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RADIO ABSORBING PROPERTIES OF THIN GOLD FILMS IN 8÷11,6 GHZ BAND

The results of measurements of absorbing properties of gold films of 8–20nm thickness deposited on a polymer substrate in the frequency band 8÷11.6 GHz electromagnetic radiation are presented.

Keywords: electromagnetic radiation, radar absorbing materials, nanoscale gold films, VSWR, 3-cm wavelength range.

Introduction. Reducing the impact of electromagnetic radiation (EMR) on technical devices and biological objects, especially due to the sharp increase in the number of sources of electromagnetic radiation (communication, consumer electronics, information systems, etc.), is an important task in a wide frequency band.

The development of new, improved radar absorbing materials (RAM) is one of the main components of the task of protection from EMR (along with screening, the use of design elements, etc.).

There are resonant absorbers, which are one type of RAM [4]. They use semitransparent metal films. If such film is situated at a distance of $\lambda/4$ (λ – wavelength of electromagnetic radiation) before conductive surface which has to be protected, it is provided the conditions for optimal matching at this wavelength. When several films use, with help of modern computational methods, it is possible to optimize not only the absorption band, but and number of layers, the total thickness and weight of the RAM.

Additional studies are conducted and for studying of the absorbing properties of metal films [1–2]. These works are carried out on the assumption that the film thickness is much smaller than the thickness of the skin layer in the selected band of wavelengths. At a film thickness of 10÷100 nm, this assumption holds for the microwave range.

The results of measurement of reflection and absorption of electromagnetic waves of the gold films in the frequency band 25÷37 GHz are presented in [3]. The objective of this study was to conduct similar studies in the band of 8÷12 GHz, which significantly extends the frequency range of the use of such films.

Experimental technique. For research it is used a gold film of 8÷20 nm thickness, obtained by thermal vacuum deposition on a dielectric polymer substrate of 0.1 mm thickness. Control the thickness of the film is implemented by known method of quartz oscillator.

The samples were cut with size slightly smaller than the cross section of the waveguide so that they are easily placed in him. The sample was placed between the layers of foam as shown in Figure 1. The gold film had no galvanic contact with the walls of the waveguide.

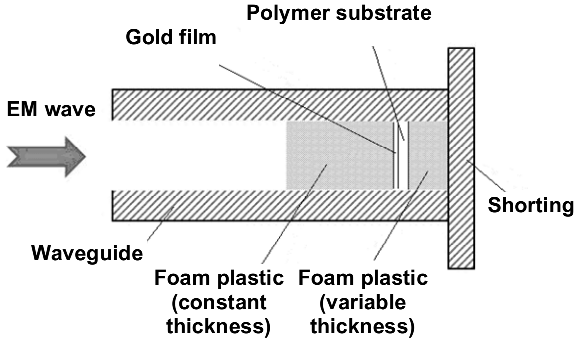

Fig. 1. The placement of the samples in a segment of the waveguide line connected to a shorting

Measurements were carried out in the frequency band 8÷11.6 GHz (3 cm wavelength range) on panoramic VSWR meter P2-65 in the section of rectangular waveguide with a cross section of 28 x 12 mm for two cases: the segment of the waveguide was joined to the shorting in the form of metal plate or to the matched load.

The 8 samples with different thickness of the gold layer on the surface were used for measurements. The samples were selected in pairs with the same thickness of gold: 8 nm, 10 nm, 15 nm, 20 nm. Measurements were performed for each sample in the pairs and compared with each other.

This technique has allowed to verify the correctness of the data by collecting and comparing statistical information and to establish the correctness of the gold film deposition (i.e. its uniformity and accuracy of thickness determination).

We used a set of foam plates with thickness of 0.25 mm, 0.5 mm, 0.85 mm, 1 mm, 1.3 mm, 1.5 mm for change of the distance between the sample and the shorting

The waveguide segment with a sample, the matched load and the shorting were joined to the measuring waveguide line at four points so as to avoid any cracks, gaps and distortions in the joints. The sample was placed between the foam plates so that it remained in horizontal position.

