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Fabrication, Structural and Optical Properties for (Polyvinyl Alcohol–Polyethylene Oxide– Iron Oxide) Nanocomposites

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NANOCOMPOSITES were usually used for different fields in an industrial applications with low cost and low weight. In this paper, nanocomposites from polyvinyl alcohol-polyethylene oxide- iron oxide nanoparticles have been fabricated. The iron oxide nanoparticles were added to polymer blend by different weight percentages are (2, 4 and 6) wt.%. The structural and dielectric properties of (PVA-PEO-Fe_2O_3) nanocomposites were studied. The results showed that the dielectric constant, dielectric loss and electrical conductivity of (PVA-PEO) blend are increased with the increase in iron oxide nanoparticles concentrations. The dielectric constant and dielectric loss are decreased while the electrical conductivity increases with the increase in frequency of applied electric field. The optical measurements showed the absorbance of (PVA-PEO-Fe_2O_3) nanocomposites is increased with increasing of the concentrations of iron oxide nanoparticles. The indirect energy gap (E_g) of (PVA-PEO) blend decreases with the increase of the concentrations of iron oxide nanoparticles. The optical constants such as absorption coefficient, extinction coefficient, refractive index, real and imaginary dielectric constants and optical conductivity of (PVA-PEO) blend varied with the increase of the weight percentages of iron oxide nanoparticles.

Keywords: Conductivity, Nanocomposites, Dielectric properties, Polymer blend, Iron oxide, Energy gap, Extinction coefficient.

Introduction

Composite materials based on a polymeric matrix with embedded metal nanoparticles have gain attention due to their properties such as electrical, mechanical, optical and chemical properties that can be used in the development of biomedical devices, solar cells, sensors, capacitors among others. A hybrid material consists of soluble polymers with inorganic component with excellent mechanical, optoelectronics and dielectric properties due to the combination of the organic and inorganic components, and it can be deposited as a thin film in different substrates. Therefore, the number of contributions in the development of hybrid composites based on polymers and nanoparticles with high permittivity, low cost, and easily tunable properties, have become a hot topic in the research of materials [1]. Usually, polymer materials have desirable high breakdown strength and easy processability, but they have undesirable low dielectric permittivity and poor heat tolerance, caused by their covalent bond structures. Contrary to polymer materials, high-k ceramic materials have a favorable high permittivity and strong thermal resistance, but they have an undesirable low breakdown strength and high mechanical brittlement, that stems from their ionic bond structures. Nowadays, the hybridization strategy has been widely used to achieve high-performance materials. Therefore, the composite dielectric materials prepared via blending polymer and high-k ceramic have been largely developed to combine the advantages of both components. In these composite dielectrics, adding high-k ceramic with a higher Young's modulus compared to the polymer would improve the mechanical strength of the polymer and thus the electrical breakdown strength of the polymer.

Furthermore, the processability of composite dielectrics would be well retained, attributed to a low Young's modulus (namely high flexibility) of the polymer component [2].Polymers and particularly hybrid composites (organic–inorganic) are attracting increasing attention from researchers because of their use in many industrial sectors [3]. Polyvinyl alcohol is an essential polymer, due to its physical and chemical features and so it attracted researchers' attention over the years. This polymer can be a powder, film and fiber forms. It has a semi-crystalline nature arises from the role of OH group and the hydrogen bonds. Due to its low protein adsorption characteristics, biocompatibility and high water solubility, PVA is commonly used in medical devices [4]. Poly(ethylene oxide) is a semi-crystalline, biocompatible, biodegradable, nonionic and water-soluble polymer of considerable industrial significance, which finds applications in many different branches of industry. It is commercially available in a wide range of molecular weights (20000–8000000) [5].

Materials and Methods

Nanocomposites films prepared from polyvinyl alcohol- polyethylene oxide- iron oxide nanoparticles byusing casting method by dissolving 1 gm of (PVA and PEO) in 20 ml of distilled water by using magnetic stirrer for 1 hour. The iron oxide nanoparticles were added to polymer blend with concentrations are (2, 4 and 6) wt.%. The dielectric properties of (PVA-PEO-Fe_2O_3) nanocomposites were measured in frequency range from 100 Hz to 5×10^6 Hz by using LCR meter type (HIOKI 3532-50 LCR HI TESTER).To measure the optical properties of (PVA-PEO- Fe_2O_3)nanocomposites in range of wavelength (200-1100) nm, The UV/1800/ Shimadzu spectrophotometer device has been used. FTIR spectra for nanocomposites were recorded by FTIR (Bruker company, German origin, type vertex—70) in wave number range 400–4000 cm^{-1}.

The dielectric constant ($\acute{\varepsilon}$) of nanocomposites is defined by the equation [6]:

$$\varepsilon^{-} = \frac{C_p}{C_o} \quad ....(1)$$

Where, C_p is parallel capacitance and C_o is vacuum capacitor

The dielectric loss (ε'') is given by the equation [6]:

$$\varepsilon'' = \acute{\varepsilon} \, D \quad ....(2)$$

where, D: is dispersion factor of nanocomposites.

The A.C electrical conductivity is determined by the following equation [7]:

$$\sigma_{A.C} = w \, \varepsilon'' \varepsilon_o ....(3)$$

Where, w is the angular frequency.

Absorption coefficient (α) iscalculated as the following equation:

$$\alpha = 2.303 \, (A/t) ....(4)$$

A: is the absorbance. For amorphous polymers, indirect transition model can be computed as:[8].

$$\alpha h\upsilon = D(h\upsilon - E_g)^x ....(5)$$

Where D is a constant, $h\upsilon$ is the photon energy, E_g is the optical energy band gap, x = 3 for forbidden indirect transition and x = 2 for allowed indirect transition.

Refractive index (n) is determined by following equation:

$$n = ...(6)$$

Where R is the reflectance, can be got by :

$$R = 1 - A - T ....(7)$$

The extinction coefficient (k) is determined by the following equation:

$$k = ...(8)$$

Where λ is the wavelength of incident light. The dielectric constant is classified into two parts real (ε_r), and imaginary (ε_{im}).It can be computed each of the real and imaginary parts of dielectric constant (ε_r and ε_{im}) as the following equations:

$$\varepsilon_r = n^2 - k^2 ....(9)$$

$$\varepsilon_{im} = 2nk ....(10)$$

Optical conductivity (σ_{op}) can be determines as:[9].

