UDC 621.396
DOI: 10.15587/1729-4061.2017.91642

DEVELOPMENT OF RADIOISOTOPIC-PLASMA TECHNOLOGY FOR THE PROTECTION OF RADIO ELECTRONIC MEANS FROM POWERFUL ELECTROMAGNETIC RADIATION

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Запропонована радіоізотопно-плазмова технологія створення поглинаючих матеріалів для захисту радіоелектронних засобів (РЕЗ) від впливу електромагнітного випромінювання (ЕМВ). Розроблено узагальнену структуру матеріалу, проведено аналіз фізичних механізмів, що відбуваються за рахунок використання радіоізотопних та гексаферитових елементів. Одержано аналітичний вираз для коефіцієнта відбиття та розроблено методику визначення діелектричної проникності матеріалу, виконані оцінки його захисних властивостей

Ключові слова: потужне електромагнітне випромінювання, радіоізотопно-плазмова технологія, коефіцієнт відбиття, діелектрична проникність

Предложена радиоизотопно-плазменная технология создания поглощающих материалов для защиты радиоэлектронных средств (РЭС) от воздействия электромагнитного излучения (ЭМИ). Разработана обобщенная структура материала, проведен анализ физических механизмов, возникающих за счет использования радиоизотопных включений. Получено аналитическое выражение для коэффициента отражения и разработана методика определения диэлектрической проницаемости материала, выполнены оценки его защитных свойств

Ключевые слова: мощное электромагнитное излучение, радиоизотопно-плазменная технология, коэффициент отражения, диэлектрическая проницаемость

1. Introduction

Design and development of telecommunication systems, improvement in radiolocation systems, in the systems for satellite communication are accompanied by the creation and application of generators of powerful electromagnetic radiation (EMR). Generators of powerful pulse radiation with nanosecond duration are actively being developed at present. They include linear induction electron accelerators, relativistic ultra-high frequency (UHF) generators with the virtual cathode, relativistic magnetrons, Cherenkov generators and generators of diffraction emission. These generators are characterized by significant peak power (units to tens gigawatts). When REM enter the zone of action of such generators, there may occur both the disturbance in the process of receiving information and the disturbance in their functional integrity [1]. The provision of reliable operation of radio-electronic means (REM) under conditions of powerful pulse EMR impacts necessitates the application of appropriate means of protection [2, 3].

To protect REM from EMR, the groundings, shielding dischargers, hybrid filters, transformers and chokes, disconnecting switches and other electromechanical protecting devices can be used. Shielding dischargers have a long response time; disconnecting switches are characterized by the large inertia. The application of filters, transformers and chokes is connected to the need for power removal, and of all of the above-mentioned devices without exception – to low stability to the effect of EMR energy [1]. Thus, these instruments, based on the reflection (removal) of EMR energy, do not provide for the total reflection (removal) of energy. There are also approaches to the creation of protection based on grouping, zoning and subsequent distribution of special REM by stability.

Screening has become the commonest means for the purpose of REM protection. However, the provision of effective screening is connected both to the complexity of fabricating the screens without heterogeneities and design defects and to the selection of materials, which would enable significant electrical and magnetic losses [4, 5]. Thus, a general problem is in the absence of contemporary efficient means of protection, which provide for reliable operation of REM under conditions of powerful pulse EMR impacts. Solving this problem is possible by using the means of REM protection from EMR based on the radioisotopic-plasma technologies. For this purpose, it is proposed to use radioisotopic elements at the surface and inside the matrix of semiconducting coating. These elements will provide for a considerable increase in the absorption of EMR due to the occurrence of non-equilibrium state of the electronic subsystem of solid-state plasma. Furthermore, they will lower the level of reflected energy of falling EMR due to the alignment of free space with characteristics of the absorbing medium itself. These technologies can also be used for the protection of REM along basic channels of reception due to the creation of preliminary ionization in the waveguide input circuits.

