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## Effect of Ag Nanoparticles on the Dielectric Properties of PVA–PEG Polymer Blend

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Using casting technology, nanocomposites are created from a mixture of polyvinyl alcohol (PVA), polyethylene glycol (PEG) doped with silver (Ag) nanoparticles (NPs) in their different amounts: 0, 2, 4, and 6 wt.%. At frequencies ranging from 100 Hz to 5 MHz, the A.C. electrical properties of PVA–PEG–Ag nanocomposites are studied. Experimental results indicate that an increase in proportion of Ag NPs led to an increase in A.C. electrical properties of the PVA–PEG mixture, including dielectric constant, dielectric loss, and A.C. electrical conductivity. Moreover, when frequency increases from 100 Hz to 5 MHz, A.C. electrical conductivity increases, while the dielectric constant and dielectric loss decrease. The improved dielectric properties of PVA–PEG–Ag nanocomposites make them suitable for a range of electricity and energy storage applications. The study provides a new understanding of materials' design for electrical and electronic applications.

За допомогою технології лиття нанокомпозити створюються із суміші полівінілового спирту (ПВС), поліетиленгліколю (ПЕГ), легованих наночастинками срібла (Ag) у різних кількостях: 0, 2, 4 та 6 мас.%. На частотах від 100 Гц до 5 МГц досліджували електричні властивості змінного струму у нанокомпозитах ПВС–ПЕГ–Ag. Експериментальні результати показують, що збільшення частки наночастинок срібла приводить до поліпшення електричних властивостей змінного струму у суміші ПВС–ПЕГ, включаючи діелектричну проникність, діелектричні втрати й електропровідність змінного струму. Більше того, коли частота збільшується від 100 Гц до 5 МГц, електропровідність змінного струму збільшується, тоді як діелектрична проникність і діелектричні втрати зменшуються. Поліпшені діелектричні властивості нанокомпозитів ПВС–ПЕГ–Ag роблять їх придатними для широкого спектру застосувань електрики та накопичення електроенергії. Дослідження забезпечує нове розуміння розробки матеріалів для електричних і електронних застосувань.

**Key words:** polyvinyl alcohol (PVA), polyethylene glycol (PEG), silver (Ag) nanoparticles, PVA-PEG-Ag nanocomposites.

**Ключові слова:** полівініловий спирт (ПВС), поліетиленгліколь (ПЕГ), наночастинки срібла (Ag), нанокompозити ПВС-ПЕГ-Ag.

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## 1. INTRODUCTION

Recently, there has been a significant and pressing need for the synthesis of new materials with high dielectric constant and low dielectric loss for embedded microelectronic applications. Polymer composites are active materials that offer a perfect way to integrate electrical or dielectric qualities for microelectronic applications. Furthermore, there are several low-cost dielectric applications, for which they may be employed. There are several low-cost materials available; thus, great efforts are being made to locate ones that work [1, 2]. The primary reason for the extensive research on polymer nanocomposites is not their vast range of uses, but rather their physical characteristics. These studies have shown that incorporating a small percentage of the nanoparticles into the polymer matrix results in properties that are noteworthy for a variety of applications, including microwave absorbers, charge storage capacitor systems, and electrostatic dissipation [3, 4]. Due to their interesting physical and chemical properties, polymers have received a lot of attention recently. The electrical and microelectronics sectors, as well as the insulation industry, widely use polymers. There are several uses for distinct polymer films in biology, technology, and medicine, including pure and doped versions with various additives [5, 6].

Many studies have focused on PVA (doped and unsaturated) polymer films because of their inexpensive cost and outstanding durability in industry [7]. It is utilized in a variety of applications, including polymerization aids that break down polyvinyl acetate to make adhesives, paper coatings, paper adhesives, thickeners, chemical-resistant protective gloves, eye therapy, polymerization in coated nanobeads, and culinary items [8–12]. In addition to being extremely water-soluble and nontoxic, polyethylene glycol (PEG) is also very soluble in most organic solvents. Furthermore, the majority of these properties can be shared by the blended product when PEG is combined with other polymeric materials [13–16]. The resultant nanocomposite-materials' chemical and physical properties change, when metal-oxide nanoparticles are added to polymers. Obviously, these properties depend on the type of nanoparticles used

and how they are prepared [17, 18].

