Producing and investigation of radiation-absorbent coatings based on conductive polymers

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Abstract. PANI and PEDOT:PSS films were produced on a dielectric substrate and characterized by optical and electron microscopy. The absorption coefficient of electromagnetic radiation in films is measured using a coplanar transmission line. The possibility of using conductive polymers (PANI and PEDOT:PSS) as the basis for conformal radiation-absorbent materials designed to protect bio- and technosphere objects is shown.

1. Introduction

Increase of the level of electromagnetic background and the concentration of sources of electromagnetic radiation (EMR) requires the development and creation of effective means of protection. The effectiveness of the use of systems for protecting objects of the bio- and technosphere from an exposure of electromagnetic radiation depends on values of shielding and/or absorption coefficients in a given frequency range. Materials, which are used to protect bio- and technosphere objects, preserving conformal properties to a certain degree, that means repeating the shape of the object surface, can be divided into two main groups: radiation-absorbent textiles and flexible radiation-absorbent materials (RAM) [1].

Conductive polymers can be used as the basis of RAM of both groups. The conductive composition of poly(3,4-ethylenedioxythiophene) and polystyrene sulfonate (PEDOT:PSS) demonstrates high p-type conductivity and manufacturability. PEDOT:PSS layers for RAM can be applied onto a dielectric substrate using centrifuging, dipping or irrigation. Polyaniline (PANI) is another promising conductive polymer. It is characterized by a high specific capacity due to the large number of redox reactions, good electronic properties due to protonation, high thermal stability and low cost.

2. Experimental methods

Within the framework of this work, films of conducting polymers (PEDOT:PSS, PANI), which were previously investigated as electrodes for ionic polymer electroactive actuators, were obtained on a dielectric substrate [2, 3].

PEDOT,PSS aqueous (Sigma-Aldrich) dispersion was used in order to fabricate PEDOT:PSS films. In order to obtain a polyaniline dispersion, a solution containing 0.228 g of \((\text{NH}_3)_2\text{S}_2\text{O}_8\) and 1 ml of distilled water was added to a solution containing 0.255 ml of aniline, 1 ml of 10 M HCl and 7 ml of distilled water. The reaction mixture was kept for 24 hours in a water bath at 20 °C [3]. The resulting suspension has a dark green color typical for the protonated emeraldine form of PANI, which
has the highest stability and the lowest resistivity. Then the suspension was filtered to obtain a solid PANI, from which a suspension of a given concentration was prepared.

PANI and PEDOT:PSS films were fabricated with the help of irrigation, followed by drying in an oven at a temperature of 40 °C. The thickness of films ranged from 50 to 200 microns.

The surface morphology of obtained films was characterized by optical (Hirox KH-7700, Japan) and scanning electron microscopy (Helios Nanolab 400, USA). The 4200-SCS semiconductor characterization system (Keithley, USA) and the M150 probe station (Cascade Microtech, USA) were used to measure the surface resistivity by the four-probe method. In order to measure the EMR absorption coefficient, a method was used that is based on a coplanar transmission line with a characteristic impedance of 50 Ω, designed for the frequency range 50–2000 MHz [4,5], and a vector network analyzer ZVB-20 (Rohde & Schwarz, Germany). The absorption coefficient \( L (\%) \) was calculated by the formula:

\[
L = \left(1 - \left| S_{21} \right|^2 - \left| S_{11} \right|^2 \right) \cdot 100,
\]

where \( |S_{21}| \) and \( |S_{11}| \) – modules of the complex transmission and reflection coefficients, respectively.

3. Experimental results

Images of films obtained by optical (figure 1) and scanning electron microscopy (SEM) (figure 2) show that the PANI film consists of individual particles with up to several tens of nanometers in size and the PEDOT:PSS sample is a continuous film. Thus, the PANI film can be characterized by strong roughness.

**Figure 1.** Optical micrographs of obtained films – PANI (a) and PEDOT:PSS (b), the scale is 50 μm.

**Figure 2.** SEM-images of obtained films – PANI (a) and PEDOT:PSS (b).
The results of measurements of the resistivity and the EMR absorption coefficient in PANI and PEDOT:PSS films are shown in table 1. The resistivity of the PEDOT:PSS film is 2–4 times higher than that for the PANI film. The EMR absorption coefficient at a frequency of 1 GHz is 1.7 times higher and at a frequency of 2 GHz – 1.5 times higher for the same film thickness. This fact can be explained by a significant difference in roughness, resulting in a less absorption of EMR for a PANI film.

| Film material | Thickness of polymer film, mm | Resistivity, Ohm cm | EMR absorption coefficient at 1 GHz, % | EMR absorption coefficient at 2 GHz, % |
|---------------|--------------------------------|---------------------|--------------------------------------|---------------------------------------|
| PEDOT:PSS     | 0.11                           | 440                 | 80                                   | 91                                    |
| PANI          | 0.11                           | 220                 | 48                                   | 59                                    |
|               | 0.12                           | 120                 | 65                                   | 74                                    |
|               | 0.14                           | 112                 | 67                                   | 76                                    |
|               | 0.16                           | 112                 | 65                                   | 81                                    |

The EMR absorption coefficient in a PANI film increases 1.4 times at a frequency of 1 GHz and 1.37 times at a frequency of 2 GHz with an increase in film thickness of 1.45 times. Frequency dependences of the EMR absorption coefficient are shown in Figure 3. As it can be seen from Figure 3, an increase in the PANI film thickness above 0.12 mm does not lead to a significant change in the absorption coefficient. Apparently, it is due to the formation of a thin continuous conductive layer in which the electric field lines of electromagnetic wave are looped. At frequencies higher than 0.56 GHz, the EMR absorption coefficient in the PEDOT:PSS film is higher, since a continuous conductive layer is formed directly during application (figures 1, 2).

![Figure 3](image-url)
4. Conclusions
The results obtained within the framework of this work show the possibility of using conductive polymers PANI and PEDOT:PSS as the basis for conformal RAM designed to protect bio- and technosphere objects from the EMR exposure of cellular base stations and other household and industrial sources of electromagnetic contamination. These films can also be used as a flexible polymer conductive electrodes in various devices, such as actuators based on electroactive polymers.

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