As is true for any absorbing screens, it is relevant in the application of radioisotopic-plasma technologies as the shielding ones to conduct an assessment of absorbing and reflecting properties of materials, which implement these technologies.

In addition, further development of generating systems, as well as a growing threat of electromagnetic terrorism, specifically emphasizes the relevance of research into the field of devising effective technologies for the REM protection from powerful electromagnetic radiation.

2. Literature review and problem statement

A significant number of publications is devoted to the questions of development of effective technologies and means of REM protection from the impact of powerful electromagnetic radiation in UHF and EHF ranges. Thus, article [2] presents results of creating the multilayer structure of material based on the absorbing films of hydrogenated carbon with ferromagnetic nanoparticles. There was created a number of designs, which ensure the absorption of EMR larger than 10 dB in the range of frequencies 8–80 GHz; the results are demonstrated of exploring dynamic characteristics of polymeric composition radiomaterials based on multiwall carbonic nanotubes and nano-dimensional powders of ferrites with hexagonal structure. A possibility is shown of obtaining the magnitude of magnetic permeability of examined samples at a certain weight concentration of ferrite powders in frequency range from 3 to 13 GHz, close to air medium. Paper [4] proposed an approach to the evaluation of influence of structural heterogeneities of electromagnetic screen on its shielding properties. In article [5], studies are conducted of composite materials based on hexaferrite and barium aluminates. It is shown that the given composite materials provide for an effective protection of biological and technical objects from EMR in the range of frequencies 70–90 GHz, weakening it on average to 30 dB. Paper [6] presents data that characterize a development of the scientific direction, connected to examining the interaction between EMR and a substance. Characteristics of absorbing materials that are promising for applying in the economy are examined. Article [7] represents results of investigating frequency dependences of the dielectric and magnetic permittivities of composition radiomaterials, which are the mixture of nano-dimensional powders of ferroelectrics and ferrites. The measurements were carried out by the resonator method at frequencies 3–13 GHz. It is demonstrated that it is possible to change electromagnetic characteristics by the addition of ferroelectric to the ferrimagnetic material.

Paper [8] demonstrates a possibility of changing electromagnetic characteristics of composition radiomaterials by adding ferroelectric to the ferromagnetic material. Article [9] proposed wide-band absorbing coatings based on the carbon films with ferromagnetic nanoparticles, which anable the absorption of EMR larger than 10 dB in the range of frequencies 8–80 GHz. Work [10] examined the possibility of designing effective wide-band radio-absorbing coatings using active media for which, as a result of existence of an external energy source, the Kramers-Kronig relations are not valid. It was noted that such coatings did not comply with the inequality, which restricts the broadbandness of passive radio-absorbers. It is shown that the examined two-layered circuit may serve as effective radio-absorber, which exceeds passive coatings by its characteristics, but preserves stability to self-excitation at that. Simple technical realization is proposed for the examined active radioabsorbing coating RAC. Article [11] investigated the application of metamaterials for creating new types of the radioabsorbing materials. There was developed a radioabsorbing material with low value of the reflection coefficient over a wide range of incidence angles of electromagnetic wave for both polarizations of the wave based on metamaterial with negative values of dielectric and magnetic permittivities.

At the same time, despite a wide spectrum of conducted studies into the field of creating effective protective materials, the application of radioisotopic-plasma technologies in terms of designing the means for REM protection from the impact of powerful pulse EMR is not being examined. Known approaches to the development of radioabsorbing coating RAC, techniques for the estimation of their effectiveness, analytical relationships cannot be directly used for exploring the properties of materials with the application of radioisotopic-plasma technologies. This is linked to the occurrence of new physical mechanisms due to the application of radioisotopic elements and, accordingly, to a change in the electrophysical and electrodynamic properties of protective material.

3. The aim and tasks of the study

The aim of present work is the assessment of the absorbing and scattering properties of materials based on the application of radioisotopic-plasma technologies for the protection of REM from the impact of powerful pulse EMR.

