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A Transparent Radio Frequency Shielding Coating Obtained Using a Self-Organized Template

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Abstract—We present a simple and affordable technology for producing a thin-film transparent radio-shielding material. The material is a silver micromesh coating produced using a self-organized template. The results of a study of the radio-shielding properties of these coatings in the *X* and *K* bands are presented. The micromesh coating with a sheet resistance of 6.8 Ω/sq and integrated optical transmission of 83.6% is characterized by a shielding efficiency of 28.4 dB at a frequency of 8 GHz, which corresponds to a shielding of 99.85% of radiation. Reflection is the main mechanism for shielding radio waves by micromesh coatings.

Keywords: self-organized template, micromesh coating, shielding of electromagnetic radiation.

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In the 1980s, the fundamental possibility of intercepting spurious radio emission from a personal computer monitor (TEMPEST-leakage; TEMPEST stands for "transient electromagnetic pulse emanation standard") with its subsequent decoding was shown. In the literature, the technique is called "van Eck interception" [1]. Shielding is used to prevent parasitic radio emission from the monitor and other transparent objects. For electromagnetic shielding of such objects, it is necessary to use materials that combine optical transparency of more than 80% with sheet resistance R_s of less than 10 Ω/sq. The low sheet resistance value enables the material to shield electromagnetic radiation in the radio frequency range effectively by at least 20–30 dB or shield 99–99.9% of the incident radiation power. The main materials used for radio shielding of transparent objects are transparent conductive oxides, for example, ITO, AZO, etc. [2], thin films of single-walled carbon nanotubes [3, 4], composite films based on nanotubes and conducting polymers [5], films of metal nanowires [6, 7], and lithographic mesh micro- and nanostructures [8]. In this work, we propose a silver micromesh (MCM) coating obtained using a self-organized template as a transparent radio-shielding material.

The formation of a self-organized template is described in detail in [9]. In this work, egg white was selected as a material for the formation of a self-organized template. An egg white solution with a yolk concentration of 3 mL/L was applied by the Meyer rod method onto PET substrates 50 μm thick. The thickness of the egg white layer t_w was 35.56 μm (Meyer rod 14) for sample Ag MCM 1 and 71.1 μm (Meyer rod 28) for sample Ag MCM 2. After application, the liquid film was dried at room temperature of 21°C and humidity of ~50%. The egg white film cracks during drying, which is the final stage in the formation of a self-organized template [9].

Silver was deposited onto self-organized templates by the magnetron sputtering using an Emitech K575XD setup (Quorum Technologies, United Kingdom). The thickness of the silver film on the satellite plate was ~200 nm. After silver deposition, the template was washed in distilled water [9]. The morphology of micromesh coatings was studied by scanning

Table 1. Thickness of the egg white layer t_w, fill factor *FF*, optical transparency T_{opt}, and sheet resistance R_s for samples Ag MCM 1 and Ag MCM 2

Coating type	t_w, μm	*FF*, %	T_{opt} (550 nm), %	R_s, Ω/sq
Ag MCM 1	35.56	10.2	90.2	11.2
Ag MCM 2	71.1	15.5	83.6	6.8

