Effect of NaI Doping on the Electrical Properties of PVA Polymer Thin Film Prepared by Spin Coating Technique

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Abstract: In this study, pure polyvinyl alcohol (PVA) polymer films and films doped with sodium iodide (NaI) at varying weight ratios (2%, 5%, 10%, 15%) were prepared using the spin coating technique at room temperature. The electrical properties of the polymer were investigated before and after doping. Experimental results revealed that electrical conductivity increases with higher doping ratios across all polymer films. Additionally, the dielectric constant decreases with increasing frequency but increases with higher doping weight ratios at the same frequency.

Keywords: Polyvinyl alcohol, doping, sodium iodide, spin coating, electrical properties.

1. Introduction:

Polymers have played a crucial role in human life since the dawn of civilization. Natural polymers such as wood, starch, and cellulose have long been utilized by humans. Early humans fashioned clothing from cotton, wool, silk, and animal hides and used natural polymers in their diets, such as vegetable oils and animal fats [1][2].

However, natural polymers eventually became insufficient due to limited resources and the increasing demand for such materials. This prompted the development of synthetic alternatives. Research in this field has advanced rapidly, leading to the production of a wide range of synthetic polymers, which now play an indispensable role in modern life. Synthetic polymers are significant due to their versatile physical and mechanical properties, enabling them to compete with traditional materials [1].

Numerous research studies have focused on investigating the physical properties, including optical, electrical, structural, thermal, and mechanical [3][4].

In a study conducted by Hashim et al. 2012, the electrical properties of polyvinyl alcohol (PVA) polymer doped with titanium dioxide (TiO_2) were investigated. The researchers prepared films of PVA doped with varying weight percentages of TiO_2 (0%, 10%, 15%, 20%) and different thicknesses at temperatures ranging from (30 to 80)C^0. The findings revealed that the electrical conductivity of the films increased with both the doping concentration of TiO_2 and the temperature [5].

In 2011, Abdullah et al. conducted a comprehensive investigation into the conductive properties of polyvinyl alcohol (PVA) blended with sodium iodide (NaI). The study aimed to evaluate the influence of sodium iodide on enhancing the electrical characteristics of PVA over a frequency range of 1kHz to 20MHz and at a constant temperature of 350K. Key parameters analyzed included dielectric permittivity, dielectric loss, and electrical conductivity. The results revealed a notable increase in electrical conductivity with both higher frequencies and elevated concentrations of sodium iodide, underscoring the significant role of NaI in optimizing the electrical performance of PVA-based materials [6]. This study focuses on the electrical properties of polyvinyl alcohol (PVA), a polymer known for its cost-effective production and widespread applications in packaging, paper manufacturing, and electrical coatings [7].

The chemical formula of polyvinyl alcohol is $[CH_2CH(OH)]_n$. It appears as white granules and is characterized by its solubility in water. Although PVA dissolves slowly in cold water, it readily dissolves in hot water. Moreover, it is a non-toxic material, making it suitable for various applications [8].

In this work, two types of samples are prepared, pure PVA thin films and (NaI) doped PVA thin films of different concentration levels. The samples are prepared using spin coating at room temperature.

2. Experimental Set Up:

2.1 Sample preparation:

The samples were prepared in the form of thin films of polyvinyl alcohol (PVA) doped with NaI at various weight percentages (2%,5%,10%,15%) using the spin coating technique in a way that aligns with previous studies [9,10]. Initially, 1g of polyvinyl alcohol (PVA) was dissolved in 25mL of distilled water using a magnetic stirrer at a temperature of 60°C for one hour to ensure complete dissolution of the polymer in the water. The polymer solution was then left to cool for 24hours at room temperature. Subsequently, NaI was added to the polymer solution at varying weight percentages (2%,5%,10%,15%) and stirred for 20 minutes to achieve a homogeneous gel-like mixture of PVA doped with sodium iodide. The resulting solution was deposited onto glass substrates at room temperature and left for three days to allow complete solvent evaporation. This process resulted in thin films of (0.001±0.019) mm measured by the micrometer.

3. Electrical Measurements:

3.1 Conductivity of thin films:

To determine the electrical conductivity (σ), the direct current (I) was measured for all samples by systematically varying the applied voltage (V) at room temperature. Subsequently, the resistance (R) of each sample was calculated. Electrical conductivity is defined as the reciprocal of resistivity (ρ) and is expressed mathematically as:

$$\sigma = \frac{1}{\rho} = \left(\frac{L}{R.A}\right) \ldots\ldots\ldots (1)$$

Where (L) represents the distance between the electrodes, (A) is the surface area and (R) is the resistance.