To achieve the set aim, the following specific tasks are to be solved:

– to develop the structure of absorbing material and to define physical mechanisms, which occur in the semiconducting matrix under the action of radioisotopic elements;

– to establish an interrelation between the reflecting properties of absorbing material and the structure and basic electrophysical parameters of the structural elements;

– to devise a procedure and to assess absorbing properties of the material whose creation involved the application of radioisotopic-plasma technology.

4. Designing the structure of absorbing material and defining physical mechanisms that occur in the semiconducting matrix under the action of radioisotopic elements

The realization of radioisotopic-plasma technology is possible based on putting the radioisotopic elements at the surface and introducing them into the semiconducting matrix, which consists of semiconducting layers different in thickness. It is proposed to use clean sources of alpha (α)-particles as the radioisotopic inclusions, for example, polonium – 210 (Po – 210).

A schematic structure of the absorbing material is shown in Fig. 1.

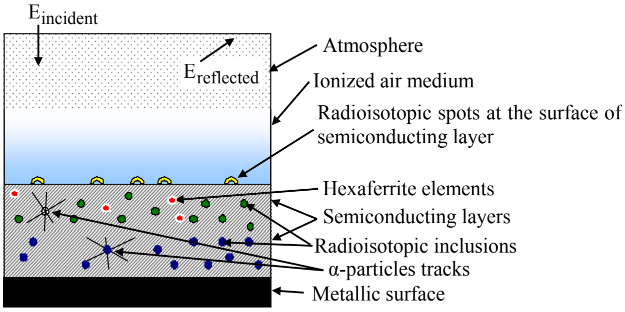

Fig. 1. Schematic structure of the absorbing material

In a general case, absorbing material is a multilayer structure, which contains one ionized air layer and several semiconducting layers with radioisotopic elements different in activity (Fig. 1).

In accordance with the structure of absorbing material, represented in Fig. 1, the incident electromagnetic wave (EMW) meets the ionized air layer first along its way. Ionization occurs both due to the radioactive spots, applied at the surface of the semiconducting matrix, and due to the α-particles departing from it, caused by radioisotopic elements. These sources of ionization through smooth decrease in the concentration of charged particles lead to the creation of a self-consistent part in the absorbing material. In addition, the radioactive elements applied at the surface of semiconducting matrix lead to the occurrence of non-equilibrium state of the electronic subsystem of air medium.

A number of semiconducting layers is defined by both the requirements to the reflecting properties of absorbing material and by the requirements to its mass-and-size characteristics. The application of radioisotopic elements with the activity, different in magnitude, will provide for the expansion of frequency range of absorbing material.

The non-equilibrium distribution of electronic subsystem of the solid-state part of material will lead to the occurrence of an imaginary part of dielectric permittivity. An increase in the tangent of angle of electrical losses will be ensured as a result. Furthermore, the use of hexaferrites in the semiconducting matrix will provide for an increase in magnetic losses.

Thus, absorbing material as a result of applying α-radioactive and hexaferrite elements will become a medium, which simultaneously realizes properties of the known plane-layered, gradient and geometrically heterogeneous radioabsorbing materials (RAM).

5. Determining an interrelation between the reflecting properties of absorbing material and the structure and basic electrophysical parameters of the structural elements

A basic characteristic of any RAM is its reflection coefficient R(λ, θ). Based on this, in accordance with the structure of material proposed above, let us examine the passage of plane wave through it and determine R(λ, θ).

We shall explore a material that has one semiconducting layer. The structure of the material is given in Fig. 2.

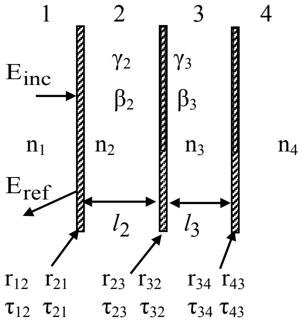

Fig. 2. Structure of absorbing material with one semiconducting layer

The bilayer structure of material occurs due to the ionized air layer (Fig. 1).

