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Attenuation of the normal component of the reflected electromagnetic wave by combined radio-absorbing coatings.

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A combined radar-absorbent coating on a solid metal surface was studied. The structure of such coatings was developed, an experimental investigation of their frequency dependences was conducted, and scattering diagrams of both the combined surface and its constituents were obtained. The research findings of attenuating abilities for the proposed multi-layer structures are demonstrated.

Keywords: Diagram of scattering, reflection of electromagnetic waves, metamaterials, ultrathin conductive films, combined coatings.

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The design of attenuating coatings relies on two fundamental physical principles: scattering and absorption. Without touching on the issues of design of a specialized surface geometry for scattering of the incident electromagnetic energy [1], we note that the normal component of a reflected wave in the scattering diagram may be attenuated by applying specific coatings to an object [2]. The majority of absorbing coatings converting electromagnetic waves into the vibrational energy of atoms are multicomponent [1,3]. Among these materials are ultrathin films with a nanoscale-thickness conducting layer and small mass and size [4] (compared to bulk specialized structures), which absorb up to 50% of the incident electromagnetic energy and, owing to their frequency-independent properties, have the capacity to attenuate signals within a wide frequency range [5,6].

Another approach to attenuating the normal component of a reflected wave is based on scattering of incident radiation and involves the use of attenuating surfaces that are more topologically complex. Specifically, the design of various types of metamaterials based on elementary resonators allows one to set negative permittivity and permeability in a certain frequency band and thus establish the conditions for destructive interference of a reflected wave [7,8].

The aim of the present study is to examine the parameters of a combined absorbing coating, which integrates the structures mentioned above into a single complex coating with both absorbing and scattering properties. An ultrathin conducting film deposited onto a sitall dielectric substrate served as the front part of the structure. The next conducting layer was a metastructure consisting of rectangular resonators positioned on an FR4 glass-reinforced epoxy laminate material with a metal mirror at the other side of it.

The method of bistatic measurement of the dependence of the reflected radiation level on the receiving antenna angle was used to obtain scattering diagrams. The setup for these measurements was fitted with two pyramidal horn antennas type P6-40 with an aperture of $625\,\mathrm{mm}^2$. A G7M-40 frequency synthesizer, which served as a microwave generator, was connected via a waveguide line to the output of one of these antennas. A PLS-26 power meter, which measured the received power level, was connected to the output of the other antenna. The position of the radiating antenna was fixed; it produced a linearly polarized incident electromagnetic wave with its Poynting vector being normal to the surface structure. The receiving antenna rotated around the sample within the range of angles from 0 to 180° with respect to the radiating antenna and monitored the received power level; the rotation step was $\Delta\varphi = 5.0 \pm 0.1^\circ$. The studied structure was positioned on a dielectric holder (Fig. 1) at a distance of more than six wavelengths of incident radiation from the radiator and the receiving antenna.

Interacting elements in the form of elementary strip resonators were used to reveal the additional effect of density attenuation of a wave incident on ultrathin films. Each component of the resulting surface (checkered metasurfaces with different orientations of conducting resonator elements and ultrathin conducting film structures) was examined to achieve the maximum attenuation of a reflected wave. Their frequency dependences and scattering diagrams were studied. The obtained frequency dependences demonstrated that the magnitude of a back-reflected electromagnetic wave depends directly on the coefficient of transmission (T) of this wave through the structure. This assertion was verified in experiments where scattering diagrams corresponding to various sections of the frequency characteristic (sections with the highest, the lowest, and intermediate values of the transmission factor) were obtained. The results revealed that the degree of attenuation in all the selected subranges increased with decreasing T. It was found in this series of experiments that metastructures consisting