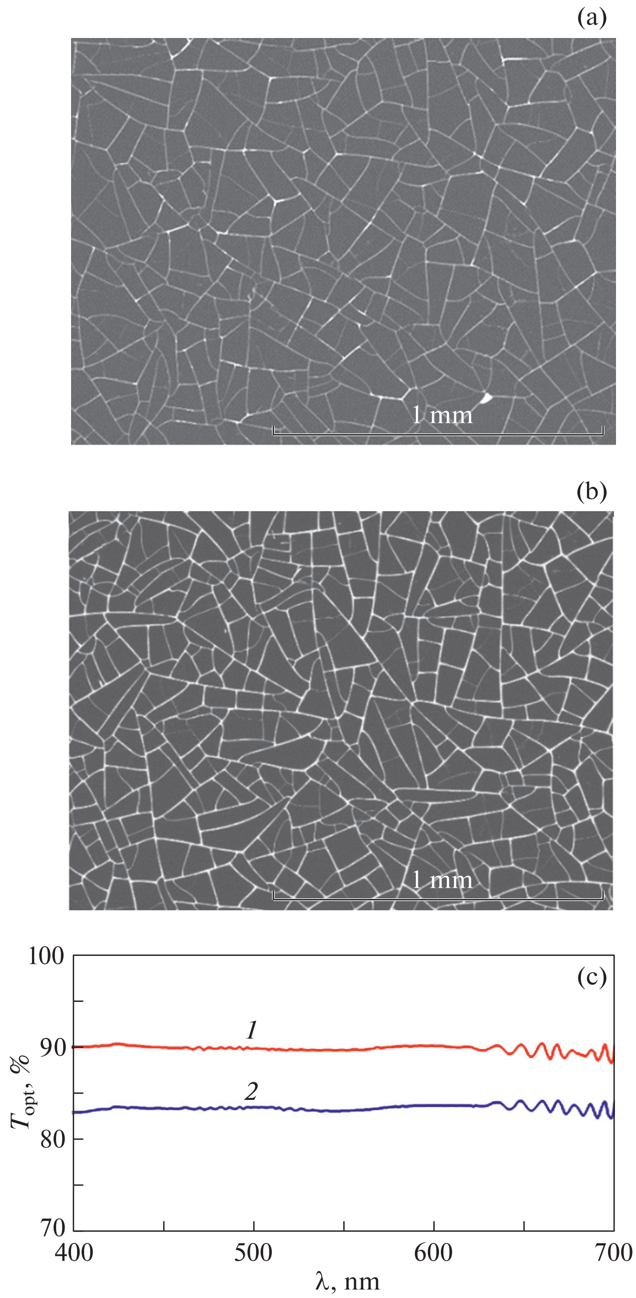

Fig. 1. SEM images of (a) Ag MCM 1 and (b) Ag MCM 2. (c) Optical transmission of samples (*1*) Ag MCM 1 and (*2*) Ag MCM 2.

electron microscopy (SEM) using a Hitachi TM3000 microscope (Japan) at an accelerating voltage of 15 kV.

The spectral dependence of the optical transmission of silver micromesh coatings was measured in the range of 400–700 nm using a Shimadzu UV-3600 spectrometer (Japan). The current–voltage characteristics of the coatings were measured using an IPPP-1 device (Belarus). The specific sheet resistance of the coatings was calculated from the slope of the current–voltage characteristics.

The shielding efficiency (SE) of electromagnetic radiation of the prepared samples was determined by the waveguide method in the *X* range (8–12 GHz) and *K* range (18–26 GHz). For this purpose, the parameters of the reflected and transmitted electromagnetic wave (S_{11}, S_{21}) were measured using a Rohde & Schwarz ZVA 50 vector network analyzer (VNA) (Germany). The samples of silver micromesh coatings under study had a rectangular shape (3 × 4 cm in size). The samples completely covered a waveguide window measuring 23 × 10 mm for the *X* band and 11 × 5.5 mm for the *K* band.

SEM images of coatings Ag MCM 1 and Ag MCM 2 are shown in Figs. 1a and 1b. Statistical processing of the SEM images gave an average cell size of 63 ± 22 μm for Ag MCM 1 and 67 ± 25 μm for Ag MCM 2. The crack width is 3.3 ± 0.8 μm for Ag MCM 1 and 5.4 ± 1.4 μm for Ag MCM 2. The fill factor (*FF*) can be calculated by the equation $FF = (1 - (p - w)^2/p^2) \times 100\%$, where p is the average cell size of the template and w is the average crack width. Figure 1c shows the spectral dependences of the optical transmission of coatings Ag MCM 1 and Ag MCM 2 in the range of 400–700 nm.

Table 1 presents the main data on the geometric and optoelectrical characteristics of the obtained micromesh coatings. An increase in the thickness of the egg white layer on the sample leads to an increase in the fill factor and, as a consequence, to a decrease in sheet resistance and optical transparency (Table 1).

