Influence of cadmium sulfide nanoparticles on structural and electrical properties of polyvinyl alcohol films

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Abstract. Cadmium sulfide (CdS) nanoparticles have been synthesized by hydrothermal method and dispersed in poly vinyl alcohol (PVA) matrix in varying amounts by weight. Subsequently, PVA/CdS nanocomposites have been synthesized with the objective of investigating the effect of CdS nanoparticles on structural and electrical properties of PVA films. Structural properties were analyzed by Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD) and scanning electron microscopy (SEM) techniques. Differential scanning calorimetry (DSC) was used to investigate thermal properties of PVA/CdS nanocomposites. Electrical properties were measured by using high frequency LCR meter and were found to be strongly dependent on frequency and nano CdS content. Dielectric constant decreased with increase in frequency and with increase in nanofiller concentration. AC conductivity and dielectric loss increased with frequency and decreased with increase in nano CdS content.

Keywords: nanocomposites, cadmium sulfide, electrical properties, polyvinyl alcohol

1. Introduction

Use of nanoparticles in numerous applications has become a major area of interdisciplinary research in recent times. The method of nanoparticle synthesis is an important factor in determining the type of application. The research, particularly on semiconductor nanoparticles is motivated by its possible uses in various fields like nonlinear optics, solar cells, light-emitting devices, electronics, biological labels, and catalysis. The size-dependent mechanical, optical and electronic properties are very much essential. When a particle approaches the size of a few nanometers, its diameter becomes equal to or less than the bulk semiconductor exciton diameter (for cadmium sulfide it is 5–6 nm [1]), such that quantum confinement of electron-hole pairs increase the band gap relative to that in the bulk materials. Hence, the control of

particle size allows tuning of the band gap which gives the desired above mentioned electronic and optical properties. Reinforcement of inorganic nanoparticles inside solid polymer matrices are attracting increased attention because the combination of both these materials provides a simple route to stable and processable materials having properties of both components incorporated in the matrix [1].

However, these composites normally cannot be re-dissolved while protecting the colloidal state of nanoparticles. The single polymer molecule represents an important type because isolated nanocomposites based on a single molecule can be obtained, which have very desirable processing characteristics. Mainly, all the applications which are based on single polymer molecule can be applied to the single molecule-nanoparticle composites also. In most of these cases, the nano-

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composites were further used in various applications in their thin-film form [1].

Composite materials consisting of metal nanoparticles embedded in transparent host matrix have attracted the attention of researchers as advanced technological materials for use in solar cells for photoelectric conversion, transistors for electronic switches [2–6] because of their unique optical, electronic [7], mechanical [8] and structural [9] properties. Large interfacial area between the nanofiller and polymer matrix is a key advantage of nanocomposites since the nanomaterials have high aspect ratio and high surface area. Similarly the dielectric properties of polymers doped with micro and nano fillers have also attracted considerable attention, due to their technological importance for devices such as heating elements, electrical igniters, electrodes for fuel cells and crucibles for vacuum induction furnaces and electric feed [10]. Polymer nanocomposites are known to possess good barrier, mechanical properties, reduced flammability, increased heat distortion temperature and reduced solvent uptake [11].

The study of the effect of temperature on dielectric and frequency is one of the most convenient and sensitive methods of investigating polymer structure. The polarization of dielectric is contributed by dielectric, polar and ionic means [12]. Electronic polarization occurs during very short intervals of time, ionic polarization in the range of a few seconds whereas the dipole polarization takes relatively longer durations.