$$\sigma_{op} = ...(11)$$

Results and Discussion

Fig.1 show the photomicrographs for (PVA-PEO-Fe_2O_3) nanocomposites . The figure shows that the Fe_2O_3 nanoparticles is aggregated as a clusters at lower concentrations. When increasing the concentrations of Fe_2O_3 nanoparticles, the nanoparticles form a continuous network inside the (PVA-PEO) nanocomposites at concentration 4 wt% for nanocomposites.
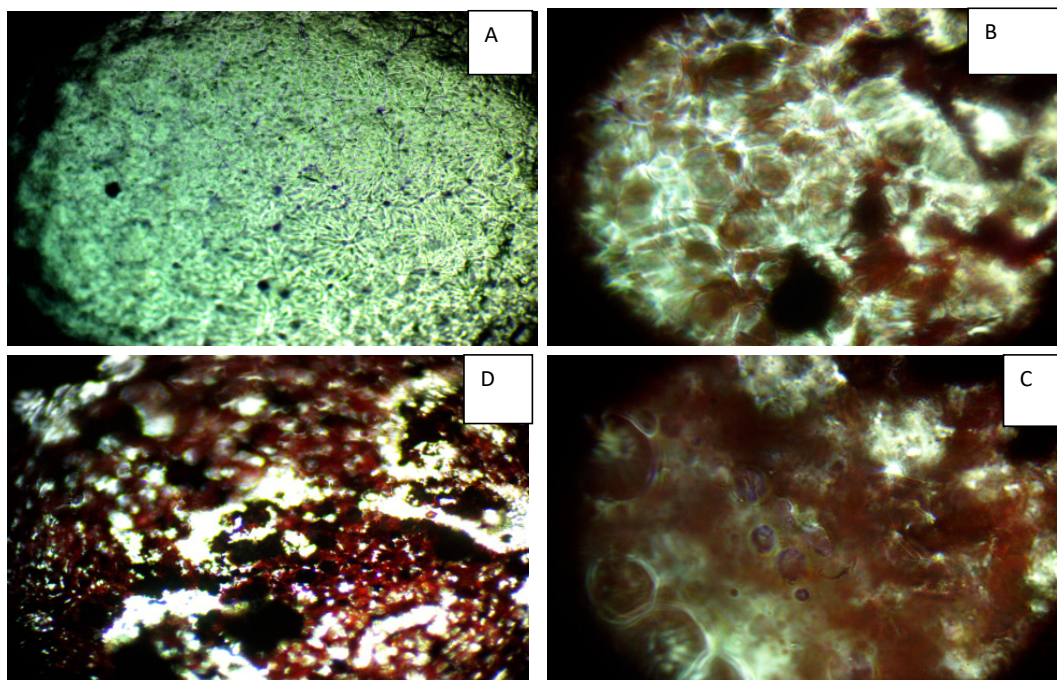
Fig.1. Photomicrographs (x40) for(PVA-PEO-Fe$_2$O$_3$) nanocomposites : (A) for pure (B) for 2 wt.% Fe$_2$O$_3$nanoparticles(C) for 4 wt.% Fe$_2$O$_3$ nanoparticles (D) for 6 wt.% Fe$_2$O$_3$ nanoparticles.

Figure 2 shows the FTIR spectra of (PVA-PEO-Fe$_2$O$_3$) nanocomposites . For all samples of nanocomposites are showed broad bands at around 3255.41 cm^{-1} and 3648.3 cm^{-1} are observed because of OH groups in the polymers matrix chain. The other bonds as (C-O-C) group can be noted in the bands at (1088) cm^{-1} were attributed to the PVA film was not so transparent. Peaks at (2900- 2908) cm^{-1} were due to the presence of C-H groups. The C=C stretching mode appear in the bands at (1708-1698) cm^{-1}.the peak at (1089-1096) cm^{-1} the band be strong for all samples of nanocomposites this is due to the stretching mode of C-O group. The two strong bands observed at around (1418 cm^{-1} and 842 cm^{-1})are due to the stretching and bending modes of CH$_2$ group respectively[10] .

The change in spectral of (PVA-PEO) involves shift in some bonds and change in the intensities due to iron oxide nanoparticles. The interaction between Fe$_2$O$_3$NPs and polymer blend causes these changes. From the FTIR studies note that there are no interactions between (PVA-PEO) blend and Fe$_2$O$_3$NPs. From figures are noted the transmittance decreases slightly with the increase of Fe$_2$O$_3$NPs concentrations because of the increase in density of nanocomposites [11].

The variation of dielectric constant and dielectric loss for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with frequency at room temperature are shown in Figure 3 and   Figure 4. As shown in Figures, the dielectric constant and dielectric loss are decreased with the increase of frequency. High values of dielectric constant and dielectric loss at lower frequencies may be because the dipoles have sufficient time to get align to the electric field. Decrease in dielectric constant and dielectric loss at higher frequencies may be associated with the inability of dipoles to align rapidly with the rapidly changing applied field [12]. From Figures 3 and 4the dielectric constant and dielectric loss are increased with the increase of iron oxide nanoparticles concentrations, this behavior attributed to increase of the charge carriers inside the nanocomposites [13], as shown in Figure 1.

Figure 5 shows that the variation of A.C electrical conductivity of nanocomposites with frequency. As shown in figure, the A.C electrical conductivity increases with the increase of frequency, this is due to the space charge polarization [14]. Also, the Figure 5 shows the electrical conductivity increases with the increase of iron oxide nanoparticles concentrations, this behavior attributed to the increase charge carrier numbers which are caused to decrease the resistivity and increase the conductivity of polymer blend [15].
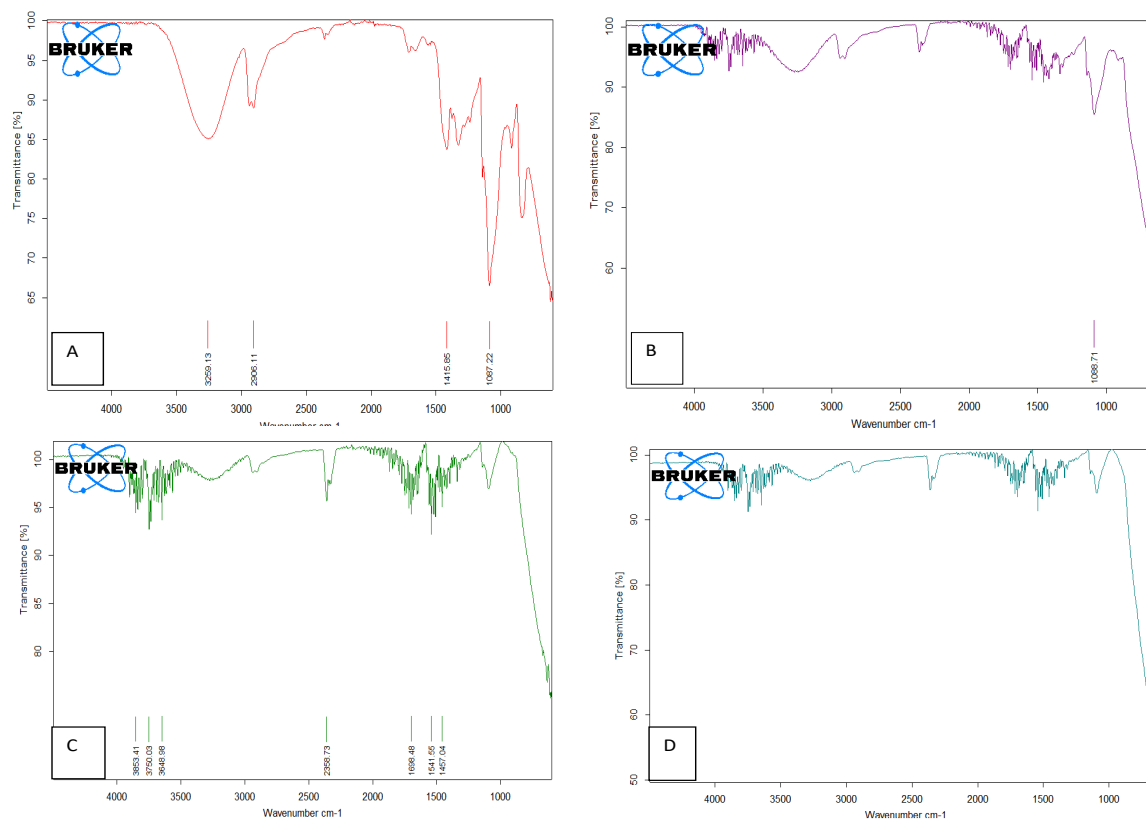
Fig.2. FTIR spectra for (PVA-PEO-Fe$_2$O$_3$) bionanocomposites A- (PVA-PEO) blend B- 2 wt.% Fe$_2$O$_3$NPs C- 4 wt.% Fe$_2$O$_3$NPs D- 6 wt.%. Fe$_2$O$_3$NPs.
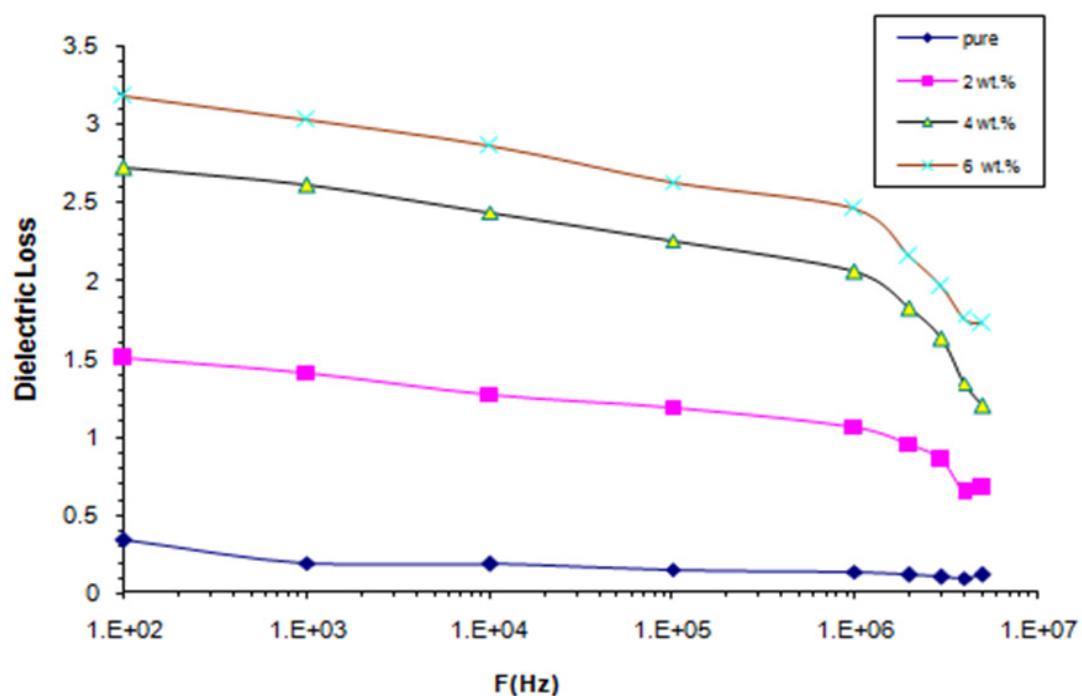