Shielding of electromagnetic radiation occurs through absorption and reflection. In the case of thick-film structures, it is also necessary to take into account multiple reflections [10]. The coefficients of reflection (R), transmission (T_{SHF}), and absorption (A) of the power can be expressed as

$$R = \frac{P_r}{P_i} = (10^{(0.1S_{11})}) \times 100\%, \quad (1)$$

$$T_{SHF} = \frac{P_t}{P_i} = (10^{(0.1S_{21})}) \times 100\%, \quad (2)$$

$$A = 100\% - T_{SHF} - R, \quad (3)$$

where P_i, P_r, and P_t are the powers of the incident, reflected, and transmitted waves; parameters of the scattering matrix S_{11} and S_{21} should be taken in decibels. The overall shielding efficiency can be characterized based on the value of the transmission coefficient as

$$SE = -10 \log T_{SHF}. \quad (4)$$

The frequency dependences of shielding efficiency SE and reflection coefficient S_{11} for samples Ag MCM 1 and Ag MCM 2 in the *X* and *K* ranges are shown in Fig. 2. The value of SE slightly decreases with increasing frequency, which means that the shielding efficiency of electromagnetic radiation decreases. A decrease in shielding efficiency with increasing frequency is

Table 2. Shielding efficiency *SE*, transmission coefficient T_{SHF}, and reflection coefficient *R* for coatings Ag MCM 1 and Ag MCM 2 at boundary frequencies

Coating type	*SE* (8 GHz), dB	T_{SHF} (8 GHz), %	*R* (8 GHz), %	*SE* (26 GHz), dB	T_{SHF} (26 GHz), %	*R* (26 GHz), %
Ag MCM 1	23.1	0.49	89.3	15.5	2.82	80.5
Ag MCM 2	28.4	0.15	93.1	18.5	1.4	86.1

accompanied by a decrease in S_{11}. This is manifested in the fact that the fraction of the incident power, which is reflected from the samples, decreases. The value of shielding efficiency for Ag MCM 1 in the *X* band smoothly decreases from 23.4 dB at a frequency of 8 GHz to 19.2 dB at a frequency of 12 GHz; in the *K* band, it takes values of 19.2 and 15.4 dB at 18 and 26 GHz, respectively. The decrease in shielding efficiency and S_{11} with increasing frequency is associated with the frequency dependence of the sheet resistance of the metal from which the sample is made. For ordinary conductors with a metallic type of conductivity, the active part of their sheet resistance increases with increasing frequency in proportion to the root of the frequency [10].

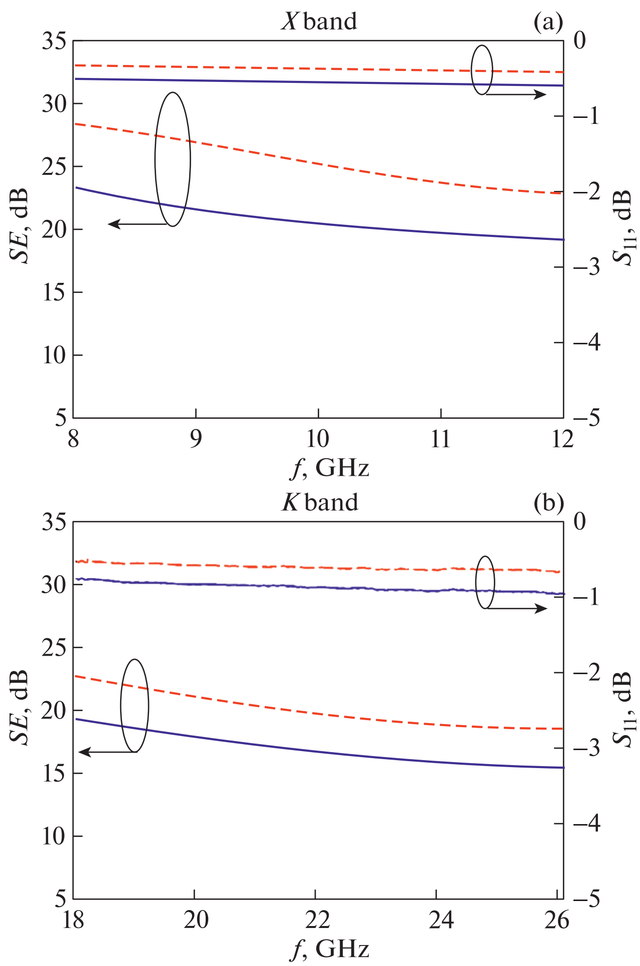

Fig. 2. Frequency dependences of shielding efficiency *SE* and reflection coefficient S_{11} in the (a) *X* and (b) *K* bands; (solid curves) Ag MCM 1, (dashed curves) Ag MCM 2.

