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Influence of Cobalt Oxide/Zirconium Dioxide Nanoparticles on the Structural and Electrical Behaviour of PVA for Electronic Applications

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In this work, we study the effect of cobalt oxide and zirconium dioxide nanoparticles on polyvinyl alcohol with different weight percentages (0, 1, 2, 3 wt.%). Samples are prepared by using solution-casting method. The structural and dielectric characteristics of PVA–CoO–ZrO_2 nanocomposites are investigated. Optical microscope images show that the additive distribution of nanoparticles in the blend is homogeneous, and CoO–ZrO_2 nanoparticles form a continuous network inside the polymer, when the concentration reached 3 wt.%. Fourier-transform infrared-spectroscopy spectra show a shift in some bands and a change in the intensities; this indicates the considerable not chemical interaction between the polymer and CoO–ZrO_2 nanoparticles. The experimental results show that the dielectric constant and dielectric loss of PVA–CoO–ZrO_2 nanocomposites are increasing with the increase of cobalt oxide and zirconium oxide nanoparticles' concentration and are decreasing with the increase of frequency of the applied electric field; on the other hand, the A.C. electrical conductivity is increasing with the increase of frequency and concentration of nanoparticles. Finally, these results show that the PVA–CoO–ZrO_2 nanostructures may be useful in different nanoelectronic devices.

У даній роботі досліджується вплив наночастинок оксиду Кобальту та діоксиду Цирконію на полівініловий спирт (ПВС) із різним ваговим співвідношенням (0, 1, 2, 3 мас.%). Зразки готують методом лиття розчину. Досліджено структурні та діелектричні характеристики нанокомпозитів ПВС–CoO–ZrO_2. На знімках оптичного мікроскопа видно, що адитивний розподіл наночастинок у суміші є однорідним, а наночастинки CoO–ZrO_2 утворюють безперервну мережу всередині полімеру, коли концентрація досягла 3 мас.%. Спектри інфрачервоної спектроскопії на основі перетворення Фур'є показують зсув деяких смуг і зміну інтенсивностей; це вказує на значну нехемічну взаємодію між полімером і наночастинками CoO–ZrO_2. Результати експериментів свідчать, що діелектрична проникність і діелектричні втрати нанокомпозитів ПВС–CoO–ZrO_2 зростають зі збільшенням концентрації наночастинок оксиду Кобальту й оксиду Цирконію та зменшуються зі збільшенням частоти прикладеного електричного поля; з іншого боку, електропровідність змінного струму зростає зі збільшенням частоти та концентрації наночастинок. Нарешті, ці результати показують, що наноструктури ПВС–CoO–ZrO_2 можуть бути корисними в різних пристроях наноелектроніки.

Key words: nanocomposites, cobalt oxide, zirconium oxide, FTIR, dielectric properties.

Ключові слова: нанокомпозити, оксид Кобальту, оксид Цирконію, інфрачервона спектроскопія на основі перетворення Фур'є, діелектричні властивості.

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1. INTRODUCTION

Nanocomposites (NCs) have garnered a lot of attention recently. It takes a lot of effort to alter the anon structures utilizing cutting-edge synthetic methods. The qualities of nanocomposites materials depend on their morphology and interfacial properties in addition to the characteristics of their individual parents. Anon materials differ from discrete atoms, molecules, or general substances in terms of their physical, chemical, and biological properties. Producing nanoparticles (NPs) allows for the modification of materials' fundamental properties without changing their chemical makeup, including melting point, magnetic properties, charge capacity, and even colour [1, 2]. In general, nanotechnology involves the development of materials or devices having dimensions that fall within the range of 1–100 nm in at least one dimension. Bottom-up, which entails transforming individual atoms and molecules into nanostructures and is more similar to biology, or top–down, which entails shrinking the size of large structures to the minor design, such as photonic applications in nanoelectronics and nanoengineering, are both methods used in nanotechnology [3, 4].