Experimental results. Measurements were carried out for each values of the four thickness of gold film separately. The VSWR were measured at the distances changing from the film to the shorting.

For a visual representation of the data, they were grouped by the values of the gold film thickness and the distances between the sample and the shorting in the case of measurements with the shorting and by the values of the gold film thickness in the case of measurements with matched load.

The results of VSWR measurement for the sample with the gold film thickness of 8 nm in depending on the frequency are shown in Figure 2, where show the different cases according to the distance between the sample and the shorting.

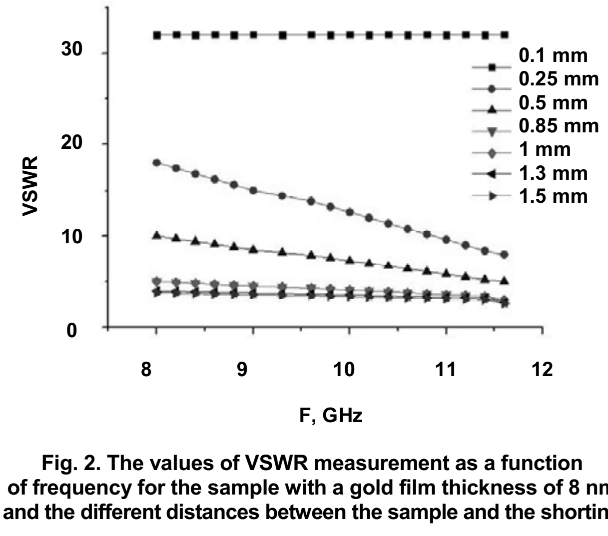

Fig. 2. The values of VSWR measurement as a function of frequency for the sample with a gold film thickness of 8 nm and the different distances between the sample and the shorting

The figure shows that the VSWR value depends on the distance between the sample and the shorting. Sharp drop of VSWR values to about 4–4.5 VSWR is noticeable with increasing distance between the shorting and the gold film.

The results of VSWR measurement for the sample with the gold film thickness of 10 nm in depending on the frequency and in the cases of the different distance between the gold film and the shorting are shown in Figure 3.

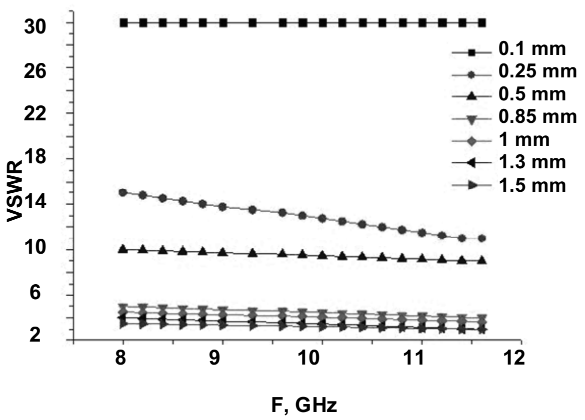

Fig. 3. The values of VSWR measurement as a function of frequency for the sample with a gold film thickness of 10 nm and the different distances between the sample and the shorting

As in the case of the 8 nm gold film we see qualitatively similar dependence of VSWR from the distance between the sample and the absorbing. It should be noted that increasing the thickness of the gold film on 2 nanometers has led to a greater drop in the value of VSWR with increasing the distance to the shorting to the level 2.5–3 that correspond of more than of 80% level of energy absorption.

The results of VSWR measurement for the sample with the gold film thickness of 15 nm in depending on the frequency and in the cases of the different distance between the gold film and the shorting are shown in Figure 4.

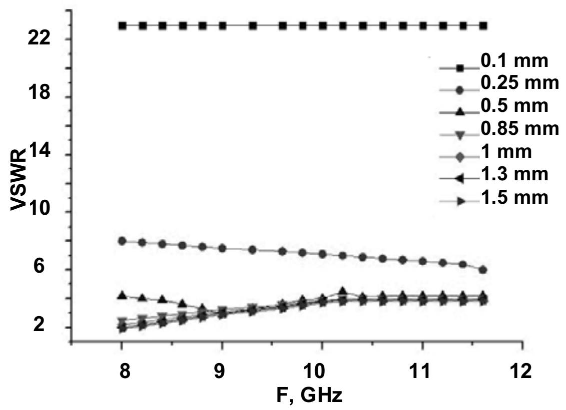

Fig. 4. The values of VSWR measurement as a function of frequency for the sample with a gold film thickness of 15 nm and the different distances between the sample and the shorting

We see that increasing the film thickness of 15 nm leads already to a gradual increase in the values of VSWR compared to the film thickness of 10 nm.

