URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Nanocomposites Based on Opal Matrixes and Magnetic Materials for Medical Electronics

Yury V. Gulyaev[1], **Alexander S. Bagdasaryan**[1], **Alexey F. Belyanin**[2], **Sergey A. Bagdasaryan**[3], **Elena R. Pavlyukova**[1]

(1) Kotelnikov Institute of Radioengineering and Electronics RAS, Moscow, RF, http://www.cplire.ru

(2) Central Research Technological Institute "Technomash", Moscow, Russia

(3) Scientific Engineering Center "Technological developments of telecommunication and radio frequency identification", Moscow, RF

Nanocomposites based on Opal Matrixes and Magnetic Materials

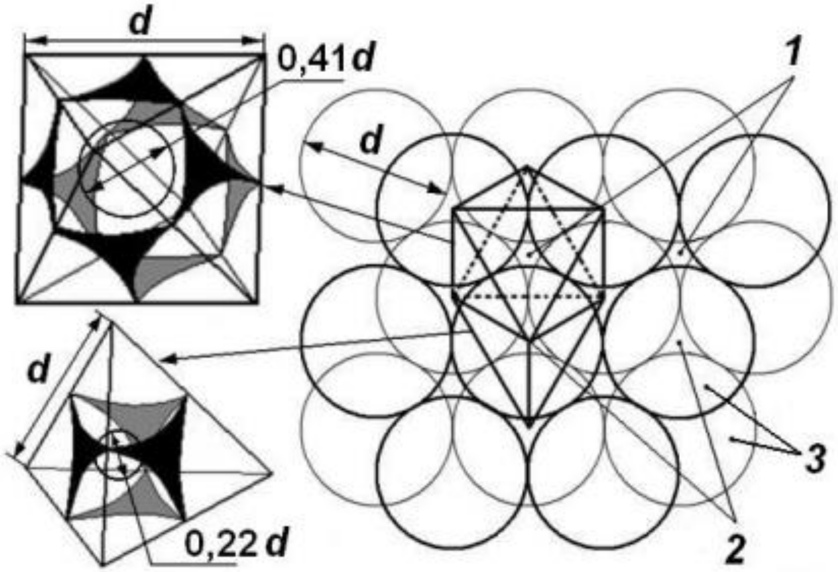
- The processes for obtaining of 3D magnetic nanocomposites, due to the synthesis of $Ni_XZn_{1-X}Fe_2O_4$ and $Co_XZn_{1-X}Fe_2O_4$ crystallites in communicating spatially ordered inter-spherical voids, occupying about 26% of the opal matrix volume, are discussed.
- The composition and structure of nanocomposites are 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.

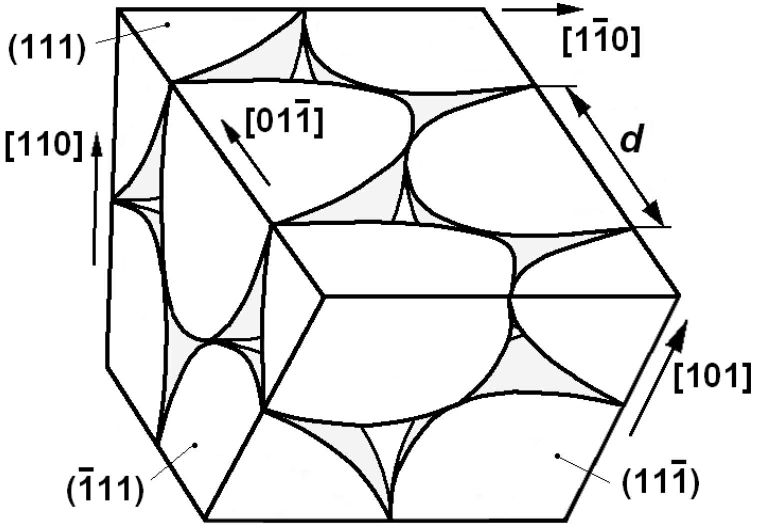
Opal Matrixes Filled with Nanoparticles

- 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.
- Opal matrixes can be used for creating of the phase velocity control devices in a wide frequency range.
- The developed metamaterials provide new solutions in the development of electronic devices for various applications, including for medicine.

