Fabrication and studying the dielectric properties of (polystyrene-copper oxide) nanocomposites for piezoelectric application

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ABSTRACT

The preparation of (polystyrene-copper oxide) nanocomposites have been investigated for piezoelectric application. The copper oxide nanoparticles were added to polystyrene by different concentrations are (0, 4, 8 and 12) wt.%. The structural and A.C electrical properties of (PS-CuO) nanocomposites were studied. The results showed that the dielectric constant and dielectric loss of (PS-CuO) nanocomposites decrease with increase in frequency. The A.C electrical conductivity increases with increase in frequency. The dielectric constant, dielectric loss and A.C electrical conductivity of polystyrene increase with increase in copper oxide nanoparticles concentrations. The results of piezoelectric application showed that the electrical resistance of (PS-CuO) nanocomposites decreases with increase in pressure.

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1. INTRODUCTION

Nanotechnology has attracted a great deal of attention in the last few years as miniaturization and nanomaterials are often foreseen to be the key for a sustainable future. In this regard, an essential part of the scientific community is currently focused on a very challenging and relevant research's direction, which is the synthesis of novel nanostructured hybridmaterials capable of absorbing the photonic energy coming from the sunlight with the aim of turning it into electrical or chemical energy. Whereas, growing concerns regarding energy and environmental problems have stimulated extensive researches on solar energy utilizations. Among them, various strategies are explored for photocatalytic hydrogen production for fuel cells and/or degradation of organic dyes using semiconductor photocatalysts. From the point of view of the materials, photocatalysts require a series of characteristic properties depending on their applications, including particle size, specific surface area or space between the electronic levels, among others [1]. In recent years’ energy conversion devices based on organic semiconductors are an emerging research field with substantial future prospects and it has attracted great attention due to the advantages of light weight, flexibility, and low cost of production with the possibility of fabricating large area devices based on solution processing. Polymeric materials have been the subject of intense scientific and technological research because of their potential applications. In particular, conducting polymers have been extensively investigated in the area of electronics and optoelectronics due to their attractive properties. Polymeric dielectric materials have been preferred because of their dielectric and physical properties over a wide range of temperatures and frequencies [2]. Polymers have drawn a considerable interest in device fabrication because of their extraordinary inherent properties, like easy processability, flexibility, high mechanical strength, etc. The electrical and optical properties of polymers can be tailored to a desired limit through suitable doping. Further, polymers, on doping with noble metal nanoparticles, show novel and distinctive properties obtained from unique combination of the inherent characteristics of polymers and novel properties of metal nanoparticles. Due to this exclusive combination, polymer–metal nanocomposites are considered as advantageous candidates for device applications in various fields, like optics, mechanics, electronics, etc. It opens a new gateway in developing the materials for improved performance in many potential applications like optical devices, biomedical sciences, coating materials and SERS based sensors etc. However, the utility of these nanocomposites in various technological applications is limited due to their synthesis method. Several physical and chemical methods have been reported for the synthesis of different metal-polymer nanocomposites, but the precise control on the size, shape and uniform distribution of embedded nanoparticles in the host matrix is difficult to achieve [3]. The studies of metal oxide nanoparticles/Polymer nanocomposites are generating increasing interest due to their potential applications in household electronics, recording heads, memory and microwave devices. The addition of inorganic nanoparticles to polymers allows the modification of the polymer physical properties as well as the implementation of new features in the polymer matrix [4]. Critical infrastructures, including highways, buildings,bridges, aircraft, ships, and pipelines, form the lifeline ofeconomic and industrial hubs and are sometimes subjected tosevere loading conditions due to extreme events such asearthquakes, hurricanes, and other natural disasters duringtheir lifetime. To prevent catastrophic failures and subsequentloss of life, it is essential to continuously monitor the state of thestructure and identify any initiation of damage in real time byusing structural health monitoring (SHM) techniques, inparticular strain sensing. SHM provides an autonomousway of tracking changes in the system in real time using acombination of instrumentation systems and analytical methods. Instrumentation systems consist primarily of transducers to measure physical quantities, such as strain, displacement, and acceleration, which can give insight into the behavior of structures. Among the quantities of interest for SHM, strain is a local and direct measure of the state of the structure and is thus widely used as a reliable indicator of the damage induced in the structure. Hence, strain sensors are used extensively in SHM applications. Strain gauges or transducers can be broadly classified into optical sensors, resistance-based sensors, and piezoelectric sensors. Among them, resistance-based sensors form the major portion of commercially available foil strain-gauge sensors [5].

