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Enhancement of Structural and Dielectric Properties of PVA–$BaTiO_3$–CuO Nanostructures for Electronic and Electrical Applications

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In this work, we study the effect of the barium titanate oxide and copper oxide nanoparticles (NPs) on polyvinyl alcohol (PVA) with different weight percentages (0, 2, 4, 6 wt.%). The solution casting technique is used to make the samples. Images taken with an optical microscopy reveal that the distribution of NPs in the mixture is homogeneous, and $BaTiO_3$–CuO NPs exist in a continuous network within the, polymer at the concentration of 6 wt.%. FTIR spectra, display a variation in bonds' positions and intensity. This indicates the non-chemical interaction between the polymer and $BaTiO_3$–CuO NPs. The experimental results show, when the concentration of $BaTiO_3$–CuO NPs within the samples rises, their dielectric constant and dielectric loss are increased, while they are decreased by increasing of frequency. A.C. electrical conductivity is increased with increasing of frequency and concentration of $BaTiO_3$–CuO NPs. Finally, the results show that the PVA–$BaTiO_3$–CuO nanostructures may be useful in a variety of nanoelectronics devices.

У даній роботі досліджено вплив наночастинок (НЧ) оксиду титанату Барію та оксиду Купруму на полівініловий спирт (ПВС) із їхніми різними масовими частками (0, 2, 4, 6 мас.%). Для виготовлення зразків використовувалася техніка лиття з розчину. Зображення, одержані за допомогою оптичної мікроскопії, показують, що розподіл НЧ у суміші був однорідним, а НЧ $BaTiO_3$–CuO у концентрації 6 мас.% розташовуються у неперервній сітці всередині полімеру. Спектри інфрачервоної спектроскопії на основі Фур'є-перетвору відображають зміну положення та інтенсивности зв'язків. Це свідчить про нехемічну взаємодію між полімером і НЧ $BaTiO_3$–CuO. Експериментальні результати показують, що зі збільшенням концентрації НЧ $BaTiO_3$–CuO у зразках збільшуються їхні діелектрична проникність і діелектричні втрати, та вони зменшуються зі збільшенням частоти. Електропровідність змінного струму зростає із збільшенням частоти та концентрації НЧ $BaTiO_3$–CuO. Нарешті, результати показують, що наноструктури ПВС–$BaTiO_3$–CuO можуть бути корисними в різних пристроях наноелектроніки.

Key words: nanocomposites, barium titanate oxide, copper oxide, FTIR, dielectric properties.

Ключові слова: нанокомпозити, оксид титанату Барію, оксид Купруму, інфрачервона спектроскопія на основі Фур'є-перетвору, діелектричні властивості.

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1. INTRODUCTION

The use of nanocomposites (NCs) has become more popular lately. Ingenious synthetic methods are now being used to bring the anon structures under control. Nanocomposites materials have unique properties that are influenced by both their parent materials' and the nanocomposites' morphology and interfacial features. Unlike atoms, molecules, or bulk matter, anon materials have distinct physical properties [1, 2], and added chemically features of a biological nature. It is feasible to alter the melting point, magnetic characteristics, charge capacity, and even colour of materials without altering their chemical compositions by forming nanoparticles (NPs) and, then, applying them to the materials [3, 4].

Nanotechnology typically involves the creation of materials or devices with dimensions between 1 and 100 nm in at least one dimension. Both the top-down and bottom-up approaches to nanotechnology are used with the former involving the modification of existing large structures to the minor design (such as photonic applications in nanoelectronics and nanoengineering) and the latter more closely resembling biology [5, 6].

Research in nanotechnology is massive because of it will be important to society in the 21st century. It is possible that brand-new software may soon be accessible. Nanotechnology has many potential uses because applications with nanoscale structural characteristics have physical, chemical, and biological properties that are quite different from their macroscopic counterparts [7, 8].

