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Enhanced Dielectric Characteristics of Cr_2O_3 Nanoparticles Doped PVA/PEG for Electrical Applications

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ABSTRACT

This study examines the dielectric properties of polyvinyl alcohol (PVA)/polyethylene glycol (PEG) doped with chromium oxide (Cr_2O_3) nanoparticles, with the aim of leveraging these properties in electronic and electric nanodevices. The effect of Cr_2O_3 nanoparticle concentration on the dielectric constant, dielectric loss, and AC electrical conductivity of the composites was systematically investigated. The results demonstrate that both the dielectric constant and dielectric loss decrease with increasing frequency, but increase with the concentration of Cr_2O_3 nanoparticles. Conversely, AC electrical conductivity was found to increase with both frequency and Cr_2O_3 nanoparticle concentration. The enhanced dielectric properties of the PVA/PEG/Cr_2O_3 nanocomposites make them suitable for various applications in the field of electronics and energy storage. The study provides new insights into the design of materials for electrical and electronics applications.

1. INTRODUCTION

Composites of polymer matrix as sustainable matters are used in large series of fields in the view of composites sufficient range of chemical structures, properties, applicability, possible reusability as one among the ability of economy and construction. Amid this materials group, it included gained significant focus relate to the rising requiringfor extra light weight and exorbitantly behavior matters. The mixing conventional polymer medium with nanosize substances as reinforcements display a broad series of additional normal characters relate to tiny size, individual shape, and great area of surface [1].

Polymer composite substances are employed in a huge variety of fields since they often possess more desirable mechanical characteristics than granular or ceramic composites, comprising improved tensile strength, elastic modulus and as a result flexibility. Composites have excellent potential for a variety of industrial applications because of their exceptional characteristics like elevated hardness, elevated melting point, lesser density, lesser coefficient of thermal expansion, elevated thermal conductivity, superior chemical stability and enhanced mechanical characteristics such as superior specific strength, enhanced wear resistance and specific modulus. Composites are utilized in making solar cells, laser diodes and light emitting diodes (LED), optoelectronic device elements, industrial applications in aircraft, military and car industry [2, 3].

Wide series of composites of polymer/nanomaterial fields has sustained to interested the researchers consideration due to their different distinguished optical, structural, mechanical and electrical characteristics [4].

PVA was employed in topical years as a easy polymer with particular characteristics including elevated chemical stability, stable of environmentally, biodegradable, optical and electric characteristics. The PVA key characteristic is semi-crystalline character is the existence of both crystalline and amorphous sections that cause effects of interfacial crystal/amorphous to raise physical properties [5].

PVA is a water soluble with good thermal and mechanical characterizations. Poly (vinyl alcohol) has broad uses in applications like electronic, building, medicine and other industries [6]. PEG is one of the mainly significant polymers relate to its exhibited attractive performances and characteristics like commercial, non toxic, and non expensive [7].

Cr_2O_3 is one of the mainly significant transition oxide as a result of its excellent catalytic, gas sensing, electrical and magnetic characteristics in addition to being one of the mainly stable coloring [8]. Nanocomposites are a navel kind of substances complete with nano-sized filler. Inorganic nanoparticles mixed among organic (polymer) are called organic/inorganic hybrids [9].

Nanocomposites based on a polymer substance with entrenched nanostructures include increased consideration ascribed to their optical, electronic, mechanical, chemical and electrical characteristics which create it can be utilize in the improvement of biomedical and industrial devices. Polymers substances consist of characteristics assemble the requests for the elastic electronics consist of less deposition temperatures, simple stage of fabricating and elevated breakdown strength. In electronics fields, polymers are typically used components. Polymers have various advantages of durability, lightweight, low cost and processability [10].