In this study, poly vinyl alcohol (PVA) has been used as a host matrix for incorporating cadmium sulfide (CdS) nanoparticles due to its water soluble, transparent and highly durable nature. It is a semi-crystalline hydrophilic polymer with a 1,3 glycol structure. Due to its biodegradability and non-toxicity it is highly suitable for environmental processes [13, 14]. The primary focus here is to explore the effects of CdS nanoparticles loading on properties of PVA/CdS composite films. Crystallinity of pure CdS nanopowder and prepared PVA/CdS nanocomposites was studied by X-ray diffraction (XRD) analysis. Scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) techniques were used to investigate the surface morphology of prepared films and influence of CdS nanoparticles on

structural characteristics of PVA films. The dielectric constant, dielectric loss and conductivity of PVA/CdS nanocomposite films at different frequencies were studied in order to probe the role of nanofiller in PVA matrix. Also, the effect of CdS content on thermal properties of PVA/CdS nanocomposites was investigated in detail.

2. Experimental procedure

2.1. Reagents and materials

All chemicals used were of analytical grade and used without further purification. Cadmium nitrate, $[\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}]$ ($\geq 99\%$), Nice Chemicals Pvt. Ltd, Cochin, India, Thiourea $[\text{NH}_2\text{CSNH}_2]$ AR grade ($\geq 99\%$), and L-valine $[\text{C}_5\text{H}_{11}\text{NO}_2]$ BO grade were obtained from SDFCL (SD Fine–CHEM LIMITED), Mumbai, India. PVA $[\text{C}_2\text{H}_4\text{O}]_n$ LR grade having molecular weight from 85 000 to 124 000 (86–89%) was obtained in powder form from SDFCL (SD Fine – CHEM LIMITED), Mumbai, India. Double distilled water was used for dissolution and casting of PVA films.

2.2. Synthesis and characterization of CdS nanoparticles

CdS nanoparticles were prepared using hydrothermal method [15, 17]. An aqueous solution was prepared by mixing 3.08 g of Cadmium nitrate ($\text{Cd}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$), 2.285 g of Thiourea (NH_2CSNH_2) and 0.3518 g of L-valine ($\text{C}_5\text{H}_{11}\text{NO}_2$) were dissolved in 80 mL of distilled water to form a solution. Here, thiourea and L-valine act as fuel and stabilizer respectively. The fuel used here supplies required energy for the reaction. The solution is kept in teflon lined stainless steel container and stirred for 30 minutes. Then the container was placed in an autoclave at a temperature of 180–200 °C, for 4 hours, and later allowed to cool to room temperature. The product was then washed thoroughly with distilled water and ethanol, and centrifuged. The residue was heated at 80 °C for an hour to produce nano powder of CdS. The overall reaction can be represented as shown by Equation (1):

2.3. Fabrication of PVA/CdS nanocomposite films

PVA/CdS nanocomposite films were prepared by solution intercalation film casting method. Films were cast from a CdS water suspension, in which PVA was dissolved by heating at 75–80 °C for 4 hr with constant stirring on a water bath. The solid content of the PVA solution was maintained at 7.5% by wt. The solution was then ultrasonicated at 80–90 °C for 30–40 min for uniform distribution of nanomaterial in the solution and to minimize any possible agglomeration and immediately poured into a clean glass mould and then dried at room temperature for 48 hours. PVA nanocomposite films were cast with different solutions containing varying amounts viz. 0.5, 1, 1.5 and 2 wt% of CdS nanoparticles. The casted films were free from air bubbles with uniformly dispersed CdS nanoparticles in PVA matrix. The thickness of the nanocomposite film samples casted were in the range of 0.18–0.22 mm [16].

2.4. Measurements

FTIR spectra of the samples were measured in the spectral range of 4000–500 cm^{-1} using FTIR in transmittance mode with resolution of 4 cm^{-1} . XRD analysis was recorded using Bruker's D-8 advanced wide-angle X-ray diffractometer. The X-ray source was Ni-filtered Cu-K α radiation (40 kV, 30 mA). The dried membranes of uniform thickness (~200 μm) were mounted on a sample holder and the X-ray tracings were recorded in the range of 0–80° at a speed of 8° per min. Surface images were recorded by SEM (Model JSM-5910-JEOL JAPAN) at an operating voltage of 5 kV. For the electrical characterization of composites, high frequency LCR meter (Agilent 4294A) was employed having a frequency range from 4 kHz to 1 MHz. The test was carried out at constant voltage of 1 V and at room temperature. DSC measurements of neat PVA and PVA/CdS nanocomposites were performed using a NETZSCH DSC 200F3 instrument in the temperature range of 30 to 250 °C in nitrogen atmosphere. Both the heating and cooling rates were maintained at 10 °C·min⁻¹.