Polyvinyl alcohol (PVA) was one of the first commercially available polymers and finds widespread usages today in a variety of semi-conductor-related applications. PVA dissolves rapidly and completely in water. Hydroxyl groups are common in organic compounds [9]. Many different types of nanoparticles find the PVA to be an ideal host media. Motivating this effort is the hope of fabricating ultra-transparent films with superior optical properties. Flexibility is exceptional, and dielectric strength is very strong, thus, they have gained a lot of attention due to their excellent dielectric qualities. Nanocomposite films of polymer and ceramic, to wit, gains have been made in transducers, interest due to the widespread usage of the ferroelectric ceramic powder barium titanate ($BaTiO_3$) [10, 11]. Copper oxide is a very significant metal oxide. Superconductivity at high temperatures, electronic correlations, and non-toxicity are just a few of the impressive physical features of CuO, the simplest member of the family of copper compounds. The very tiny band gap in its crystal structure gives it intriguing photovoltaic and photoconductive capabilities [12, 13].

2. EXPERIMENTAL WORK

The casting process was used to create the (polyvinyl alcohol, barium titanate oxide and copper oxide) nanocomposites. They were made by dissolving 1 g of PVA in 40 millilitres of distilled water at 70 degree Celsius by using a magnetic stirrer for 45 minute. The $BaTiO_3$–CuO nanoparticles add to the polymer with different concentrations (0, 2, 4, and 6 wt.%). Container for the solution was a Petri dish drying takes three days at room temperature. The samples were examined using a Nikon-73346 optical microscope, a kind popularized by the Olympus brand, with a magnification capability of (×10) and a camera for microscopic photography. Fourier transform infrared spectroscopy (Bruker, German origin, type vertex-70) is used to investigate PVA–$BaTiO_3$–CuO NCs in the wave number range 1000–4000 cm^{-1}. In the frequency range from 100 Hz to 5 MHz, the dielectric properties of PVA–$BaTiO_3$–CuO nanocomposites were measured using an LCR Meter.

To get the dielectric constant (ε'), we use equation [14, 15]

$$\varepsilon' = C_p/C_0, \tag{1}$$

where C_p signifies capacitance; C_0 is a vacuum capacitor.

Dielectric loss (ε'') is given by [24]:

$$\varepsilon'' = \varepsilon' D, \tag{2}$$

where D is displacement.

The A.C. electrical conductivity is computed as follows [16, 17]:

$$\sigma_{\text{A.C.}} = \omega \varepsilon_0 \varepsilon'', \tag{3}$$

where ω is the angular frequency.

3. RESULTS AND DISCUSSION

Figure 1 shows the optical microscopy images of PVA–$BaTiO_3$–CuO nanocomposite samples at different concentrations with ×10 magnification. Images (*a*, *b*, *c*, and *d*) demonstrate, however, that there is noticeable variation among the specimens: when the barium titanate oxide and copper oxide nanoparticles' concentration reaches 3 wt.% for PVA–$BaTiO_3$–CuO nanocomposites, the nanoparticles arrange themselves in a continuous network. This path network spans the nanocomposites and allows electric current to flow between them [20, 21].

The atomic or ionic interactions in PVA–$BaTiO_3$–CuO nanocomposites have been studied using Fourier transform infrared spec-