The results of VSWR measurement for the sample with the gold film thickness of 20 nm in depending on the frequency and in the cases of the different distance between the gold film and the shorting are shown in Figure 5.

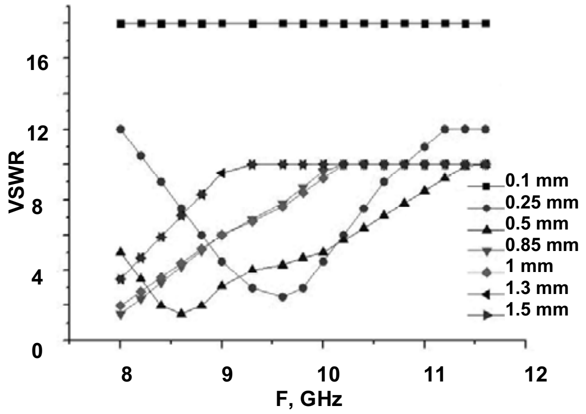

Fig. 5. The values of VSWR measurement as a function of frequency for the sample with a gold film thickness of 20 nm and the different distances between the sample and the shorting

We see that if the thickness of the gold film 20 nm value of VSWR already has significant frequency dependence. The value of VSWR is significantly higher than in cases of thickness 10÷15 nm. A similar trend was observed for measurements on duplicate sample.

The results of VSWR measurement depending on the frequency in case of connecting to the matched load for samples with different thickness of the gold film are shown in Figure 6.

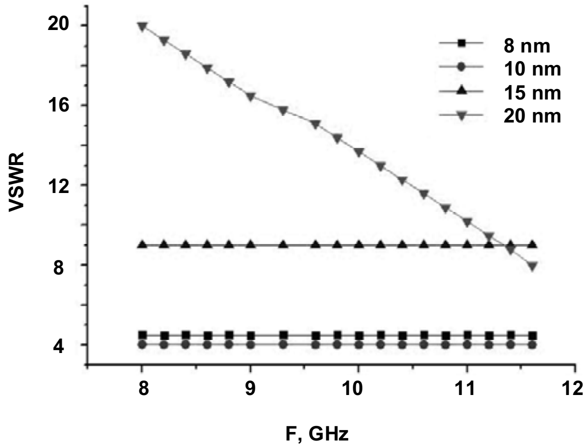

Fig. 6. The frequency dependence of VSWR for the samples with different thickness of gold film in case of connecting to the matched load

The obtained results allow clear that the optimal thickness of the gold film, for EMR absorption in 3-sm wavelength range is in the range of 8 to 15 nm.

Conclusions. The value of VSWR depends on the film thickness. The higher film thickness, the greater the reflection coefficient in the case of matched load (see Figure 6).

At a certain film thickness and the distance to a shorting the reflection is lower than in the case of a matched load. This suggests that there is an antiphase compensation reflected and incident waves, which is not resonant in nature and occurs throughout the all frequency range of measurement.

When the film thickness was 10 nm and the distance from a shorting was equal to 1.5 mm, VSWR across the all 3-cm measurement range was less than 3, which corresponds to more than 80% absorption of the incident electromagnetic radiation.

The obtained results showed high levels of absorption of electromagnetic energy by structures based on nanoscale gold films in a 3-cm wavelengths and prospects of using these structures in the design of real RAM.

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РАДІОПОГЛИНАЮЧІ ВЛАСТИВОСТІ ТОНКИХ ПЛІВОК ЗОЛОТА В ДІАПАЗОНІ ЧАСТОТ 8÷11,6 ГГЦ

Наведені результати вимірювання поглинаючих властивостей плівок золота товщиною 8–20 нм, що нанесені полімерну підкладку в смузі частот 8 ÷ 11,6 ГГц електромагнітного випромінювання.