3. Results and discussion

3.1. Fourier transform-infrared spectroscopy (FTIR)

Any possible interaction between PVA matrix and CdS nanoparticles can be understood by FTIR analysis. The FTIR spectra of PVA and CdS reinforced PVA nanocomposite films are shown in Figure 1. The spectrum shows peaks at 3285, 2923, 1724, 1373, 1239, 1087, and 842 cm^{-1} . The broad peak around 3285 cm^{-1} indicates stretching of hydroxyl groups (O–H) [40] and peaks at 2923 and 2850 cm^{-1} are due to C–H asymmetric stretching vibration. The peaks observed at 1724 and 1373 cm^{-1} correspond to C=O stretching (of vinyl acetate group of PVA), out-of-phase deformation and in-plane deformation of the methyl group respectively. The peak at 1239 cm^{-1} corresponds to the C–O–C out of phase stretching and the peak at 1087 cm^{-1} was due to the COS stretching vibration mode and also indicates the C–O stretch of secondary alcoholic groups. Out-of-

Figure 1. FTIR samples of PVA loaded with CdS nanoparticles at (a) 0 wt%, (b) 0.5 wt%, (c) 1.0 wt% (d) 1.5 wt%, (e) 2 wt%

phase stretching vibration was observed at 842 cm^{-1} due to sulfate ions in are linked with water molecules by hydrogen bonding [41].

The vibration absorption peak of Cd–S bond at 405 cm^{-1} is observed in the spectrum. The observed at peak at 3285 cm^{-1} is very broad when compared to the as synthesized complex, which is purely due to the adsorbed moisture by the sample. The peak observed at 2923 cm^{-1} evidences the capping of alkyl group over the formed CdS. There was no form of additional peak in IR spectra; however a small shift in the peak position of the band is observed (which is not considerable) corresponding to C=O stretch and C–O–C stretch vibrations indicates physical interaction between hydroxyl groups of PVA and nano CdS. The hydroxyl groups of PVA have a very strong tendency to form charge-transfer complex with CdS nanoparticles through chelation.

3.2. X-ray diffraction analysis

Figure 2 shows XRD patterns of the synthesized CdS nanoparticles. Comparison with the standard (JCPDS No 41- 4019) [15] clearly revealed the formation of single phase CdS with a hexagonal crystal structure. The crystalline nature of pure nano CdS was observed by various sharp peaks shown in Figure 2. Seven separate diffraction peaks can be seen at the 2θ values of 24.98° , 26.5° , 28.14° , 31.8° , 43.8° , 48.2° and 51.9° . It was observed that varying the solvent during synthesis of nano CdS presented preferential growth in different crystalline directions [18]. Similarly it can be believed that a less pronounced preferential growth occurred in the nanocomposite film samples of this study.

Figure 2. XRD profile of pure CdS nanoparticles

Figure 3. XRD profiles of (a) 0 wt%, (b) 0.5 wt%, (c) 1 wt%, (d) 1.5 wt%, (e) 2 wt% CdS nanoparticles loaded PVA nanocomposites

XRD patterns of pure polyvinyl alcohol and PVA/CdS nanocomposites having 0.5, 1, 1.5 and 2 wt% of CdS respectively are shown in Figure 3. All the composites showed a peak at approximately $2\theta = 19.4^\circ$ [19] corresponding to (1 0 1) crystal plane for polyvinyl alcohol, which indicates the semi-crystalline nature of PVA. The crystalline nature of PVA results from the strong intermolecular interaction between PVA polymer networks. The mean particle size of synthesized nano CdS calculated by using Scherrer equation was found to be 37.68 nm.