Reflection coefficient R_0 from the bilayer structure of material is possible to represent by expression:

$$R_0=\dot{r}_{14}=$$
$$=\frac{\dot{r}_{12}+(\dot{\tau}_{12}\dot{\tau}_{21}-\dot{r}_{12}\dot{r}_{21})\dot{r}_{23}e^{-\gamma_2\beta_2}e^{-\gamma_2}+(\dot{\tau}_{23}\dot{\tau}_{32}-\dot{r}_{23}\dot{r}_{32})\dot{r}_{34}e^{-\gamma_3\beta_3}e^{-\gamma_3}}{1+\dot{r}_{12}\dot{r}_{23}e^{-\gamma_2\beta_2}e^{-\gamma_2}+\dot{r}_{23}\dot{r}_{34}e^{-\gamma_3\beta_3}e^{-\gamma_3}},\quad(1)$$

where r is the coefficient of EMW reflection from the layer; τ is the coefficient of transmission; β is the phase increment of EMW between the layers; l is the thickness of layer; γ is the attenuation index of reflected emission.

Parameters that are included in expression (1) are determined by dielectric permittivity ε_i and conductivity σ_i of separate layers.

In a general case, in accordance with the generalized structure of absorbing material (Fig. 1), its dielectric permittivity can be described by the following expression:

$$\varepsilon(\omega,\vec{k})=1+\varepsilon_m+\sum_{i=1}^{N}\delta\varepsilon_{e_i}(\omega,\vec{k})+$$
$$+\sum_{j=1}^{M}\delta\varepsilon_{ne_j}(\omega,\vec{k})+i\left(\frac{4\pi}{\omega}\left(\sigma_{eff}(\omega,\vec{k})+\alpha_e E^2\right)\right),\qquad(2)$$

where ε_m is the dielectric permittivity of semiconducting layer;

$$\sum_{i=1}^{N} \delta\varepsilon_{e_i}(\omega,\vec{k})$$

is the contribution to dielectric permittivity from radioactive and hexaferrite elements themselves;

$$\sum_{j=1}^{M} \delta\varepsilon_{ne_j}(\omega,\vec{k})$$

is the contribution to dielectric permittivity from the non-equilibrium states of electronic subsystems of semiconducting layer and air medium;

$$\frac{4\pi}{\omega}\left(\sigma_{eff}(\omega,\vec{k})+\alpha_e E^2\right)$$

is the contribution to the imaginary part of dielectric permittivity from radioactive elements; α_e is the effective non-linear conductivity; E is the mean value of electric field; $\omega, \vec{k}$ is the frequency and wave vector, respectively.

In accordance with expression (2), physical mechanisms, which occur under the impact of radioactive elements in the adjacent air medium and semiconducting matrix, are determined by dielectric permittivity ε_i and by conductivity σ_i of separate layers of absorbing material. Based on this, a study of the absorbing properties of material predetermines the need for determining its dielectric permittivity.

6. Procedure for the assessment of absorbing properties of material with the application of the radioisotopic-plasma technologies

Dielectric permittivity of a substance, which determines the behavior of medium (of material) in the external electromagnetic field, is a function of distribution of electrons:

$$\varepsilon^l(\omega,\vec{k}) = 1+\delta\varepsilon^l, \quad \delta\varepsilon^l = \frac{4\pi e^2}{k^2}\int d\vec{v}\,\frac{1}{\omega-\vec{k}\vec{v}}\,\vec{k}\,\frac{\partial f}{\partial \vec{v}}, \tag{3}$$

$$\varepsilon^t(\omega,\vec{k}) = 1+\delta\varepsilon^t, \quad \delta\varepsilon^t = \frac{4\pi e^2}{k^2\omega}\int d\vec{v}\,\frac{\left[\vec{k}[\vec{v}\vec{k}]\right]}{\omega-\vec{k}\vec{v}}\,\frac{\partial f}{\partial \vec{v}}. \tag{4}$$