Nanotechnologies are essential 21st-century technologies, and tremendous research effort is put out in this area. Possibly, new applications will be made accessible soon [5]. Because applications with structural features at the nanoscale level have physical, chemical, and biological capabilities that differ noticeably from those of their macroscopic counterparts, nanotechnology is advantageous in many ways [6]. One of the first and best-selling polymers, polyvinyl alcohol (PVA), is still widely utilized in a variety of applications, including semiconductors. PVA is readily soluble in water and in organic compounds that contain hydroxyls [7–9]. The development of cobalt nanoparticle powders (CoO) has received constant attention in recent years due to their excellent potential for usage as rechargeable batteries, ceramic pigments, catalysts, magnetic materials, gas sensors, and solar energy absorbers [10, 11]. Due to its excellent mechanical and aesthetically pleasing outcomes, zirconium oxide (ZrO_2) is one of the most promising restorative materials. Zirconium oxide, sometimes known as ZrO_2, is a chemical with significant technical consequences. It offers outstanding corrosion resistance, high strength, toughness during transformation, and exceptional chemical and microbiological resistance [12]. Future nonelectric devices may use ZrO_2 as an important dielectric material for transistor insulators [13].

2. EXPERIMENTAL WORK

Nanocomposites were produce from polyvinyl alcohol and cobalt oxide–zirconium oxide NPs using the casting technique, which involved dissolving polyvinyl alcohol in 40 ml of distilled water for 45 minutes while stirring with a magnetic stirrer at temperature 70°C to achieve a more homogeneous solution. A Petri plate was used to store the fluid. After drying the fluid gradually over three days at room temperature, polymer mix nanocomposites were produced. The PVA–CoO–ZrO_2 NCs from the petri dish were taken out and used for tests. Using an optical microscope of the Olympus model Nikon-73346 with a ×10 magnification and a camera for microscopic photography, samples were tested at various concentrations. The Fourier transform infrared spectroscopy in the wave number range 1000–4000 cm^{-1} is used to study PVA–CoO–ZrO_2 NCs (Bruker Company, German origin, type vertex-70). LCR meters were used to measure the PVA–CoO–ZrO_2 nanocomposites' dielectric properties in the frequency range (100 Hz to 5 MHz). The equation was used to compute the dielectric constant [14, 15]:

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

where C_p is capacitance and C_0 is a vacuum capacitance. The dielectric loss can be calculated using the equation [16]

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

where D is displacement. A.C. electrical conductivity calculated from these equations [17, 18]:

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

where ω is the angular frequency ($\omega = 2\pi f$).

3. RESULTS AND DISCUSSION

Figure 1 displays images of PVA–CoO–ZrO_2 nanocomposites' films that were photographed for samples at various concentrations (1) ×10. However, as seen in the pictures, the samples were substantially dissimilar from one another *a*–*d*. When the concentration of cobalt oxide and zirconium oxide nanoparticles inside polyvinyl alcohol films reaches weight percent of 3 wt.% for PVA–CoO–ZrO_2 nanocomposites, a continuous network is formed. Charge carriers can move through the nanocomposites due to the network of channels that run through them [19, 20].

As seen in Fig. 2, FTIR has been used to investigate the interactions between atoms or ions in the PVA–CoO–ZrO_2 nanocomposites. These interactions may alter the vibrational modes of the nanocomposites [21]. The FTIR transmittance spectra of films formed of PVA–CoO–ZrO_2 nanocomposites with different ratios of CoO–ZrO_2 nanoparticles are shown in Fig. 2, *a*–*d*. These spectra were collected in the 400–4000 cm^{-1} region at ambient temperature. The intermolecular form of hydrogen bonding between the polymer and the nanoparticles may be the origin of the stretching vibration of the hydroxyl group OH of PVA, which is given a broad band of roughly 3300 cm^{-1} in the FTIR spectra of PVA films [22].