The aim of this work is to prepare PVA-PEG films blended with nanocomposites impregnated with Ag nanoparticles and examine their A.C. electrical properties.

## 2. MATERIALS AND METHODS

Movies were made using a casting method to create PVA-PEG-Ag nanocomposites (NCs). The PVA-PEG formulation was created by dissolving 1 g of polymers in 30 mL of distilled water at various concentrations. Ag nanoparticles (NPs) were added at weight ratios of 0, 2, 4, and 6% to the polymer mixture. Using an LCR meter (HIOKI 3532-50 LCR HI TESTER), A.C. electrical properties of the PVA-PEG-Ag NCs were measured in the frequency range from 100 Hz to 5106 kHz.

Following equation can be used to compute dielectric constant ( $\epsilon'$ ) [19, 20]:

$$\epsilon' = C_p/C_0, \quad (1)$$

where, as the vacuum capacitor ( $C_0$ ) is denoted, by the symbol  $C_p$ , the capacitance is denoted.

The dielectric loss ( $\epsilon''$ ) was computed using the equation [21, 22]

$$\epsilon'' = \epsilon', \quad (2)$$

where  $D$  is the dispersion factor.

To compute electrical conductivity, the equation is used as follows [23, 24]:

$$\sigma_{A.C.} = \omega\epsilon''\epsilon'. \quad (3)$$

## 3. RESULTS AND DISCUSSIONS

Figure 1 shows the frequency-dependent changes in the dielectric constant of PVA-PEG-Ag nanocomposites. It was noted that dielectric constant values are high only at lower frequencies that may indicate the presence of interfacial polarization [25, 26] only at low frequencies; if interfacial polarization occurs at higher frequencies, it becomes less pronounced. Higher frequencies may cause the materials' polar molecular rotational motion to be too slow to achieve equilibrium with the use of an applied electric field [27, 28].

Figure 2 shows the increase in dielectric constant with increasing concentration of Ag NPs. Until the concentration reaches 6% of Ag

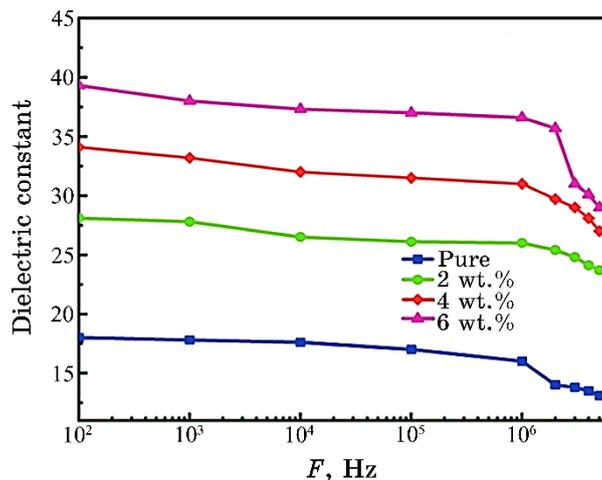


Fig. 1. The dielectric constant of PVA-PEG-Ag NCs changing with frequency.

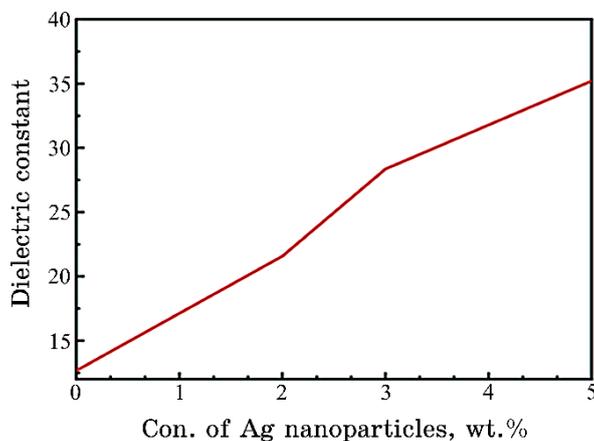


Fig. 2. Variation in the dielectric constant for PVA-PEG-Ag NCs with Ag NPs' concentration.