Upon conducting integration in (3) over angles and making use of the fact that

$$\lim_{v\to 0}\frac{1}{x+iv} = P\frac{1}{x} - i\pi\delta(x)$$

(symbol P means that, at integration, special feature in point x=0 should be understood in the sense of principal value [7]), we shall obtain:

$$\mathrm{Re}\ \delta\varepsilon = \frac{16\pi^2 e^2}{k^2}\int dv\,\frac{v^2 f(v)}{(\omega/k)^2 - v^2},$$

$$\mathrm{Im}\ \delta\varepsilon = \frac{8\pi^3 m^2 e^2}{\omega^2}\left(\frac{\omega}{k}\right)^3 f\left(\frac{\omega}{k}\right). \tag{5}$$

When examining the non-equilibrium states of electrons in a solid-state part of the material, one must take into account that the electrons, while scattered on electrons and ions, interact not only between themselves, but also with the natural fluctuations of medium. Therefore, when exploring the relaxation of electrons at high energies, it is necessary to use the nonlinear kinetic equation, recorded in the form of the law of conservation of the number of particles:

$$\frac{\partial f(p,t)}{\partial t} + \mathrm{div}(\vec{\Pi}) = \psi(p, f(p,t)), \tag{6}$$

with collision integral in the Lenard-Balesku form:

$$I_{st} = -\mathrm{div}(\vec{\Pi}), \quad \Pi_i = D_{ij}\frac{\partial f(p,t)}{\partial p_j} + F_i f(p,t), \tag{7}$$

and sources and sinks of particles $\psi(p,f)$.

Components of the vector of particle flux Π_i in the phase space are determined through the tensor of diffusion in phase space D_{ij} and frictional force F_i. These magnitudes are defined by both the function of particle distribution and by the dispersion properties of medium.

For a function of particle distribution with the exponential asymptotic behavior of the form:

$$f = AE^{-S} = A(2m)^{-S}p^{2S},$$

expression for dielectric permittivity of the medium can be represented as follows:

$$\varepsilon(\omega,k) = 1 - \frac{16\pi^2 m^2 A e^2}{\omega^2}\left|\frac{\omega m}{k}\right|^S \left(\frac{\omega}{k}\right)^3 \alpha(S) +$$
$$+ i\frac{8\pi^3 m^2 A e^2}{\omega^2}\left|\frac{\omega m}{k}\right|^S \left(\frac{\omega}{k}\right)^3, \tag{8}$$

where

$$\alpha(S) = \int_0^\infty \frac{\xi^{S+2}}{1-\xi^2}\,d\xi.$$

Omitting intermediate transforms, let us write down expression for the collision integral:

$$I_{st} = \frac{16\pi A^2 e^4 k_{max}^4}{\omega_p^4 m} E^{2(S+1)} \frac{(4S+7)(4S+9)}{(S+1)(2S+9)(2S+7)}. \tag{9}$$

Two solutions follow from the obtained relationship: $S=-9/4$ and $S=-7/4$.

The solution $S=-7/4$ corresponds to the constancy of particle flux in the phase space. The second solution corresponds to the constancy of energy flow in the phase space.

In the case of a two-component nature of the function of electrons distribution in the solid-state plasma, substantial changes in the dispersion of plasma oscillations may occur; in this case, dielectric permittivity can be represented by the following relationship:

$$\varepsilon(\omega,k) = 1 - \left(\omega_p/\omega\right)^2 + \left(k_{ds}/k\right)^2 + i\left(\nu_{eff}/\omega\right), \tag{10}$$

where $k_{ds} = \omega_{ps}/V_i$ is the Debye wavevector (a magnitude, inverse to the square of Debye radius); ω_{ps} is the frequency of acoustic plasma oscillations; V_i is the speed of electronic sound; ν_{eff} is the magnitude of effective attenuation.