The band corresponding to the asymmetric stretching vibration of CH_2 can be observed at 2930 cm^{-1}. The peaks at 1710 and 1652 cm^{-1} have been linked to the C=O, C=C stretching mode. The absorption

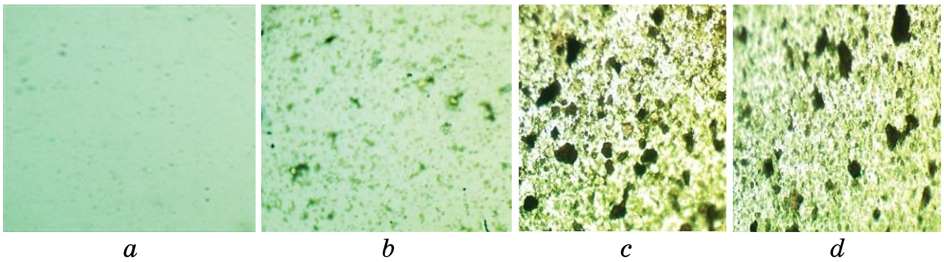

Fig. 1. Display photomicrographs (×10) of PVA–CoO–ZrO_2 nanocomposites in the following configurations: (*a*) for PVA; (*b*) for 1% CoO–ZrO_2; (*c*) for 2% CoO–ZrO_2, and (*d*) for 3% CoO–ZrO_2.

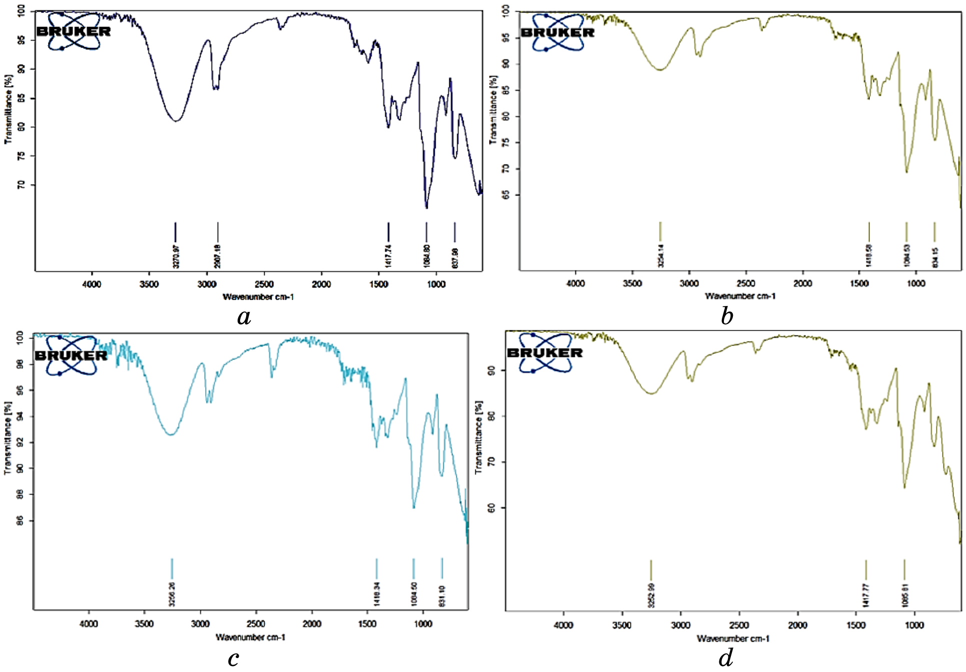

Fig. 2. The FTIR spectra for the PVA–CoO–ZrO_2 nanocomposites (*a*) for PVA mix (*b*) for CoO–ZrO_2 at 1%, (*c*) for CoO–ZrO_2 at 2%, and (*d*) for CoO–ZrO_2 at 3%.

peak at 1240 cm^{-1} has been ascribed to the wagging CH group [23]. The carbonyl groups on the (PVA) backbone may be seen spanning from C to O in the band at about 1105 cm1. While the C–H bending of out-of-plane rings is attributed to the absorption band at about 962 cm^{-1}. The region at 1698 cm^{-1} that corresponds to the pyrrolidone C=O group. The interactions are illustrated in the FTIR spectra of the structures at the vibrational band at 1698 cm^{-1}. CoO(OH) has a hexagonal structure, and an octahedral site containing a divalent metal cation is co-ordinated by six hydroxyl oxygen atoms [24, 25].

