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Study of the polymer nanocomposite on the base of iron oxide nanoparticles to the application as magnetoresistive field sensors

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Abstract

In the present work nanocomposites based on PVC+Fe_3O_4 obtained by solution blending method. The structure of the nanocomposite based on PVC+Fe_3O_4 was studied by X-ray diffraction method. The XRD measurement prove formation of the nanocomposite based on the PVC polymer and iron-oxide nanoparticles. The change in the resistivity of nanocomposites based on PVC+Fe3O4 under the influence of a magnetic field has been studied. The data shows that the value of the negative magnetoresistivity decreases with repeating measurem This decrease is associated with the magnetic memory of the sample. Temperature dependence of the samples' resistivity shows that is stable for 60-160℃ temperature diapason. This result supports the high potential of PVC+10%Fe3O4 samples as magnetoresistive sensor

Keywords: polyvinyl chloride; iron oxide; polymer nanocomposite; magnetoresistance

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1. Introduction

Polymer nanocomposites are a vital category of materials that exhibit excellent physical and chemical properties that are inaccessible to individual components acting alone. Traditionally, the term "composite" materials refer to some multi-phase, multi-component systems that combine several materials that differ in composition or shape on a macro scale to obtain specific properties or characteristics of the final material. At the same time, the individual components of the system retain their individuality and properties to such an extent that they exhibit an interfacial boundary and work in a certain "synergistic ensemble", achieving an improvement in properties that are inaccessible to each component separately[1]. Over the past decade, nanocomposites have been receiving increased attention from both academic and industrial science due to such important mechanical properties as good deformation properties and elasticity along with increased strength even with a small number of nano-additives. The reason for this is that nano-additives have a significantly higher surface area-to-volume ratio compared to micro- and macro-additives. Other distinctive properties of polymer nanocomposites include gas impermeability, fire resistance, resistance to wear and mechanical damage, as well as improved optical, magnetic, and electrical properties. Nanocomposite materials based on ferromagnet filler and dielectric matrix are one of the most promising materials due to the presence of tunnel spin-dependent conductivity, which leads to the appearance of several galvanomagnetic effects like negative magnetoresistivity[2-3]. Magnetoresistance is the change in the electrical resistance of a material in a magnetic field. All substances exhibit magnetoresistance to some extent. However, in nanosystems, the value of the change of electric resistivity under a magnetic field is extremely high. Based on the magnetoresistive effect, magnetic field sensors are created. Magnetoresistance is used to study the electronic energy spectrum, the mechanism of scattering of current carriers by a crystal lattice, as well as to measure magnetic fields. In addition, this effect is used in devices for measuring magnetic, electrical, mechanical, and other physical quantities, automation and signaling systems, and in information storage media[4-6].

2. Experimental part

In the present work the change in the resistivity of nanocomposites based on PVC+Fe_3O_4 under the influence of a magnetic field has been studied. The PVC+Fe_3O_4 structure is obtained in the following sequence: Polyvinyl chloride (PVC), whose granule size is *0.5-1.0* microns, is dissolved in its solvent at a temperature of *120℃* until the solution becomes transparent.

Fe_3O_4 nanoparticles depending on mass concentration of polymer was added into the primary solution, and intensively mixed for *2* hours. After solvent evaporation, texture was shaped by hot pressing technique. The structure of the nanocomposite based on PVC+Fe_3O_4 was studied by Rigaku Mini Flex 600 HRD diffractometer.

Measurements were taken at room temperature, between 20 and 70 degrees of the 2 theta values. Figure 1 shows an X-ray diffraction pattern of pure PVC and

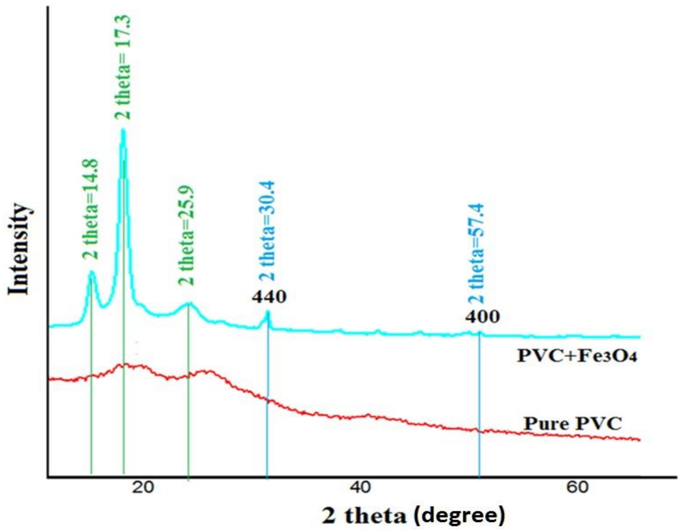

Fig. 1. The X-ray diffraction pattern of pure PVC and PVC+Fe_3O_4 nanocomposite samples

PVC+Fe_3O_4 nanocomposite samples. The XRD measurement prove formation of the nanocomposite based on the PVC polymer and iron-oxide nanoparticles [7].