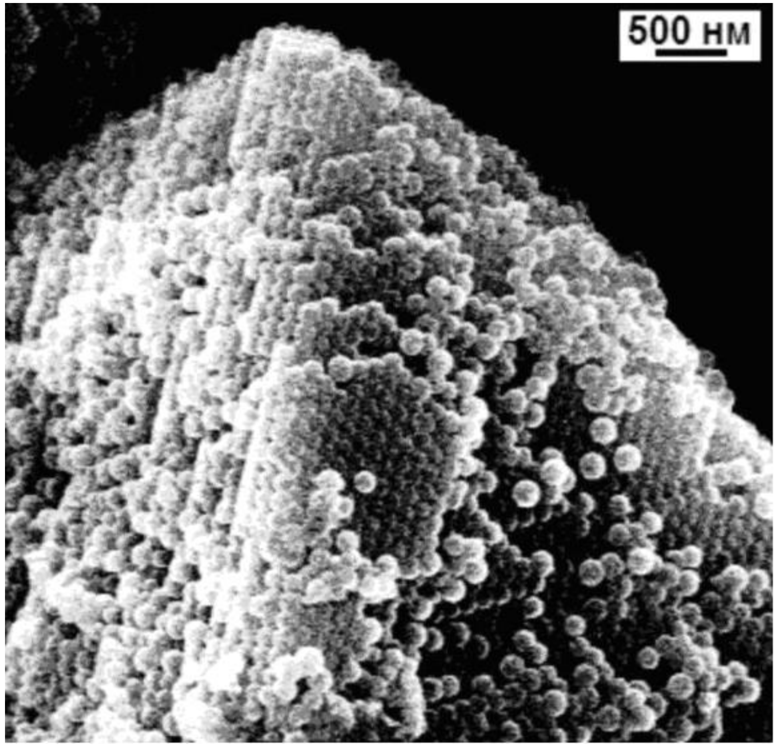
The structure of opal matrixes and nanocomposites

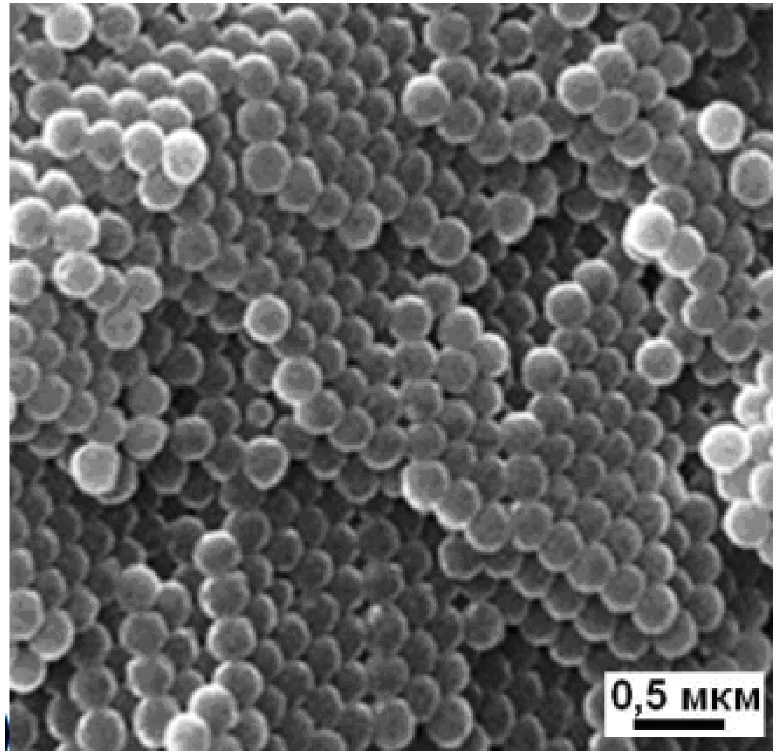
- Samples of opal matrixes with a volume of up to 3 cm^3 with a diameter of SiO_2 spherical particles of ~ 260 nm (Δd ≈ 4%) and single domain sizes (regions of the correct packing of spherical particles) ≥ 0.1 mm^3 were made.
- The synthesized substances filled > 20% of inter-ball voids.





The structure of opal matrixes and nanocomposites





Raster electronic microscopy (REM) images of general view and surface of the separate massive macroparticle

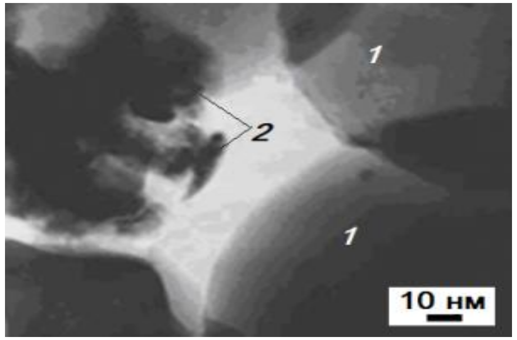
The structure of opal matrixes and nanocomposites

