International Journal of Chemical Science
www.chemicaljournals.com
Online ISSN: 2523-2843, Print ISSN: 2523-6075
Received: 17-08-2024, Accepted: 16-09-2024, Published: 01-10-2024
Volume 8, Issue 2, 2024, Page No. 16-20

Characteristics of PVA film embedded with Cr_2O_3 nanoparticles: Optical, electrical, and viscosity

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Abstract
In order to explore their potential applications in advanced materials, this study examines the optical, electrical, and viscosity properties of polyvinyl alcohol (PVA) films embedded with chromium oxide (Cr_2O_3) nanoparticles. In order to assess the impact of different $Cr3O_3$ nanoparticle concentrations on the material's characteristics, PVA films were created using the solution casting method. The optical characteristics were examined using UV-Vis spectroscopy, which showed a marked decrease in optical transmittance with increasing nanoparticle concentration, suggesting increased light absorption. The semiconducting nature of the nanoparticles was attributed to the improvement in electrical conductivity observed with an increase in Cr_2O_3 content, as measured by means of a four-point probe method. The measurement of the viscosity of the PVA-nanoparticle solution shows that the viscosity increases with the addition of Cr_2O_3, indicating that the viscosity is related to the interaction between the nanoparticles and PVA chains. The interaction of the films' optical, electrical, and viscosity properties points to potential uses in sensors, optoelectronic devices, and materials for nanocomposite materials with adjustable characteristics.

Keywords: PVA film optical properties, electrical properties, viscosity properties, Cr_2O_3 nanoparticles

Introduction

Metal and metal oxide nanoparticles [1, 2, 3] combined polymers have attracted widened application by these hybrid materials [4]. It is well established that certain polymers, as dielectric materials, are excellent host matrices for encapsulation of metal nanoparticles like silver, gold, copper, and so forth, as they act both as reducing as well as capping agents and also provide environmental and chemical stability [5, 6, 7]. At the same time, these embedded nanoparticles inside the polymer matrix also affect the properties of the host itself [8, 9, 10, 11]. Particularly, polymer-metal-nanoparticles composites are promising functional materials in several fields such as optical, electrical, thermal, mechanical, and antimicrobial properties [12, 13, 14, 15, 16]. Many reports in the literature [17, 18] show attempts for synthesis of metal nanoparticles based polymer nanocomposites, with the possibility of variation in their optical and electrical properties for their application in high performance capacitors, conductive inks, and other electronic components. For their application in optoelectronic, electrical, and optical devices, biomedical science, and sensors, main key points are selection of polymer-metal nanoparticles combination, controlling the particles size, their concentration, and distribution within the polymer matrix [19, 20, 21].

In this paper, we have reported the preperation of poly (vinyl alcohol)-Cr_2O_3nanocomposites. PVA is water soluble, easily processable, having good film forming and adhesive nature for applications in optical coating and opto-electronic devices. Further, it is also considered as a good host matrix for metal nanoparticles [22]. It is also recognized as one of the very few vinyl polymers soluble in water with a high transparency, excellent thermal stability, chemical resistance, high mechanical strength, moderate, dopant dependent electrical conductivity and good flexibility. A remarkable and advantageous feature of nanoparticles prepared using these techniques in contrast to those prepared using chemical synthesis is smaller in particle size and absence of uncontrolled by-products [23]. Systematic studies related to the effect of embedding Cr2O3 nanoparticles on the optical and electrical behaviour of the PVA matrix are scare. A, Hassan *et al*., has reported the synthesis of nano-sized Cr_2O_3 by sol-gel method and mixed with PVA to produce nanocomposites films.DSC studies of these films showed the thermal stability and degree of crystallinity of the PVA were reinforced by the addition ofCr_2O_3nanoparticles [24]. In this endeavour, we have carried out a systematic study on the effect of embedding of different concentration of Cr2O3 nanoparticles on optical and electrical properties.

Material and methods

In our lab, we use biological and electrochemical approaches to produce chromium oxide nanoparticles in three distinct ways. After this, films containing nanocomposites of Cr2O3 and PVA were produced.

- **Method 1 (Biologicalmethod)**

The MukiaMaderaspatana plant extract is combined with the potassium dichromate solution in a beaker and agitated for 10–15 minutes. When the solution's color shifted from orange to green, chromium (III) oxide nanoparticles began to develop.

