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Nanocomposites Based on Opal Matrixes and Magnetic Materials for Medical Electronics

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Abstract

The processes for obtaining of 3D magnetic nanocomposites, due to the synthesis of $Ni_XZn_{1-X}Fe_2O_4$ and $Co_XZn_{1-X}Fe_2O_4$ crystallites in communicating spatially ordered inter-spherical voids, occupying ~ 26% of the opal matrix volume, are discussed. The composition and structure of nanocomposites investigated by Electron microscopy and X-ray diffractometry. The advantages of the application of magnetic nanocomposites samples containing crystallites with a size of 15–50 nm in medical electronics are considered.

1 Introduction

Now the intensive research are executed in the search for new materials with magnetic properties. The application of magnetic materials as 3D nanoarrays of crystallites with sizes of 10–50 nm will make it possible to widen the frequency range of their application, since the frequency limitations are usually associated with the dispersion of the dielectric and magnetic conductivities common for bulk materials. A new direction for the development of 3D nanocomposites is the introduction of various compounds into porous matrixes with pores of the nanometer range. To fill the pores of the porous matrix with various substances, the method of synthesis of compounds directly in the pores is generally implemented. As a porous matrix with an ordered lattice of pores opal matrixes are promising [1,2]. Opal matrices are the regular packing of spherical particles of amorphous SiO_2, the diameters of which, depending on the formation conditions, can vary within specified limits from ~ 200 up to ~ 700 nm [2]. At Figure 1 a) REM image for the surface of an opal matrix sample The opal matrixes are characterized by a connected regular grid of nanopores between spherical particles of SiO_2. The system of interconnected and spatially ordered inter-spherical pores occupies ~ 26% of the opal matrix volume. Opal matrixes, the pores of which are filled with nanoparticles of various substances, are metamaterials having new properties that are difficult to achieve for monolithic substances and can be used for creating of the phase velocity control devices in a wide frequency range [2]. The developed metamaterials provide new solutions in the development of electronic devices for various applications, including in medicine [2-6]. The paper [3] presents the results of measuring the X-ray energy spectra induced by pulsed laser impacts on opal matrixes at wavelengths (l): 1040 nm (IR), 510 nm jointly with 578 nm, 366 nm (UV). According to the results of spectral studies, it was found that the induced X-rays are low-intensity soft X-radiation with photon energy of 0.08–2.47 keV and with wavelength of 15.2–0.5 nm. The introduction of laser radiation into an optical fiber is widely used to solve a large number of practical problems: in medicine for endoscopic studies, pyrometry, spectroscopy, and others. Placing OM at the output of an optical fiber with laser radiation makes it possible to deliver X-ray radiation directly to the irradiated object [5]. When fiber is added to transmit data to a Raman spectrometer, the effectiveness of a local X-ray effect on substandard formations can be monitored.

2 Results and discussions

The structure of opal matrices and nanocomposites based on them. Samples of opal matrices with a volume of up to 3 cm3 with a diameter of SiO_2 spherical particles of ~ 260 nm (Δd ≈ 4%) and single domain sizes (regions of the correct packing of spherical particles) ≥ 0.1 mm3 were made (Fig. 1a). The synthesized substances filled> 20% of inter-ball voids. The structure of opal matrices and nanocomposites based on them. Samples of opal matrices with a volume of up to 3 cm3 with a diameter of SiO2 spherical particles of ~ 260 nm (Δd ≈ 4%) and single domain sizes (regions of the correct packing of spherical particles) ≥ 0.1 mm3 were made (Fig. 1a). The synthesized substances filled> 20% of inter-ball voids. At Figure 1.b) TEM image of nanocomposites based on opal matrixes containing crystallites pores are presented.

a) b)

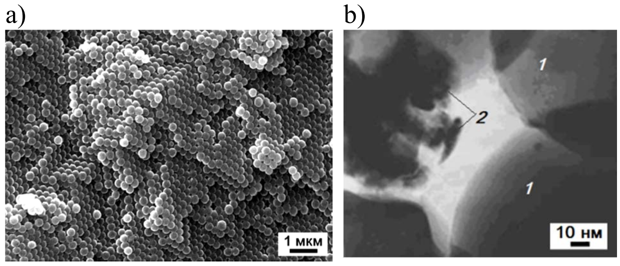

Figure 1. a) REM image for the surface of an opal matrix sample; b) TEM image of nanocomposites based on opal matrixes containing crystallites pores: $Co_XZn_{1-X}Fe_2O_4$; (1 - spherical particles of SiO_2; 2 - synthesized crystallites)

