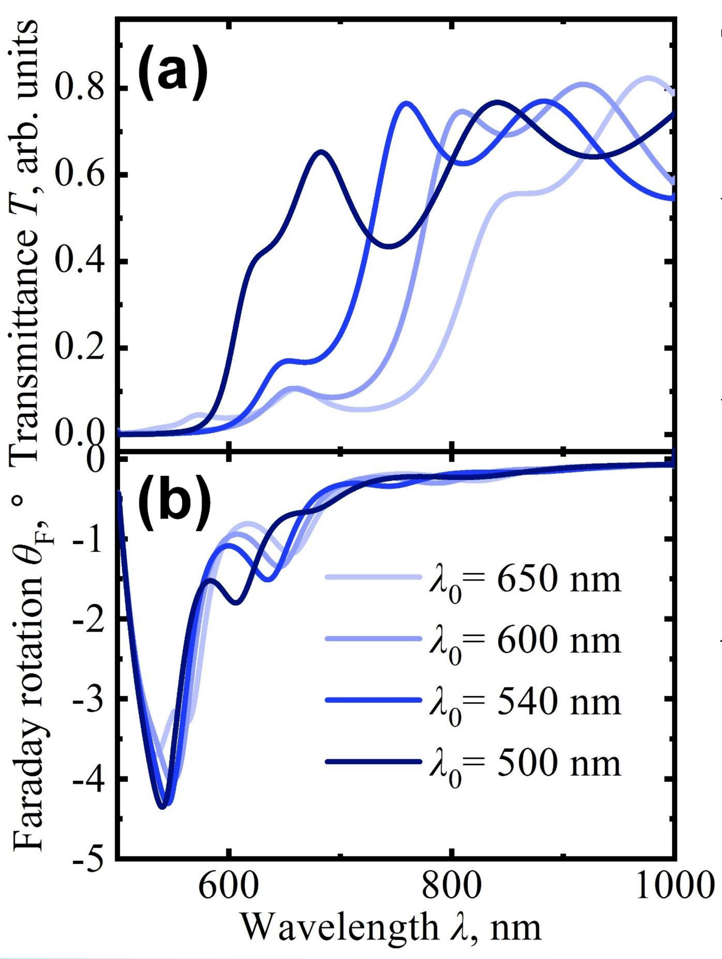
Optical spectra (a) of (SiO_2-Au) films annealed at 965 °C and different time: I – 5 min; II – 10 min; III – 20 min ; IV – 40 min. V is spectrum of film annealed at 1100 °C during 3 hours with continuous heating and cooling. f=0.32.

AFM-images of (SiO_2-Au) films III.





Simulation of structure GGG/(SiO_2-Au)/SiO_2/G1/G2/[SiO_2/TiO_2]^3



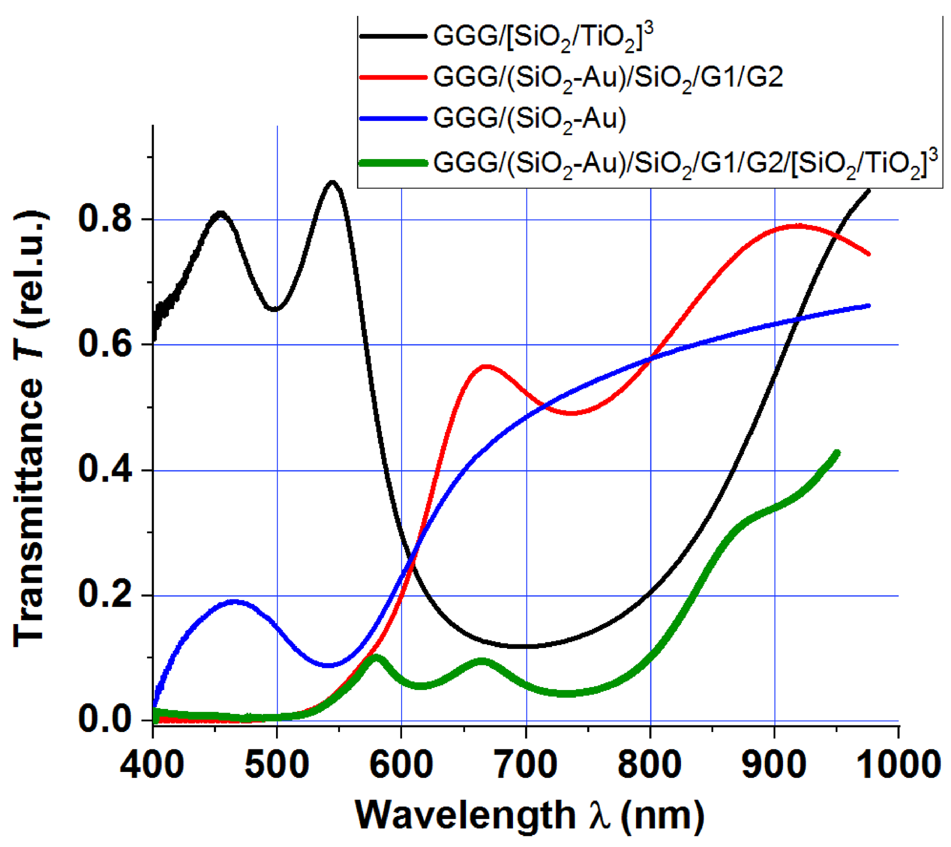
The model parameters of layers were as follows:

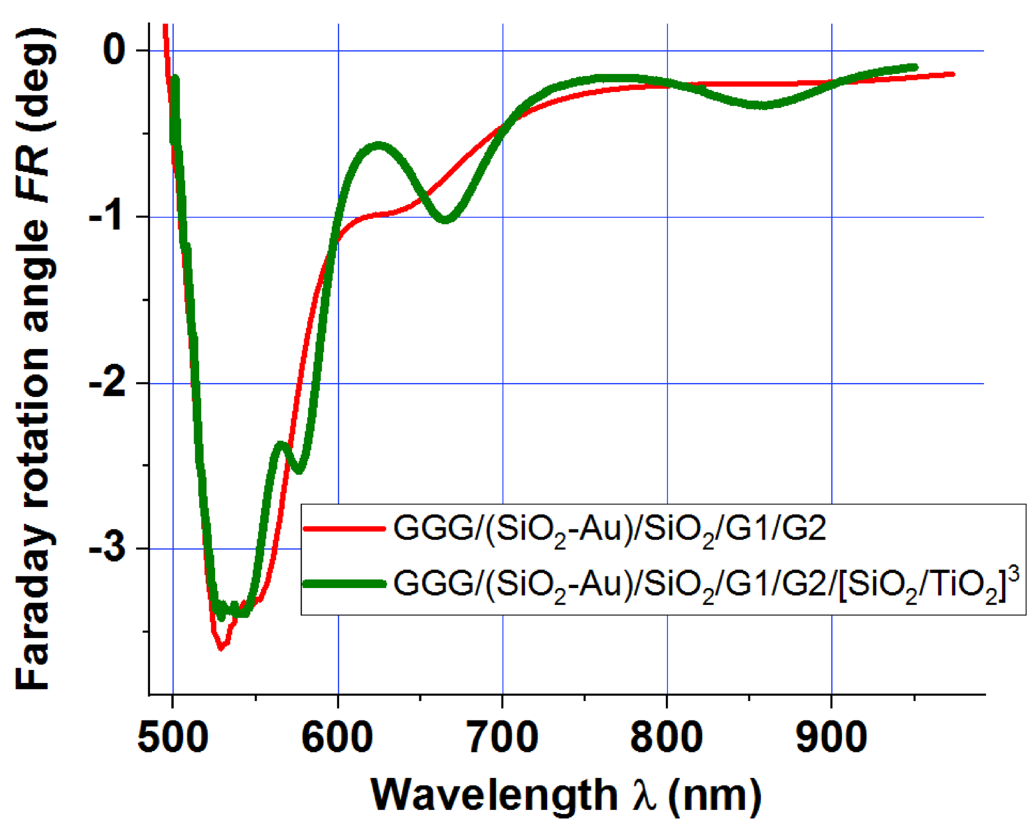
m = 3;
the thicknesses of layers of titanium dioxide $h_{(TiO2)}$ = 52.5 – 70 nm;
silicon dioxide $h_{(SiO2)}$ = 75.7 –101 nm;
composite $h_{(SiO2\text{-}Au)}$ = 130 nm;
buffer silicon dioxide $h_{(SiO2)}$ = 101 nm;
G1 $h_{(G1)}$ = 67 nm;
G2 $h_{(G2)}$ = 335 nm.

At real optical parameters of the composite, only resonance states corresponding to the defect mode are observed in the spectra of structure.

Experimental realization of structure GGG/(SiO_2-Au)/SiO_2/G1/G2/[SiO_2/TiO_2]^3

Modeling of the properties and optimization of conditions for the synthesis of magnetophotonic crystal with composite (SiO_2-Au) layer were carried out. It is shown that the highest values of the Faraday rotation can be achieved in the short-wavelength region of the spectrum. A technology has been developed for obtaining composites with desired properties for applications in magnetophotonics.





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