In all the considered frequency ranges, sample Ag MCM 2 shields electromagnetic radiation more efficiently than sample Ag MCM 1. For example, at a frequency of 10 GHz, the shielding efficiency is 20 and 25 dB for Ag MCM 1 and Ag MCM 2, respectively. This is explained by the fact that the sheet resistance (R_s) for Ag MCM 2 is smaller than that for Ag MCM 1 (Table 1).

The values of shielding efficiency and the coefficients of transmission T_{SHF} and reflection *R* for coatings Ag MCM 1 and Ag MCM 2 at the boundaries of the studied ranges are given in Table 2.

Using Eqs. (1)–(3), we can estimate the fraction of the incident power that is absorbed in the sample. For example, $SE = 28.4$ dB and $S_{11} = -0.31$ dB at a frequency of 8 GHz for Ag MCM 2. In this case, only 0.15% of the incident power passes through the sample under study. Such a significant attenuation is because the overwhelming part (93.1%) of the incident power is reflected from the sample.

Thus, the paper presents the results of a study of the radio-shielding properties of silver micromesh coatings in the *X* and *K* bands. The micromesh coating has a shielding efficiency value of 28.4 dB at 8 GHz, which corresponds to 99.85% radiation shielding. The proposed coatings can be used for shielding transparent objects, such as displays of computers and smartphones, as well as for glazing buildings in the case of high requirements for information security.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

1. W. van Eck, Comput. Security **4**, 269 (1985). doi.org/ https://doi.org/10.1016/0167-4048(85)90046-X

2. Y.-J. Choi, K.-M. Kang, H.-S. Lee, and H.-H. Park, Thin Solid Films **583**, 226 (2015). https://doi.org/10.1016/j.tsf.2015.04.001
3. H. Xu, S. M. Anlage, L. Hu, and G. Gruner, Appl. Phys. Lett. **90**, 3119 (2007). https://doi.org/10.1063/1.2734897
4. K. F. Akhmadishina, I. I. Bobrinetskii, R. A. Ibragimov, I. A. Komarov, A. M. Malovichko, V. K. Nevolin, and V. A. Petukhov, Inorg. Mater. **50**, 23 (2014). https://doi.org/10.7868/S0002337X14010011
5. A. S. Voronin, M. M. Simunin, F. S. Ivanchenko, A. V. Shiverskii, Yu. V. Fadeev, I. A. Tambasov, I. V. Nemtsev, A. A. Matsynin, and S. V. Khartov, Tech. Phys. Lett. **43**, 783 (2017). https://doi.org/10.1134/S1063785017090127
6. I. Anoshkin, I. Nefedova, I. S. Nefedov, D. Lyubchenko, A. Nasibulin, and A. Raisanen, Micro Nano Lett. **11**, 343 (2016). https://doi.org/10.1049/mnl.2015.0582
7. M. Hu, J. Gao, Y. Dong, K. Li, G. Shan, S. Yang, and R. K.-Y. Li, Langmuir **28**, 7101 (2012). https://doi.org/10.1021/la300720y
8. Y. Han, J. Lin, Y. Liu, H. Fu, Y. Ma, P. Jin, and J. Tan, Sci. Rep. **6**, 25601 (2016). https://doi.org/10.1038/srep25601
9. A. S. Voronin, M. M. Simunin, Yu. V. Fadeev, F. S. Ivanchenko, D. V. Karpova, I. A. Tambasov, and S. V. Khartov, Tech. Phys. Lett. **45**, 366 (2019). https://doi.org/10.1134/S1063785019040187
10. Y. Liu and J. Tan, Prog. Electromagn. Res. **140**, 353 (2013). https://doi.org/10.2528/PIER13050312

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