- **Electrochemical Method 2 (InpresenceofK$_2$Cr$_2$O$_7$an dH$_2$SO$_4$)**

It is possible to electrochemically synthesize chromium oxide nanoparticles using platinum electrodes. See Figure 3.6 for a visual of the experimental setup. A solution of potassium dichromate at 0.3M concentration was settled upon. The components of the electrochemical cell are the platinum electrodes, the voltage source, and the reaction chamber. The experiment included a 20 mL solution of potassium dichromate and a 5 mL solution of concentrated

sulfuric acid (conc.H2SO4). Positive 12V at 70 mA-90 mA was supplied by the battery eliminator (Neulite India). Three hours passed during which time the experiment was constantly stirred. The color changed dramatically, going from bright orange to emerald green. During two hours at a temperature of 1,000 degrees Celsius, the aforesaid solution was allowed to evaporate slowly. The sulphate test was positive for the dried substance that was collected. In addition, moisture and sulfate as sulfur dioxide were removed by calcining the material at temperatures between 6500C and 7000C.

- **Electrochemical Method 3 (Inthepresenceof(Pt/Cr)andNaHCO$_3$)**

The experimental setup is shown in Figure. Electroplating a chromium layer from a chromium nitrate solution onto a platinum electrode (Pt/Cr) was one method used (0.1M). In a reaction chamber, Cr2O3 nanoparticles were synthesized using a 20 ml NaHCO3 solution. Power was supplied at 12V with 30 mA flowing via a Pt/Cr anode and a Pt cathode. Three hours passed during which time the experiment was done with continual stirring and temperature.

PVA-Cr_2O_3 nanocomposite films preparation

Mixing various quantities of generated $Cr_2O_3$from above-mentioned different processes to PVA solution yields PVA-Cr_2O_3 nanocomposite films with variable concentrations (0.125%, 0.25%, and 0.5%) of Cr_2O_3 nanoparticles. This was accomplished by preparing a 1% PVA solution in de-ionized water, adding varying amounts of Cr_2O_3 while stirring at 500 rpm for an hour to create a uniform viscous solution, and then ultrasonicating the mixture.

Result and discussion

- **Optical characterization**

Spectrophotometer readings of the UV/Vis absorption spectra are taken between 190 and 1100 nm (Shimadzu-1700 series). Optical absorption spectra for pure PVA and its composites with different amounts of Cr2O3 nanoparticles are shown in Figure. This band is due to the absorption of Cr2O3 nanoparticles into the material. Shifting the nanocomposite films' optical absorption margins from 430 to 360 nm towards the shorter wavelength region [1]. This nanometer-scale blue shift in the optical absorption edge [24] is evidence that Cr2O3 particles are present in the PVA matrix.

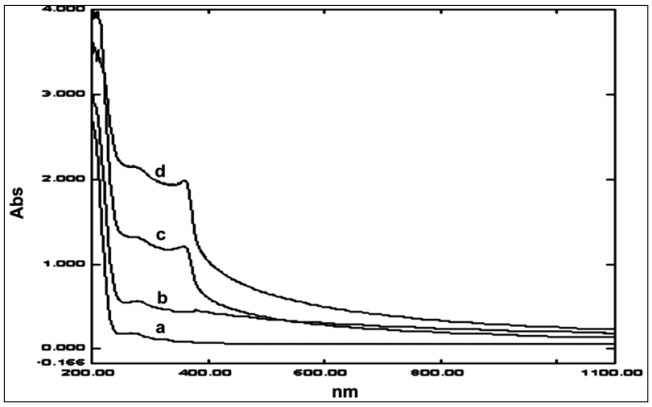

Fig 1: PVA-Cr2O3 nanocomposite film optical absorption spectrum (a) PVA, (b) 0.125% Cr2O3 nanoparticles, (c) 0.25% nanoparticles, and (d) 0.5% nanoparticles

- **Fouriertransforminfra-redspectroscopy**

Absorption spectra are acquired using an ATR (Attenuated total reflectance) instrument attached to a single beam Fourier transform-infrared spectrometer (Bruker Tensor 27-43875). The figure shows 400-400cm-1 FTIR spectra of pure PVA (spectrum a) and PVA-Cr2O3 nanocomposite films (spectrums b-d). In addition, Cr=O vibrational peaks in the range 967-1037cm-1, Cr-O vibrational peaks in the range 585-641cm-1, and Cr-O-Cr vibrational peaks in the range 1046-1085cm-1 [1] suggest that Cr2O3 nanoparticles are dispersed throughout the intersites of the PVA polymer matrix. The inclusion of Cr2O3 nanoparticles directly in the PVA film results in a rise in the vibrational intensity of O-H, C-H, and C=O groups in the PVA matrix, as seen in the figure.