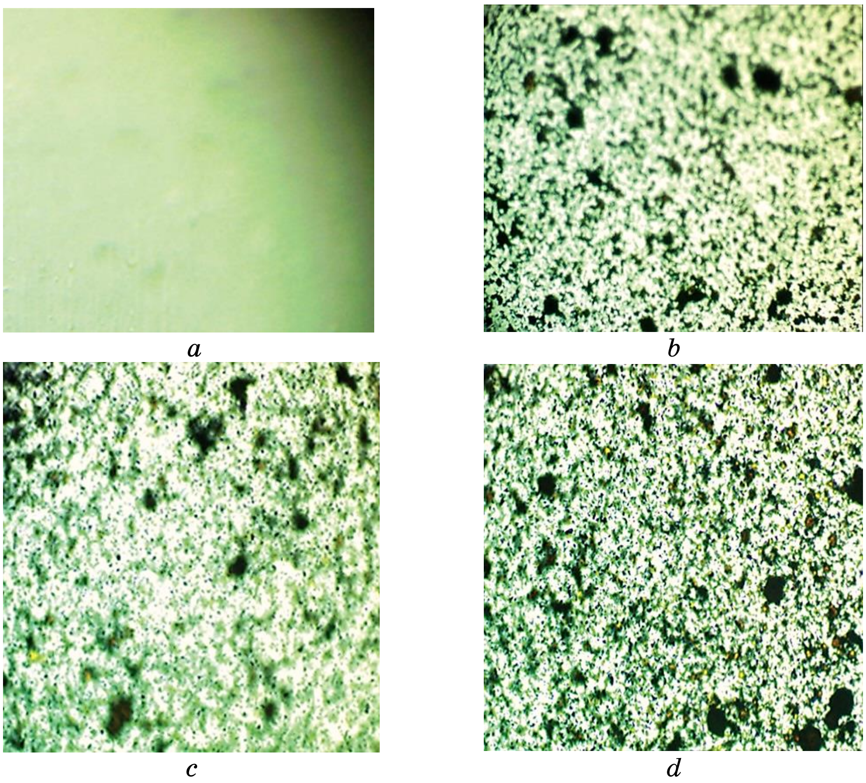
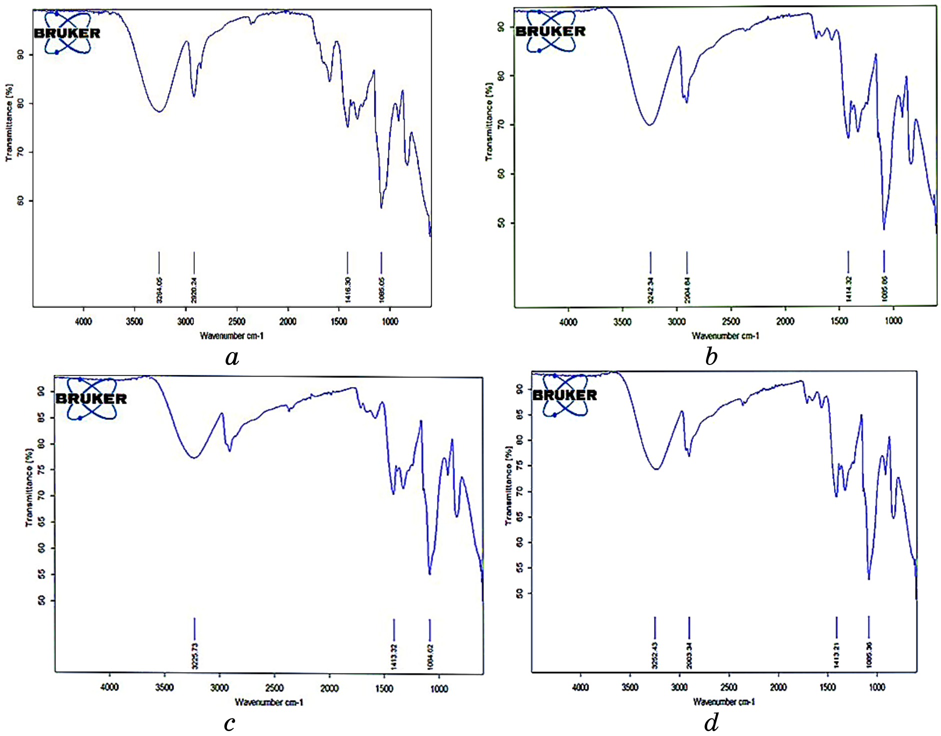


Fig. 1. The photomicrographs (×10) for PVA–$BaTiO_3$–CuO nanocomposites: (*a*) for PVA; (*b*) for 2 wt.% of $BaTiO_3$–CuO; (*c*) for 4 wt.% of $BaTiO_3$–CuO; (*d*) for 6 wt.% of $BaTiO_3$–CuO.



a *b*

c *d*

Fig. 2. FTIR spectra for PVA–$BaTiO_3$–CuO nanocomposites: (*a*) for PVA; (*b*) for 2 wt.% of $BaTiO_3$–CuO; (*c*) for 4 wt.% of $BaTiO_3$–CuO; (*d*) for 6 wt.% of $BaTiO_3$–CuO.

troscopy (FTIR) (see Fig. 2). Their state may change as a result of these interactions.

