SMART MATERIALS FOR ENVIROMENTAL AND ENERGY EFFICIENCY USES – DIELECTRIC AND EMC BEHAVIOUR

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REZUMAT: Acesta lucrare investighează comportamentul dielectric şi electromagnetic ale unor compozite conductive de poliacrilonitril. Filmele compozite de poliacrilonitril /n-metil-pyrrole au fost preparate prin polimerizarea de pyrrole intr-o matrice de poliacrilonitril [1]. Concentraţii diferite de n-metil-pyrrole au fost adăugate la soluţia de poliacrilonitril/dimetilformamidă pentru a realiza polimerizarea pyrrol-ului. Cantitatea de n-metil pyrrole a fost variata, pentru a investiga influenţa concentratiei acesteia asupara proprietatilor dielectrice si electromagnetice si, in special eficienta de ecranare a materialului

Cuvinte cheie: proprietati dielectrice, modelare electromagnetica, simulari, spectroscopie dielectrica, protectia mediului.

ABSTRACT. This paper investigates the dielectric and electromagnetic behavior of polyacrilonitrile composites thin films. Polyacrylonitrile/N-Methyl-Pyrrole composite thin films were prepared by polymerization of pyrrole on polyacrylonitrile matrix [1]. Different concentrations of n-methyl-pyrrole were added to the polyacrylonitrile/dimethylformamide solution to achieve polymerization of pyrrole. The amount of n-methyl pyrrole was varied in order to investigate the influence of the concentration on the dielectric and also on electromagnetic properties in special electromagnetic shielding of the composite polymer.

Keywords: dielectric properties, electromagnetic modeling, simulations, dielectric spectroscopy, enviromental protection,

1. INTRODUCTION

Electromagnetic pollution is a term given to all the electromagnetic fields of various frequencies caused by existing artificial sources. The introduction in the 1990s of mobile phones using the digital Global System for Mobile Communications (GSM) with bandwidths of 900 and 1800 MHz and the further introduction of the Universal Mobile Telecommunications System (UMTS) have led to widespread use of this technology and to a substantial increase in the number of mobile phone base stations all over the world. This development has raised public concerns and substantial controversy about the potential health effects of the radiofrequency electromagnetic field emissions of this technology. A small part of the population attributes some strange symptoms of ill-health, such as sleep disturbances or headache to exposure to electromagnetic fields. This phenomenon is described as electromagnetic hypersensitivity or "environmental intolerance with attribution to electromagnetic fields" [2]. Additionally, individuals who are hypersensitive to electromagnetic fields often claim to be able to perceive radiofrequency electromagnetic fields in their daily life. People are generally exposed to mobile phone base stations radiation under far-field conditions, i.e. radiation from a source located at a distance of more than one wavelength. This results in relatively homogenous whole-body exposure.

Mobile phone base stations exposure can occur continuously but the levels are considerably lower than the local maximum levels that occur when someone uses a mobile phone handset. A recent study [3] that measured personal exposure to radiofrequency electromagnetic fields in a Europe population sample demonstrated that the average exposure contribution from mobile phone base stations is relevant for cumulative long-term whole-body exposure to radiofrequency electromagnetic fields. In the scope to reduce human exposure to this type of radiations there are used electromagnetic screens.

2. MATERIALS AND METHODS

Now, because the synthesis of new materials is well represented in research and in industrial development, the arsenal of materials available for the realization of shielding structures is always increasing. Most shielding structures are fabricated by means of standard (i.e., nonmagnetic), conductive materials or by means of ferromagnetic materials, which are often preferred

for their mechanical properties rather than their ferromagnetic behavior.

Generally, the materials used for this type of shielding are not pure and any variation in their chemical composition is able to modify their conductivity [6]. Some materials whose main function is not that of shielding EMC fields have also been modified in their chemical composition or structure in order to provide them some EM performance while maintaining their original features.

The materials under test were obtained with the kind support of Istanbul Technical University [4-5].

