Ministry of Education of the Republic of Belarus

Educational institution
“Belarusian State University of
Informatics and Radioelectronics”

UDC:004.932

THESIS

Design and Optimization of multilayer Electromagnetic screen based on dielectric materials with different dielectric constants

For the degree of Master of Technical Sciences
Specialty 1-98 80 01 Methods and systems of protection, information security

Chief of Security Department

________________ T.V. Barbotka

Master Student

__________Ali Ibrahim Lawah

Supervisor

_______________I.A. Vrublevsky

Minsk 2019

INTRODUCTION

The most effective, durable, environmentally friendly and harmless to users is the use of passive means of protecting information from leakage through technical channels, namely, shielding electromagnetic radiation, creating shielding systems for premises in which information is processed, and shielding systems for technical means of information processing and their components. The ambiguity and complexity of tasks that exist in the field of information security require the use of multifunctional quality shielded volumes and structures, the creation of which is possible only with the use of highly efficient shielding materials.

One of the promising areas is the creation of electromagnetic radiation screens based on layers of porous anodic alumina with embedded carbon-containing compounds. On the one hand, anodic aluminum oxide is a dielectric, which has a porous microstructure with controlled parameters, and on the other hand, samples obtained in organic acids can contain amorphous carbon, which serves as an active phase to reduce the reflection coefficient of electromagnetic radiation. (EMR). For effective shielding EMR and creation of shielding systems for information processing equipment based on porous anodic alumina, it is necessary to establish interaction patterns EMR with such inhomogeneous dielectric and multilayer screens based on it.

GENERAL CHARACTERISTICS OF WORK

The purpose of this work is to study the effectiveness of new designs of screens. EMR based on aluminum and aluminum oxide of porous type, the study of the reflection coefficient and attenuation of electromagnetic radiation and the development of recommendations for its use for information protection systems on widescreen panels of electromagnetic screens. To achieve this goal it was necessary to solve the following tasks.

Study the possibility of using as a material for shielding aluminum oxide of the porous type:

Investigate the characteristics of reflection and attenuation EMR in non-uniform dielectric structures based on aluminum oxide;

– Analyze the state of research and use of screens EMR based on multilayer, composite and porous dielectric materials.

– Computer simulation methods and experimental studies to determine the shielding characteristics of multilayer materials based on porous aluminum oxide.

– To investigate the influence of structural elements of screens based on dielectric structures with aluminum oxide on the shielding characteristics and to develop the design of a multilayer screen based on heterogeneous dielectric structures.

The thesis presents the results of experimental studies performed by the author personally and in co-authorship. The definition of the structure, goals and objectives of the work, discussion and synthesis of the main scientific results of the study were conducted jointly with the supervisor I.A.Vrublevsky (Candidate of Technical Sciences). The materials included in the thesis were reported and discussed at XX International Scientific and Technical Conference «Modern means of communication "(Minsk, Belarus, 2019.); IX International Scientific and Practical Conference "Information Resource Management" (Minsk, Belarus, 2018).

The total volume of the master thesis is 60 pages, of which 50 pages are the main text, 33 figures on 10 pages, a bibliography from 20 sources, including 2 own publications of the another on 2 pages.

MAIN PART

In the introduction and in the general description of the work, the main directions of research are determined, the relevance of the thesis topic is substantiated, the purpose and objectives of the work are stated, the main provisions for the defense are set forth, and the need for research in this area is shown.

The first chapter describes the main screen designs. EMR and the characteristics of the radio absorbing materials used to create the screens. It is shown that the screening of electromagnetic waves is one of the most effective means of protecting an object from information leakage on the electromagnetic channel and the basis of environmental safety. To create a favorable electromagnetic environment and ensure the requirements for the electromagnetic safety of an object, which includes counteracting unauthorized access to information with the use of special technical means; screens are used to shield electromagnetic waves. To modern screens EMR, The following requirements are met: high absorption of electromagnetic waves in a wide frequency range, minimal reflection, no emission of harmful substances, incombustibility, small dimensions and weight.