There are many studies on metal oxide and metal oxide doped polymer to employ in various applications like electronics and optoelectronics [11-17], sensors [18-25], antibacterial [26-30], thermal energy storage [31-36] and radiation shielding [37-42]. In recent years, investigations on the polymers electrical characteristics of included concerned greatly consideration for polymers applications in electronic as well as optical appliances. The polymers conduction for electricity were expansively investigated to appreciate the polymers charge transport nature [43]. This work deals with preparation of PVA/PEG/Cr_2O_3 nanocomposites films and investigating the AC electrical characteristics to employ in different electrical and electronics fields.

2. MATERIALS AND METHODS

Polyvinylalcohol(PVA)/polyethylene glycol (PEG)/chromium oxide (Cr_2O_3) nanostructures were prepared by casting method. The polymeric solution (70%PVA/30%PEG) fabricated by dissolving of 1gm in distilled water (30 ml). The Cr_2O_3 NPs added to (PVA/PEG) solution among contents (1, 2, and 3) wt.%. The dielectric characters of blend/Cr_2O_3 films measured at (f=100 Hz to 5×10^6 Hz) by LCR meter.

The dielectric constant, $\acute{\varepsilon}$ determined by [44]:

$$\acute{\varepsilon} = C_p\, d/\varepsilon_o\, A \tag{1}$$

where, C_p is matter capacitance, thickness (d in cm), A is the area (in cm^2).

Dielectric loss, ε'' is given by [45]:

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

where, D is dispersion factor.

The $A.C$ electrical conductivity is defined by [46]:

$$\sigma_{A.C} = 2\pi f\, \acute{\varepsilon}\, D\, \varepsilon_o \tag{3}$$

3. RESULTS AND DISCUSSION

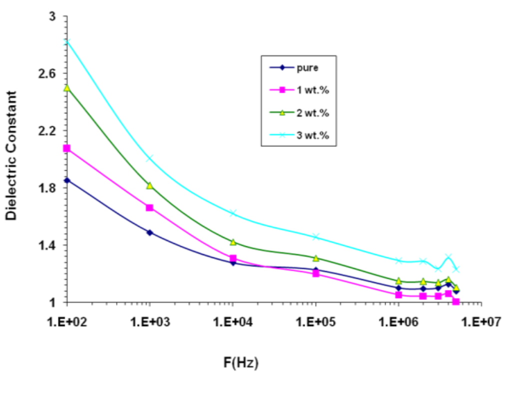

Figure 1. Variation of ε' of PVA/PEG/Cr_2O_3 films among frequency

Figures 1 and 2 display the variations of the real part (ε') and the imaginary part (ε") of the complex permittivity of PVA/PEG/Cr_2O_3 nanocomposites films, respectively, with frequency. As can be inferred from these figures, both ε' and ε" exhibit high values at lower frequencies. With an increase in frequency, a noticeable reduction in the values of ε' and ε" for PVA/PEG can be observed, an effect attributed to interfacial polarization, often referred to as the Maxwell-Wagner effect.

Further insights into the influence of Cr_2O_3 nanoparticles (NPs) content on the performance of ε' and ε" in the blend/Cr_2O_3 films are provided in Figures 3 and 4. It is quite evident from these figures that as the content of Cr_2O_3 NPs increases, there is a corresponding increase in the values of ε' and ε". This trend suggests an enhancement in the number of charge carriers induced by the Cr_2O_3 NPs [47-56].

Figures 5 and 6 illustrate the variations in the AC electrical conductivity ($\sigma_{A.C}$) of the blend/Cr_2O_3 nanocomposites films in relation to frequency and the ratio of Cr_2O_3 NPs. From these figures, it can be discerned that the σA.C values for the blend/Cr_2O_3 films increase alongside frequency and Cr_2O_3 NPs ratio. The rise in $\sigma_{A.C}$ values with frequency is associated with the hopping mechanism and polarization effect. Additionally, the increase in conductivity values with a rising additive ratio can be attributed to an increase in the number of charge carriers and the formation of a network of nanoparticles within the composite [57-64].

