UDC 620.22:621.3.029.6

RADIATION SHIELDING PROPERTIES OF SiO$_2$–Me^{II}Fe$_{12}$O$_{19}$ NANOCOMPOSITE MATERIALS PREPARED BY SOL-GEL METHOD

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SiO$_2$ materials containing different magnetic fillers Me^{II}Fe$_{12}$O$_{19}$ are obtained by the sol-gel method. It is studied the weakening of electromagnetic radiation in the frequency range 8–11.5 GHz by the materials obtained with the use of panoramic attenuation measurers and panoramic standing wave voltage coefficient measurers. It is also estimated the attenuation contribution of the radiation reflection from the material surface. The materials obtained can be used as a first layer of electromagnetic radiation absorbing materials which reduce the level of reflected energy.

INTRODUCTION

The natural radiation background is constantly being added by various new sources of electromagnetic pollution including electromagnetic ultrahigh frequency waves. Some of them are household appliances, cellular and satellite communications, medical equipment, radio installations, etc. [1]. Problems of electromagnetic security appear when one uses devices or systems of ultra-high frequency because long lasting and systematic influence of ultrahigh frequency radiation yields negative effects on the human body. Therefore, the problem of protecting the population and the environment from the powerful radio emission is very important.

An effective way to reduce to an acceptable level the natural and man-made disturbance, which interfere the work of electronic systems, is based on the application of shielding and absorbing materials. Their operation is based on the electromagnetic radiation weakening by the magnetic, dielectric, and resistive losses in the material. It is known that electrically conductive or magnetic particles can be used as the radio wave absorbing materials, if they contain in their composition components that provide energy losses of ultra-high frequency radiation [2–4]. Such particles are usually distributed in a carrier matrix.

For the research we selected a mesoporous silica matrix as a carrier matrix and used superfine powders of hexagonal ferrite of strontium and barium as magnetic fillers. Some of them contained additionally an admixture of iron oxide phases and some other substances of various chemical natures.

EXPERIMENTAL

The SiO$_2$–Me^{II}Fe$_{12}$O$_{19}$ nanocomposite materials containing different magnetic fillers were prepared by the sol-gel method. The flowchart of the sol-gel process is shown in Fig. 1. Silica sol was prepared by the combined alkoxide-colloidal method: first stage – the hydrolysis of tetraethylorthosilicate (TEOS) with catalyst HCl; the second stage – dispergation of aerosil T-30 (Wacker GmbH, Germany) in the hydrolyzate and centrifugal separation of agglomerates. In the next stage we injected fine-dispersed powder of various magnetic fillers (Me^{II}Fe$_{12}$O$_{19}$) into the sol. The resulting mixture was carefully mixed and treated in an ultrasonic basin at 44 kHz for a few minutes for better dispersion and more uniform distribution of magnetic particles in the sol. That was followed by the gelation process and gel drying process. The gels were dried at the temperature of about 60°C for 4–5 days.

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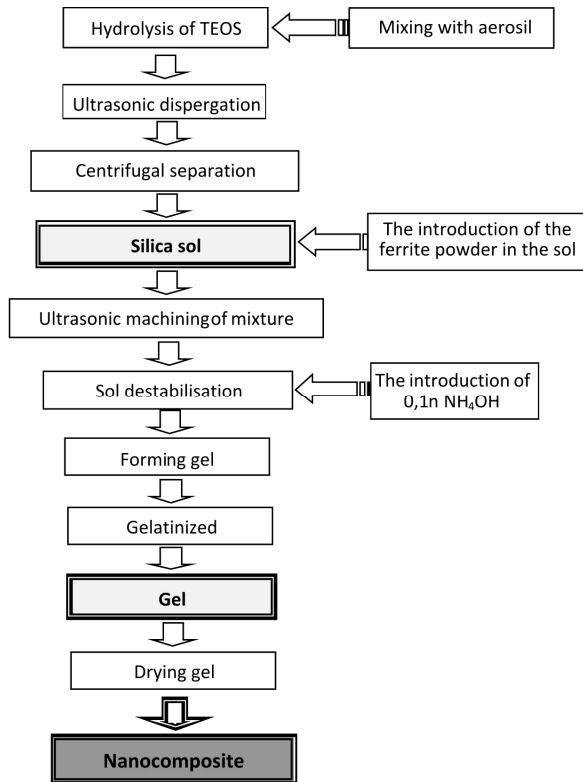
Fig 1. The scheme of synthesis of nanocomposite materials

The samples were disks with a diameter of (30±2) mm and a thickness of 4 mm. The concentration of magnetic fillers in the samples was 30% wt.