Fig.1 Depicts the electrical circuit designed for measuring electrical conductivity at room temperature.

Fig. 2 Illustrates the electrical circuit employed for determining the dielectric constant.

3.2 Dielectric Constant:

Alternating current (AC) electrical measurements were conducted to determine the capacitance, which was subsequently used to calculate the dielectric constant (ε) at three distinct frequencies (10, 50, 100)kHz. The dielectric constant is formally defined as the ratio of the capacitance of the material with a dielectric (C_D) to the capacitance in a vacuum (C_0) [11].

$$\varepsilon = \frac{C_D}{C_0} \ldots\ldots\ldots (2)$$

$$C_0 = \varepsilon_0 \frac{A}{d} \ldots\ldots\ldots (3)$$

$$\varepsilon = \frac{C_D . d}{\varepsilon_0 . A_0} \ldots\ldots (4)$$

where (ε_0) *is* the permittivity of free space, (A) is the area of the capacitor plate and (d) is the distance between the capacitor plates.

4.Results:

The electrical conductivity of the thin films was determined at room temperature based on equation (1). As illustrated in figure (3), The conductivity demonstrates a significant increase, from ($2.21{\times}10^{-9}\Omega.cm^{-1}$) to ($3.69{\times}10^{-9}\Omega.cm^{-1}$) by increasing the doping level up to 5%, then it stabilizes at high doping ratios. This behavior can be attributed to an increase in ion concentrations, reaching a critical threshold where additional ions or molecules impede the natural movement of existing ions causing scattering, thereby inducing an abrupt transition in conductivity.

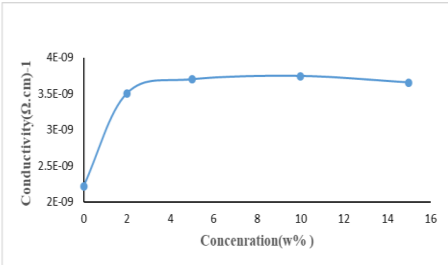

Fig.3 The variation in electrical conductivity of the samples at room temperature.

Consequently, the enhanced mobility of ions and electrons within the material emerges as a key factor in augmenting its electrical conductivity.

The dielectric constant of the fabricated films was determined at room temperature for frequencies of 10kHz, 50kHz, and 100kHz, based on equation (4), is shown in figure (4). It shows that the dielectric constant exhibits a decreasing trend with increasing frequency for all polymer films. Notably, at lower frequencies, the films demonstrate higher dielectric constant values, whereas rising frequency results in a reduction of these values.

This behavior can be attributed to the fact that, at low frequencies, the time interval is sufficient for the dipoles to align and orient the molecules in the direction of the applied electric field. In contrast, at higher frequencies, the time interval becomes insufficient for the molecules to realign with the external electric field direction.

Additionally, it is observed from the figure that, at a given frequency, the dielectric constant values decrease as the weight percentage of the added salt (NaI) increases, this phenomenon may be attributed to a reduction in polarizability.

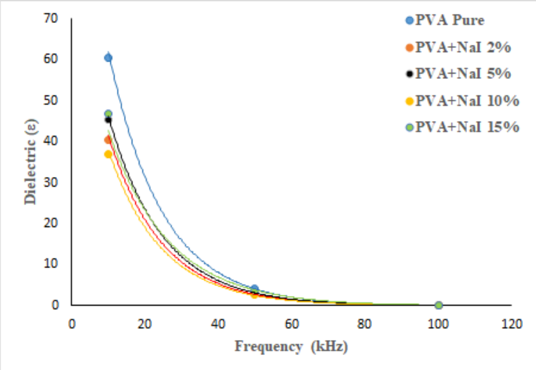

Fig.4 The variation of the dielectric constant of the samples as a function of frequency at room temperature is presented.

5. Conclusion:

In this study, pure polyvinyl alcohol (PVA) polymer films and those doped with varying weight ratios (2%,5%,10%,15%) of sodium iodide (NaI) were produced at room temperature using the spin coating technique. The electrical properties of the polymer were examined both before and after doping. Experimental results indicated that electrical conductivity improved with higher doping levels in all polymer films. Furthermore, the dielectric constant decreased with increasing frequency but rose with higher weight ratios at a given frequency. These findings suggest that the prepared films are suitable for use in the production of some electrical components such as electric batteries.

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