Polymerization was carried out in a flat-bottomed flask equipped with a stirrer and a condenser by the addition of cerium (IV) dissolved in HNO3-water to an aqueous solution of monomer and oxalic acid. All operations were conducted in water at 25 oC. Polymerization started with addition of cerium (IV) solution at 25 oC water bath temperature and reaction concentrations of oxidant, monomer, and acid as following: [Ce(IV)]=2×10-2 M, [HNO3]=0.1 M, [OA]= 2×10-2 M, [AN]= 2.4 M. After 1 hour, the temperature was increased up to 60 oC and was kept at this temperature for 1 hour. After 2 hours of polymerization, the resulting polymer was precipitated, filtered and washed with distilled water. The filtered polymer was dried at room temperature. The polymerization chain is presented below: 0.375 g of polymerized polyacrylonitrile (PAN) was dissolved in 10 ml dimethylformamide (DMF) and then 50 µl of N-methyl-Pyrrole was added to the solution. This solution was mixed for about one hour at room temperature. After one hour, to the solution was added ceric ammonium nitrate (CAN) to achieve polymerization of N-Methyl-Pyrrole. Temperature was increased up to 80˚C for about 15 minutes to evaporate the solvent and to obtain a viscous solution. This viscous solution was casted as a film on a glass substrate area. The homogeneity of viscous solution was acquired by using four-sided film applicator. In the final the casted solutions were dried in a 600 mmHg vacuum stove for 24 hours at 60˚C to evaporate the solvent. The whole procedure was repeated for 100, 150 and 200 µl N-methyl-pyrrole added to the initial solution.

Dielectric measurements were performed by Novocontrol Broadband Dielectric Spectrometer - schematic represented in Figure 1 (Alpha-A High Performance Frequency Analyzer) at room temperature in frequency range between 10^6 and $3x10^9$ Hz.

The calibration of spectrometer was performed using WINDETA software which is a complete package of programs that can control with high precision the measurements of components, samples and interfaces with powerful electric and electronic equipment [7].

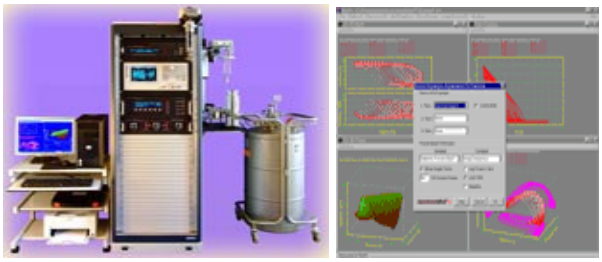


Fig.1. Dielectric Novocontrol System with WinDeta software package

Electromagnetic simulations that prove the electromagnetic performances of the material have been performed. The software used for simulations was CST Microwave Studio. The solver of CST package is based on a rectangular meshing scheme, which has been shown in many studies to be the most efficient time domain method available. In the scheme field values are distributed around the edges and face centres of mesh cells, but the software has always had the ability to arbitrarily slice a cell into two regions - one dielectric field region and one metal region through the method PBA® (Figure 2) - Perfect Boundary Approximation. PBA allows the modelling of arbitrary curved surfaces, thus reducing the need for finer meshing and eliminating all staircase approximation errors. PBA also takes into account the thickness of metallic sheets or strip lines within one grid cell, without explicitly meshing it [8].

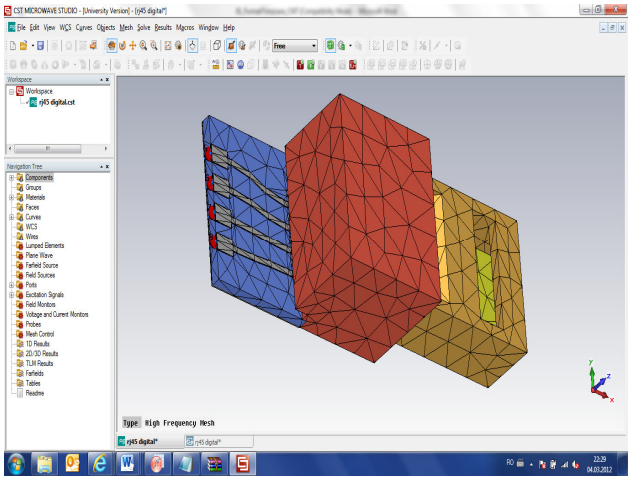


Fig.2. CST MWS solver

3. RESULTS

Dielectric spectroscopy results

The dielectric parameter as a function of frequency is described by the complex permittivity in the form:

$$\varepsilon^*(\omega) = \varepsilon'(\omega) - \varepsilon''(\omega) \quad (1)$$

where the real part $\varepsilon'(\omega)$ and imaginary part $\varepsilon''(\omega)$ are the components for the energy storage and energy loss, respectively, in each cycle of the electric field.