Figure 3 illustrates the connection between the dielectric constant and the concentration of nanoparticles at 100 Hz. This graph shows how the weight percentages of cobalt oxide and zirconium oxide enhance the dielectric constant. The cause of this rise in the composites' dielectric constant values [26]. The microscopic images of samples of PVA–CoO–ZrO_2 nanocomposites at various concentrations clearly demonstrated this. The cobalt oxide, zirconium oxide, and nanoparticles adopt the shape of clusters or separated groups at a low concentration of 1 wt.%, which causes the dielectric constant to become about low [27]. The dielectric constant rises in direct propor-

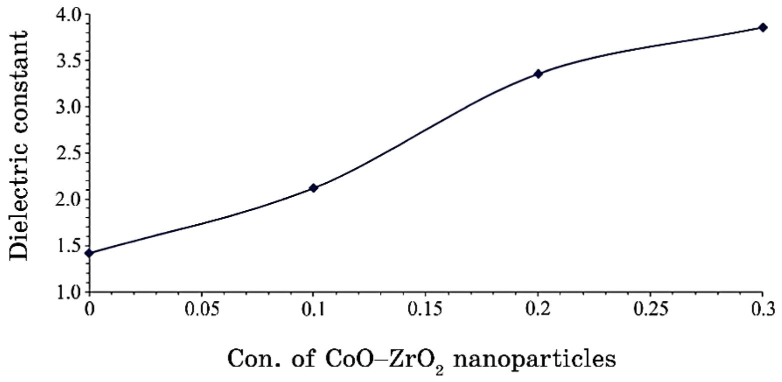

Fig. 3. The concentration of PVA–CoO–ZrO$_2$ nanocomposites affecting the dielectric constant.

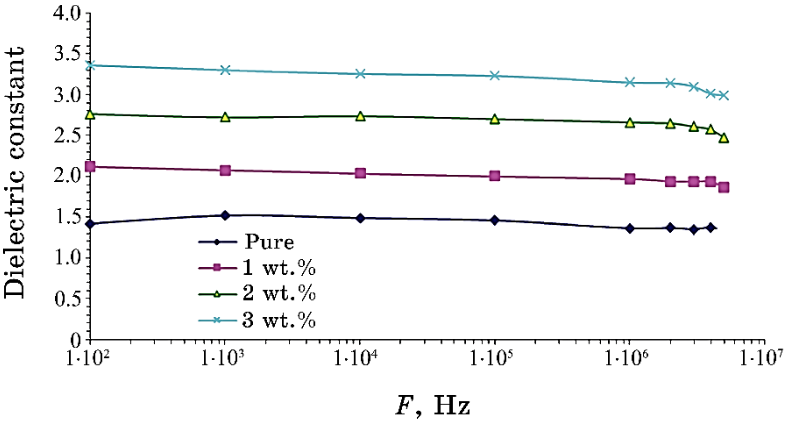

Fig. 4. The dielectric constant for PVA–CoO–ZrO$_2$ nanocomposites varying with frequency.

tion to the volumetric rate of the nanoparticles when cobalt oxide and zirconium oxide nanoparticles are present in the nanocomposites at high concentrations (3 wt.%), on the other hand [28, 29].