A dispersion of the longitudinal oscillations in the domain of small wave numbers in this case proves to be equal to:

$$\omega^2 = \frac{\omega_p^2}{1+\left(\omega_{ps}/kV_i\right)^2} = \frac{\omega_p^2}{1+k_{ds}/k}, \tag{11}$$

and has acoustic (linear form) form:

$$\omega = c_s k_{ds},$$

where $c_s = \sqrt{n/n_s}\,v_i$ at $k << \omega_{ps}/v_i$, n is the equilibrium concentration of electrons of solid-state plasma; n_s is the non-equilibrium concentration of electrons of solid-state plasma.

Debye radius r_d is connected to the function of electrons distribution by relationship:

$$r_d = \left|\frac{4\pi e^2}{m}\int\left(\vec{k}\frac{\partial f(v,t)}{\partial \vec{v}}\right)\frac{d\vec{v}}{\vec{k}\vec{v}}\right|^{-\frac{1}{2}}. \tag{12}$$

Hence, we shall obtain expression for r_d in the semiconducting layer of material with the non-equilibrium state of electrons with power distribution:

$$k_{dq}^2 = r_d^{-2} =$$

$$= \left|\frac{4\pi m v^3}{3T}\left(\frac{T}{E_F(q-1)+T}\right)^{\frac{q}{q-1}} {}_2F_1\left[\frac{3}{2},\frac{q}{q-1},\frac{5}{2},\frac{m(q-1)v^2}{2E_F(q-1)-2T}\right]\right|. \tag{13}$$

The Debye wavevector may be expressed through the values of equilibrium and non-equilibrium concentration of electrons in the solid-state plasma:

$$k_{dq} = k_{d0}\sqrt{\frac{n_s}{n}\left|\frac{(s(q)+3)s(q)}{s(q)+1}\left(x_1/x_2\right)^{s(q)}x_1\right|},$$

where $x_1 = v_1/v_i$; $x_2 = v_2/v_i$; $s(q) = 1/(1+q)$; v_1 and v_2 are the velocities of electrons, which limit the interval of power function of electrons distribution.

In accordance with the value of power of the non-equilibrium function of electrons distribution, obtained earlier (s=–7/4), let us determine the Debye wavevector:

$$k_{dq} = k_{d0}\frac{v_1}{v_T}\sqrt{\frac{36}{35}\frac{n_q}{n}\left(\frac{v_1}{v_2}\right)^{3/7}} = \omega_p\sqrt{\frac{36}{35}\frac{n_q}{n}\frac{v_1}{v_i v_T}\left(\frac{v_1}{v_2}\right)^{3/7}}.$$

Dispersion dependence for the function of electrons distribution with the power of S=–7/4 at source intensity 70 mkKu/cm^2 is shown in Fig. 3.

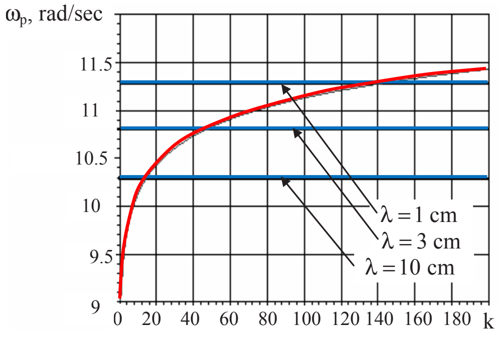

Fig. 3. Dispersion dependence for the non-equilibrium function of electrons distribution in InP at temperature 685 K and intensity 70 mkKu/cm^2

Numerical calculations of dispersion dependence demonstrate that in the semiconducting layer of material EMW with frequency larger than 3 GHz can propagate and attenuate, up to the plasma frequency of semiconductor. The calculations are performed for semiconductor of the group AIIIBV – indium phosphate (InP), which has plasma frequency of 740 GHz. Attenuation of oscillations with wavevector $k = 2\pi/\lambda$ in the semiconducting layer can be determined by formula:

$$\frac{\gamma}{\omega} = 0.5\sqrt{\frac{\pi}{2}}\frac{1}{\left(k/k_{dq}\right)^3}\exp\left(-\frac{3}{4}\left(k_{dq}/k\right)^2\right). \tag{14}$$

Results of calculating the dependence of EMW attenuation intensity on the wavelength are represented in Fig. 4.