For the dielectric characteristics of irradiated and unirradiated composite samples, the measured capacitance, $C(\omega)$ was used to calculate the dielectric constant, $\varepsilon'(\omega)$ using the following expression:

$$\varepsilon'(\omega) = C(\omega)\frac{d}{A} \quad (2)$$

where d is sample thickness and A is surface area of the sample.

For dielectric loss, $\varepsilon''(\omega)$ is:

$$\varepsilon''(\omega) = \varepsilon'(\omega) \cdot \tan\delta(\omega) \quad (3)$$

where tan δ is tangent delta.

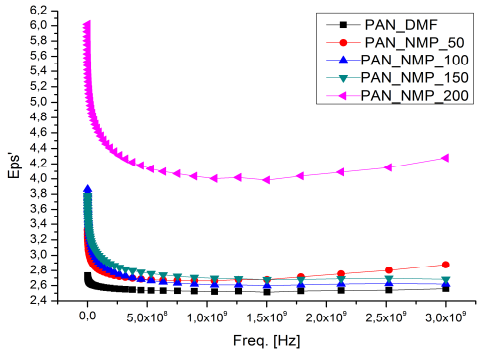


Fig.3. Relative permittivity for composite films of PAN with different concentrations of NMPy

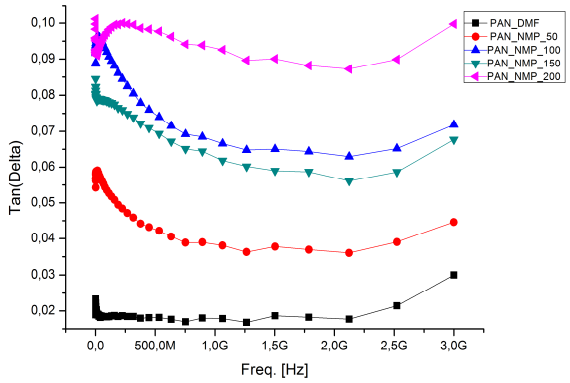


Fig.4. Tan delta for composite films of PAN with different concentrations of NMPy

The dielectric permittivity as it showed in Fig.ure 3 decrease with the increasing of frequency. It also can be observed that relative permittivity increases with the concentration of NMPy. Therefore this fact can be attributed to the tendency of dipoles in polymeric samples to orient themselves in the direction of the applied field.

The tangent loss parameter is related to the ability of the material to be penetrated by an electric field and dissipate energy as heat. As depicted in figure 4 by increasing the concentration of initially added n-methyl-pyrrole the tangent loss increases.

Electromagnetic behavior

Electromagnetic solvers simulate the Maxwell's equations [11] and their variations on a computer depending on electromagnetic field and material properties. The results were obtained in transient solver, which can cover the entire broadband frequency behavior of the simulated device from only one calculation run (in contrast to the frequency stepping approach of many other simulators). This solver is very efficient for most kinds of high frequency applications such as connectors, transmission lines, filters, antennas and many more. This simulator is equipped with the new Multilevel Subgridding Scheme (MSS™) which helps to improve the meshing efficiency and thus can significantly speed up simulations especially for complex devices.

Electromagnetic simulation results show the S (scattering) parameters for the structure. In the shielding theory the typical macroscopic parameters that define the reflectance, transmittance and absorption are defined relative to the electromagnetic power and are related to the S parameters [12] as shown in equations (4), (5), (6):

$$R = |S_{11}|^2 \quad (4)$$

$$T = |S_{21}|^2 \quad (5)$$

$$A = 1 - R - T = 1 - |S_{11}|^2 - |S_{21}|^2 \quad (6)$$

The structure designed under numeric tests is a material sample with defining dimensions 45 mm x 20 mm x 4 mm and the materials properties, electric permittivity and loss angle tangent, were parametric varied with the values from dielectric measurements previously performed corresponding of different percentages of N-methyl-pyrrole (NMP) in the base matrix of Polyacrylonitrile (PAN). The discretization

was made in tetrahedral meshing for better accuracy – Figure 5.