The frequencies, at which the nanocomposites vibrate, are referred to the FTIR. Figures 2, *a*, *b*, *c*, *d* show the transmission spectra of films made of PVA–$BaTiO_3$–CuO nanocomposites with varying concentrations of $BaTiO_3$–CuO nanoparticles at ambient temperature, namely, between 400 and 4000 cm^{-1}. The stretching vibration of a hydroxyl group (OH) may be seen in the FTIR spectrum of PVA films; this may be because of the intermolecular kind of hydrogen bonding between the polymer and nanoparticles [22, 23]. At roughly 2930 cm^{-1}, you will find the band that corresponds to CH_2, an asymmetric stretching vibration. The C=O, C=C stretching modes are responsible for the 1710 cm^{-1} and 1652 cm^{-1} peaks. The wagging (CH) family has been identified as the source of the absorption peak at 1240 cm^{-1}. The PVA backbone contains carbonyl groups, which undergo C–O stretching at about 1105 cm^{-1}. Out-of-plane ring C–H bending is responsible for the in-band absorption at

962 cm^{-1}, meanwhile, pyrrolidone C=O group is represented by a band at 1698 cm^{-1} [24, 25]. FTIR spectra of interacting structures show that the vibrational band at 1698 cm^{-1} corresponds to the C=O stretching.

Barium titanate ($BaTiO_3$) is a ferroelectric ceramic powder with excellent dielectric properties, making it an attractive candidate for use as a piezoelectric transducer based on polymer nanocomposite films [26, 27].

Figure 3 demonstrates connection between dielectric constant and concentration of $BaTiO_3$–CuO nanoparticles at 100 Hz. This figure indicates that the dielectric constant increases, when weight percentages of barium titanate oxide and copper oxide rise.

This is well shown in the microscopic photos taken for samples of PVA–$BaTiO_3$–CuO nanocomposites at different concentrations. At a

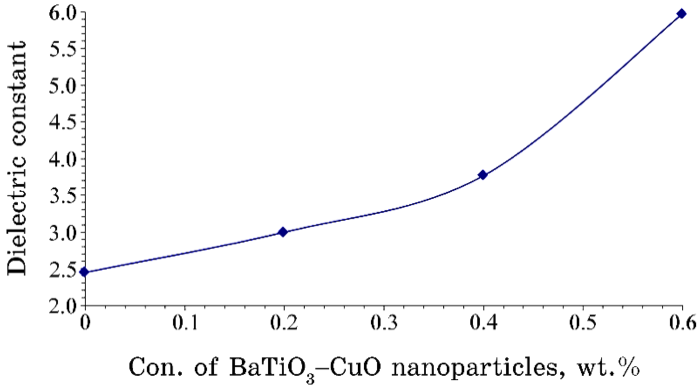


Fig. 3. Variation of the dielectric constant with concentration of $BaTiO_3$–CuO nanoparticles.

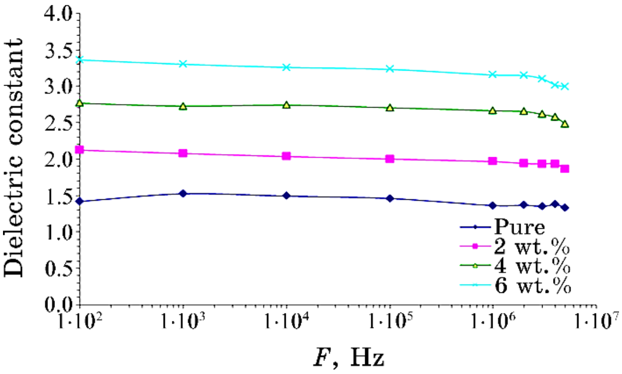


Fig. 4. Variation of the dielectric constant with frequency for PVA–$BaTiO_3$–CuO nanocomposites.

low concentration of 2 wt.%, the barium titanate oxide and copper oxide nanoparticles form a clusters or aggregates; hence, the dielectric constant is low [28, 29]. On the other hand, at high concentrations 6 wt.%, barium titanate oxide and copper oxide nanoparticles form a continuous network within the nanocomposites, so, the dielectric constant rises in proportion to the volumetric rate of the barium titanate oxide and copper oxide nanoparticles [30, 31].

