Electromagnetic characteristics of materials based on ultrafine hexaferite powders

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Abstract. The electromagnetic characteristics of composite materials based on nanosized powders of W-type hexaferites are considered in the article. It is shown that not only the composition, but also the mechanical treatment affects the electromagnetic parameters. This article presents the frequency dependence of the complex magnetic and dielectric permittivity of a system of W-type hexaferites. The studies were carried out on a universal wide-band measuring complex based on the Agilent PNA-X N4257A Vector Network Analyzer. The results are presented in the frequency range from 2 to 14 GHz.

1. Introduction

The problem of developing magnetic radio-absorbing materials remains relevant at present time due to the expansion of the areas of their application, in particular, the active introduction of microwave radiation into household appliances, navigation systems, communications and computing [1-3]. A new impetus in the development of radio-absorbing materials is caused by a surge of interest among scientists and development engineers in nanosized powders of hexaferites, the static properties of which are fundamentally different from the bulk material [4]. The relevance of the problem is confirmed by numerous conferences, seminars and symposia held by different countries and the growing flow of scientific publications in various journals on this topic.

Materials operating in a wide frequency range are required for radio-absorbing coatings, and coatings made of these materials must have: low thickness, low weight, good radio-absorbing properties, and negligible reflection of electromagnetic radiation. The electromagnetic compatibility of individual units of high-frequency radio electronics is ensured by the use of radio-absorbing materials, the effectiveness of modern communication means is increased, and the protection of users from the harmful effects of the microwave range is formed. Coatings based on magnetodielectric materials, which can be made in the form of solid samples or serve as fillers for elastomers, work most effectively on a metal surface with high electrical conductivity, where the antinode of the magnetic field is located.

Ferrites of various compositions, powders of iron and nickel carbonyls are used as magnetic materials. Ferrites with a hexagonal crystal structure (hexaferites) compare favorably with materials that have high dispersion frequencies determined by the resonance of domain walls and natural
ferromagnetic resonance (NFMR). A significant increase in the imaginary component characterizing the loss of electromagnetic radiation in matter is observed in these regions, along with a rather sharp decrease in the value of the real component of the complex magnetic permeability $\mu^* = \mu' - i\mu''$.

The system of W-type hexaferrites was selected as a specific object of research. This system is interesting as a model material for studying a fundamental phenomenon in magnetically ordered structures - a spin-orientation phase transition [5].

Hexaferrite powders were obtained using the following technology. Massive pieces of ceramic were ground in a mortar (initial powder). After that, mechanical activation was carried out in a planetary mill at a factor of energy intensity of 15g, which corresponds to a soft processing mode (in this case, the ratio of grinding balls to a sample by weight is 5:1). The static characteristics (specific and remanent magnetization, the magnitude of the anisotropy field) of the synthesized nanosized materials are given in Table 1. The measurements were carried out according to the methods described in [6].

The resulting nanosized powder was compacted into a calibrated thin-walled quartz tube with a known volume to determine the complex values of the magnetic permittivity. The studies were carried out on a universal wide-band measuring complex based on the Agilent PNA-X N4257A Vector Network Analyzer. The resonators were used as a measuring cell. They are built from waveguide elements of standard measuring lines, which are manufactured with great care at the factory. The block diagram of the measuring setup is shown in Figure 1.

Table 1. Specific and residual magnetization, dependence of the magnitude of the anisotropy field on the time of mechanical activation

| Processing time, s | Specific magnetization $\sigma$, Gs$\cdot$cm$^3$/g | Residual magnetization, $(B_r/B_s)\times 10^2$ | Anisotropy field $H_a$, Gs |
|-------------------|-----------------------------|-------------------------------|----------------------|
| 0                 | 73.00                       | 26                            | 1000                 |
| 30                | 69.25                       | 9.76                          | 1300                 |
| 60                | 63.82                       | 12.9                          | 1555                 |

Figure 1. Block diagram of an experimental setup based on the Agilent PNA-X N4257A Vector Network Analyzer
2. Results and discussion

The main idea of the resonator method is to observe the resonance curve of the measuring cell into which the sample under study is introduced. The shift of the resonance frequency and the growth of the line width, which can be used to calculate, occurs when the sample is placed in the cavity of the cavity resonator. Multimode provides a relative broadband of the resonator method, and allows one to restrict oneself to a small number of measuring cells with sufficient resolution (on 7 resonators 120 points in the range from 2 to 14 GHz). The software described in [7, 8] was used to calculate the complex values of the permittivity and permeability.

The studies carried out have shown (Figure 2, 3) that the measured values significantly depend not only on the composition of the material, but also on the time of mechanical processing of nanosized powders.

It can be seen that in the region of 6 - 7 GHz, a pronounced EFMR is observed for materials subjected to machining. The EFMR frequency for this material increases by 16% with a change in time from 30 to 60 seconds with an increase in processing time. At the same time, a decrease in the value of the imaginary component of the magnetic permeability, which is associated with a decrease in the specific magnetization, is observed. A change in the EFMR frequency is associated with a change in the magnitude of the an anisotropy field. Thus, the investigated dynamic parameters (dielectric permittivity and magnetic permeability) are in good agreement with the measured static characteristics.

As expected, no features were found at the complex dielectric constant. The main mechanisms that form the electrical properties of ferrites are electronic $\omega_{ep} \approx 10^{16}$ and ionic polarizations $\omega_{ep} \approx 10^{13}$, the critical frequencies of which lie in the region of electronic transitions and optical branches of the phonon spectrum. Therefore, a weak frequency dependence of $\varepsilon^*$ is observed in the microwave range.

The calculation of the reflection coefficient of a normally incident electromagnetic wave on a plane-parallel surface was carried out according to the data obtained. The reflection coefficient itself was calculated using the well-known formula for the case when a radio-absorbing layer of nanosized hexaferrite powder is located on an ideally conducting surface.

$$R = 20 \log \left( \frac{Z_m - Z_0}{Z_m + Z_0} \right)$$

(1)

Figure 2. Frequency dependence of the complex permeability of nanosized powders of the hexaferrite system Co$_{0.7}$Zn$_{1.3}$W
Figure 3. Frequency dependence of the complex permittivity of nanosized powders
of the hexaferrite system Co$_{0.7}$Zn$_{1.3}$W

For the case when a radio-absorbing layer of nanosized hexaferrite powder is located on an ideally
cconducting surface. In formula 1 $Z_0 = \sqrt{\mu_0/\varepsilon_0}$ – is the wave number of free space, $Z_m$ is the impedance
at the interface between free space and absorbing material, determined by the formula

$$Z_m = \sqrt{\frac{\varepsilon_0}{\mu_0} \tan h \left(2\pi f \sqrt{\mu_0 \varepsilon_0 \varepsilon d}\right)}$$

(2)

where $f$ is the frequency of the electromagnetic field, $d$ is the thickness of the material, $\mu$, $\varepsilon$ are the
complex magnetic and dielectric permittivities of the material.

Figure 4 shows the frequency dependence of the reflection coefficient for nanosized powders with
different activation times. It can be seen that the most broadband (at a level of 10 dB) is a sample with
a 30 s processing time, the operating range of which lies in the 5.5 ÷ 10.5 GHz band.
3. Conclusion

This article presents the frequency dependence of the complex permeability and complex permittivity, as well as the reflection coefficient of nanosized powders of hexaferrite of the Co(0.7)Zn(1.3)W system.

Thus, it can be seen from the results obtained that nanotechnology for the production of hexaferrites makes it possible to change their dynamic characteristics, that is, to create materials with the desired properties.

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