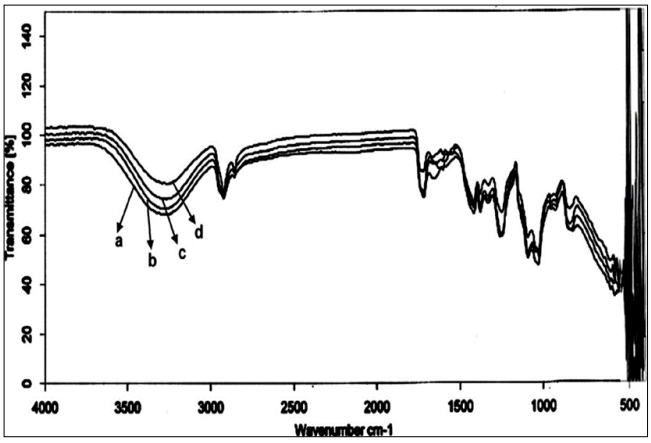

Fig 2: PVA pure film and Cr_2O_3 nanoparticles doped FTIR spectrum in PVApolymerfilms in thewavenumber400-4000cm^{-1}

- **X-raydiffractionstudies**

With a Cu k wavelength (λ 1.5406) and a scanning range of 00 to 1000, an X-ray diffractometer (Panalytical X-pert) renders crystallographic interpretations. The XRD patterns of pure PVA (curve a) and PVA-Cr2O3 (curves b, c, and d) nanocomposite film at three different Cr2O3 nanoparticle concentrations (0.125%, 0.25%, and 0.5%) are shown in Figure. Figure shows that the relative intensity of this peak decreases after Cr2O3 nanoparticles are embedded in a PVA matrix, and that at 0.5% doping of Cr2O3, new peaks at 2 values of 24.60, 36.30, 50.20, and 63.60 correspond to the crystal plane of (012), (110), (024), and (214) of crystalline Cr2O3 [1] begin emerging with increased intensities. Characteristic peaks demonstrate that Cr2O3 nanoparticles indeed occur in the amorphous phase of PVA.

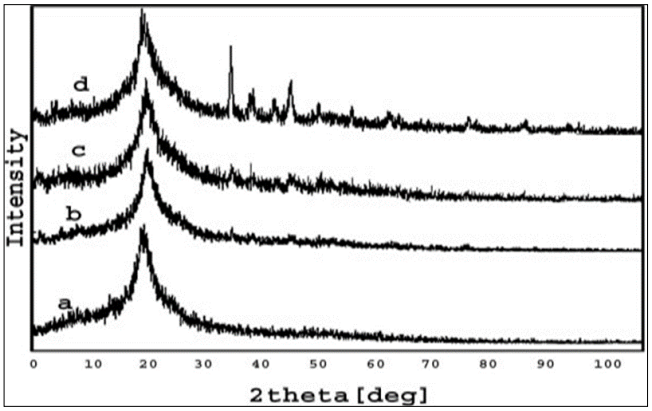

Fig 3: PVA polymer with Cr2O3 nanoparticle doped PVA film X-ray diffraction; (a) PVA, (b)0.125%, (c) 0.25%,and (d) 0.5%

- **Scanningelectronmicroscopy(SEM)**

Before and after doping with Cr2O3 nanoparticles at varying filling levels, the surface morphology of polymeric films is examined by scanning electron microscopy (ZESIS). The surface morphology and composition of a PVA film made using the solution casting method are shown in Figure. SEM images of Cr2O3 nanoparticle-filled PVA films are shown in Figure. All formulations' nanoparticles had roughly spherical forms and exhibited agglomeration.