Figure 4 indicates a frequency-dependent change in the dielectric constant of PVA–$BaTiO_3$–CuO nanocomposites. It is clear from the graph that, when the frequency is increased, the proportion of total polarization is contributed by the space charge decreasing, and hence, the dielectric constant values fall [32, 33].

As the frequency of the applied electric field rises, the contribution of the space charge polarization to the overall dielectric constant decreases across the board for the PVA–$BaTiO_3$–CuO nanocomposites. For the simple reason that ions are heavier than electrons, its polarization responds only minimally to changes in field frequency, whereas the other forms of polarization don't show up until later on. The electrons respond to the oscillations of the field even at too high pitch. At higher frequencies, only electronic polarization is detectable because of the small mass of electrons [34, 35].

Figure 5 presents the frequency dependence of the dielectric loss for PVA–$BaTiO_3$–CuO nanocomposites. Levels of dielectric loss are high at low applied frequency, but they drop down dramatically at higher frequencies. The drop was due to increase the space charge polarization contribution [36, 37].

Figure 6 demonstrates the impact of nanoparticles' concentration

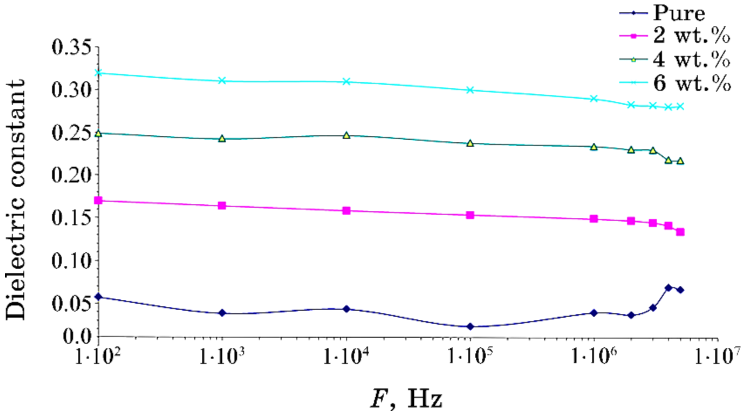


Fig. 5. The dielectric loss *versus* frequency for PVA–$BaTiO_3$–CuO nanocomposites.

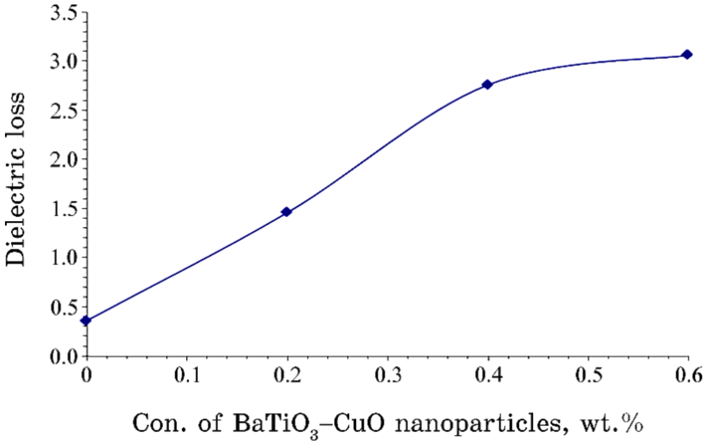


Fig. 6. Variation of dielectric loss with a concentration of nanoparticles for PVA–$BaTiO_3$–CuO nanocomposites.