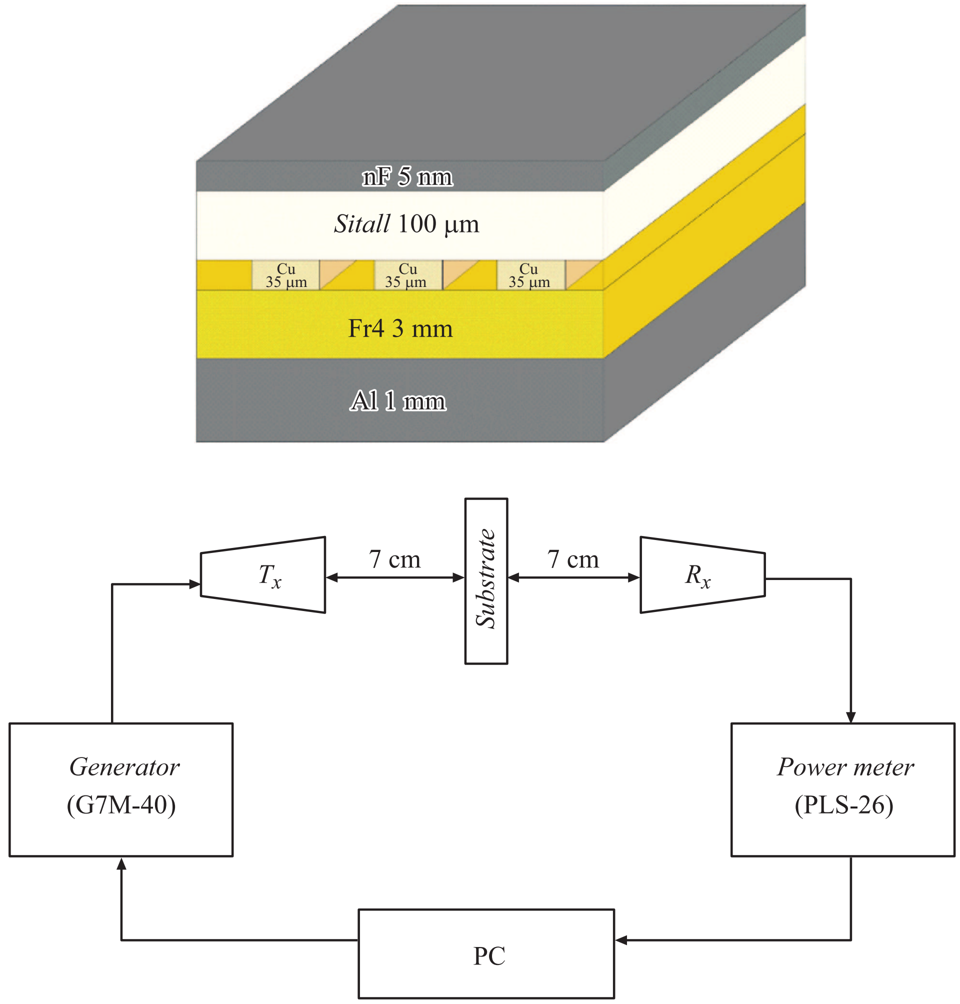

Figure 1. Elements, combined structure, and measurement diagram.

of alternating vertical and horizontal elements with their resonance frequency falling within the 20–22.5 GHz range have the smallest main lobe of the scattering diagram. However, it should be noted that the end frequency range depends directly on the geometric size of resonators and their positioning on a cell; thus, one may adjust the actual frequency characteristics of a surface to match a specific range.

Nanometer aluminum-based conducting films (nF), which were deposited onto dielectric sitall substrates using ion and magnetron techniques, served as absorbing elements. The results of earlier experimental and theoretical studies of absorption of electromagnetic waves in the 2–25 GHz frequency range [6,9] revealed that the absorbing properties of thin films depend directly on their surface resistance. It was concluded based on these results that Ohmic losses in the interaction of an incident electromagnetic wave with a nanometer conducting layer are the key attenuation mechanism. The absorption factor may reach 50% at a certain film thickness. Films of the following thicknesses were examined in the present study: 3, 5, 7, 10, and 120 nm. The obtained experimental data and the corresponding theoretical model [6] suggest that the absorption coefficient was dominant in ultrathin aluminum films with a thickness of 5 nm, which have the capacity to absorb as much as 25% of the energy of an incident wave interacting with them. Reflectance R was dominant in thicker samples, while transmittance governed the response of thinner ones. Thus, 5-nm-thick samples were chosen based on the overall assessment to be used in the design of a combined attenuating surface. The structures mentioned above may serve as radio coatings independently, but it appears to be practical to construct a combined coating, since their base attenuation mechanisms differ.