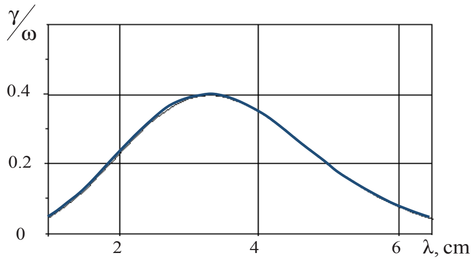

Fig. 4. Graph of dependence of electromagnetic radiation attenuation on the wavelength at source intensity 70 mkKu/cm^2

For parameters that determine functional state of the semiconducting layer: $c_q = 2\cdot10^8$ cm/s (for energy 5 eV): $\omega_p = 10^{10}-10^{11}$ 1/s; λ=3 mm – 10 cm; $v_2 = 4\cdot10^8$ cm/s, we shall obtain $\gamma/\omega = (1000...2000)n_s/n$.

Thus, magnitude γ/ω, included in the expression for evaluating the EMW attenuation factor in the semiconducting layer of absorbing material, is determined by numerical value of ratio n_q/n.

Attenuation factor can be determined in accordance with expression:

$$K_a = 10\lg\left(\exp\left[-2\frac{\gamma l}{\omega\lambda}\right]\right). \tag{15}$$

For the intensity of radioisotopic source 70 mkKu/cm^2, thickness of the semiconductor layer of material l=0.1 cm in the centimeter waveband (CM WB) and l=0.01 cm in the millimeter waveband (MM WB), for the provision of radiation safety, the n_q/n magnitude is 3.5. As a result, in accordance with formula (14), we shall obtain value of ratio $\gamma/\omega = 3500$. Under these conditions, due to the non-equilibrium properties of semiconducting layer, the EMW attenuation factor in the frequency range from 3 to 100 GHz may reach magnitudes on order of 70 dB.

Mathematical modeling of scattering of flat EMW on the ground-based objects was conducted using two types of material:

– single-layer absorbing material without ionization of the adjacent air medium with the following parameters: thickness – 1 mm, dielectric and magnetic permittivity – $\varepsilon = 12.8 + j12$, $\mu = 2.6 + j0.5$;

– bilayer absorbing material with the additional ionization of air medium adjacent to the material with parameters

$\varepsilon = 1 + j0.5$, $\mu = 2.6 + j0.5$; parameters of the semiconducting layer correspond to parameters of the single-layer material.

Chernozem with dielectric permittivity $\varepsilon = 7 + j0.1$ was used as the underlying surface. Calculation of effective scattering surface (ESS) was performed in the range of azimuthal angles from 0 to 180° with step in 1°. Frequency of the probing signals is 37.5 GHz. Polarization of the probing signal is vertical. When probing in the plane of the earth, the angle of elevation was selected equal to 0.5°.

Results of calculating the dependence of object's ESS with a single-layer material at frequency 37.5 GHz are shown in Fig. 5. Results of calculating the object's ESS with the use of bilayer material with the ionization of air medium, adjacent to it, are shown in Fig. 6. Bold lines in the graphs (Fig. 5, 6) indicate ESS of the object with a coating; thin lines correspond to ESS of the ideally conducting model of the object.