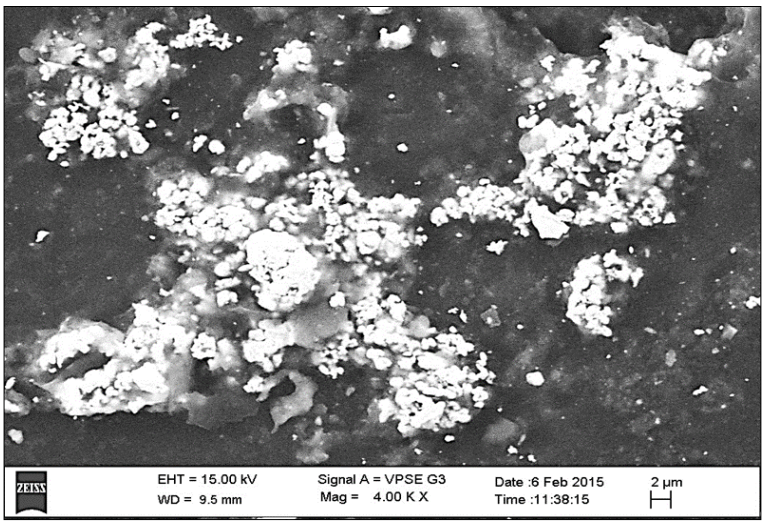

Fig 4: SEM of 0.125% Cr_2O_3 nanoparticles filled PVAfilm

- **Viscosity measurements**

Using an Ostwald viscometer, we measured the solution viscosities of pure PVA and PVA-Cr2O3 nanocomposite at varying concentrations created using three distinct procedures. The Ostwald viscometer is the most common device of its kind. Care must be taken to ensure that all measurements are conducted with a consistent volume of the solution [23] while using this viscometer, which is a basic glass capillary device.

Table 1: Samples of PVA-Cr2O3 nanocomposites were produced at varying Cr2O3 concentrations and their viscosities were measured

Concentration of Cr_2O_3 C(g/dl)	Concentration Of PVA (g/dl)	Flow time,t (sec)	Relative viscosity $t/t_0=\eta_r$	Specific viscosity $\eta_r-1=\eta_{sp}$	Reduced viscosity η_{sp}/C (dl/g)	$\ln\eta_r$	Inherent viscosity $\ln\eta_r/C$ (dl/g)	Intrinsic viscosity $[\eta]$(dl/g)
0.0119	0.0008	146.17	1.0592	0.0592	74.00	0.0575	71.87	73.25
	0.0012	155.98	1.0892	0.0892	74.33	0.0854	71.16	
	0.0016	166.36	1.1195	0.1195	74.68	0.1128	70.50	
0.0238	0.0008	150.10	1.0876	0.0876	109.50	0.0839	104.87	106.20
	0.0012	162.29	1.1333	0.1333	111.08	0.1251	104.25	
	0.0016	175.41	1.1804	0.1804	112.75	0.1658	103.62	
0.0475	0.0008	155.00	1.1231	0.1231	153.87	0.1160	145.00	147.20
	0.0012	170.14	1.1881	0.1881	156.75	0.1723	143.58	
	0.0016	186.72	1.2565	0.2565	160.31	0.0228	142.68	

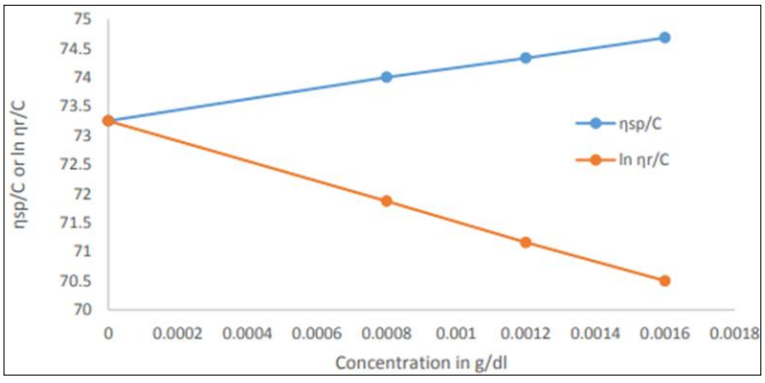

Fig 5: Plots of η_{sp}/C versus C and $\ln\eta_r/C$ versus C for PVA- Cr_2O_3nanocompositesamplesofmethod1with0.0119g/dlofCr_2O_3 nanoparticles

- **Frequency-dependentconductivity**

Using a conductivity bridge instrument, we determine the AC conductivity of PVA and Cr2O3 nanoparticle-embedded PVA films at 50 Hz and 1000 Hz. Figure displays the conductance values at room temperature, and figure displays a plot of conductivity as a function of frequency and concentration for PVA and Cr2O3 nanoparticles implanted PVA films of varied concentrations. Dispersion at low frequencies is shown in AC conductivity, but conductivity falls off sharply with increasing frequency. The electrode-electrolyte contact experiences polarization effects, which cause the low frequency dispersive zone. The non-Debye behavior of the polymer system is shown by a drop in conductivity and an increase in charge buildup at the electrode electrolyte interface with a corresponding drop in the number of mobile ions [22].