Fig.3. variation of dielectric constant for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with frequency.
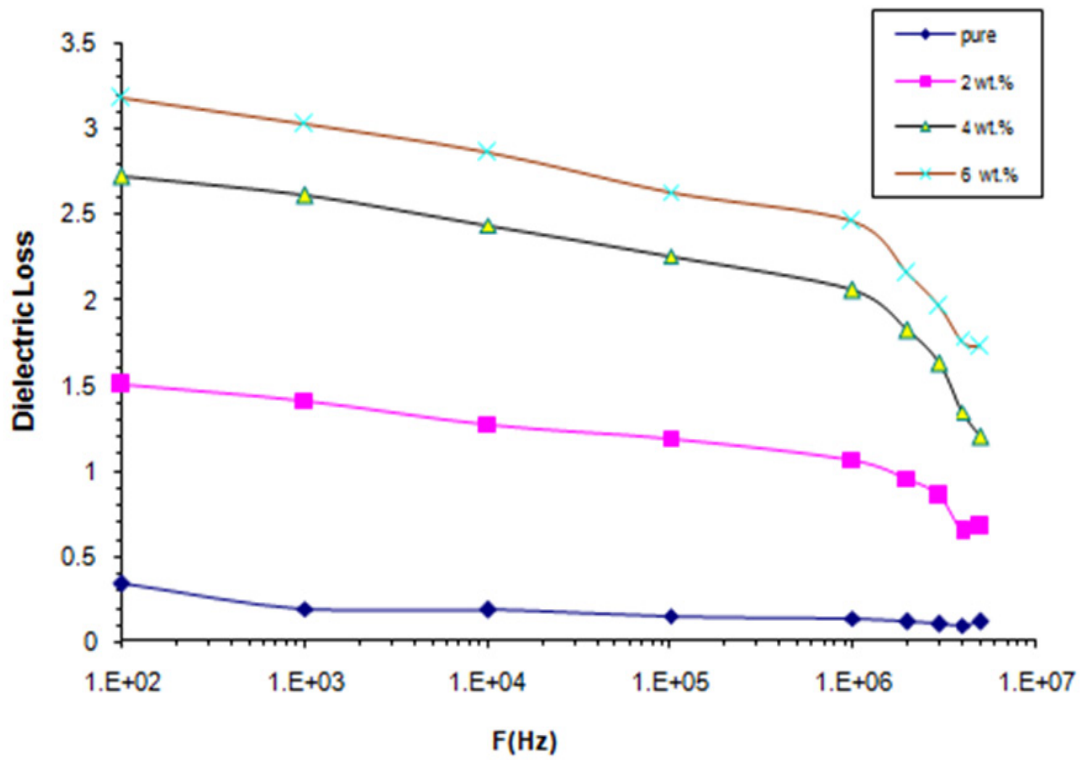
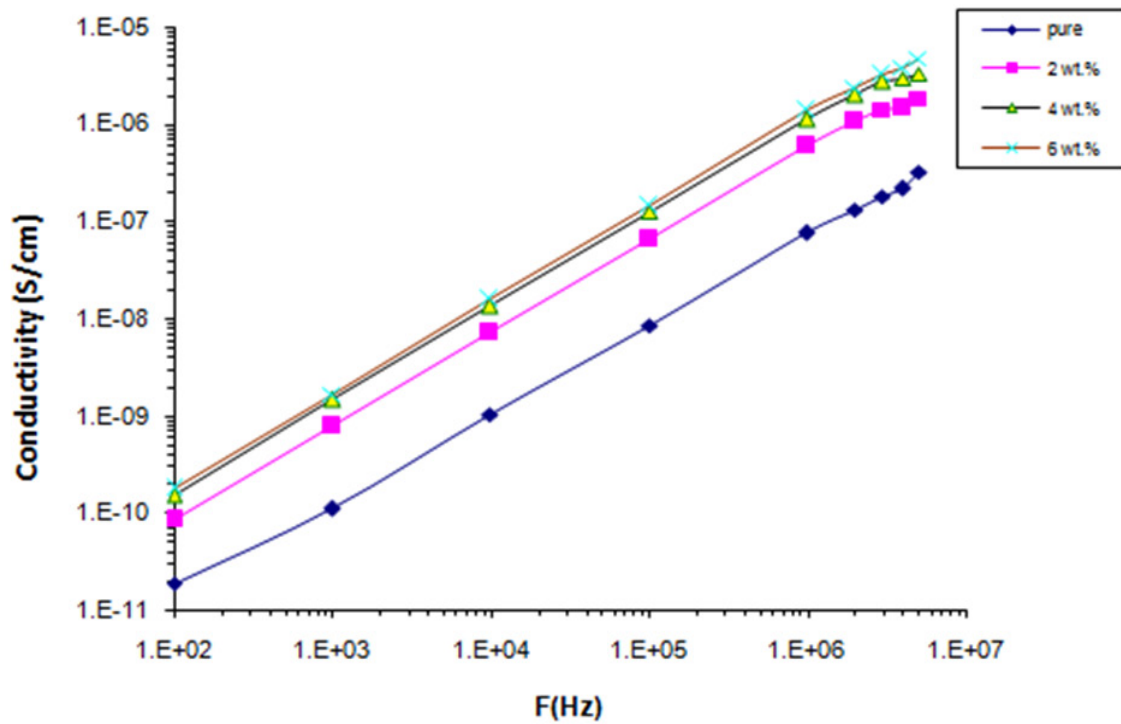**Fig.4. Variation of dielectric loss for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with frequency.**

Fig. 5. Variation of A.C electrical conductivity of nanocomposites with frequency.

To know the effects of iron oxide filler on the optical properties of (PVA-PEO) blend, UV-visible absorption spectra for (PVA-PEO-Fe_2O_3) nanocomposites was measured.