The second chapter substantiates the use of aluminum oxide and aluminum in the construction of electromagnetic shields. A technique has been proposed and developed for producing films of porous anodic alumina with embedded carbon-containing compounds for creating screens of electromagnetic radiation. For the formation of a porous anode Al_2O_3 with embedded carbon-containing compounds (amorphous carbon in the form of bulk polymer carbon structures), the method of electrochemical oxidation of aluminum in a 0.3 M aqueous solution of oxalic acid at a constant anodizing voltage of 60 V and in a 0.3 M aqueous solution of glycolic acid at an anodizing voltage of 180 V was used. The formation of amorphous carbon incorporated into anodic alumina was ensured by successive reactions of dissociative adsorption, dehydrogenation, decarboxylation, dehydrocyclization, and polycondensation of oxalate and glycolate ions from the electrolyte volume. Various structural changes in anodic alumina were created due to the oxidation of amorphous carbon on the surface and in the pores. Al_2O_3 in the process of annealing in the temperature range of 373 ... 1273 K with an electronic control unit B170.

The methods for producing thin films of NiCr and aluminum on Al_2O_3 for multilayer screens of electromagnetic radiation.

For measuring the shielding characteristics of the studied samples of electromagnetic radiation screens, a panoramic meter of standing wave coefficients was used (VSWR) and attenuation with the waveguide measuring path. Reflection coefficients EMR and transmissions for the experimental samples studied were determined in the frequency range of 8 ... 12 GHz.

The third chapter presents the results of theoretical and experimental studies of the characteristics of electromagnetic radiation screens based on structures with aluminum oxide. To model the characteristics of the reflection EMR multilayer screen used a special program to calculate the reflectivity of structures containing up to five layers in the environment Excel.

The reflection coefficients and transparency for the three-layer structure were calculated in the wavelength range of 2.0 ... 3.0 cm. The frequency dependences of the reflection coefficient were simulated EMR for a three-layer structure containing lithium niobate, aluminum oxide and a thin film of NiCr, depending on the thickness of lithium niobate in the frequency range of 8 ... 12 GHz.

The thickness of the lithium niobate was chosen equal to 0.7; 0.9; 1.2; 1.5 or 1.7 mm; for the optical constants, the values were n = 9.0 and k = 0.05. The thickness of the anodic aluminum oxide was set to 0.07 mm, for the optical constants, the values n = 2.82 and k = 0.05 were used. For NiCr films, the thickness is 0.0005 mm, the optical constants n = 450.0 and k = 0.5. As the results of computer simulation showed, all the frequency dependences of the reflection coefficient had a minimum of the reflection coefficient at the wavelength of half-wave resonance. With increasing thickness of lithium niobate in a multilayer screen, the position of the minimum of the reflection coefficient shifted to the low-frequency region.

Thickness effect studied Al_2O_3 on frequency dependence of the reflection coefficient of a multilayer screen on the example of two thicknesses: 70 and 140 μm. It is established that with increasing thickness Al_2O_3 the resonance minimum varied slightly from 9.2 to 9.1 GHz without changing the amplitude.

The fourth chapter is devoted to the development of designs of Electromagnetic radiation screens based on aluminum oxide and recommendations for their use. The scheme of formation of porous anodic aluminum oxide for screens is presented EMR. The sequence of operations of the developed process includes the operations of surface preparation and electrochemical polishing of the original aluminum foil A99

(Gost 11069-74, Gost 25905-83) thick 100 μm, masking chemically resistant varnish one side of aluminum foil, electrochemical anodizing of aluminum, chemical layer removal, selective chemical etching of aluminum and quality control.

The design of a multilayer screen of electromagnetic radiation comprising lithium niobate, porous anodic Al_2O_3 with a film of NiCr. It is shown that the deposition of NiCr. Films with a specific surface resistance of less than 27.4 Ohm on the surface of anodic aluminum oxide when used in the construction of a multilayer screen in the composition $LiNbO_3$ and porous Al_2O_3 leads to к redistribution of wave energy. As a result, the reflection coefficient EMR decreases with a simultaneous increase in attenuation EMR.

It is proposed to use a two-layer glass-alumina structure with a thin layer of aluminum in the construction of electromagnetic radiation screens. It is shown that the minimum value of the reflection coefficient (not more than –10 dB) in the range of 8… 12 dB had a structure when using glass with a thickness of 2 mm. For glass 1 mm and 4 mm thick, the two-layer structure showed reflection coefficients of no more than –7 dB and –3 dB respectively. Weakening EMR sample with a glass thickness of 1 mm was not less than 13dB. The frequency dependence of the reflection coefficient and attenuation for the screen EMR, containing glass, 2 mm thick and Al_2O_3, 1 mm thick with aluminum film thickness 0,5 μm.

To create shielded volumes of buildings and premises, the construction of wall panels of electromagnetic-acoustic information protection with multilayer screens using rolled anodized aluminum has been proposed.