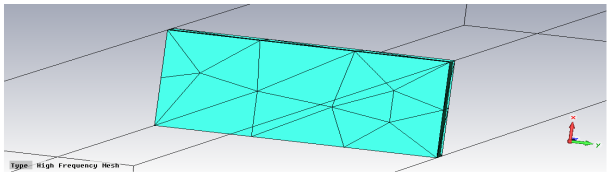


Fig. 5. Tetrahedral meshing of the structure

It was investigated the interaction between a plane wave and an infinitely large sheet of conductive polymer with material's parameters obtained in the dielectric measurements, at normal incidence. The boundary conditions are set to electric wall (both walls on x directions) and magnetic wall (y direction walls) as shown in Figure 6. An input wave port is placed at some space from the structure; the second (exit) wave port is added only when losses inside the structure are taken into account.

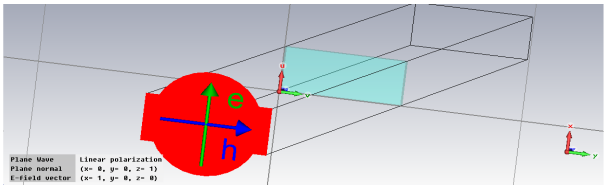


Fig. 6. Boundary conditions and plane wave

The simulations of the electromagnetic behaviour for the structure was made using parametric sweep simulations tool of the CST software for different values of dielectric permittivity (ε) and loss tangent (tg δ) obtained previously with dielectric spectroscopy.

The frequency range for de solver was set in the range 0.1 to 5 Ghz because it covers the frequencies most used in the domestic mobile communications (GSM, UMTS, Wi-Fi, Bluetooth),the target application of the structure propose and of course for investigate the behaviour of the material for other applications depending on frequency band..

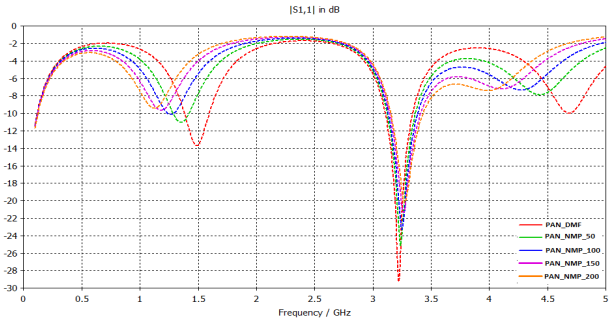


Fig. 7. Reflectance vs. frequency

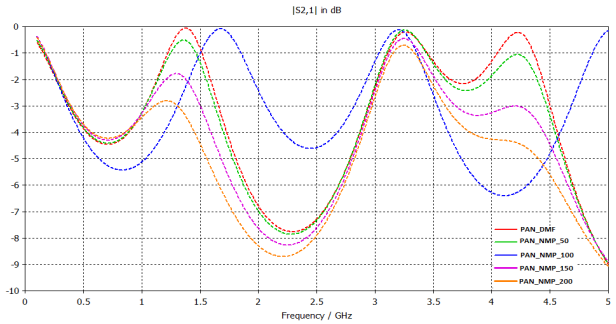


Fig.8. Transmission of radiation through screen depending on dielectric losses

Typical results are those from Fig. 7 and Fig. 8 Figure 7 shows the S_{11} parameter, defining the electromagnetic reflective properties of the material. In Fig.8, S_{21}, the electromagnetic transmission through the structure is plotted.

