Dielectric/Conductivity Spectra and Magnetic Properties of 3D-Nanocomposites of Metallic Particles Confined in Opal Matrices

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Abstract - **Structure and composition of metamaterial samples are studied on the basis of lattice packing SiO_2 nanospheres (opal matrices) with included clusters of crystalline phase in interspherical nanospacing related to electrically active or with high inductivity. Real and imaginary components of inductivity of synthesized metamaterials are investigated in range 1 MHz - 2 THz.**

Keywords - **nanocomposites, meta-materials, SHF-technics.**

Artificial compact three-dimensional opal matrices with 25-40 vol% porosity with pores of complex topology and sizes from zero up to ~50 nm were prepared by sedimentation of X-ray amorphous silica nanoballs of ~250 nm diameter [1]. Impregnation procedure was used to introduce Co, Fe and Ni nanoparticles into the opal matrix [1]. The composites were deoxidized by additional annealing in hydrogen atmosphere. The embedded particles have irregular shape and size from 5 to 50 nm. Their concentration does not exceed 5-7 vol%. Dielectric and conductivity spectra were studied in a broad frequency range from 1 MHz to 2 THz using microwave and terahertz techniques [2]. Frequency independent conductivity (conductivity plateau) in the whole frequency range was observed for the opal matrices - (Fe) and opal matrices - (Fe, Ni) composites corresponding to the linear (in log-log scale) decrease of dielectric loss. We attribute this conductivity plateau to the dc conductivity in percolated network of Fe- or (Fe, Ni)-clusters. No significant contribution of other mechanisms to conductivity was observed; therefore filler concentration in these compositions is considered to be above the percolation threshold. In the case of opal-Ni, opal-Co and opal-(Ni, Co, Fe) composites, dielectric/conductivity dispersion was observed with a loss maximum above 10 GHz.

We can attribute it to the ac conductivity in finite Ni-, Co- or (Ni, Co, Fe)-clusters (i.e., to the dynamics of the charge carriers in the fractal conducting network). The conductivity plateau corresponding to dc conductivity in percolated clusters could be probably observed below 1 MHz. At any case, contribution of the dc conductivity is a few orders of magnitude lower then the THz conductivity values. Consequently, these compositions are considered to be below or near the percolation threshold.

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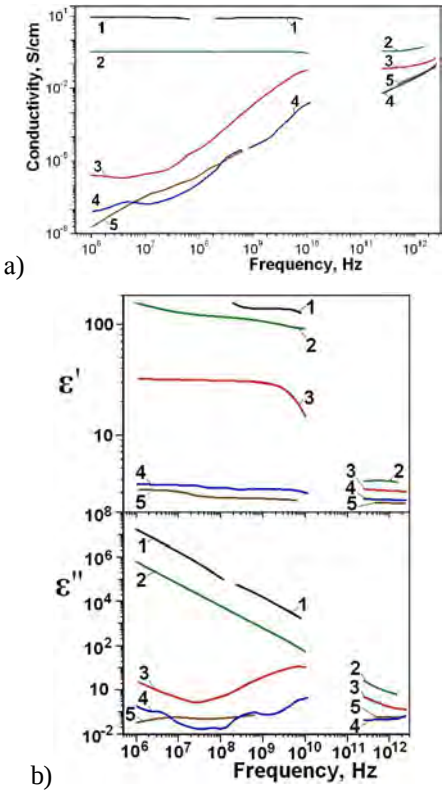

Fig. Frequency dependence of: a) the microwave conductivity, and b) the real (ε') and imaginary (ε") of the dielectric components (permittivity) of nanocomposites - opal matrices source (5) and interspherical nanospacing which are filled with clusters: 1 - Ni + Fe, 2 - Fe, 3 - Ni + Fe + Co, 4 - Ni

Magnetic properties were studied in the temperature range 2-300 K under the applied magnetic field up to 50 kE. Analysis of the magnetization curves allows supposing ferrimagnetic and superparamagnetic properties of the composites. The superparamagnetic properties can be explained accounting small size of metal nanoparticles (down to 10-15 nm).

REFERENCES

[1] V. V. Ustinov, A. B. Rinkevich, D. V. Perov, M. I. Samoylovich, S. M. Klescheva, "Anomalous magnetic antiresonance and resonance in ferrite nanoparticles embedded in opal matrix," *Journal of Magnetism and Magnetic Materials.*, vol. 324, pp.78-82, 2012.

[2] D. Nuzhnyy, P. Vanek, J. Petzelt, V. Bovtun, M. Kempa, I. Gregora, M. Savinov, R. Krupkova, V. Studnicka, J. Bursik, M. I. Samoylovich, W. Schranz, "Properties of $BaTiO_3$ confined in nanoporous Vycor and artificial opal – opal," *Proc. Appl. Ceram.*, vol. 4, pp.215-223, 2010.