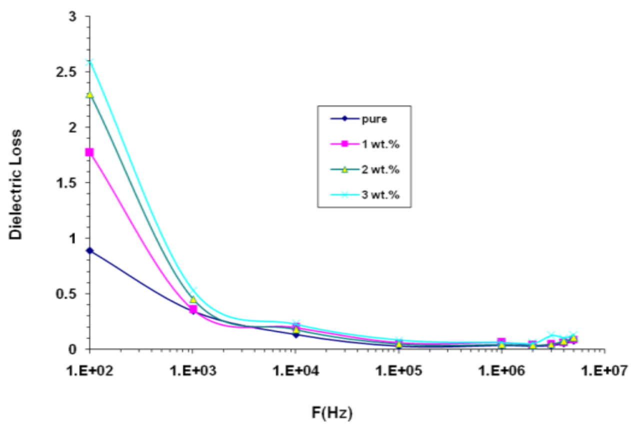

Figure 2. Variation of ε" of PVA/PEG/Cr_2O_3 films among frequency

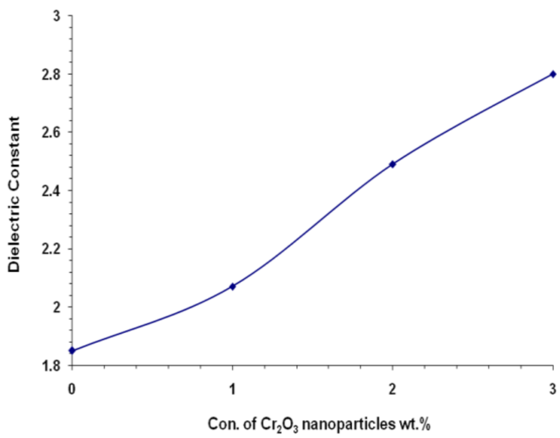

Figure 3. Performance of ε' among Cr_2O_3 NPs content of PVA/PEG/Cr_2O_3 films

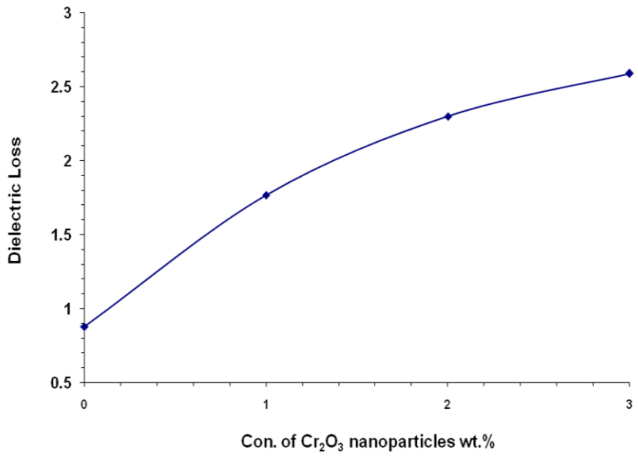

Figure 4. Performance of ε" among Cr_2O_3 NPs content of PVA/PEG/Cr_2O_3 films

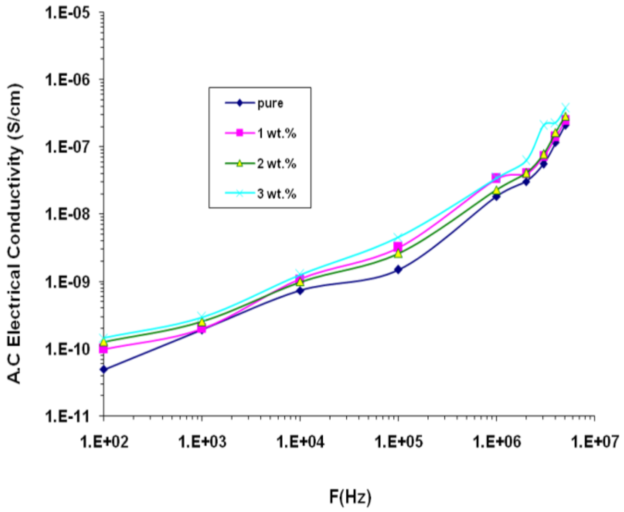

Figure 5. $\sigma_{A.C}$ behavior of PVA/PEG/Cr_2O_3 films among frequency

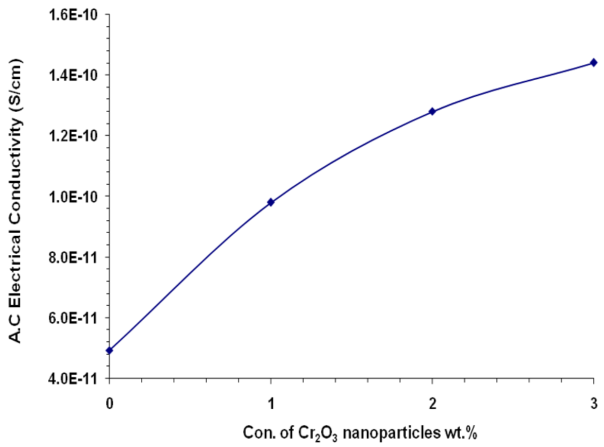

Figure 6.variation of $\sigma_{A.C}$ among Cr_2O_3 NPs content of PVA/PEG/Cr_2O_3 films

The dielectric properties of the films made from polyvinyl alcohol (PVA), polyethylene glycol (PEG), and chromium oxide (Cr_2O_3) nanoparticles were thoroughly investigated in this study. It was observed that the dielectric constant, a key parameter in understanding the electrical behavior of the PVA/PEG matrix, exhibited a notable increase with a rise in the content of Cr_2O_3 nanoparticles up to 3wt.%. Additionally, this dielectric constant showed elevated values at lower frequencies, followed by a discernible decrease as the frequency increased.

The dielectric loss, another significant property of the PVA/PEG/Cr_2O_3 nanocomposites films, was found to increase as the frequency reduced, with the highest values recorded at low frequencies. Furthermore, the dielectric loss of the polymer blend showed a noticeable increase with an augment in the content of Cr_2O_3 nanoparticles.

Another key observation was related to the AC electrical conductivity of the PVA/PEG/Cr_2O_3 nanocomposites films. It was found that the AC electrical conductivity escalated with an increase in frequency, spanning from 100Hz to 5MHz, and also with an increase in the content of Cr_2O_3 nanoparticles. This finding sheds light on the potential of these composites in applications where higher electrical conductivity is desired.