Shielding properties research of the material samples are related to the shielding effectiveness measurement, i.e. to the measurement of the electric and magnetic components of the electromagnetic field in the same point of space before and after the material installation. The attenuation coefficient of electromagnetic radiation and the reflection coefficient of electromagnetic waves from the sample characterise the effectiveness of screening of the samples. To study the shielding characteristics of the generated samples, we used panoramic extinction meters in the examination of the extinction coefficient. To estimate the energy reflection value, we used the panoramic standing wave voltage coefficient meters working on the principle of separation and direct detection of levels of incident and reflected waves. In the measuring process the signal proportional to the incident power was selected by the incident wave oriented detector and the signal reflected from load was selected by the reflected wave oriented detector.

RESULTS AND DISCUSSION

Characteristics of derived SiO$_2$–Me^{II}Fe$_{12}$O$_{19}$ materials interaction with electromagnetic radiation showed that all the investigated materials weaken the electromagnetic radiation in the range of 8–11.5 GHz (Fig. 2).
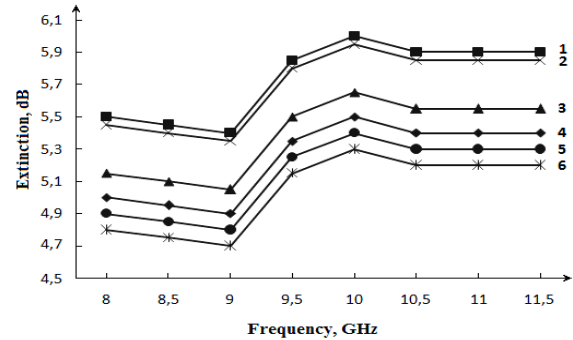
Fig.2. Frequency dependence of the extinction of electromagnetic radiation as it passes through SiO$_2$ based materials with different magnetic fillers: □ – BaFe$_{12}$O$_{19}$+α-Fe$_2$O$_3$; x – BaFe$_{12}$O$_{19}$+Zn; Δ – BaFe$_{12}$O$_{19}$; ◊ – BaFe$_{12}$O$_{19}$+α-Fe$_2$O$_3$ (Peccini's method); o – SrFe$_{12}$O$_{19}$ (with dope); * – SrFe$_{12}$O$_{19}$

The extinction of electromagnetic radiation consists of reflection and absorption. The first is due to scattering at different angles at the interaction with the structural irregularities of the composite material. The second is a consequence of dielectric and magnetic losses as well as of energy transfer to other species such as heat [1, 5].

The increase of the absorbed energy amount is a positive factor in the effectiveness assessing of the radio absorbing materials. On the other hand, the reflected energy should be as small as possible. It is essential that the wave is not reflected at the surface of the material but goes deeply into it almost normally to the surface regardless of the angle of incidence.

Therefore, to estimate the contribution of the reflection from the surface into the electromagnetic radiation extinction by the SiO$_2$–Me^{II}Fe$_{12}$O$_{19}$ composite materials produced, we measured the standing wave voltage coefficient (K_{SWV}). Since the reflection coefficient of electromagnetic waves from the sample is

$$K_{ref} = 10 \lg \frac{P_{ref}}{P_{inc}} \qquad (1)$$

and the modulus of the reflection coefficient (R) is associated with the measured value of K_{SWV} as

$$R = \frac{K_{SWV} - 1}{K_{SWV} + 1}, \qquad (2)$$

the reflection coefficients were calculated following the formula

$$K_{ref} = 20 \lg \frac{K_{swv} - 1}{K_{swv} + 1} . \qquad (3)$$

The reflection coefficients calculated for the electromagnetic radiation incidence on the materials investigated are given in Table 1.

All the investigated composite materials reflect electromagnetic radiation poorly. The best results were demonstrated by the materials containing barium hexaferrite ($BaFe_{12}O_{19}$) and barium hexaferrite with alpha-ferric oxide ($BaFe_{12}O_{19}+\alpha\text{-}Fe_2O_3$) produced by Peccini's method. Depending on the incident radiation frequency they reflect 4–9% and 3–6% of the incident radiation, respectively.

Taking the incident electromagnetic radiation to be 100% and defining that the extinction of the electromagnetic radiation (E) due to the sample is determined by the ratio of the incident wave signal (P_{inc}) and the signal passed through the sample (P_{tr})

$$E = 10 \lg \frac{P_{inc}}{P_{tr}} \qquad (4)$$

and

$$P_{inc} = P_{ref} + P_{abs} + P_{tr} , \qquad (5)$$

we calculated the part of the incident radiation absorbed as it passes through the composite SiO_2–$Me^{II}Fe_{12}O_{19}$ material. Frequency dependence of the absorption of radiation propagating through the composite materials based on SiO_2 with magnetic fillers of different composition and structure is shown in Fig. 3.

The analysis of the results obtained indicates that due to the combination of all three parameters, that characterise the properties of radio absorbing and radio shielding materials, the most promising samples are those which contain barium hexaferrite ($BaFe_{12}O_{19}$, No.3) and barium hexaferrite with the addition of alpha-iron oxide ($BaFe_{12}O_{19}+\alpha\text{-}Fe_2O_3$,

No.1, No.4). But the best reflection coefficient was demonstrated by the sample No.4.