XRD profiles of the composites showed no shifting or broadening of peak at $2\theta = 19.4^\circ$, but showed appearance of smaller new peaks at 24.98° , 26.4° , 28.16° , 30.65° , 44.33° , 47.92° , 51.81° and 54.48° which clearly indicated the presence of CdS nanoparticles inside the PVA matrix.

3.3. Thermal characterization of the PVA/CdS nanocomposites

Differential scanning calorimetry (DSC)

The thermal properties of PVA/CdS composite films were analyzed by DSC [39] to investigate the effect of CdS filler content on glass transition temperature

(T_g), melting temperature (T_m), heat of fusion (ΔH), percentage crystallinity ($\% x_c$) and crystallization temperature (T_c) of PVA. DSC analysis was performed in successive cycles of heating and cooling as shown in Figure 4. Outline of the DSC data corresponding to these curves is shown in Table 1.

During heating of a sample, for example, from room temperature to its decomposition temperature, peaks with positive and negative $\Delta H/dt$ may be recorded; each peak corresponds to a heat effect associated with a specific process, such as crystallization or melting. The important information from DSC curves is the temperature at which process occurs and the peak temperature is associated and the temperature at which maximum reaction rate occurs.

The analysis was carried out from 25 to 250 °C of temperature at a rate of 10 °C/min. All peak values have been shown in Table 1. The incorporation of CdS nanoparticles decreased the T_g and T_m of PVA. This decrease may be due to the agglomeration of CdS nanoparticles, which decreases the polymeric network strength and also the intermolecular inter-

action between PVA chains. The values of T_g and T_m do not vary much with the content of CdS in the matrix which indicates that the PVA barely interacts with the nanoparticles. It may be due to increase in the free volume (which may also be due to adsorption because of the limited mobility of the adsorbed chains). The suppressed melting point shows that the interaction with the nanofiller hampers crystallization. This may also explain the larger supercooling (lower T_c).

Although an increase in the nanoparticle content does not affect crystallinity (melting enthalpies in Table 1 are almost unchanged), it can be concluded that the presence of the CdS-nanofiller prevents crystal thickening. The observed effects can be explained by the reduced mobility of the PVA chains attached to the surface of the CdS nanoparticles. This is also supported by the FTIR data given above.

The glass transition, strictly speaking, is not a true phase transition, because the first derivative of the heat capacity curve is a continuous function of temperature as shown by phase-modulated DSC measurements. This means that the polymer shows signs of a spectrum of glass transition temperatures, each corresponding to different segmental relaxations. Figure 4 tells not just a shift of the slope in the heat capacity curve to higher temperatures with an increase of the content of the inorganic phase, but also a lengthening of its temperature range. It seems that incorporation of CdS into the polymer matrix affects the distribution of chain segments, most likely due to a change in chain packing density in the surrounding area of the surface of the nanofillers.

Table 1. Thermal properties of PVA/CdS nanocomposites showing T_g , T_m , ΔH_m , $\% x_c$ and T_c as a function of CdS content in PVA matrix

Composition [wt%]		T_g [°C]	T_m [°C]	ΔH_m [J/g]	$\% x_c$	T_c [°C]
PVA	CdS					
100.0	0.0	81.6	224.3	40.54	4.390	189.8
99.5	0.5	71.3	189.1	40.89	5.768	95.2
99.0	1.0	68.4	190.2	41.49	4.572	118.5
98.5	1.5	71.2	191.5	37.29	4.408	109.9
98.0	2.0	69.2	190.0	35.72	4.171	118.6

Figure 4. (a) DSC heating curve and (b) cooling curve of pure PVA and PVA/CdS nanocomposites