TEM image of nanocomposites based on opal matrixes containing crystallites pores

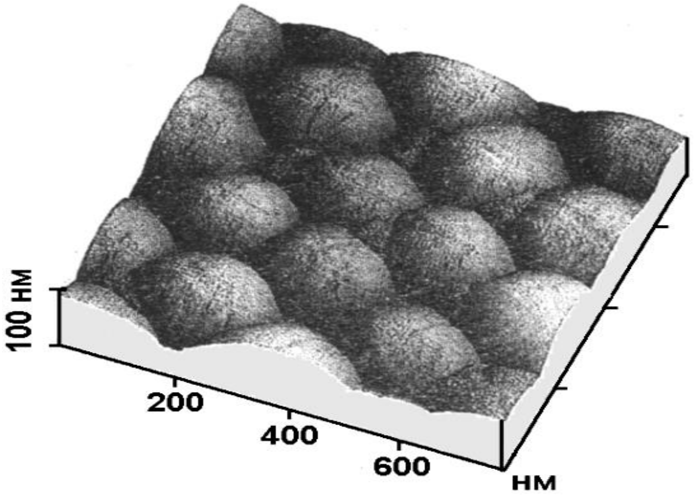
$Co_XZn_{1-X}Fe_2O_4$;

1 - spherical particles of SiO_2;

2 - synthesized crystallites)



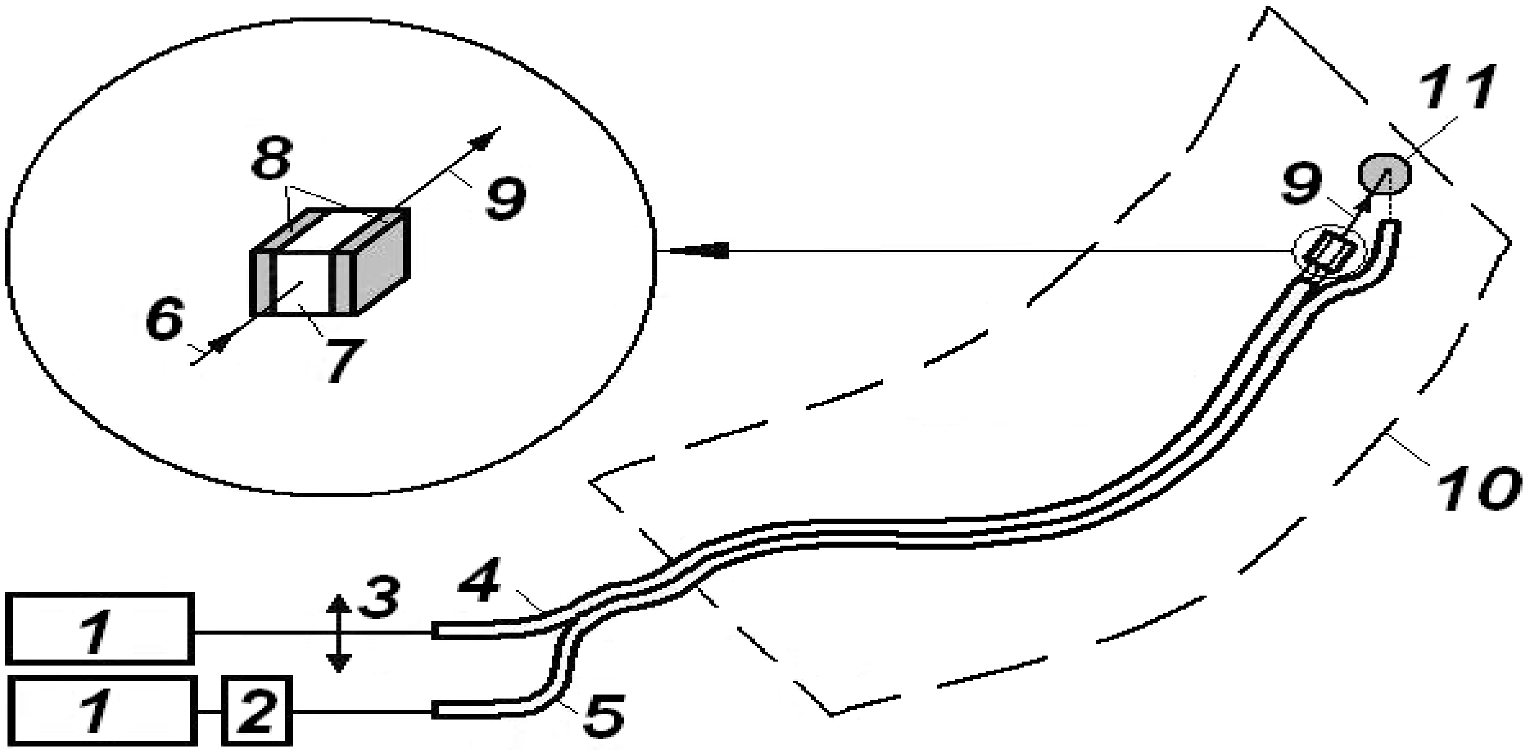
Atom-force microscope image



Generation of directed pulsed X-radiation

- There were made measuring the X-ray energy spectra induced by pulsed laser impacts on opal matrixes at wavelengths: 1040 nm (IR), 510 nm jointly with 578 nm, 366 nm (UV).
- It was found that the induced X-rays have 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- radiation directly to the irradiated object. 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.