NPs, this activity can be explained by interfacial polarization, a phenomenon that occurs, when two surfaces within PVA-PEG-Ag NCs are separated by an oscillating electric field, leads to an increase in charge carriers [29–32].

Figure 3 shows the increase in frequency leading to a decrease in dielectric loss. This is due to the reduced effect of space charge polarization. The number of charge carriers accumulated at the electrode-sample interface of PVA-PEG-Ag NCs increases due to the additional charges generated by polarization and low-frequency die-

lectric-loss values [33–35]. These may be a result of the Maxwell–Wagner effect, which occurs with charge-carrier migration at the interface, or polar radicals with a dipole moment and mobile ionic contaminants [36, 37].

Figure 4 shows low concentrations of Ag NPs leading to a decrease in dielectric-loss values. When concentrations of Ag NPs rise until they reach 6% by weight, dielectric loss increases, as network of nanostructures of nanocomposite continues to grow within the

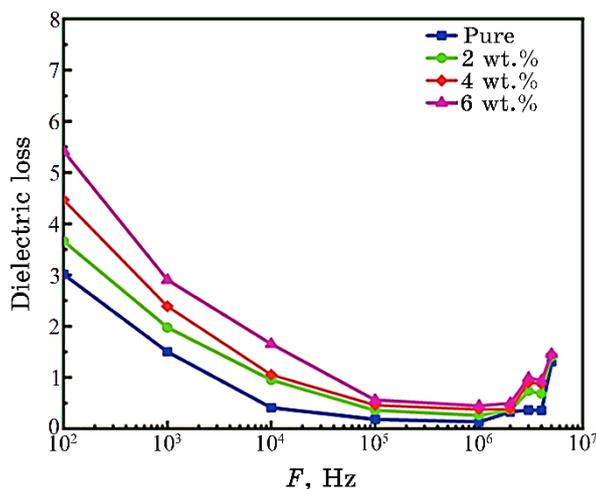


Fig. 3. Dielectric loss in PVA-PEG-Ag nanocomposites varying with frequency.

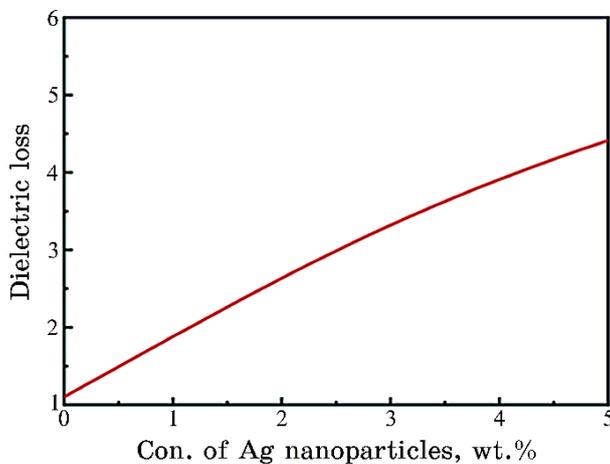
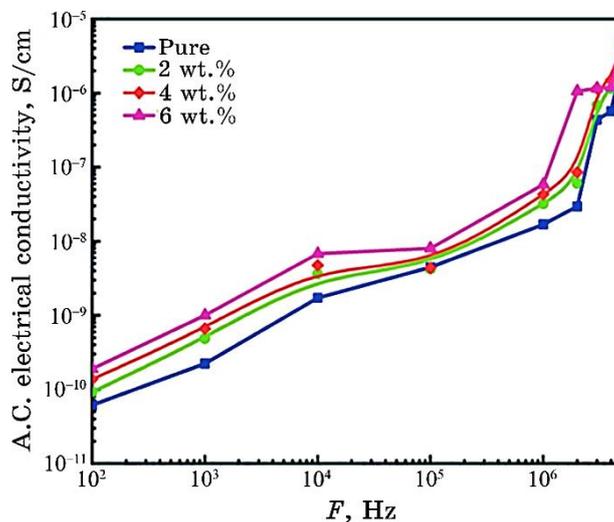