4. CONCLUSIONS

This study encompasses the formulation of nanocomposite films made from a blend of polymeric substances and chromium oxide (Cr_2O_3) nanoparticles, followed by an in-depth analysis of their dielectric characteristics. The motivation behind this research lies in the potential application of these nanocomposites in various electric and energy storage devices.

The dielectric characteristics investigated in this study include the real part (ε') and the imaginary part (ε") of the complex permittivity, along with $\sigma_{A.C}$. These parameters are essential for understanding the behavior of the materials under different electrical conditions.

When examining the results for the PVA/PEG/Cr2O3 nanocomposites films, a distinct trend was observed. The values of ε', ε", and $\sigma_{A.C}$ for the PVA/PEG blend were found to increase with the rising content of Cr_2O_3 nanoparticles. This suggests an enhancement in the composite's electrical characteristics as the nanoparticle concentration increases.

Furthermore, the study found that while ε' and ε" values of the PVA/PEG/Cr_2O_3 nanocomposites films decreased with increasing frequency, the $\sigma_{A.C}$ experienced an upward trend. This indicates a complex interplay between frequency and the dielectric properties of the material.

Taken together, these findings suggest that the PVA/PEG/Cr_2O_3 nanocomposites films could be well-suited for application in electric and energy storage fields. Their unique dielectric properties make them potential candidates for further research and development in these areas.

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