3.4. Scanning electron microscopy (SEM)

Surface morphology of PVA and PVA/CdS nanocomposite films was understood from the SEM images shown in Figures 5. The images clearly show CdS nanoparticles which have porous, agglomerated, acicular (Needle like components) structure, size below 80 nm and also confirmed from the images reported elsewhere [20, 21]. The varying sizes obtained may be due to agglomeration of the nanoparticles which takes place in order to minimise the high surface energy that exists in individual nanoparticles. Figure 6 shows SEM images of (a) neat PVA, (b) PVA–0.5 wt% CdS, (c) PVA–1.0 wt% CdS, (d) PVA–1.5 wt% CdS, (e) PVA–2.0 wt% CdS. From these images, it was observed that nanoparticles were agglomerated at all concentrations at varying degree. These agglomerated CdS nanoparticles were seen homogeneously distributed throughout the PVA matrix at lower concentrations. Agglomeration of these nanoparticles lead to big masses as seen in some of the images such as in Figure 6b–6e. The white spots shown in all the SEM images (Figure 6) are CdS nanoparticles. As a result of agglomeration, the particle sizes were seen to increase with increase in filler concentration. The mean particle size obtained from the images was 40 nm (approximately same as obtained from Scherrer formula) while the largest particle size obtained due to agglomeration was 240 nm. The nanoparticles were seen to be dispersed closely to each other in PVA matrix with increase in nanofiller concentration from 0.5 to 2.0 wt%. This is because with increase in nanofiller loading, the number of particles increases and so the interparticle distance decreases.

3.5. Effect of CdS nanoparticles addition on different electrical properties of PVA matrix

3.5.1. Dielectric permittivity

The effective dielectric permittivity in nanocomposites is determined by dielectric division in the bulk of the composite material. In the present case, these are: polarization associated with PVA as well as CdS nano particles and interfacial polarization at the PVA-nanoparticle interfaces. The prepared nanocomposites have a large volume fraction of interfaces where interfacial polarizations are most likely to occur. Several dielectric properties of polymer nanocomposites have been evaluated in the past and the permittivity values in nanocomposites are reported to be lower than that of base polymers when insulating oxides are used as the fillers [12, 22–25].

In order to investigate the effect of nanoparticles on PVA matrix, CdS nanoparticles were incorporated into PVA matrix and analyzed for dielectric properties. Measurements of capacitance C (in Farad) and loss tangent were made over the range from 4 Hz to 1 MHz. The dielectric constant (ϵ_r or ϵ'), dielectric loss (ϵ'') and electrical conductivity values were calculated from capacitance and loss tangent using the Equations (1)–(3). The frequency-dependent ϵ' , ϵ'' and $\tan \delta$ values of the PVA/CdS nanocomposites at different filler concentrations are presented in Figure 7 and 8, respectively.

The dielectric parameter as a function of frequency is described by the complex permittivity in the form given by Equation (2):

$$\epsilon^*(\omega) = \epsilon'(\omega) - i\epsilon''(\omega) \quad (2)$$

Figure 5. SEM image of CdS nanoparticles taken at (a) micrometre and (b) nanometre scale

Figure 6. SEM photomicrographs of PVA loaded with CdS nanoparticles at (a) 0 wt%, (b) 0.5 wt%, (c) 1.0 wt%, (d) 1.5 wt%, (e) 2.0 wt%

where $\varepsilon'(\omega)$ is real part and $\varepsilon''(\omega)$ imaginary part are the components for energy storage and energy loss respectively in each cycle of the electric field.

The measured capacitance C was used to calculate the dielectric constant, $\varepsilon'(\omega)$ using the Equation (3):

$$\varepsilon'(\omega) = \frac{C \cdot t}{A \cdot \varepsilon_0} \quad (3)$$

where t is the film thickness in [m], A is surface area of sample in [m^2], ε_0 is the permittivity of air ($8.85 \cdot 10^{-12}$ F/m) and ω is the angular frequency in [s^{-1}] given by $\omega = 2\pi f$; and f is frequency in [s^{-1}].