The angular power distribution revealed that the shape of the scattering diagram remains essentially unchanged if a thin-film coating is positioned on the face of the metal plate (Fig. 2, *a*), although quantitative attenuation of the reflected wave is observed within the 0–45° range. Figure 2, *b* demonstrates that the field distribution pattern changes considerably following the addition of a metastructure to the metal plate. This structure suppresses the main lobe of

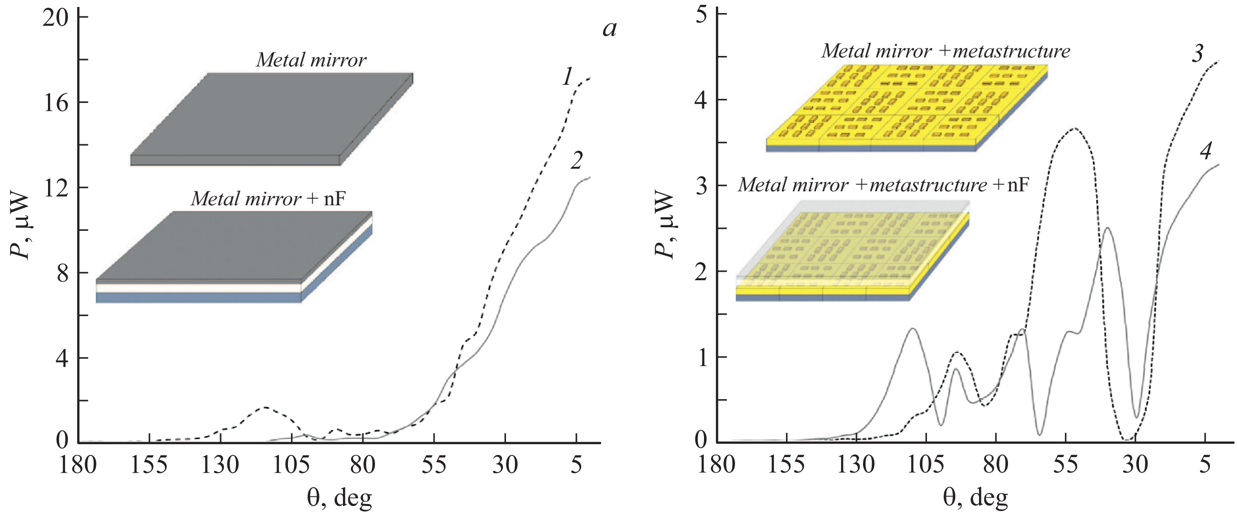

Figure 2. Angular power distribution for the metal mirror (*1*), the nanometer film and the metal mirror (*2*), the metastructure and the metal mirror (*3*), and the combined coating (*4*).

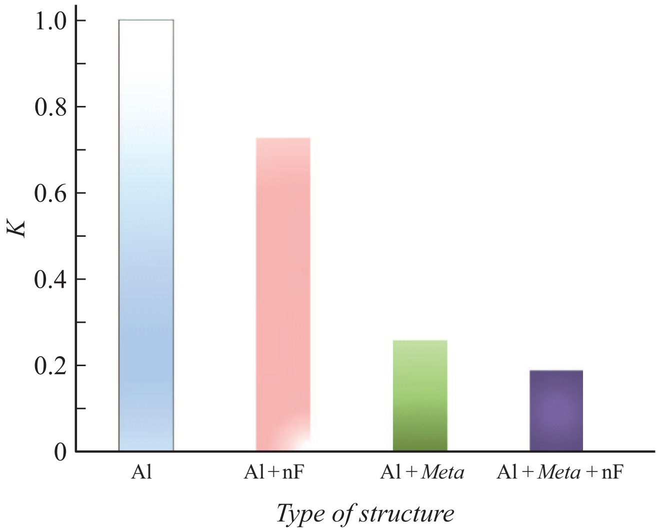

Figure 3. Relative reflection coefficient for different types of structures.

the reflected wave and induces the formation of a side lobe of a considerable amplitude within the 30–85° range (the maximum amplitude corresponds to an angle of 55°). When a surface thin-film layer is added to the metastructure, the reflected power amplitude is attenuated further within the entire studied diagram section. However, it should be noted that the shape of side lobes also changes in this case, and their peak values shift by 10° toward the main lobe.

To illustrate more clearly the effect of attenuation of the normal component of a reflected wave, the obtained data were compared in relative terms, as a ratio of received powers of the studied structures and the metal mirror at 0° (Fig. 3):

$$K = \frac{P_m}{P_{pl}},$$

where P_m is the received power for the studied structure at 0° and P_{pl} is the received power for the metal mirror at 0°.

The obtained data indicate that, compared to the metal mirror, the proposed combined structure features a low level of normally reflected power. Therefore, combined structures of this type have a wide range of applicability as attenuating coatings.

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Conflict of interest

The authors declare that they have no conflict of interest.

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