For films of porous anodic alumina, the IR absorption spectra and the effect of a mask of porous anodic alumina on the visualization of an object with heat points on the screen of an uncooled thermal imager were studied. The use of masks of films of porous alumina dramatically reduced the passage of thermal radiation from heat sources and reduced the temperature of thermal points. It is shown that films of porous anodic aluminum oxide effectively scatter and absorb infrared radiation with a wavelength of 8 ... 14μm and can be used as a masking coating. As a result, a heated object on a thermal background loses its contrast and becomes hardly noticeable.

CONCLUSION

It was established that carbon-containing anodic alumina obtained in an electrolyte based on an aqueous solution of oxalic acid, with an ordered porous structure and perpendicular arrangement of pores relative to the sample surface, showed stability of shielding characteristics up to annealing temperatures of 550 °C. Weakening EMR anodic alumina with carbon-containing inclusions reached values –3,7…–2 dB with reflection coefficient –9…–6 dB in the frequency range of 8.0 ... 12.0 GHz.

It is show that the deposition of NiCr films with a specific surface resistance of less than 27.4 Ohm, on the surface of anodic aluminum oxide when used in the construction of a multilayer screen in the composition $LiNbO_3$ and porous Al_2O_3 leads к redistribution of wave energy. As a result, the reflection coefficient EMR decreases with a simultaneous increase in attenuation EMR. For the screen as part of lithium niobate (thickness 1.2 mm), porous anodic Al_2O_3 (thickness 70 μm) with a film of NiCr with a specific surface resistance of 12.4 Om in the frequency range 6 ... 18 GHz attenuation EMR reaches values up to 24 dB, and the reflection coefficient in the frequency range 8 ... 13 GHz is reduced to –11,5 dB.

Computer simulation of the characteristics of a multilayer screen of electromagnetic radiation in the composition of lithium niobate, aluminum oxide and NiCr film based on their optical parameters and layer thicknesses showed the possibility of determining the position of the resonant minimum for the dependence of the reflection coefficient EMR on frequency. It was revealed that by choosing the thickness of lithium niobate in the range of 0.7 ... 1.7 mm in the construction of a multilayer screen consisting of lithium niobate and aluminum oxide with a thin film of NiCr, the position of the resonance minimum for the reflection coefficient can be adjusted EMR in the frequency range 7.0 ... 13.0 GHz. It was found that the variation in the thickness of the layer of aluminum oxide, according to the results of computer simulation, does not to offset the resonant minimum of the reflection coefficient EMR for the proposed multi-layer screen.

It is propose to use a two-layer glass-alumina structure with a thin layer of aluminum in the construction of electromagnetic radiation screens. It is shown that the minimum value of the reflection coefficient (no more than –10 dB) in the range of 8 ... 12 dB had a structure when using glass with a thickness of 2 mm.

LIST OF PUBLICATIONS

1-A. **Lawah Ali Ibrahim**. Data processing and analysis of SEM-images of surface of nonporous materials by means of ImageJ software // procedures for 54 scientific conference of BSUIR students. Minsk, 23–27 April 2018, – P.54-55.

2-Using the imagej software for determining parameters of microstructure of nonporous materials by the results of sem image processing / N. V. Lushpa;**Lawah,A.I**; // BIG DATA Advanced Analytics: collection of materials of the fourth international scientific and practical conference, Minsk, Belarus, May 3 – 4, 2018 / editorial board: M. Batura [etc.]. – Minsk, BSUIR, 2018. – P. 136 – 138.

The results of studies of the microstructure parameters of nanoporous materials using the ImageJ pro- gram are presented. Pore diameter of the nanoporous anodic aluminum oxide was determined from the results of pro- cessing the SEM images of the film surface. An algorithm for processing images for determining the pore diameter in nanoporous materials was proposed. The results obtained for the nanoporous structure of the materials under investigation are in a good agreement with those available in the literature.
Key words: nanoporous materials; surface morphology; microstructure; SEM images, ImageJ.

Advances in the development of science and technology are inextricably linked with the devel- opment of new materials for various industrial applications. In the last decade in the field of science and technology, a new direction, such as nanotechnology, has been actively developed. Nanotechnol- ogies are aimed at the creation and application of nanostructured materials, the main properties of which are determined by a special structure, including ordered elements ranging in size from 1 to 100 nm. The size and structure of nanoparticles have a significant effect on the physic-chemical charac- teristics and properties of nanomaterials. Therefore, an important task is the development of special methods and techniques of research aimed at studying the structural, morphological, topological, me- chanical, electro-physical, optical, biological characteristics of nanomaterials and nanosystems, analyzing the quantities of nanoparticles and measuring nanoscale for individual elements.