Phase composition of nanocomposites. Phase transformations, including crystallization of compounds of various types, depended on the heat treatment conditions (temperature and duration), as well as on the chemical properties of the intermediate compounds, their thermal stability, and their ability to interact with SiO_2. An analysis of X-ray diffraction patterns showed the presence of crystalline phases $Ni_{0,5}Zn_{0,5}Fe_2O_4$ and $Co_{0,5}Zn_{0,5}Fe_2O_4$ in the voids of the opal matrices. The size of crystallites (regions of coherent X-ray scattering) of substances synthesized in voids was 15–50 nm. The crystallite size was determined from the broadening of diffraction maxima in x-ray diffraction patterns. In addition to crystalline phases, the studied samples contained X-ray amorphous phases. The degree of crystallinity (concentration of the crystalline phase in the mixture of amorphous and crystalline components) of the synthesized substances depended on the heat treatment conditions and in some cases reached 60% (by volume). The crystallite size did not depend on the degree of crystallinity of the synthesized substances. Crystallites of substances with spinel structure according to x-ray phase analysis had an equiaxed shape.

Magnetic properties. The magnetic moment of samples of various nanocomposites $Ni_XZn_{1-X}Fe_2O_4$ and $Co_XZn_{1-X}Fe_2O_4$was measured. A hysteresis loop characteristic of ferromagnets is observed, while the value of the coercive force indicates the nanostructured magnetic phase. Measurements of samples obtained under various conditions of high-temperature heat treatment showed that there is an effect on the measured parameters, the concentration of the crystalline phase in the composition of the synthesized substances. At Figure 2. the results of loss measurements (I) for reflection coefficient (II), and decoupling between arms (III) in the frequency range 28–37 GHz of the Y-circulator with nanocomposites based on opal matrices, the pores of which are filled with $Ni_{0.5}Zn_{0.5}Fe_2O_4$ crystallites (1) and $Co_{0.5}Zn_{0.5}Fe_2O_4$ (2) are presented.

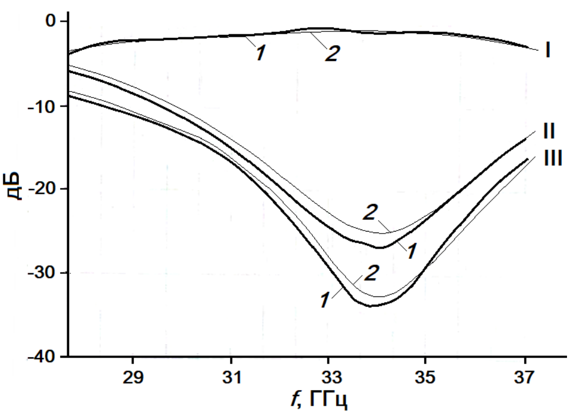

Figure 2. Measurements of losses (I) for reflection coefficient (II), and decoupling between arms (III) in the frequency range 28–37 GHz of the Y-circulator with nanocomposites based on opal matrices, the pores of which are filled with $Ni_{0.5}Zn_{0.5}Fe_2O_4$ crystallites (1) and $Co_{0.5}Zn_{0.5}Fe_2O_4$ (2)

3 Conclusion

In the report we present the conditions for the formation of opal matrices (3D packages of spherical particles of amorphous SiO2 with a diameter of ~ 260 nm), which form an ordered system of inter-ball voids; as well as nanocomposites based on opal matrixes containing a 3D lattice filling the voids of crystallites of magnetic substances. The characteristics of a Y-circulator with samples of nanocomposites based on opal matrices, the voids of which are filled with crystallites, are under consideration. An improvement in the characteristics of the Y-circulator in comparison with the application of ferrite (Ni-Zn-spinel) by ≥ 20% is demonstrated. This result can be successfully applied in wireless monitoring systems for biological signals of the human cardiovascular system.

4 Acknowledgements

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5 References

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