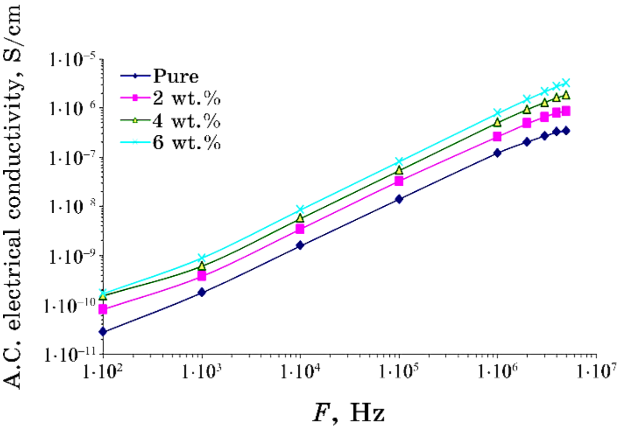


Fig. 7. Variation of A.C. electrical conductivity with frequency for PVA–$BaTiO_3$–CuO nanocomposites.

on the dielectric loss of PVA–$BaTiO_3$–CuO nanocomposites at 100 Hz. This figure shows that the dielectric loss rises with increasing of $BaTiO_3$–CuO nanoparticles. This is due to increase of the charge carriers caused by increase of nanoparticles' concentration [38, 39].

Figure 7 shows that PVA–$BaTiO_3$–CuO nanocomposites have a frequency-dependent A.C. conductivity. The observed rise in A.C. current is a result of low-frequency space charge polarization and charge carrier hopping conductivity with increasing frequency (see Fig. 7) because of charge carrier hopping and electrical polarization; high-frequency gains in conductivity are limited [40].

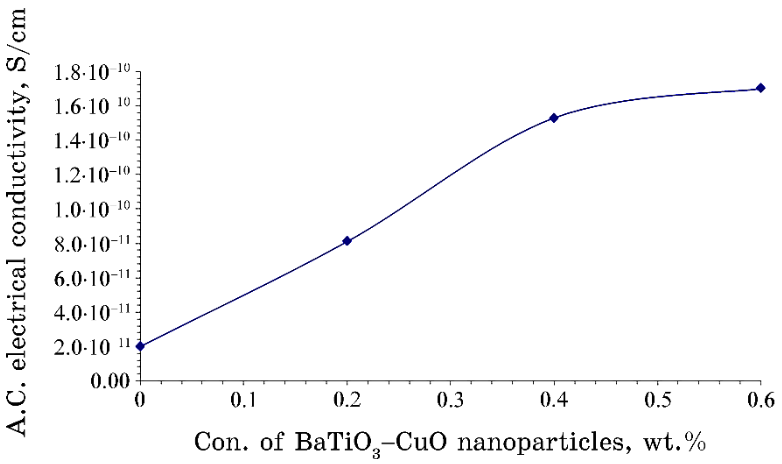


Fig. 8. Variation of the A.C. electrical conductivity with different concentrations of nanoparticles for PVA–$BaTiO_3$–CuO nanocomposites.

Figure 8 shows the relationship between A.C. electrical conductivity and $BaTiO_3$–CuO nanoparticles at 100 Hz. In this figure, we can see that the A.C. electrical conductivity increases as the nanoparticles' concentration rises. This improvement is due to the influence of space charges [41].

4. CONCLUSIONS

In this work, the fabrication of PVA–$BaTiO_3$–CuO nanocomposites has been investigated as promising materials to employ in various electronics nanodevices like sensors, electronic gates, and transistors.

Optical microscopy analysis of the nanocomposites' morphology confirmed that the polyvinyl alcohol is very malleable, as seen by the films' refined appearance and silky texture, uniform topography, and that the additive concentrations of $BaTiO_3$ and CuO NPs are uniformly dispersed across the films' upper surfaces.

The FTIR analysis showed that the $BaTiO_3$ and CuO NPs in the additive mixture had a physical effect on the polymer matrix.

The dielectric constant and dielectric loss increase with increasing of content of $BaTiO_3$–CuO nanoparticles, while they decrease with frequency. A.C. electrical conductivity increases with increasing of frequency and concentration of $BaTiO_3$–CuO nanoparticles.

As a result of these properties, the PVA–$BaTiO_3$–CuO nanocomposites have the potential to be a high-quality electronic material for the use in electrical applications.

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