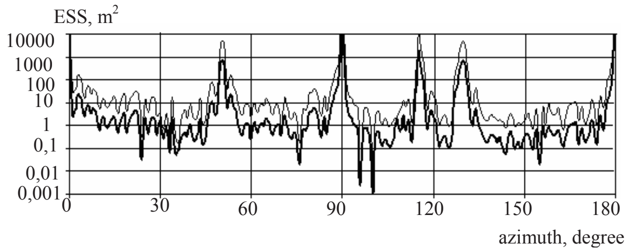

Fig. 5. ESS of the object at frequency 37.5 GHz at the elevation angle of 0.5° (single-layer material)

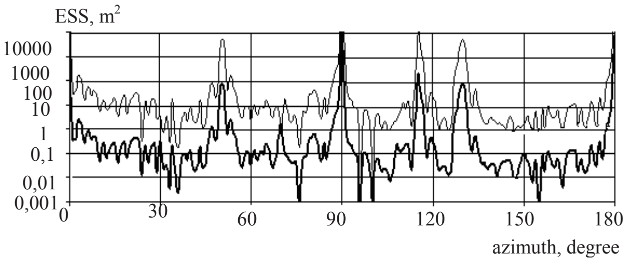

Fig. 6. ESS of the object at frequency 37.5 GHz at the elevation angle of 0.5° (bilayer material with the ionization of air medium)

Results of calculating the object's ESS at frequency 94 GHz are practically no different from the calculations at frequency 37.5 GHz; which is why they are omitted from the present article. An analysis of the obtained results of calculating the object's ESS at frequency 37.5 GHz and 94 GHz reveals:

a) the application of a single-layer material within a wide range of change in the angles of probing (along the azimuth from 0 to 180°) makes it possible to decrease the object's ESS practically by more than an order in MM BW at the thickness of coating 1 mm;

b) a bilayer material makes it possible to provide for a reduction in the object's ESS within a wide range of change in the angles of probing (along the azimuth from 0° to 180°) practically by more than two orders in MM BW at the thickness of coating 1 mm.

7. Discussion of results of the assessment of protective materials effectiveness based on the radioisotopic-plasma technology

Theoretical assessments of the EMW attenuation factor testify to the possibility in principle of applying the proposed technologies for creating the means of RES protection from the impact of EMR over a wide frequency range. The calculations performed indicate the possibility of expanding frequency range at the high level of scattering and absorption of EMR, on one hand, due to increasing the number of layers of the semiconducting matrix, and, on the other hand, by changing the intensity of radioisotopic source. In addition, an increase in the scattering and absorption of EMW can be provided by increasing the thickness of semiconducting layers. In other words, by selecting the magnitude of intensity of radioisotopic source, as well by changing the number of layers in the semiconducting matrix, it is possible to control the frequency, absorbing and scattering properties of material. The prospect of the proposed technology is, in addition, in the possibility of its application at aerial vehicles in view of the small weight-dimension characteristics of material.

8. Conclusions

1. Under the action of radioisotopic elements, in the absorbing material, which realizes radioisotopic-plasma technology, there occurs the structure of material, which includes in its composition the ionized air layer and the semiconducting matrix with the non-equilibrium state of electronic subsystem of each of the layers. The non-equilibrium distribution of electronic subsystem of the material leads to the occurrence of an imaginary part of dielectric permittivity.

2. It is demonstrated that the reflecting properties of material are determined by the comprehensive dielectric permittivity of each of the layers, defined by the physical mechanisms that occur under the impact of radioisotopic elements.

3. We devised a procedure and conducted assessment of absorbing properties of the material, which realizes the radioisotopic-plasma technology. The procedure includes:

– determining the non-equilibrium function of distribution of electron subsystem of the semiconducting layer based on the solution for the modified kinetic equation with collision integral in the Lenard-Balesku form;

– determining a dispersion dependence taking into account the non-equilibrium distribution function;

– determining a possibility of the propagation and attenuation of EMW in a semiconductor with the non-equilibrium state of electronic subsystem taking into account the possibility of occurrence of plasma oscillations dispersion;

– quantitative assessment of the EMW attenuation factor in the semiconducting layer of absorbing material. For the obtained value of power in the non-equilibrium function of electrons distribution ($S=-7/4$), the EMW attenuation factor over the range of frequencies from 3 to 100 GHz may reach 70 dB.

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