Figure 7. Dielectric constant of PVA/CdS nanocomposites as a function of log frequency

Whereas, the dielectric loss $\varepsilon''(\omega)$ is given by Equation (4):

$$\varepsilon''(\omega) = \varepsilon'(\omega) \tan \delta(\omega) \quad (4)$$

where $\tan \delta(\omega)$ is tangent delta and $\varepsilon'(\omega)$ is dielectric constant.

The dielectric properties of materials are mainly determined by their abilities to polarize at a given frequency. For multi component systems, when free charge carriers migrate through the material, space charges build up at the interfaces of the components remaining to the mismatch of the conductivities and dielectric constants of the materials at the interfaces [26, 27]. This is called interfacial polarization. The interfacial polarization in polymers having structural in homogeneities (such as nanoparticles) can be identified by low-frequency dielectric measurement based on Maxwell-Wagner-Sillars's method [27–29]. The changes in the permittivity values as a function of frequency are attributed to dielectric relaxations especially at low frequency which is due to micro-Brownian motion of the whole chain (segmental movement). Nevertheless, these changes are also affected by the interfacial polarization process known as Maxwell-Wagner-Sillars, exist in heterogeneous dielectric materials and are produced by the travelling of charge carriers [30, 31].

It is observed from Figure 7 and Figure 8 that the values of ε' , ε'' and $\tan \delta$ were found to be strongly influenced by frequency. The value of ε' , decreased with increasing frequency whereas the dielectric loss ε''

increased with frequency. This shows that strong low-frequency dispersion takes place that characterizes the frequency dependence of ε' and ε'' in PVA/CdS nanocomposite films. In general, there are four possible mechanisms that could contribute to the low-frequency dielectric behaviour of PVA/CdS nanocomposites: electrode interface, AC electrical conductivity, dipole orientation and charge carriers. In principle, at low frequencies and temperatures, all four types of polarization mechanisms contribute to the values of ε' and ε'' . As the frequency increases, the contributions of interfacial, dipolar, and ionic polarizations become ineffective, leaving behind only the AC electrical conductivity parameter. Furthermore, decrease in ε' with increasing frequency can be explained by the fact that as the frequency increased, the interfacial dipoles had less time to orient themselves in the direction of the alternating field. However, the value of ε'' increased with increasing frequency, which can be credited to the high interfacial traps formed at the PVA/CdS interface that negatively influences the electrical properties [32] that illustrate the dependence of various dielectric behaviors on CdS content and on the frequency of the applied AC field.

From Figure 7 it is observed that ε' value gradually decreased with increase in CdS loading from 0.5 to 1 wt% in the PVA matrix and further increase in CdS content had no effect and ε' was observed to be constant for 1 and 1.5 wt%. Also, less difference was observed between ε' values for 1, 1.5 and 2.0 wt% as compared to the ε' values for 0, 0.5 and 1.0 wt% CdS content. These results suggest that there is an existing threshold CdS content for the dielectric behavior of these nanocomposites.

As shown by Figure 5, the majority of nano-sized CdS particles were well-dispersed in the PVA matrix when the CdS content exceeded 1 wt% and these well-dispersed particles emerge as mini-capacitors within the composites (Figure 5d and 5e). Hence it can be said that the high values of dielectric constant for PVA/CdS composite films observed is the result of the accumulation of these nano-sized capacitors. Since these particles were fixed within the PVA matrix, the charge associated with an individual particle was confined to a small area surrounding the particle and could not jump to adjacent particles. In the investigation of a CdS/PVA composite material pre-

Figure 8. Dielectric loss of PVA/CdS nanocomposites as a function of log frequency

Figure 9. AC Conductivity of PVA/CdS nanocomposites as a function of log frequency

pared by sonication in present study, it is found that that the CdS nano-crystalline domains (~90 nm) can give rise to large dielectric constants.