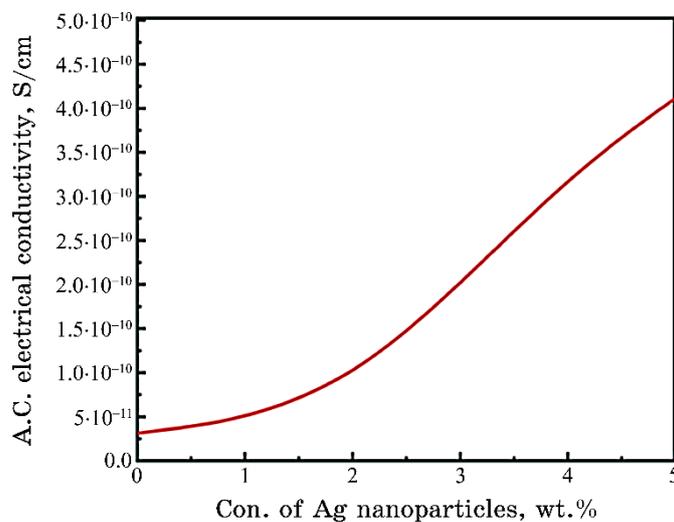
Fig. 4. Dielectric-loss variation with Ag-NPs' concentration for PVA-PEG-Ag nanocomposites.

mixture of PVA-PEG [38, 39].

Figure 5 shows variation of A.C. electrical conductivity of PVA-PEG-Ag with frequency. At high frequencies, the electrical conductivity increases. This is due to the mobility mechanism, which moves the charge carriers, and polarization of the space charge,



**Fig. 5.** A.C. electrical conductivity of PVA-PEG-Ag NCs with frequency increasing.



**Fig. 6.** Changes in A.C. electrical conductivity for PVA-PEG-Ag NCs with Ag NPs.

**TABLE.** The values of dielectric constant, dielectric loss, and A.C. electrical conductivity at 100 Hz.

Concentration of Ag, wt. %	Dielectric constant	Dielectric loss	A.C. electrical conductivity, S/cm
0	18	3.01	$6.1248 \cdot 10^{-11}$
2	28.1	3.66	$9.2317 \cdot 10^{-11}$
4	34.1	4.46	$1.3712 \cdot 10^{-10}$
6	39.3	5.41	$1.8975 \cdot 10^{-10}$

which occurs at low frequencies; these are reasons behind the significant increase in electrical conductivity with the frequency shown in this figure [40, 41]. Electron polarization and charge carriers lead to a slight improvement in electrical conductivity at high frequencies [42].

In Figure 6, the change in A.C. electrical conductivity of PVA-PEG-Ag nanocomposites with concentration of Ag nanoparticles. As shown in this figure, with increasing of Ag concentration, the electrical conductivity increases. Until the Ag-nanoparticles' concentration reaches 6 percent, density of charge carriers in PVA-PEG polymer matrix increases that enhances electrical conductivity [43].

Table displays the results for  $\epsilon'$ ,  $\epsilon''$ , and A.C. conductivity.

#### 4. CONCLUSIONS

Using the casting method, PVA-PEG-Ag films were prepared to determine A.C. electrical properties. The results showed that, when the concentration of nanoparticles is increased, both the dielectric constant and dielectric loss of PVA-PEG-Ag NCs are increased, while, with the increase of frequency, both the dielectric constant and dielectric loss are decreased. The A.C. electrical conductivity of PVA-PEG-Ag NCs increased with increasing of frequency and Ag-nanoparticles' concentration. A wide range of electrical applications can take advantage of these qualities in films.

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