Fig.6 shows the absorbance for (PVA-PEO-Fe2O3)nanocomposites . It's indicated that intensity of the peak increase with increases iron oxide filler [16]. The absorption band shifts due tospecific weightFe_2O_3NPs andthe formation ofintermolecular hydrogen bonding existing between iron ions with the adjacent OH groups of the PVA and PEO main chain. Its note (PVA- PEO) blend has low absorbance because of the distance between valence and conduction bandis higher. The increase in ironoxide nanoparticles leads to the increase in absorption for (PVA-PEO-Fe_2O_3)nanocomposites [12,17].

Figure.7 shows the plot of absorption coefficient vs. incident photon energy for (PVA-PEO) blend with different percentages of iron oxide nanoparticles Fe_2O_3NPs. Itshows the absorption low when energy is low, this means the electrons transitions are low. In the high energy, absorption becomes large this indicate the high probability for electrons transitions. Absorption coefficient for (PVA-PEO-Fe_2O_3)nanocomposites is increased by increase of Fe_2O_3nanoparticles

additive [18]. The advantage of the absorption coefficient to conclude the transition electrons nature, when the value of absorption coefficient is high in the higher energy expected direct transition of electrons. The energy and momentum conservation can by electrons andphotons, when the value of absorption coefficient low expected indirect transition of electrons. The momentum conservation is by phonons only. From the results it's indicated absorption coefficient for (PVA-PEO-Fe_2O_3)nanocomposites has values are less than (10^4 cm^{-1}) which mean it's have indirect energy band gap as shown in Fig.7[18].

Figure 8 shows the variations between absorbance edge $(\alpha h\upsilon)^{1/2}$ for (PVA-PEO-Fe_2O_3) nanocomposites as a function of photon energy. By take straight line from the upper part of the curve in direction axis (X) in value $((\alpha h\upsilon)^{1/2}=0)$ it can be get indirect forbidden energy gap transition (allowed) [15]. It can be indicated that the values of forbidden energy gap (allowed) of (PVA-PEO-Fe_2O_3) nanocomposites are decreased with increasingiron oxide nanoparticles concentration this attribute to great localize levels in the forbidden energy gap. In addition to due to oxygen vacancies of Fe_2O_3NPs which due to from non-stoichiometry [17]. Fig. 9 shows the variations between absorbance edge $(\alpha h\upsilon)1/3$ for
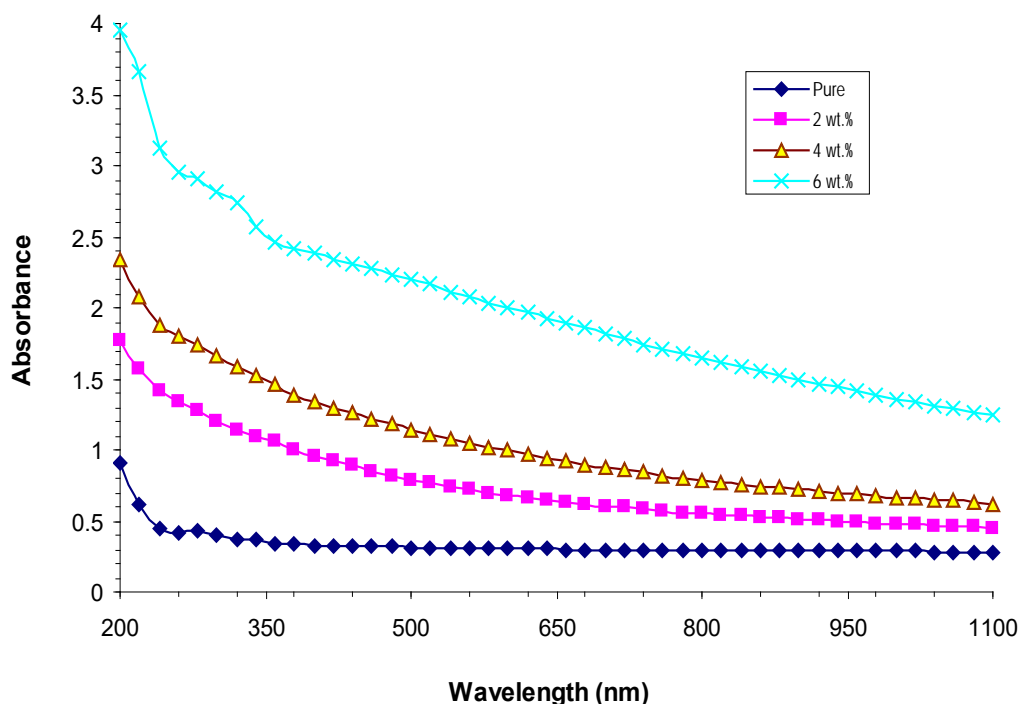

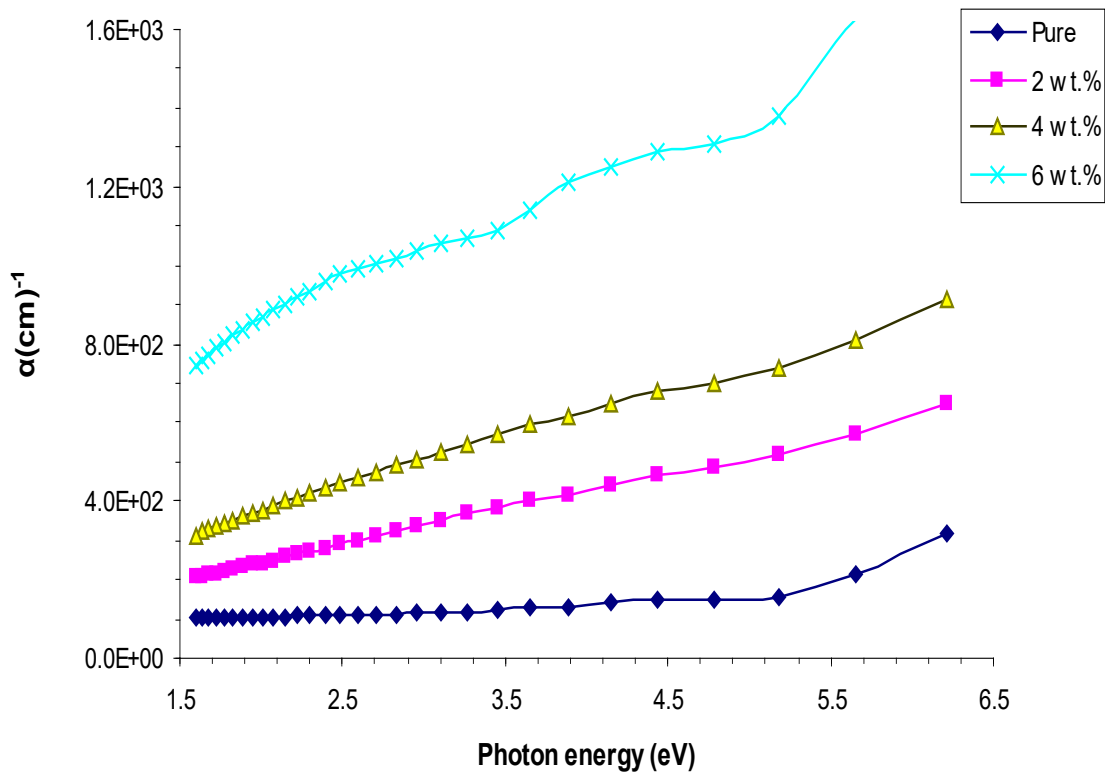**Fig. 6 . variation of absorbance for (PVA-PEO-Fe_2O_3) nanocomposites with wavelength.**