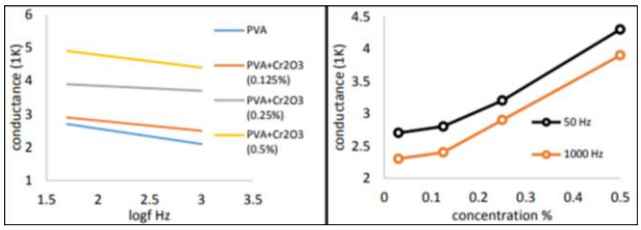

Fig 6: (a) Plots of AC conductivity versus log f and (b) concentration for PVA and PVA- Cr2O3 nanocomposite films prepared from method 1

- **Photo-voltaicactivity**

Several concentrations of PVA and PVA - Cr2O3 nanocomposite films were tested for conductivity and potential and compared in UV, sunshine, and in the dark. UV-light significantly improves the photovoltaic activity of PVA-Cr2O3 nanocomposite films compared to sunlight and total darkness. UV activity may be explained by the blue shift in the max of Cr2O3 nanoparticles from 430nm to 360nm that occurs upon implantation in a PVA matrix. It may be seen in figure and table.

Table 2: Measurement of conductivity and potential of PVA and PVA - Cr_2O_3nanocompositefilms prepared bythreedifferentmethods

Property	Sample	U-V	Sunlight	Dark
		0.05	0.04	0.04
	PVA			
	PVA+ Cr_2O_3(0.125%)	1.47	0.49	0.06
	PVA+ Cr_2O_3(0.25%)	1.88	0.52	0.06
Conductivity measurementsin µs	PVA+ Cr_2O_3(0.50%)	2.10	0.80	0.07
	PVA+ Cr_2O_3(0.125%)	1.54	0.46	0.05
	PVA+ Cr_2O_3(0.25%)	1.92	0.49	0.07
	PVA+ Cr_2O_3(0.50%)	2.33	0.50	0.05
	PVA+ Cr_2O_3(0.125%)	1.45	0.45	0.06
	PVA+ Cr_2O_3(0.25%)	2.28	0.50	0.07
	PVA+ Cr_2O_3(0.50%)	3.76	0.60	0.04
	PVA	0.014	0.009	0.006
	PVA+ Cr2O3 (0.125%)	0.120	0.010	0.009
	PVA+ Cr2O3 (0.25%)	0.138	0.041	0.007
Potential	PVA+ Cr2O3	0.157	0.086	0.009
Measurements in mV	PVA+ Cr2O3 (0.125%)	0.130	0.031	0.009
	PVA+ Cr2O3 (0.25%)	0.141	0.054	0.010
	PVA+ Cr2O3 (0.50%)	0.154	0.090	0.010
	PVA+ Cr2O3 (0.125%)	0.141	0.010	0.011
	PVA+ Cr2O3 (0.25%)	0.158	0.011	0.010
	PVA+ Cr2O3 (0.50%)	0.169	0.012	0.011

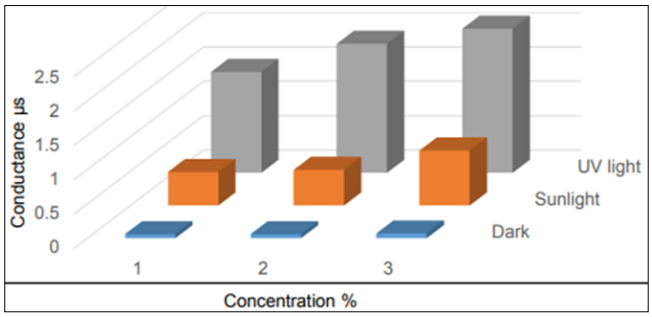

Fig 7: Conductivity measurements of PVA- Cr_2O_3 nanocomposite films of1.(0.125%) 2. (0.25%) and 3. (0.5%) prepared from method 1

Conclusion

Three distinct techniques are used to prepare solid polymer films of polyvinyl alcohol (PVA) embedded with varying weight percentages of Cr2O3 nanoparticles using the solution cast technique. Peaks in the FTIR spectra, which are indicative of chemical bonds and molecular vibrations, show that Cr2O3 is present in the PVA polymer structure. Following doping with PVA polymer, the λmax of Cr2O3 nanoparticles experienced a blue shift, moving from 430 nm to 360 nm. At room temperature, it has been observed that an increase in the concentration of nanoparticles increases the intrinsic viscosity and electrical conductivity of PVA-Cr2O3 nanocomposites.

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