Figure 4 illustrates how the dielectric constant of PVA–CoO–ZrO$_2$ nanocomposites fluctuates with frequency. This graph demonstrates how the values of the dielectric constant fall as the applied frequency increases, which in turn causes the overall polarization of the space charge to drop [30]. The dielectric constant values for all samples of PVA–CoO–ZrO$_2$ nanocomposites would decrease as the electric field frequency rose because space charge polarization contributes more to the electric field at low frequencies and less to the electric field at higher frequencies. The other polarization kinds can be seen at higher frequencies [31]. The ions' masses are greater than that for electrons. Compared to an electronic polarization, it responds to changes in field frequency more strongly. Even at very high field vibration frequencies, the electrons respond. Since electrons had such a little mass at higher frequencies, only electronic polarization was conceivable [32–34].

Figure 5 shows the frequency dependence of the dielectric loss for PVA–CoO–ZrO_2 nanocomposites. The graph unequivocally demonstrates that dielectric loss values are significant at low applied frequencies, but they decline as frequency rises. This is explained by the fact that as frequency is raised, the space charge polarization contribution decreases [35–38].

Figure 6 depicts how the concentration of nanoparticles at 100 Hz affects the dielectric loss of PVA–CoO–ZrO_2 nanocomposites.

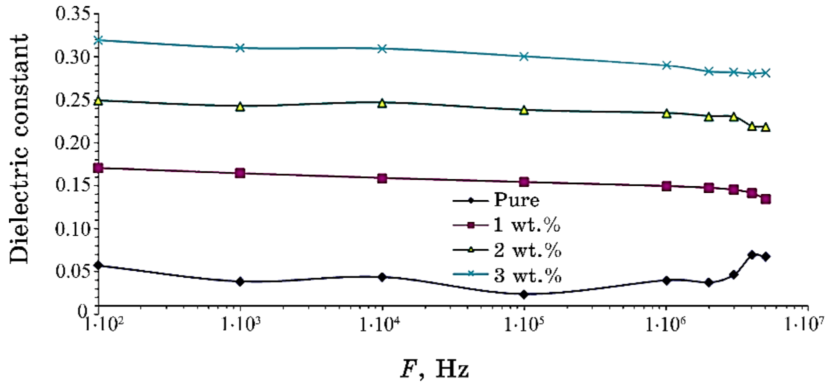

Fig. 5. The relationship between PVA–CoO–ZrO_2 nanocomposites' dielectric loss and frequency.

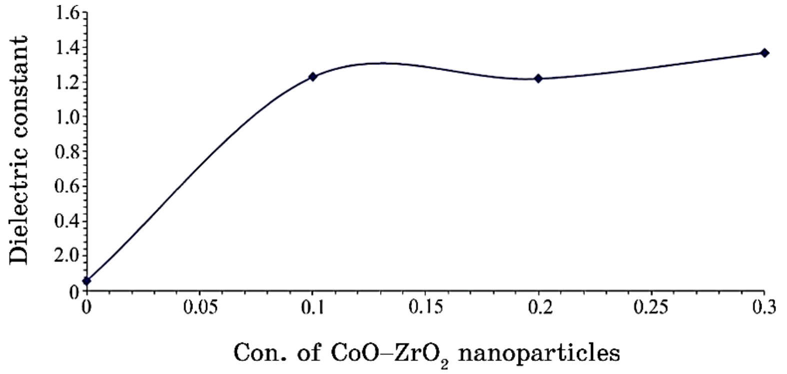

Fig. 6. The variation of dielectric loss with nanoparticle concentration for PVA–CoO–ZrO_2 nanocomposites.

This graph clearly shows how the values of the dielectric loss increase as the concentration of CoO–ZrO_2 nanoparticles increases due to an increase in charge carriers brought on by the increased concentration of nanoparticles [39, 40].

Figure 7 illustrates how the A.C. conductivity for PVA–CoO–ZrO_2 nanocomposites fluctuates with frequency. The large increase in A.C. conductivity that is depicted in the figure as frequency rises is caused by both the space charge polarization that occurs at low frequencies and the movement of charge carriers because of the hopping process [41–44]. At high frequencies, there is only a very little improvement in conductivity because of electronic polarization and hopping charge carriers [45–47].