4. ENVIROMENTAL AND ENERGY EFFICIENCY INTEGRATION

EMC Shields - base for photovoltaic cells

Whatever the material of these structures are made, screens can be used as a base for photo-sensitive substrate for the component cells of the photovoltaic panels schematic shown in Figure 9. This provides a structure with multiples properties an important increase of efficiency of buildings and cost savings, because these kinds of techniques are still expensive. Also, conductive substrate and the electric network of the united cell structure of the photovoltaic cells will increase capacity to absorb and to reflect the electromagnetic waves. This technique can be required for the protection of electric sensible areas, e.g. in hospitals, computer control-centres or buildings which are used for air traffic control.

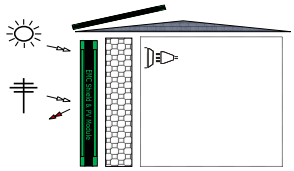


Fig. 9. Integrated EMC and Photovoltaic system

Climate control and module efficiency

Besides the capacity of shielding, radiations can warms up the screen panels. This heat can be utilized as thermal energy by rear-ventilation of the panels in facades and roofs. At the same time the shielding efficiency may increase, caused by the cooling effect of the rear ventilation, so that it is possible to achieve energy balance

in accordingly designed screening systems. In case of optimized rear ventilation, one could get in spring, and in transitional seasons respectively, a warm and pouring airflow free of charge. The thermal energy can be used for the heating of indoors. In summer the airflow would reduce the thermal load of the outer skin.

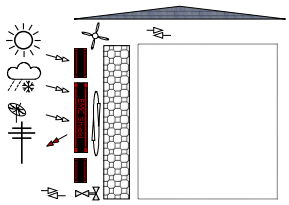


Fig.10. Integrated EMC and climate control system

In the same time can contributes to the heat insulation of buildings. These components meet all civil engineering requirements and additionally they protect against electromagnetic radiations. On the other hand, if the building is plated with conventional thermal insulation systems, the electromagnetic panels adopt the weather protection of these.

Sound insulation

If the electromagnetic shields are used in facades and roofs, contribute to the sound insulation, due to the laminated assembly and the good sound absorbing properties. The multi-layered sandwich body of common shielding components can reach a sound reduction index of up to 25dB.

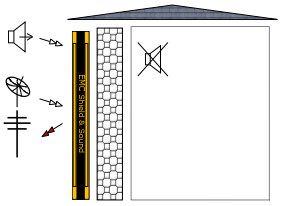


Fig. 11. Integrated EMC and sound insulation system

5. CONCLUSIONS

- ✓ The present communication shows that the different amounts of n-methyl-pyrrole have a great influence on the trend and magnitude of dielectric properties and accordingly to these, the electromagnetic characteristics. Regarding dielectric behavior we can observe that the dielectric permittivity decrease with the increasing of frequency and also with the concentration of NMPy and the tangent loss increasing together with the concentration of initially added n-methyl-pyrrole.
- ✓ Electromagnetic predictions show that the transmittance is influenced mainly by the losses in the dielectric that means that the growing percent of NMPy provide better results. We observe a good enough attenuation ranging from 10 ÷ 25 dB in the 0.1 ÷ 5 GHz bandwidth (which cover GSM band, wireless communications and power line transmitters) which indicates that these kind of materials are suitable for use in shielding applications.
- ✓ Because of the high complexity of electromagnetic phenomena, it is used numerical techniques to simulate the EMC behavior. For validation, we use another types of measurements like dielectric spectroscopy which is a very complex method for materials and fields characterization. The adoption of any numerical technique always requires knowing its basic formulation and certainly the input variables in order to apply it correctly and be aware of its accuracy, efficiency, and utility for specific problem under analysis.The computing time in the case of proposed method is less that the FEM method and the program made in Microsoft Visual C/C++ get output for Tecplot postprocessor product. In this case the graphical possibilities of our program increase and the results can be easy integrated in the design processes of the structure.
- ✓ The building integration of electromagnetic shielding components should be considered as early as possible during the design process of a building, desirably already during the preliminary draft phase. An integration of electromagnetic protection techniques is in most cases also possible and explicitly desired, if these criteria can't be met completely. A basic condition for this purpose is an interdisciplinary cooperation of architects and specialist consultants for systems and building services engineering and producers of thermal insulations systems, photovoltaic components, which can use materials with good electromagnetic proprieties.

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