Theoretical Part

The dielectric constant (έ) of (PS-CuO) nanocompositesis defined by the following equation [6-9]:

$$\acute{\varepsilon}=\frac{C_p}{C_\circ} \quad (1)$$

where, C_p is parallel capacitance and C_o is vacuum capacitor.
The dielectric loss (ε″) of nanocompositesis determined by the following equation [10,11]:

$$\varepsilon''=\acute{\varepsilon}\, D \quad (2)$$

where, D: is dispersion factor.
The A.C electrical conductivity of (PS-CuO) nanocomposites is determined by the equation [12, 13]:

$$\sigma_{A.C}=w\,\varepsilon''\varepsilon_o \quad (3)$$

where, w is the angular frequency.

2. EXPERIMENTAL PART

The films of (PS-CuO) nanocompositeswere prepared by dissolving 2 gm of polystyrenein 20 ml of chloroform by using magnetic stirrer for 1 hour to obtain more homogeneous solution. The nanocomposites were prepared with different concentrations of copper oxide (CuO) nanoparticles are (4, 8 and 12) wt.%. The samples of (PS-CuO) nanocomposites were prepared by using casting method. The samples were prepared with thickness range (200-270) μm. The dielectric properties of (PS-CuO) nanocompositessamples measured in frequency range from 100 Hz to 5×10^6 Hz by using LCR meter type (HIOKI 3532-50 LCR HI TESTER). The pressure sensor test of nanocomposites examined by measuring the resistance between two electrodes on the top and bottom of the sample for different pressures range (80-200) bar.

3. RESULTS AND DISCUSSION

The variation of dielectric constant, dielectric loss and AC electrical conductivity with frequency are shown in Figures 1-3 respectively. The rapid decrease in the dielectric constant noticed over the low frequency range 100 -100 kHz may be attributed to the tendency of dipoles in macromolecules to orient themselves in the direction of the applied field in the low frequency range. However, in the high frequency range the dipoles will hardly be able to orient themselves in the direction of the applied field, and hence the value of the dielectric constant decreases. The increase of AC electrical conductivity with frequency is common for polymeric and semiconductor samples. As the filler concentration is increased, the inorganic filler molecules start bridging the gap separating the two localized states and lowering the potential barrier between them, thereby facilitating the transfer of charge carrier between two localized states. The frequency dependent conductivity is caused by the hopping of charge carriers in the localized state. The term hopping refers to the sudden displacement of charge carriers from one position to another neighboring site and, in general, includes both jumps over a potential barrier and quantum mechanical tunneling [14]. From the Figures 1-3, the dielectric constant, dielectric loss and AC electrical conductivity of polystyrene are increasing with increase in CuO nanoparticles concentrations, this behavior due to the enhancement of the mobility of charge ions and the larger number of charge carriers in polystyrene [15] as shown in Figure 4.

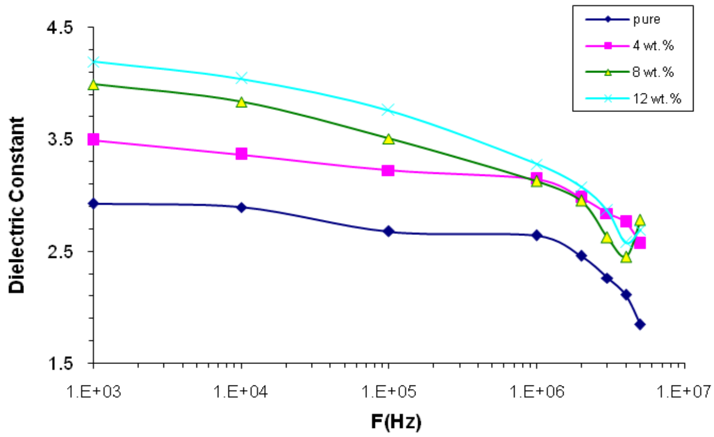

Figure 1. Variation of dielectric constant for (PS-CuO) nanocomposites with frequency