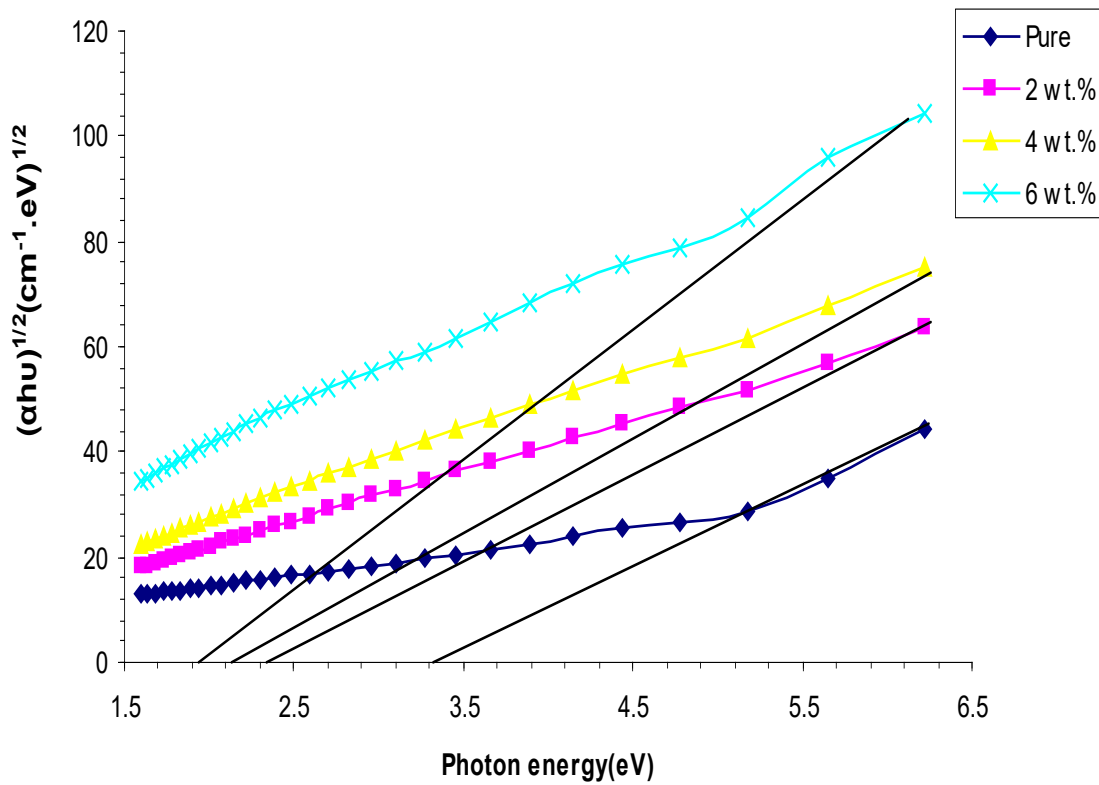**Fig.7. Variation of absorption coefficient (α) for(PVA-PEO-Fe$_2$O$_3$) nanocomposites with photon energy.**

Fig.8. Variation of (αhυ)1/2 for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with photon energy.

(PVA-PEO-Fe_2O_3) nanocomposites as a function of photon energy. Its indicate that the values of forbidden energy gap(prevent) for(PVA-PEO-Fe2O3) nanocomposites decrease with increase iron oxide nanoparticles(Fe2O3NPs) concentration this attribute to forms new levels and the transition of electrons between the tails of localize of the new levels made by the (Fe2O3NPs) additive[15,16].

To describe the attenuation of the waves must be study the extinction coefficient. Fig.10 shows the variations of extinction coefficientagainst wavelength for (PVA-PEO-Fe_2O_3) nanocomposites . It shows an increase in extinction coefficient with increasing of ironoxide nanoparticles for (PVA-PEO) blend. The increasing of extinction coefficient isattributed to high absorption coefficient. Where iron oxide nanoparticles will modify the structure of the host (PVA-PEO) blend. An interesting result that when the concentration of Fe_2O_3NPs increases the absorbance in the visible region increases [17-19].

To describe the electromagnet waves in the medium of propagation must be study refractive index. Fig.11 illustrates the plot of the variations

of refractive indexwith wavelength for (PVA-PEO-Fe_2O_3) nanocomposites . The index of (PVA-PEO) blend increases with increasing the iron oxide nanoparticles which attributed to increase the scattering of incident photon which causes to increase the reflectance.in addition to; further addition of iron oxide nanoparticles causes increasing the intensity for (PVA-PEO-Fe_2O_3) nanocomposites [20].

Figure 12 and 13 showthe variations of real and imaginary part respectively vs. wavelength for (PVA-PEO-Fe_2O_3)nanocomposites . It can be indicated that real part is greater than imaginary part due to the first is mainly proportional with square of refractive index. In addition to real part is increased with increasing (Fe_2O_3NPs) additive. Whereas the imaginary part proportional with extinction coefficient as shown in equation (11) and its increased with increasing of the ironoxide nanoparticles[21].

Figure 14 shows the optical conductivity with wavelength for (PVA-PEO-Fe_2O_3) nanocomposites . The optical conductivity is increased for (PVA-PEO-Fe_2O_3)nanocomposites due to iron oxide nanoparticles (Fe_2O_3NPs) are increased which leads to increase the absorption coefficient [22].
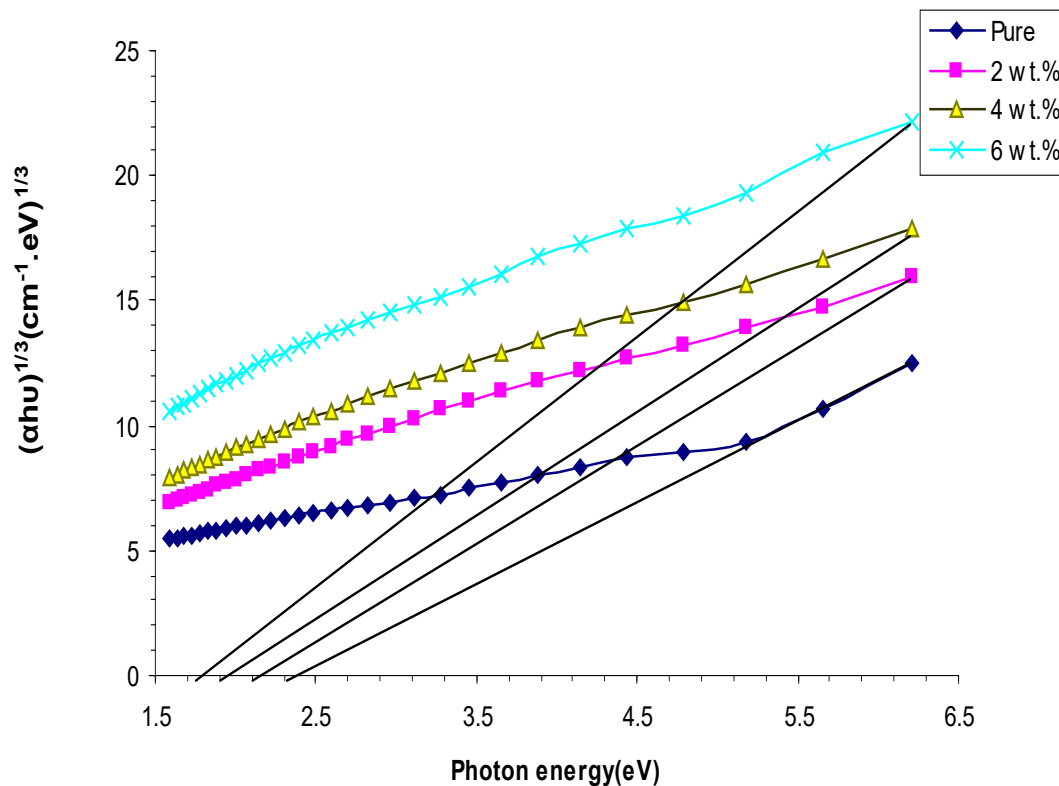