One of the promising materials for use in nanotechnology is anodic aluminum oxide with a nanoscale structure. At present, the study of the properties of anodic aluminum oxide is of great in- terest because of its unique physico-chemical properties: an array of nanosized pores, a self-organized highly ordered cellular-porous structure, and the ability to control the properties of the porous struc- ture at the formation stage [1]. The special properties of the material allow the use of nanoporous anodic aluminum oxide for such purposes as molecular separation (chemical and biochemical filtra- tion), the manufacture of sensors and biosensors, the synthesis of various nanomaterials (nanodots, nanotubes, nanowires) and as memory elements with high data recording density. To expand the areas of application of anodic aluminum oxide and increase the reproducibility of the parameters of its microstructure, it is necessary to know the patterns of formation of a nanomaterial structure and to accurately control their geometric parameters [2,3].

Since the basic properties of nanoporous anodic alumina depend on the pore size, it becomes necessary to use statistical analysis methods to process large arrays of nanosized pores and develop a methodology and algorithm to study the features of morphology and nanoscale structure and auto- mate the measurement process.

For digital processing of SEM images of the nanoporous surface of anodic alumina films, the ImageJ program was used. This program includes all the necessary functions for digital image pro- cessing. For the processing and analysis of the characteristics of the nanoporous structure of anodic alumina, the following algorithm was used in the program ImageJ:

1- Convert an image into 8 bits to enhance the contrast and simplify the subsequent analysis;
2- Elimination of random noises (which appears due to surface defects and random pore bonds) using the filter function;
3-Segmentation of the image (separation of the background from important nanoscale structures) to find the threshold value (threshold) in order to fully determine the object;
4- Analysis of selected objects;

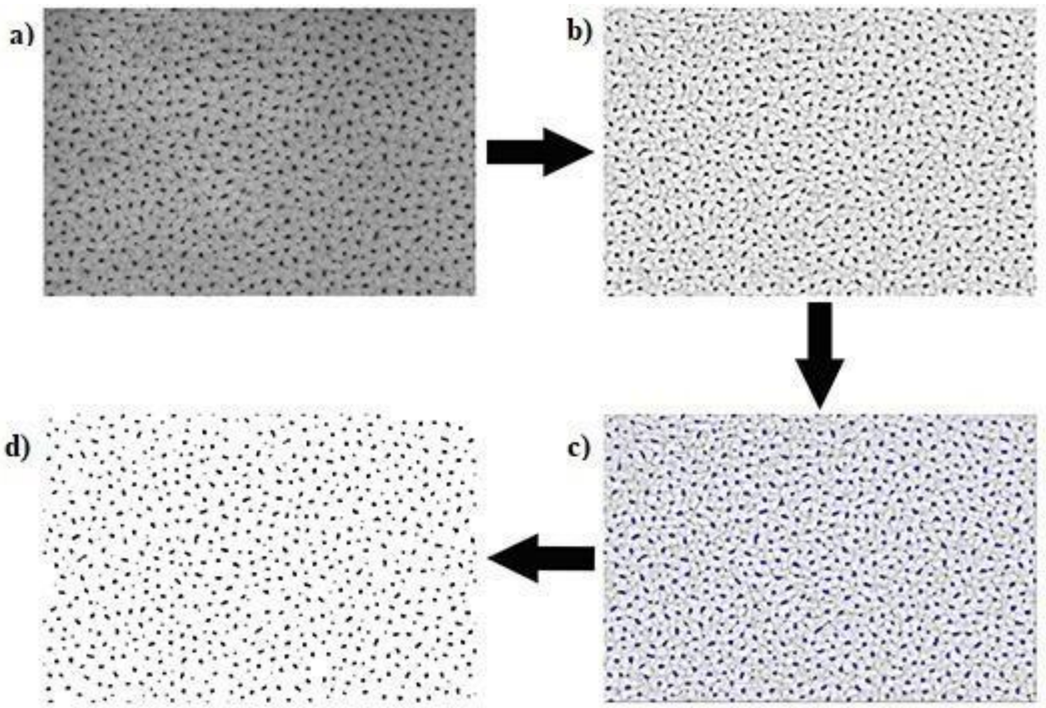

Figure 1. The processing scheme of SEM images of the nanoscale objects using ImageJ software: a) original SEM image, b) contrast enhanced image, c) thresholded image, d) final image

The ultimate task of image analysis is statistical processing of the results obtained by measuring the characteristics of a material with a porous structure, determining the average values of pore di- ameters, and also plotting graphs to visualize the analysis process. The pore diameter distribution and the mean pore diameter were calculated from the SEM images using the ImageJ image processing software.