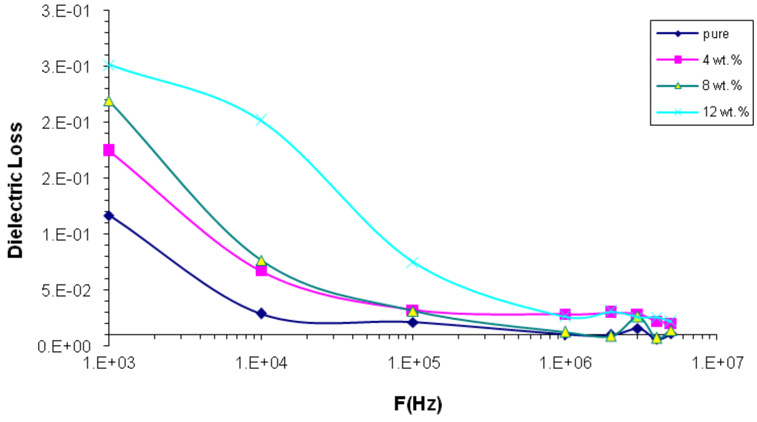

Figure 2.Variation of dielectric loss for (PS-CuO) nanocomposites with frequency

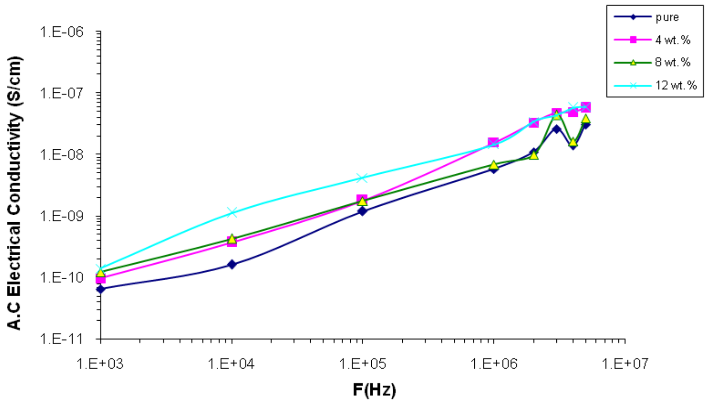

Figure 3.Variation of electrical conductivity for (PS-CuO) nanocomposites with frequency