3.5.2. Dielectric loss

Dielectric loss is the portion of energy of an alternating electric field in a dielectric medium that is converted into heat. It can be expressed in terms of either the loss angle (D) or corresponding loss tangent ($\tan \delta$). Figure 8 shows the effect of frequency on dielectric loss for PVA/CdS nanocomposites. It is seen that the dielectric loss increases with increase in frequency. This increase is substantial at high frequencies in the range of 10^5 – 10^6 Hz and may be due to heat generated within the composite as a result of rapid alignment of dipoles with the rapidly changing direction of electric field. The dielectric losses may have also increased because of increase in conduction losses with increase in frequency. In spite of these factors, the dielectric loss behaviour with frequency seems to be quite complicated and requires further study.

3.5.3. AC conductivity

AC conductivity is the alternating conductivity of sample that arises from the motion of charge carriers through the polymer and is measured using the Equation (5) [33–35]:

$$\sigma_{ac} = \frac{G_p \cdot t}{A} \quad (5)$$

where G_p is the conductance, t is the film thickness [m], A is surface area of sample [m²].

Figure 9 illustrates the dependence of AC electrical conductivity (σ_{ac}) on frequency [36]. The variation is studied in the frequency range from 4 kHz to 1 MHz at room temperature for the PVA/CdS composites. It can be noted that the AC electrical conductivity generally increased with increasing frequency; in particular, a sharp increase in σ_{ac} is found beyond 1 kHz frequency. This may be due to increased electronic interaction processes taking place inside the composites as a result of which the composites became more relatively conductive. In PVA, as the bond rotates with increased frequency, the existing flexible polar groups cause dielectric transitions. This changes the composition of the polymer chains due to the formation of charge transfer complexes. The AC conductivity increases [37] and polymer chains become more flexible.

3.5.4. Loss tangent (D or $\tan \delta$)

Variation in loss tangent ($\tan \delta$) of PVA/CdS composites as a function of frequency is shown in Figure 10. It can be seen from the figure that $\tan \delta$ decreased initially and then increased with increasing frequency in the range from 4 Hz to 1 MHz passing through a minimum at $6.5 \cdot 10^4$ Hz frequency gradually. The decrease was seen at lower concentrations of CdS nanofiller. The increase in this value indicates the increase in loss storage ratio and hence the composite becomes a semi-conductor and is similar to the ob-

Figure 10. Loss tangent of PVA/CdS nanocomposites as a function of log frequency

servations made by Chao-Hsien Ho *et al.* [38] from the studies on PANI–DBSA/PAA (polyaniline, dodecyl-benzene sulfonate and poly-acrylic acid) films. These experimental results show that ϵ' , ϵ'' and $\tan \delta$ had a strong dependence on the measured frequency. The capacitance of the PVA/CdS composites at high frequencies in the accumulation region was basically controlled by the dielectric properties of the bulk insulator.

4. Conclusions

PVA/CdS nanocomposites containing varying weight percentages of CdS nanoparticles were prepared by solution intercalation technique. Effects of CdS nanoparticles on structural and electrical properties of PVA films were observed. Various peaks obtained in FTIR analysis showed good physical interaction between PVA matrix and nano CdS. SEM analysis showed porous and acicular CdS nanoparticles which tend to agglomerate at higher concentrations in the polymer matrix. DSC analysis shows that presence of nanoparticles in PVA matrix influence thermal properties like T_g and T_m and heat capacity. Electrical properties of PVA/CdS nanocomposites have been reported for the first time probably by hydrothermal method of synthesizing the nanomaterial. These properties were observed to be strongly dependent upon applied frequency and CdS nanofiller content. Dielectric constant decreased with increase in frequency and with increase in filler concentration; AC conductivity and dielectric loss increased with frequency and

decreased with increase in CdS content. The loss tangent increased with increase in concentration of nanofiller showed that the CdS/PVA nanocomposite films can be good semiconductors.

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