Endoscopic Device Principal Schema
for generation of directed pulsed X-radiation



1 – laser; 2 – system for images of the investigated object or Raman spectra registration;
3 – optical system to focus the laser radiation; 4, 5 – fiber optic cables;
6 – laser pumping via an optical cable; 7 – opal matrix; 8 – piezoelectric plates;
9 – pulsed X-radiation; 10 – investigated cavity; 11 – object under X-ray impact

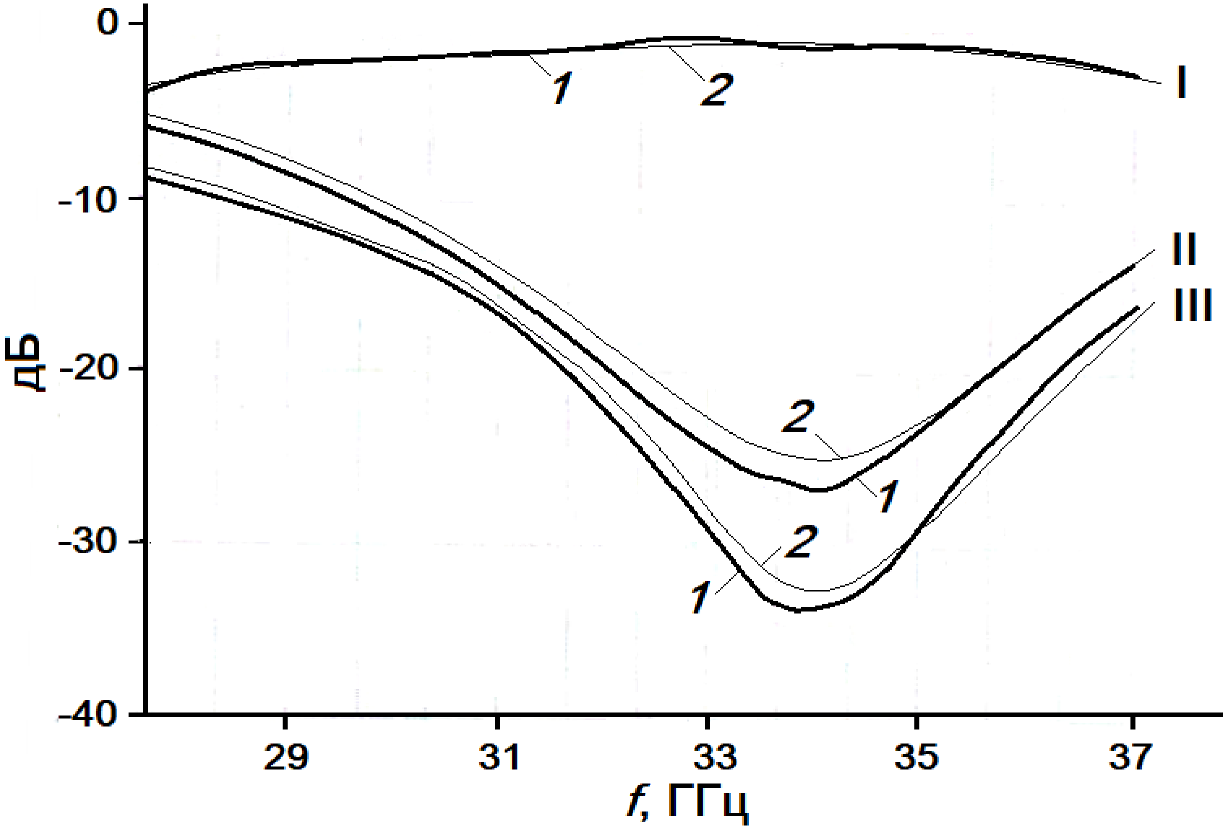
Phase composition of nanocomposites

- 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 matrixes.
- 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 ferromagnetics 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.

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 matrixes, 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)



Conclusion

- Here we present the conditions for the formation of opal matrices (3D packages of spherical particles of amorphous SiO_2 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 results can be successfully applied in wireless monitoring systems for biological signals of the human cardiovascular system, as well as in endoscopic devices.

Acknowledgements

- The authors express their acknowledgement to Russian Foundation for Basic Research for financial support of the investigation made in the framework of the grants №18-07-00282-a and №18-29-02076-mk

URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

Thank you for your kind attention!





Kotelnikov Institute of Radioengineering and Electronics RAS, Moscow, RF,
http://www.cplire.ru
E-mail: elena.pavlyukova@cplire.ru