Fig. 9 . Variation of (αhυ)1/3 for (PVA-PEO-Fe_2O_3) nanocomposites with photon energy.
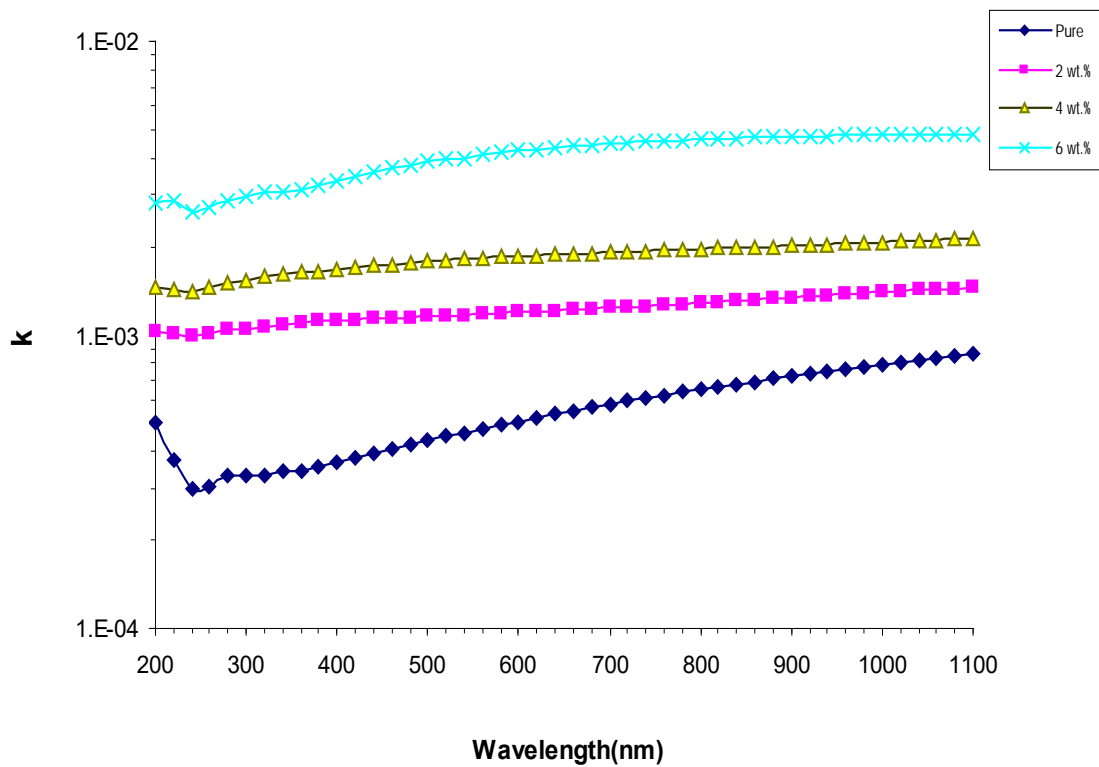
Fig. 10. Variation of extinction coefficient for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with wavelength.
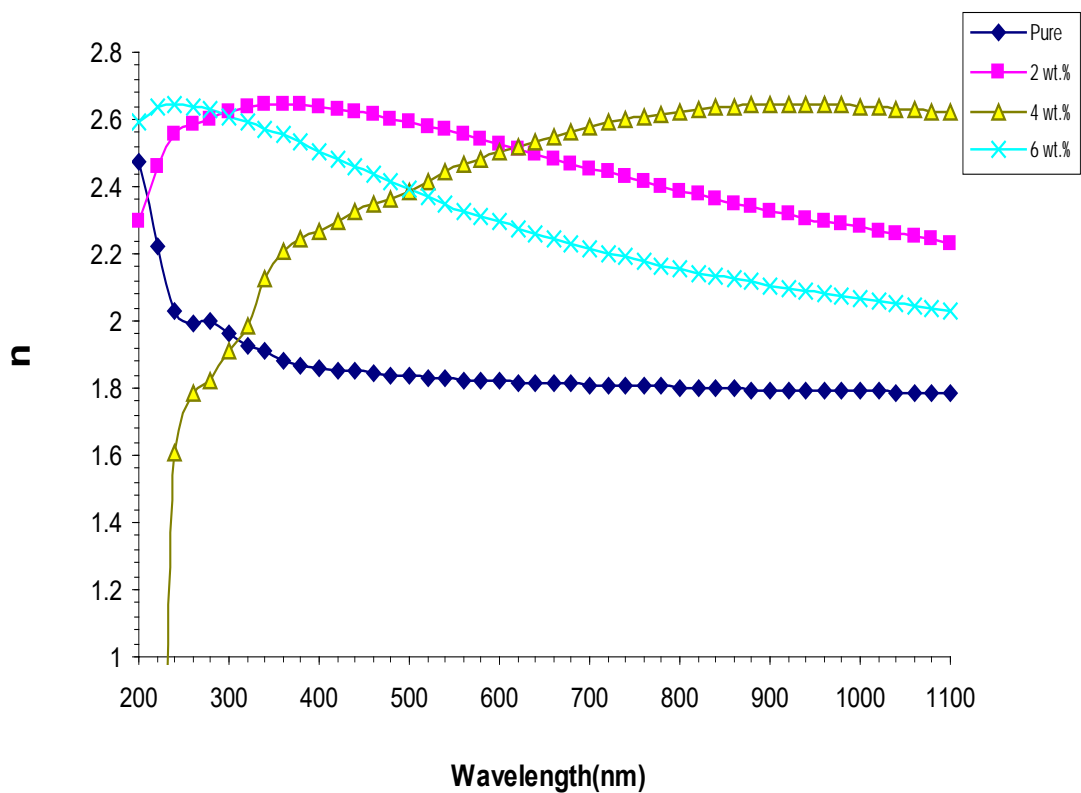

