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Effect of CdS on the Electrical Conductivity of Polyvinyl Alcohol (PVA) and Potassium Iodide (KI) thin films

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Abstract:

In the past two decades, solid polymer electrolytes (SPEs) have attracted attention as a platform for electrochemical devices. Here polymer-based electrolytes have the advantage that they can be grown in a thin film, plus they are leak-proof. In the present work, we have used PVA:KI as the host polymer–salt complex with a composition of 85:15. Further, this PVA:KI complex dispersed with different wt% of CdS. Standard solution cast techniques have been used for thin film preparation. All prepared samples are characterized to study conductivity and structural changes. A maximum ionic conductivity of 2.47 X 10-7 S/cm was observed for 9wt% of CdS. Also, the band gap of these films was calculated and found to be between 2.4 to 2.9 eV. Also, the concentration and mobility of charge carriers were calculated to explain the change in conductivity pattern. This calculation was performed with the Schutt & Gerdes model. It is observed that the conductivity pattern mainly follows the concentration of charge carriers.

1. Introduction:

Energy requirements and production are a challenge in the present scenario. Because a significant percentage of energy requirements are generated from conventional energy sources, including coal, petroleum, etc., but all these traditional energy sources are getting exhausted very fast [1]. An alternative solution to this problem is to choose some sustainable energy sources, where solar and wind power are the best examples. But there is a limit to these energy sources, which is the continuity of the energy supply. As we know, solar energy can only be generated for 8 - 10 hours unless the intensity of sunlight is high enough. And similar limits can be observed with other natural sources of energy [2]. Now here, the concept of energy storage can solve this limitation. Here it becomes essential to discuss the details of energy

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storage devices. These storage devices have three major components: electrodes, separators, and electrolytes [3].

The electrolyte is the most commonly related component in the scientific community because of its importance in the performance of these energy storage devices work. In their early stages, these electrolytes were liquid in phase. Later they were replaced by solid electrolytes (Solid polymer electrolytes in particular) due to the extent of leakage, packaging, and explosion. Although these solid polymer electrolytes (SPEs) are superior to their liquid counterparts in many areas, these SPEs still struggle with low ionic conductivity [4]. Various approaches were taken into account to enhance the ionic conductivity of SPE, including dispersion of organic and inorganic salts, plasticizers, and fillers. In the present work, we have used PVA as the host polymer and KI as salt for the preparation of SPE. Also, CdS (Cadmium Sulfate) is used as the dopant to increase the ionic conductivity of this polymer salt complex. Various characteristics were performed to analyze the structural and electrical changes.

2. Experimental:

In the course of this work, we prepared polymer thin films using polyvinyl alcohol- (PVA) [Sigma-Aldrich] and potassium iodide (KI, CDH). Standard solution cast techniques have been used for the preparation of thin films. PVA is first dissolved in distilled water during this technique and then placed on a magnetic stirrer. After some time, when PVA dissolves in water, KI is added to this solution. Here PVA:KI is taken in the ratio 85-15. When these polymer salts dissolve properly, CdS in different wt% is added to this solution and mixed at room temperature on a magnetic stirrer until a viscous solution is obtained [5]. It took around 8-10 hours of continuous stirring at 60 degrees Celsius to obtain a viscous solution. Once the solution becomes viscous, it is poured into a plastic polypropylene disc and allowed to dry under ambient conditions. After 24-36 hours of drying, uniform thin films are obtained with a thickness of approx 100-150 micrometers. The films were dried in a vacuum to remove further solvent traces. Finally, when all the films were ready, they were measured for electrical and structural properties.

3. Results and discussion:

3.1 XRD

Figure 1 shows the XRD patterns of the samples with different wt.% of CdS. The initial peaks at 19 degrees indicate the polymer-salt complex nature of PVA:KI. Further, with a higher concentration of CdS, the intensity of the peaks reduces, and it becomes broader; it indicates the decrease in the crystallinity of the films with a higher concentration of CdS. Also, the

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separate peaks at 24, 36 and 44 degrees indicate the presence of CdS as a composite in a thin film [5]. Here it would be important to mention that with a higher concentration of CdS, the crystallinity of the films decreases; hence the conductivity of the ions increases. This change is visible in the conductivity plot too.