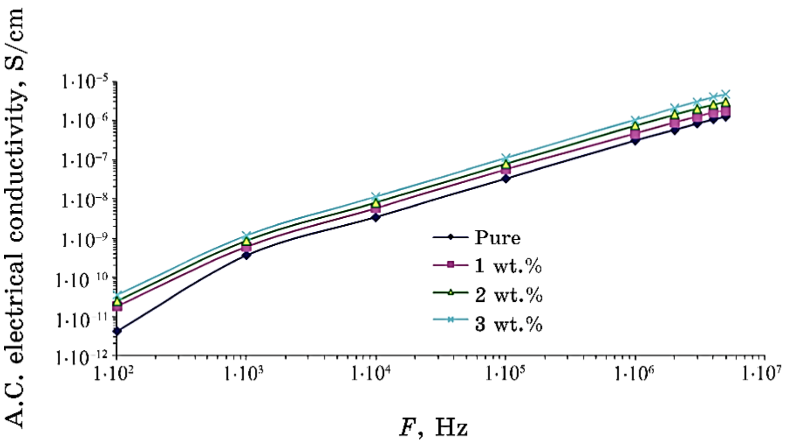

Fig. 7. The electrical conductivity of PVA–Co–ZrO_2 nanocomposites varying with frequency.

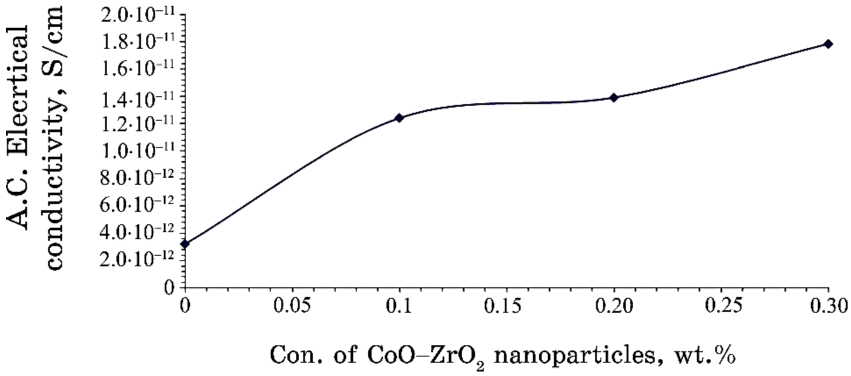

Fig. 8. Variation of the A.C. electrical conductivity with different concentrations for PVA–CoO–ZrO_2 nanocomposites.

Figure 8 displays the A.C. electrical conductivity variation with CoO–ZrO_2 nanoparticles of PVA–CoO–ZrO_2 nanocomposites at 100 Hz. This figure shows that the A.C. electrical conductivity increase with increasing of concentration of nanoparticles. This augmentation is because of the effect of the space charges [48, 49].

4. CONCLUSIONS

In this work, fabrication of PVA–CoO–ZrO_2 nanocomposites was investigated as promising materials to employ in various electronics nanodevices like, sensors, electronic gates, and transistors. The optical microscope (OM) proves the morphological properties of nanocomposites, which confirm that the polyvinyl alcohol is exceptionally miscible, as seen by its finer form and smooth, homogeneous surface, while the additive concentration CoO and ZrO_2 NPs are well distributed on the surface of the polymer blend films. The Fourier transform infrared spectroscopy (FTIR) confirmed the additive CoO and ZrO_2 NPs caused physical interaction with polymer matrix. The dielectric constant and dielectric loss of PVA–CoO–ZrO_2 decreased with increasing of frequency and increased with increasing concentration of SiC/Sb_2O_3 nanoparticles. The A.C. electrical conductivity of PVA–CoO–ZrO_2 NCs increases with increasing of frequency and concentration of SiC–Sb_2O_3 nanoparticles. Such behaviour makes it possible to be considered as excellent electronics materials for electrical applications.

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