As an object of investigation, anodic alumina films with large and small pores were used. The main pore diameter was calculated from the SEM images using the ImageJ software. Since only the data on the main pores are of practical importance, and the presence of the initial pores interferes with the analysis, some of the pores with a small diameter were not taken into account when approximat- ing. To this end, only one smaller value was left to the maximum on the pore size distribution curve.

The maximum on the Gaussian curve corresponded to dpore. To obtain correct results, the SEM images were processed at least ten times and a new time was selected each time for comparison.

To visualize the analysis process, histograms of the pore diameter distribution on the sizes using the Origin package were plotted. The algorithm used in the ImageJ program was tested using SEM images of various samples with different magnification, resolution, and pore sizes of the anodic alu- mina. Digital image processing of the nanoporous structure in the ImageJ program provided a good estimate of the pore size distributions for all the samples investigated.

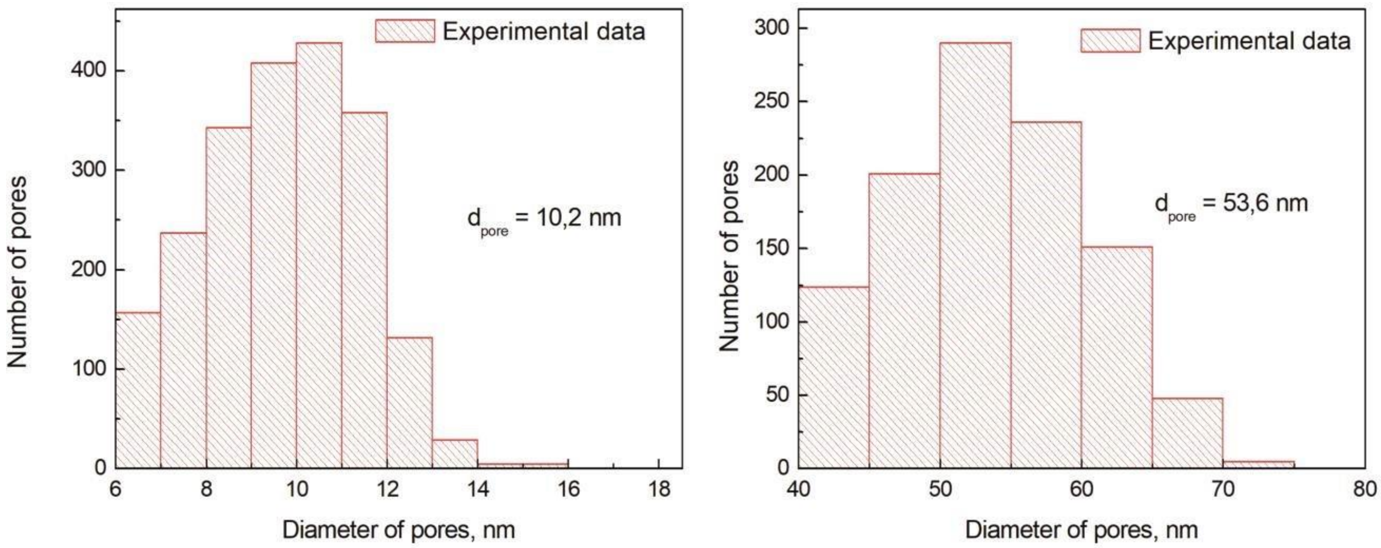

Figure 2. Histograms of the pore size distribution by the image processing results in the ImageJ pro- gram for porous anodic alumina films with small a) and large b) pore diameters

Our results shows that dpore = 10.2 nm (fig.2a) for porous alumina films obtained in sulfuric acid and dpore = 53.6 nm (fig.2b) for the anodic alumina films obtained in oxalic acid. The parameters of the structure of porous alumina films obtained in our work coincide with the data reported in [4]

The results of the studies led to the conclusion that the ImageJ image analysis program is a suitable tool for quantitative analysis of the morphology of anodic aluminum oxide films with na- noscale pores. Data processing in the ImageJ program allowed to calculate the mean pore diameter of anodic alumina films obtained under different conditions.