These nanostructure SiO_2–$Me^{II}Fe_{12}O_{19}$ materials can be used as a first layer of the electromagnetic radiation absorbers which reduce the level of the reflected energy. At the same time, to increase the effectiveness of screening, one can use a metal plate (or metal foil) as a second layer.
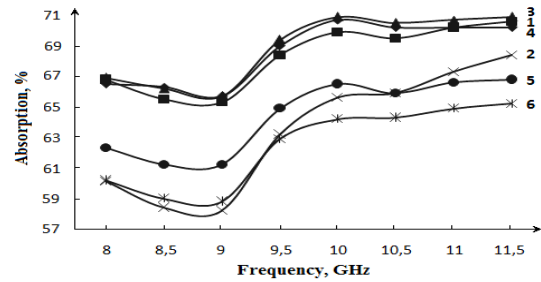
Fig.3. Frequency dependence of the absorption of radiation propagating through the composite materials based on SiO_2 with different magnetic fillers: □ – $BaFe_{12}O_{19}+\alpha\text{-}Fe_2O_3$; x – $BaFe_{12}O_{19}+Zn$; Δ – $BaFe_{12}O_{19}$; ◊ – $BaFe_{12}O_{19}+\alpha\text{-}Fe_2O_3$ (Peccini's method); o – $SrFe_{12}O_{19}$ (with dope); * – $SrFe_{12}O_{19}$

CONCLUSIONS

Nanocomposite materials based on silicon dioxide containing as fillers, magnetic ferrites of different chemical composition and structure are obtained by the sol-gel method. These SiO_2–$Me^{II}Fe_{12}O_{19}$ materials weaken electromagnetic radiation in the frequency range 8–11.5 GHz, their weakness magnitude depends on the magnetic filler and is higher for samples containing barium hexaferrite as compared to strontium hexaferrite. The part of the reflected energy for some of them is less than 6 % in the entire range of frequencies investigated. This allows recommending them for use as a first layer of absorbers of electromagnetic radiation reducing the level of reflected energy.

Table 1. The reflection coefficients of the electromagnetic radiation of frequency 8.0–11.5 GHz by the composite materials based on SiO_2 with different magnetic fillers (reflection coefficients – dB.)

	Sample	Radiation frequency							
No	filler	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
1	$BaFe_{12}O_{19}+\alpha\text{-}Fe_2O_3$ (acetat method)	-7.86	-7.56	-7.67	-7.52	-7.70	-7.97	-8.51	-8.99
2	$BaFe_{12}O_{19}+Zn$ (II)	-5.43	-5.18	-5.26	-5.43	-5.81	-6.24	-6.89	-7.52
3	$BaFe_{12}O_{19}$	-11.28	-10.65	-10.43	-10.88	-11.63	-12.51	-13.20	-13.97
4	$BaFe_{12}O_{19}+\alpha\text{-}Fe_2O_3$ (Peccini's method)	-12.30	-12.20	-12.30	-12.20	-14.12	-14.12	-14.12	-14.12
5	$SrFe_{12}O_{19}$ (with dope)	-8.51	-8.09	-8.29	-8.29	-8.51	-8.70	-9.31	-9.54
6	$SrFe_{12}O_{19}$	-7.70	-7.35	-7.52	-7.52	-7.52	-8.09	-8.51	-8.75

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Радіоекрануючі властивості нанокомпозиційних SiO₂–Me^{II}Fe$_{12}$O$_{19}$ матеріалів, отриманих золь-гель методом

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Золь-гель методом отримані SiO₂ матеріали, що містять різні магнітні наповнювачі Me^{II}Fe$_{12}$O$_{19}$. З використанням панорамних вимірювачів ослаблення та панорамних вимірювачів коефіцієнта стоячої хвилі за напругою вивчене ослаблення ними електромагнітного випромінювання в діапазоні частот 8...11,5 ГГц. Оцінено внесок відбиття від поверхні матеріалу в ослаблення випромінювання. Отримані матеріали можуть бути використані в якості першого шару радіопоглиначів електромагнітного випромінювання, яке знижує рівень енергії, що відбивається.

Радиоэкранирующие свойства нанокомпозиционных SiO₂–Me^{II}Fe$_{12}$O$_{19}$ материалов, полученных золь-гель методом

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Золь-гель методом получены SiO₂ материалы, содержащие различные магнитные наполнители Me^{II}Fe$_{12}$O$_{19}$. С использованием панорамных измерителей ослабления и панорамных измерителей коэффициента стоячей волны по напряжению изучено ослабление ими электромагнитного излучения в диапазоне частот 8...11,5 ГГц. Оценен вклад, вносимый отражением от поверхности материала, в ослабление излучения. Полученные материалы могут быть использованы в качестве первого слоя радиопоглотителей электромагнитного излучения, снижающего уровень отражаемой энергии.