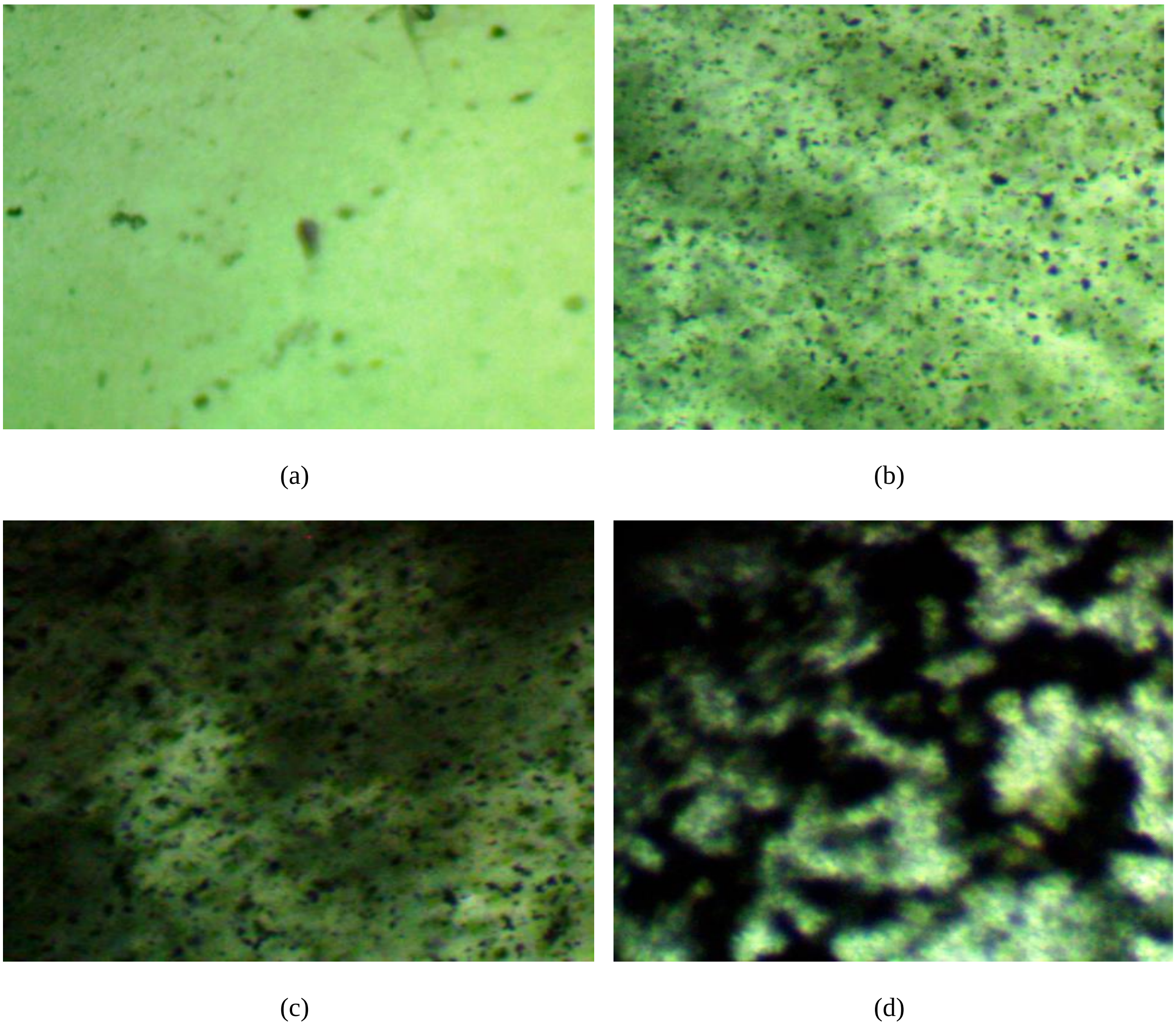

Figure 4. Photomicrographs (x10) for of (PS-CuO) nanocomposites: (a) For pure (b) For 4 wt.% CuO nanoparticles (c) For 8 wt.% CuO nanoparticles (d) For 12 wt.% CuO nanoparticles

Figure 5 shows the variation of electrical resistance for (polystyrene- copper oxide) nanocomposites with pressure. The electrical resistance decreases with increase in pressure. The decrease of electrical resistance as frequency increases may be explained as: the sample consists of multiple interlocking domains which have positive and negative charges. These domains are symmetrical within the sample, with the result that the sample has a net charge of zero. When a stress is applied to the sample this symmetry is broken, and in order to restore the symmetry these domains realign themselves, and through the realignment, generate a current and the resistance will be decreased [16, 17].

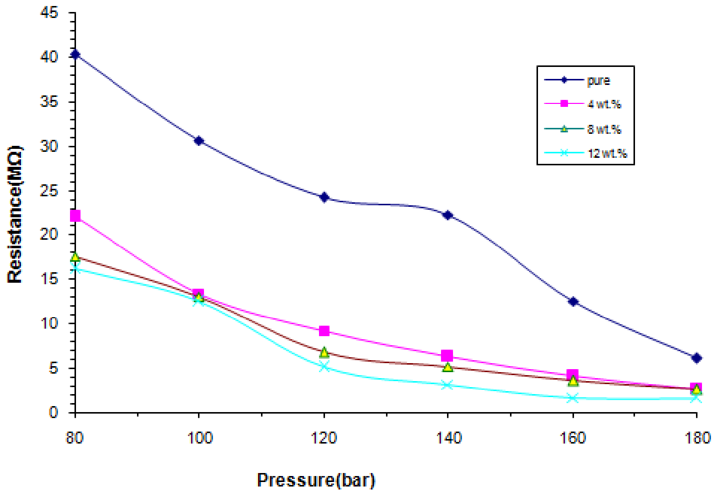

Figure 5. Variation of electrical resistance for (PS-CuO) nanocomposites with pressure

4. CONCLUSIONS

The dielectric parameters (dielectric constant, dielectric loss and A.C electrical conductivity) of (PS-CuO) nanocomposites are increasing with increase of the CuO nanoparticles concentrations. The dielectric constant and dielectric loss of (PS-CuO) nanocomposites decrease with increase in frequency while the A.C electrical conductivity increases with increase in frequency. The (PS-CuO) nanocomposites have highly sensitive for pressure. The electrical resistance of nanocomposites decreases with increase in pressure.