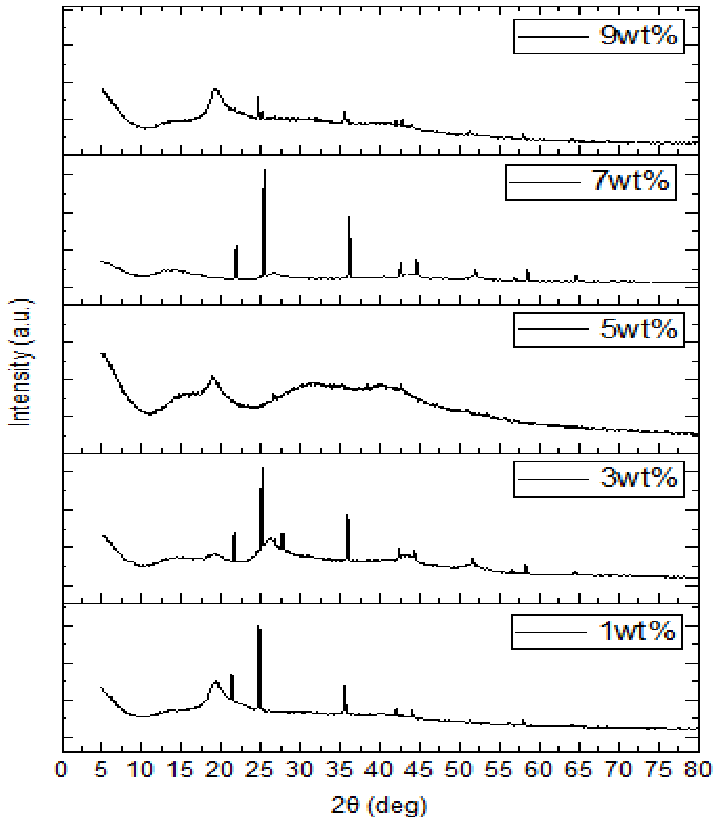

Figure-1 XRD plots for 1wt%, 3wt%, 5wt%, 7wt%, and 9wt% of CdS in PVA:KI matrix

3.2 Electrical Conductivity:

The conductivity of all the thin films was calculated with the help of impedance spectroscopy data. Here we have used the CHI660E workstation for the measurement. First, the SPE films were cut into the size of 1 X 1cm in size. Further, it was sandwiched with the help of stainless-steel electrodes and connected across the terminals of impedance spectroscopy. The samples were measured for the frequency range of 100- 0.1 MHz. The cole-cole plots were plotted with the impedance data, and bulk resistance (R_b) for all the samples was calculated. Finally, with the help of equation-1, the ionic conductivity of all the samples was calculated [6].

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$$\sigma = \frac{1}{R_b}\left(\frac{t}{A}\right) \text{---------------} Equation-1$$

Where R_b = Bulk Resistance; t= thickness of the film; A= Area of the film

Table 1 shows the ionic conductivity value for all the samples.

Table 1: Ionic Conducutvity Value for different wt% CdS at room temperature.

Samples	Bulk Resistance (R_b)	Conductivity (σ) S/Cm
1%	$8.11 \text{ X } 10^{4}$	$9.45 \text{ X } 10^{-8}$
3%	$1.30 \text{ X } 10^{5}$	$5.84 \text{ X } 10^{-8}$
5%	$5.20 \text{ X } 10^{4}$	$1.40 \text{ X } 10^{-7}$
7%	$6.02 \text{ X } 10^{4}$	$2.16 \text{ X } 10^{-7}$
9%	$7.52 \text{ X } 10^{4}$	$2.47 \text{ X } 10^{-7}$

Further, the figure-1 shows the conductivity pattern for different wt% dispersed CdS with the (PVA:KI) matrix. The figure shows that the film's conductivity increases with the increased concentration of CdS. The highest conductivity of $2.47 \text{ X } 10^{-7}$ is obtained for 9wt% of CdS.

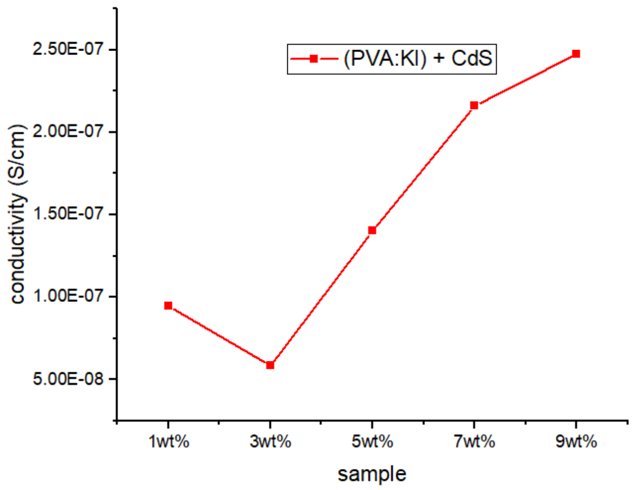

Figure-1: The conductivity plot for different wt% of CdS with PVA:KI matrix.

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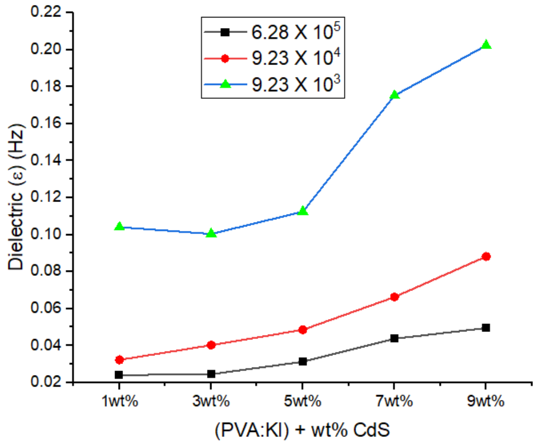
3.3 Dielectric Analysis:

The dielectric constant for all the samples was calculated at frequencies 6.28 X 10^5, 9.23 X 10^4, and 9.23 X 10^3 using impedance data. Figure 2 shows the dielectric constant plot for different wt% dispersed CdS films [7]. It can be seen that the conductivity pattern is in accordance with its dielectric plot.