Fig. 11 . Variation of refractive index for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with wavelength.
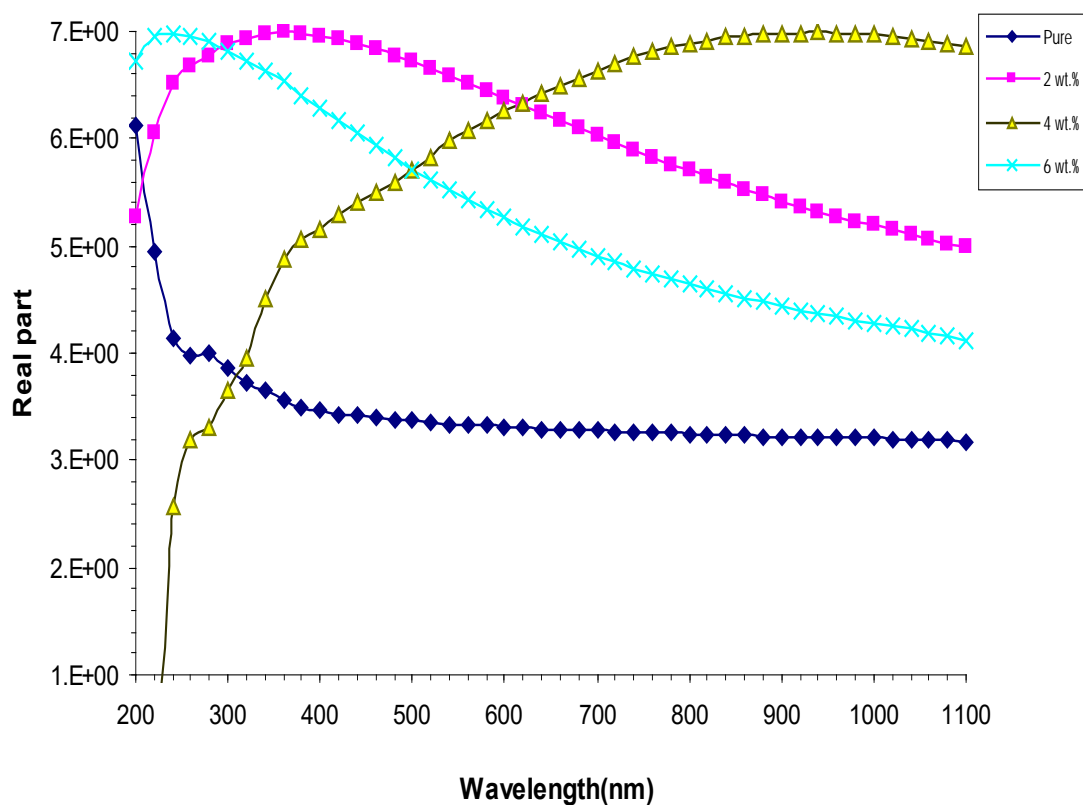
Fig. 12 . Variation of real part of dielectric constant for (PVA-PEO-Fe$_2$O$_3$) bionanocomposites with wavelength.
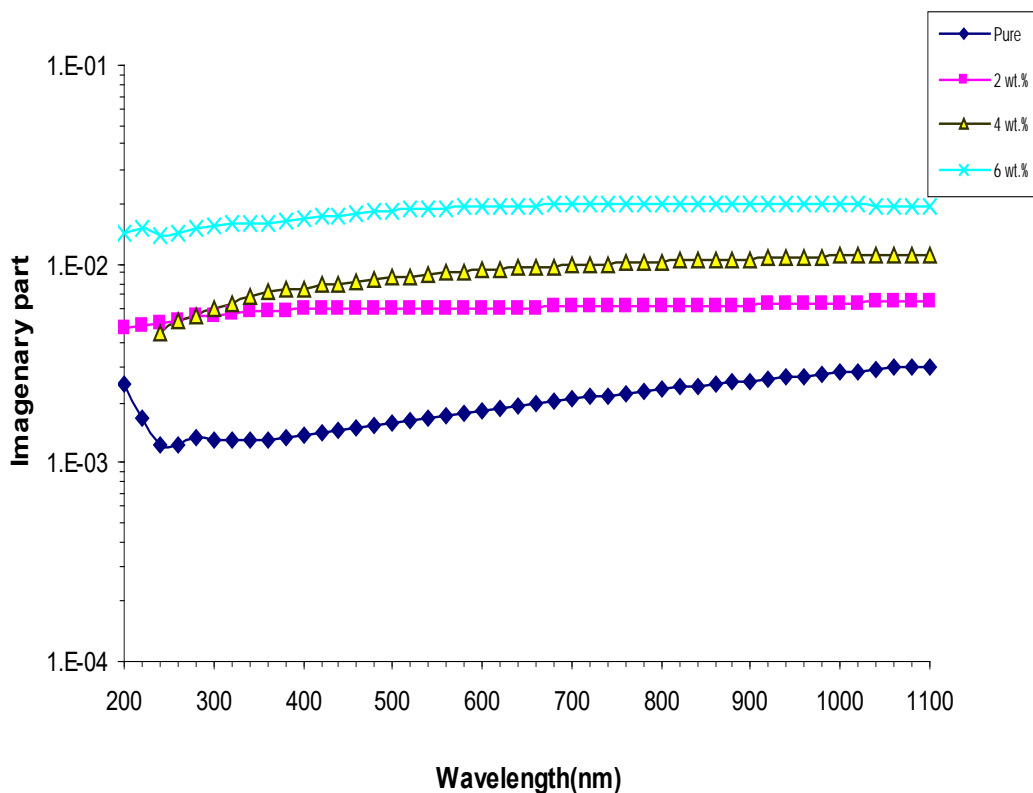

Fig .13 . Variation of imaginary part of dielectric constant for (PVA-PEO-Fe$_2$O$_3$) nanocomposites with wavelength.
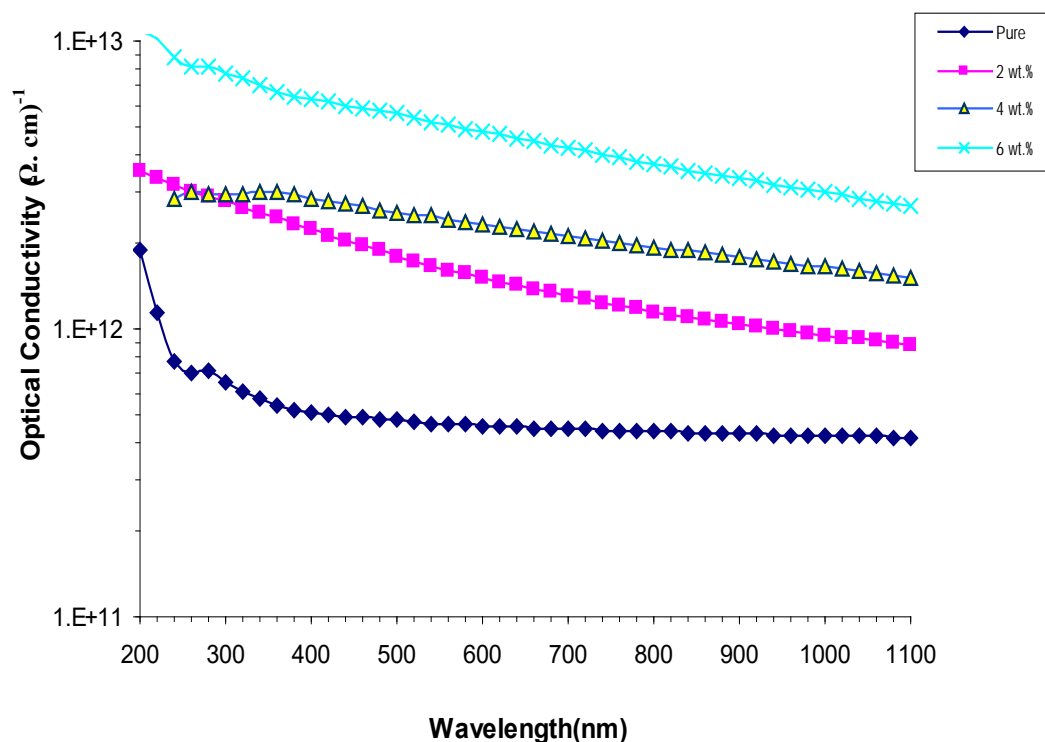
Fig. 14 . Variation of optical conductivity for (PVA-PEO-Fe₂O₃) bionanocomposites with wavelength.

Conclusions

1. The dielectric constant, dielectric loss and A.C electrical conductivity of (PVA-PEO) blend are increased with increase of the Fe2O3 nanoparticles concentrations which may be used it for different electronics applications.

2. The dielectric constant and dielectric loss of (PVA-PEO- Fe2O3) nanocomposites are decrease while the electrical conductivity increases with increase in the frequency. The results showed that the (PVA-PEO-Fe2O3) nanocomposites have good dielectric properties which can be used it for different applications in electronic industries.

3. The absorbance and optical constants (absorption coefficient, extinction coefficient, refractive index, real and imaginary dielectric constants and optical conductivity) of of (PVA-PEO) blend increase with an increase in weight percentages of iron oxide nanoparticles. The indirect energy gap (Eg) of (PVA-PEO) blend decreases with the increase of the concentrations of iron oxide nanoparticles. The results of optical properties showed that the the (PVA-PEO-Fe2O3) nanocomposites may be used for different optoelectronics applications.