Ключові слова: електромагнітне випромінювання, радіопоглинаючих матеріалів нанорозмірних плівок золота, КСХН, 3 сантиметровий діапазон довжин хвиль.

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РАДИОПОГЛОЩАЮЩИЕ СВОЙСТВА ТОНКИХ ПЛЕНОК ЗОЛОТА В ДИАПАЗОНЕ ЧАСТОТ 8÷11,6 ГГЦ

Приведены результаты измерения поглощающих свойсте пленок золота толщиной 8–20 нм, нанесены полимерную подложку в полосе частот 8 ÷ 11,6 ГГц электромагнитного излучения.

Ключевые слова: электромагнитное излучение, радиопоглощающие материалы наноразмерных пленок золота, КСВН, 3 сантиметровый диапазон длин волн.

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ZONED TARGET IN THE EXPERIMENTAL INVESTIGATION OF THE MAGNETRON SPUTTERING DEVICE WITH TWO EROSION ZONES

The Monte Carlo computer simulation program of the magnetron sputtering device with two erosion zones was build, in which the searching algorithm of the self-consistent starting positions of the secondary electrons on cathode was introduced. For the verification of the simulation results the zoned test target for the magnetron sputtering device was designed, which provides the measurements of the discharge current distributions along it surface. The comparison of the experimental results to the simulation demonstrates their compliance in the identical conditions.

Key words: zoned target, magnetron sputtering device, cathode sheath, computer simulation, Monte Carlo method

Introduction. Magnetron sputtering devices on direct current (hereafter – MSD) had found a wide application in the technology of coating of the conductive materials and their composites [12, 16, 17, 10]. Some of the latest investigations have shown the possibilities of carbon nanotubes synthesis by the magnetron sputter deposition method for wide sphere of technical applications [1–4].

The magnetic and electric fields in MSD are rather complicated, and this makes impossible an analytical description of the particles motion in them. The computer simulations of MSD based on the integration of particle motion equations and Monte Carlo collisions description are widely used now to predict the shape of erosion zone of the cathode-target [13, 14]. In the work [15] the Monte Carlo method was used to find the starting positions of secondary electrons at the cathode, which correspond to the steady state discharge operation mode and for indirect prediction of current-voltage characteristics of the discharge. The simple methods [13–15] were used for low working pressure (< 10 Pa) and they neglect the electric field changes in the cathode sheath, which provided by any variation of heavy particles (ions) density. This circumstance is eliminated in "particle-in-cell and Monte Carlo collision" method (PIC/MCC), in which every plasma species are presented as a limited ensemble of super-particles, and the Poisson equation is used to calculate the fully self-consistent electrical potential [8, 9]. This method requires more computer resources, but provides the most comprehensive description of the physical processes in MSD.

In the works [8, 9, 13–15] the MSD with single erosion zone of cathode-target ("race track") were investigated. The numerical model of the MSD with two erosion zones of the cathode-target (hereafter – CT), based on the Monte Carlo method, was built previously in the works [5, 6, 7] by authors. In the article [7] the searching algorithm of the self-consistent starting positions of the secondary electrons on the CT and the estimation of the cathode sheath thickness, based on the Child-Langmuir law, were presented. Modeling results in [6, 7] were compared with experimental data of sputtering of the multilayer target from the non-magnetic materials. There were obtained the dimensions of the internal and external CT erosion zones in the two characteristic opposite cases. There are the case of "low" discharge currents (≤ 15 mA), in which only the external discharge zone was able to ignite, and the case of the "high" currents (≥ 40 mA), when both discharge zones were ignited. Unfortunately, it was impossible to obtain from these measurements the absolute values of discharge current in the corresponding zone, which is important for checking the results of computer simulation.

The MSD with two erosion zones [11] is the module of the industrial vacuum system VUP-5 and has the area of the cathode unit about $4{,}5 \cdot 10^3 \text{mm}^2$, on which the disk-