Universal voltmeter B7-26 was used for magnetoresistance measurement. The polymer nanocomposite was first measured in the absence of a magnetic field. Then the sample was placed into the permanent magnetic field. The experiment showed that after exposure to a magnetic field, the electrical resistance of the nanocomposite decreased. The observed effect is called negative resistance. The change in electrical resistance depends on the concentration of the magnetic filler in the polymer matrix since the magnetic field acts on magnetic nanoparticles separated by a dielectric layer. In a magnetic field, the magnetic moments of ferrite nanoparticles are oriented and coupled by spin-polarization. In this case, the conductivity of the material increases, which leads to a decrease in electrical resistance. The measurement results are shown in table 1. The change in electrical resistance depends on the concentration of the magnetic filler in the polymer matrix, since the magnetic field acts on magnetic nanoparticles separated by a dielectric layer. In a magnetic field, the magnetic moments of ferrite nanoparticles are oriented and coupled by spin-polarization. In this case, the conductivity of the material increases, which leads to a decrease in electrical resistance. The data also shows that the value of the negative magnetoresistivity decreases with repeating measurement (Fig. 2). This decrease is associated with the magnetic memory of the sample. Since during the first measurement, when the sample is placed in a magnetic field, its magnetic moments, oriented in the direction of the field, cannot restore their original state after the cessation of the magnetic field on the sample. In each of the following measurements, the number of polarized spins and oriented magnetic moments increases. This phenomenon leads to a farther decrease in

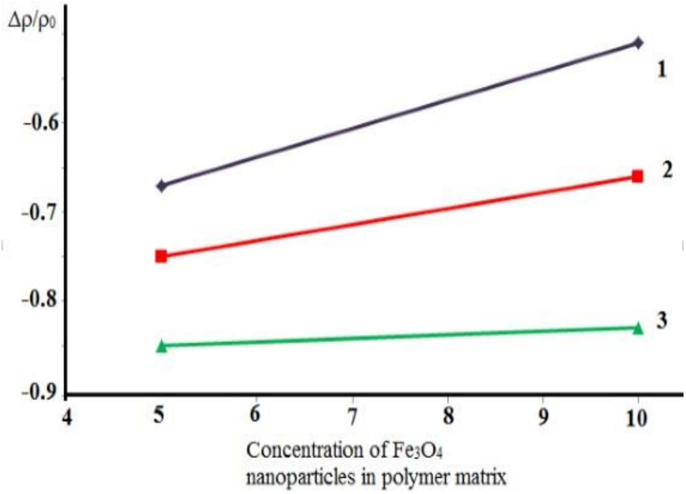

Fig.2. Magnetic resistance of PVC+ Fe3O4 nanocomposite samples: 1) first measurement 2)second measurement 3) third measurement

electrical resistance. Negative magnetoresistance is related directly to temperature dependence of resistivity of the given material. That is why the resistivity measurement of PVC+Fe_3O_4 nanocomposite depending on temperature was carried out.

Table 1. The change in electrical resistance depends on the concentration of the magnetic filler in the polymer matrix.

Nanoparticle concentration in PVC matrix	$\rho_0 \times 10^{13}$ ($Ohm \times cm$)	$\rho_h \times 10^{13}$ ($Ohm \times cm$)	$\Delta\rho/\rho_0$
5%Fe_3O_4	7,9	2,6	-0,67
5%Fe_3O_4	7,9	2	-0,75
5%Fe_3O_4	7,9	1,2	-0,85
10%Fe_3O_4	7,8	3,8	-0,51
10%Fe_3O_4	7,8	2,6	-0,66
10%Fe_3O_4	7,8	1,3	-0,83

Figure 3 shows the temperature dependence of the resistivity of polymer nanocomposites based on PVC+Fe_3O_4. Dielectric measurements of samples of

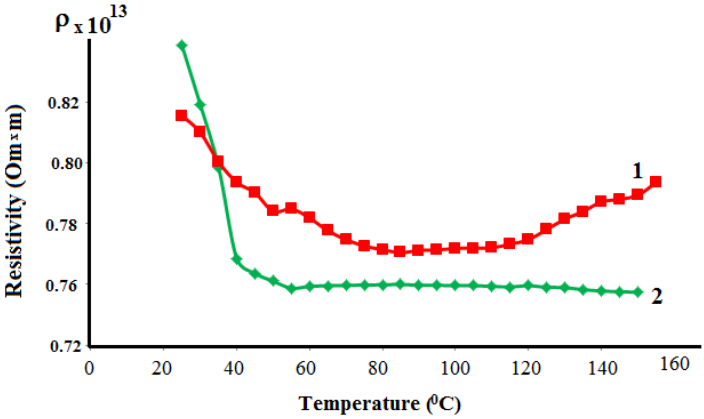

Fig. 3. Dependence of the resistivity of the nanocomposite based on PVC+Fe_3O_4 on temperature: 1) PVC+5%Fe_3O_4 2) PVC+10%Fe_3O_4

nanocomposites based on PVC+Fe_3O_4 were carried out using the device "E7-20 impedance meter". It became known that with an increase in the amount of filler in the matrix, the resistance of the material decreases. Furthermore, for PVC+10%Fe_3O_4 samples' resistivity is stable for *60-160℃* temperature diapason. This result supports the high potential of PVC+10%Fe_3O_4 samples as magnetoresistive sensor[8].

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