References

1. Roberto Ambrosio, Amanda Carrillo, Maria de la Luz Mota, Karla de la Torre, Richard Torrealba, Mario Moreno, Hector Vazquez, Javier Flores and Israel Vivaldo, Polymeric nanocomposites membranes with high permittivity based on PVA - ZnO nanoparticles for potential applications in flexible electronics, Polymers,Vol. 10, 1370; doi:10.3390/polym10121370, (2018).

2. Cheng Peng, Yefeng Feng and Jianbing Hu, Enhancing High-Frequency Dielectric Properties of Beta-SiC Filled Nanocomposites from Synergy between Percolation and Polarization, Materials, Vol.11, doi:10.3390/ma11091699, (2018).

3. Ahmed Hashim, Majeed Ali Habeeb, and Aseel Hadi, Synthesis of Novel Polyvinyl Alcohol–Starch-Copper Oxide Nanocomposites for Humidity Sensors Applications with Different Temperatures, Sensor Letters, Vol.15, No.9, (2017).

4. Hamdy M. Zidan, Elmetwally M. Abdelrazek, Amr M. Abdelghany, Ahmed E. Tarabiah. Characterization and some physical studies of PVA/PVP filled with MWCNTs. J Mater Res Technol., https://doi.org/10.1016/j.jmrt.2018.04.023, (2018).

5. Ahmed Hashim and Majeed Ali Habeeb, Structural and Optical Properties of (Biopolymer Blend-Metal Oxide) Bionanocomposites For Humidity Sensors, Journal of bionanoscience, Vol.12, No.5, (2018).

6. Hasan Hüsey in Güllü, Dilber Esra Yildiz, Frequency Dependent Dielectric Properties of ZnSe/p-Si Diode, J. of Polytechnic, DOI: 10.2339/politeknik.389636, (2019).

7. K. Praveenkumar, T. Sankarappa, J. S. Ashwajeet, and R. Ramanna, Dielectric and AC Conductivity Studies in PPy-Ag Nanocomposites, Vol. 2015, Article ID 893148, 5 pages, http://dx.doi.org/10.1155/2015/893148, (2015).

8. T. Siddaiaha, P. Ojhaa, N.Obularajugari, G. Velikanti, R. Kumara, C. Ramua.,"Structural, Optical and Thermal Characterizations of PVA/MAA:EA Polyblend Films ", Journal of Materials Research, Vol. 12, No. 5, (2018).

9. [9] M. Abdallh, O. Hamood and E. Yousif, "Study the Optical properties of Poly (vinyl alcohol) Doped Cupper Chloride", Journal of Al-Nahrain University Vol.16 ,No.1, (2013).

10. P. Kumbhakar, S.Sinha Ray, and A. L. Stepanov, "Optical Properties of Nanoparticles and Bionanocomposites", Journal of Nanomaterials, (2014).

11. P. M . Amirtharaj and D. G . Seiler," Optical Properties of Semiconductors ", Materials Technology Group Semiconductor Electronics Diyision National Institute of Standards and Technology Gaithersburg , Maryland.

12. RakhiNangia, Neeraj K Shukla and Ambika Sharma, Preparation, Structural and Dielectric Properties of Solution Grown Polyvinyl Alcohol(PVA) Film, IOP Conf. Series: Materials Science and Engineering, Vol.225, (2017).

13. Ahmed Hashim, Majeed Ali Habeeb, Aseel Hadi, Qayssar M. Jebur, and WaledHadi, Fabrication of Novel (PVA-PEG-CMC-Fe3O4) Magnetic Nanocomposites for Piezoelectric Applications, Sensor Letters, Vol.15, No.12, (2017).

14. M. A. Habeeb, A. Hashim, and A. Hadi, Fabrication of New Nanocomposites: CMC-PAA-PbO2 Nanoparticles for Piezoelectric Sensors and Gamma Radiation Shielding Applications, Sensor Letters, Vol.15, No.9, (2017).

15. A. Hashim, M. A. Habeeb, A. Khalaf, and A. Hadi, Fabrication of (PVA-PAA) Blend-

16. W. Al-Taa'y, M. A.Nabi, R. M. Yusop, E. Yousif, B. M. Abdullah, J. S., N. Salih, and S.I. Zubairi," Effect of Nano ZnO on the Optical Properties of Polyvinyl chloride Films",Hindawi Publishing Corporation International Journal of Polymer Science,(2014).

17. Rashid F.L., Hashim A., Habeeb M.A.,Salman S.R.,, Ahmed H., Preparation of PS-PMMA copolymer and study the effect of sodium fluoride on its optical properties, Journal of Engineering and Applied Sciences, 8 (5), (2013).

18. Jasim F.A., Lafta F.,Hashim A., Ali M., Hadi A.G., Characterization of palm fronds-polystyrene composites, Journal of Engineering and Applied Sciences, 8 (5), 2013, 140-142.

19. A. Hashim and Q. Hadi, Structural, electrical and optical properties of (biopolymer blend/ titanium carbide) nanocomposites for low cost humidity sensors, Journal of Materials Science: Materials in Electronics,Vol. 29, pp.11598–11604, (2018).

20. S. Azizi, B. Mansor. Ahmad, N. A. Ibrahim, M. Z. Hussein,and F. Namvar,"Cellulose Nanocrystals/ZnO as a Bifunctional Reinforcing Nanocomposite for Polyvinyl alcohol/Chitosan Blend Films: Fabrication, Characterization and Properties",Int J Mol Sci., Vol.15,No.6,(2014).

21. S. Kramadhati, K.Thyagarajan,"Optical Properties of Pure and Doped (Kno3 & Mgcl2) Polyvinyl Alcohol Polymer Thin Films", Int. Journal of Engineering Research and Development Vol. 6, No. 8 (2013).

22. Ahmed Hashim and Majeed Ali Habeeb, (2019), Synthesis and Characterization of Polymer Blend-CoFe2O4 Nanoparticles as a Humidity Sensors For Different Temperatures, Transactions on Electrical and Electronic Materials, DOI: 10.1007/s42341-018-0081-1.

تحضير، الخصائص التركيبية والبصرية للمتراكبات النانوية (بولي فينيل الكحول- بولي اثيلين اوكسايد- اوكسيد الحديد)

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المتراكبات النانوية تستعمل عادة في مجالات مختلفة في التطبيقات الصناعية مع قلة الكلفة و خفة الوزن. في هذا البحث، متراكبات نانوية من بولي فينيل الكحول- بولي اثيلين اوكسايد- جسيمات اوكسيد الحديد النانوية تم تحضيرها. جسيمات اوكسيد الحديد النانوية تم اضافتها الى خليط البوليمر بنسب وزنية مختلفة هي (2، 4، 6) نسبة وزنية. درست الخصائص التركيبية والعزلية للمتراكبات النانوية (بولي فينيل الكحول- بولي اثيلين اوكسايد- جسيمات اوكسيد الحديد النانوي). بينت النتائج ان ثابت العزل الكهربائي، الفقدان العزلي، والتوصيلية الكهربائية للخليط (PVA-PEO) تزداد مع زيادة تراكيز جسيمات اوكسيد الحديد النانوية. ان ثابت العزل الكهربائي و الفقدان العزلي يقلان بينما التوصيلية الكهربائية تزداد مع زيادة تردد المجال الكهربائي المسلط. القياسات البصرية بينت ان الامتصاصية للمتراكبات النانوية ($PVA-PEO-Fe_2O_3$) تزداد مع زيادة تراكيز جسيمات اوكسيد الحديد النانوية. فجوة الطاقة غير المباشرة (Eg) تقل مع زيادة تراكيز جسيمات اوكسيد الحديد النانوية. الثوابت البصرية (معامل الامتصاص، معامل الخمود، معامل الانكسار، ثوابت العزل الحقيقي والخيالي، و التوصيلة البصرية للخليط (PVA-PEO) تتغير مع زيادة النسب الوزنية لجسيمات اوكسيد الحديد النانوية.