REFERENCES

[1] N.G. Imam, Mohamed Bakr Mohamed, Environmentally friendly $Zn_{0.75}Cd_{0.25}S$/PVA heterosystemnanocomposite: UV-stimulated emission and absorption spectra, *Journal of Molecular Structure*, Vol.1105 (2016): 80-86.
[2] M. Obula Reddy and B. Chandra Babu, Structural, Optical, Electrical, and Magnetic Properties of PVA:Gd^{3+} and PVA:Ho^{3+} Polymer Films, *Indian Journal of Materials Science*, Vol.2015, Article ID 927364, 8 pages.
[3] Rishi Pal Chahal, Suman Mahendia, A.K. Tomar, Shyam Kumar, Optical and structural properties of gamma irradiated PVA/Ag nanocomposite films, *Appl. Sci. Lett*., Vol. 2, No. 2, (2016).
[4] Alaa J. Kadham, Dalal Hassan, Najlaa Mohammad, Ahmed Hashim, Fabrication of (Polymer Blend-magnesium Oxide) Nanoparticle and Studying their Optical Properties for Optoelectronic Applications, *Bulletin of Electrical Engineering and Informatics (BEEI)*, March 2018; Vol. 7, No. 1: 28-34.
[5] A. Hashim,A. Hadi, synthesis and characterization of novel piezoelectric and energy storage nanocomposites: biodegradable materials–magnesium oxide nanoparticles, *Ukrainian JournalofPhysics*, Vol. 62, No.12, (2017).
[6] V.P. Meshram, B.M. Suryavanshi, electrical characterization of pure and doped with ferric chloride polyvinyl alcohol thin films, *International Journal of Advances in Science Engineering and Technology*, ISSN: 2321-9009 Special Issue-1, (2015): 207-211.
[7] Dalal Hassan, Ahmed Hashim, Synthesis of (Poly-methyl Methacrylate-lead Oxide) Nanocomposites and Studying their A.C Electrical Properties for Piezoelectric Applications, *Bulletin of Electrical Engineering and Informatics (BEEI)*. December 2018; Vol. 7, No. 4, (2018): 547-551.
[8] Ahmed Hashim and Qassim Hadi, Novel of (Niobium Carbide/Polymer Blend) Nanocomposites: Fabrication and Characterization for Pressure Sensor, *Sensor Letters*, Vol.15, (2017).
[9] Ahmed Hashim and Aseel Hadi, Novel Pressure Sensors Made From Nanocomposites (Biodegradable Polymers–Metal Oxide Nanoparticles): Fabrication And Characterization, *Ukrainian Journal of Physics*, Vol. 63, No. 8, (2018).
[10] I. R. Agool, F. S. Mohammed and A. Hashim, The Effect of Magnesium Oxide Nanoparticles on the Optical and Dielectric Properties of (PVA-PAA-PVP) Blend, *Advances in Environmental Biology*, Vol.9, No.11, (2015).
[11] A. Hashim, A. Hadi, synthesis and characterization of novel piezoelectric and energy storage nanocomposites: biodegradable materials–magnesium oxide nanoparticles, *Ukrainian Journal of Physics*, Vol. 62, No.12, (2017).

[12] M. A. Habeeb, A. Hashim, and A. Hadi, Fabrication of New Nanocomposites: CMC-PAA-PbO_2 Nanoparticles for Piezoelectric Sensors and Gamma Radiation Shielding Applications, *Sensor Letters*, Vol. 15, No.9, PP. 785–790, (2017).
[13] B. Unal, M. S. Toprak, Z. Durmus, H. So¨zeri, A. Baykal, Synthesis, structural and conductivity characterization of alginic acid–Fe3O4 nanocomposite, *J. Nanopart. Res*., DOI 10.1007/s11051-010-9898-1, (2010).
[14] R. Divya, M. Meena, C. K. Mahadevan and C. M. Padma, Investigation on CuO Dispersed PVA Polymer Films", *Journal of Engineering Research and Applications*, Vol. 4, Issue 5, (2014): 1-7.
[15] Ahmed Hashim, Ibrahim R. Agool and Kadhim J. Kadhim, Novel of (Polymer Blend-Fe_3O_4) Magnetic Nanocomposites: Preparation and Characterization for Thermal Energy Storage and Release, Gamma Ray Shielding, Antibacterial Activity and Humidity Sensors Applications, *Journal of Materials Science: Materials in Electronics*, DOI 10.1007/s10854-018-9095-z, (2018).
[16] Ahmed Hashim and Aseel Hadi, A Novel Piezoelectric Materials Prepared from (Carboxymethyl Cellulose-Starch) Blend-Metal Oxide Nanocomposites, *Sensor Letters*, Vol. 15, (2017).
[17] Ahmed Hashim, Majeed Ali Habeeb, Aseel Hadi, Qayssar M. Jebur, and Waled Hadi, Fabrication of Novel (PVA-PEG-CMC-Fe_3O_4) Magnetic Nanocomposites for Piezoelectric Applications, *Sensor Letters*, Vol. 15, (2017).