Here the increase in the dielectric constant is attributed to the change in crystallinity with the increased concentration of CdS.

3.4 Concentration and Mobility

As per the conductivity plot, it is visible that the conductivity of the system increases with a higher concentration of CdS. As per the theory, the electrical conductivity of the polymer electrolytes is given by equation 2.

$$\sigma = en\mu \text{-------------} Equation - 2$$

Where e= the change, which is constant; n= concentration of charge carriers and μ= mobility of charge carriers.

As per equation 2, the change in conductivity is completely dependent on either the charge carriers' concentration or the charge carriers' mobility since the charge (e) is constant. So, these parameters were calculated to understand the contribution of n or μ in conductivity change [8]. These values were calculated with the Trukhan model [9][10] and Schutt & Gerdes Model [11], [12]. All the variables for this model were taken from impedance data. Figure 3 (a) shows the plot for the concentration of charge carriers, and Figure 3 (b) shows the plot for the mobility of charge carriers for different wt% of CdS.

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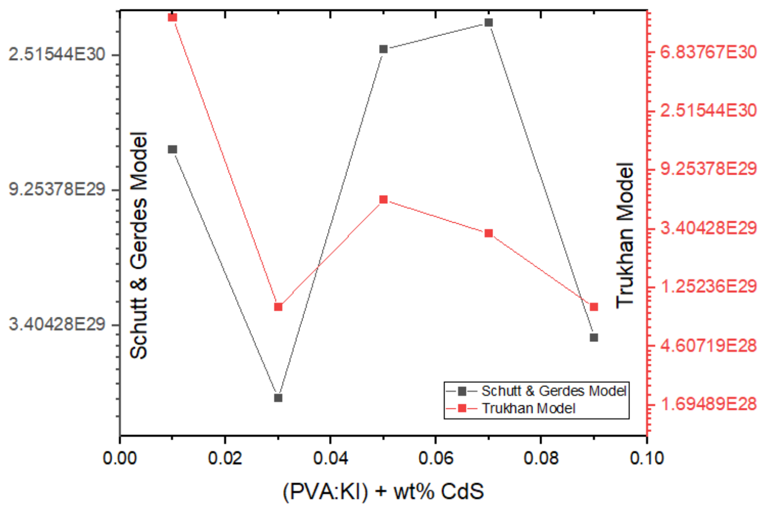

Figure-3(a) Concentration of charge carrier with wt% of CdS

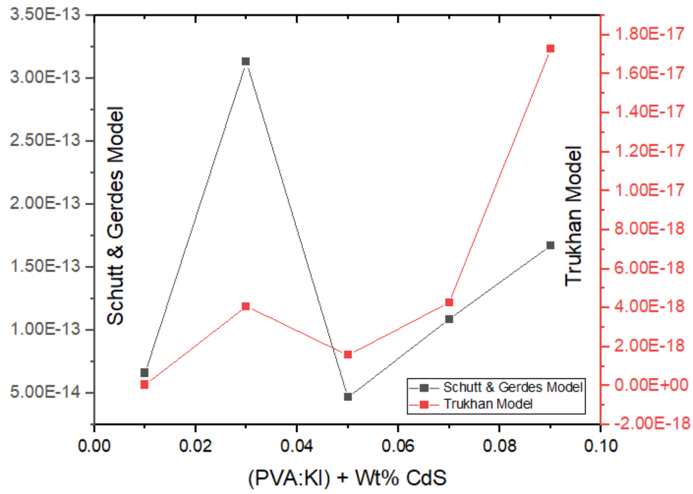

Figure-3(b) Mobility of charge carrier with wt% of CdS

From the plots of concentration and mobility of charge carriers, it can be seen that the concentration pattern predominantly follows the conductivity pattern. It shows that with a higher concentration of CdS, more free ions can move along the amorphous part of the polymer thin films [13].

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4. Conclusion

The CdS dispersed PVA:KI polymer electrolytes films were prepared with the standard solution canst technique. All the films were dried under ambient conditions to remove all the solvent traces. The thickness of all the prepared films is in the order of 100 - 200 μm. The XRD study shows the peaks for Polymer: Salt complexes at 19 and 23 degrees, while the peaks at 26, 44 and 56 degrees for CdS confirm the composite nature of the films. Further, the electrical conductivity of the films was measured with a CHI660E workstation. The highest conductivity of 2.47 X 10-7 is obtained for 9wt% of CdS. The conductivity plot also confirms that the conductivity increase with a higher concentration of CdS, which further confirms the decreases in crystallinity of the films. The same observation was confirmed with the dielectric contact plot. The concentration and mobility of the system were calculated with the Trukhan model and Schutt & Gerdes Model. Here it is observed that the change in conductivity is due to the availability of free ions due to a higher concentration of CdS in the PVA:KI system.

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