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Preparation of polymer/ferrite composites and study of their optical properties and dielectric constants

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Abstract:
This research included the preparation of films from (polymer-ferrite) compounds (FRCs). The ferrite was of the chemical composition (Ba_{1-x} Sr_x Fe_{12} O_{19}) of the (M-type) when (X = 0.0.6), as well as pure rubber and ferrite compounds, and the rubber was of the three types. (T484, CQR, EGI), the films were deposited on slides of glass by casting method. The optical properties of these compounds were measured using the ultraviolet spectrum and within the wavelength range (300-800) nm. The absorbance (A), transmittance (T), and reflectivity were determined. (R) The absorption coefficient (α), optical energy gap (E_g), extinction coefficient (K), refractive index (n), real (Є′) and imaginary (Є′′) dielectric constants, and optical conductivity ($\sigma_{a.c}$) were also estimated, knowing The value of the absorption coefficient (α) was identified. The nature of indirect electronic transfers was identified, and the energy gap values ranged between (1.79-3.83) eV. The largest value was for the pure Ferrite/T484 compound, and this value indicates that these compounds have good insulating properties.

Keywords: Optical properties, dielectrics constants, Polymer, Rubber, Hexagonal Ferrite

1-Introduction:

Ferrite magnetic compounds are composite magnetic materials that combine the elastic properties of rubber with the magnetic properties of hexagonal ferrite, making them ideal for applications that require these common characteristics. They have the unique advantage of being able to be modified for specific applications. In general, a composite material can provide a variety of applications for the production of materials. Outperform individual components, and thus compounds can be designed to exploit the best properties of the components [1]. Ferrite rubber compounds have wide application potential in the electrical and electronic industries and in various forms. They are used, for example, in magnetic memories for computers, magnetic cooling, color photography, and magnetic power transformers. Ferrite rubber compounds are also useful as microwave-absorbing materials because of their insulating properties and flexibility of design. The common properties of ferrite rubber compounds contribute to Improving the performance and efficiency of manufacturing solar and wind energy systems. It is also used in the manufacture of automobile sensors and engine parts that require flexibility and magnetism to improve performance and efficiency...etc[1]

Table 1- shows samples of ferrite-rubber compounds(FRC)

Sample	Ferrite compound	(x)	Ferrite- rubber composites (FRCs)	Weight ratio in grams
1	$BaFe_{12}O_{19}$	0	$BaFe_{12}O_{19}$ + T484 $BaFe_{12}O_{19}$ + CQR $BaFe_{12}O_{19}$ + EGI	1.5:15
4	$Ba_{0.4}Sr_{0.6}Fe_{12}O_{19}$	0.6	$Ba_{0.4}Sr_{0.6}Fe_{12}O_{19}$ + T484 $Ba_{0.4}Sr_{0.6}Fe_{12}O_{19}$ + CQR $Ba_{0.4}Sr_{0.6}Fe_{12}O_{19}$ + EGI	1.5:15

In recent years, scientists have been interested in studying the optical and electrical properties of composite materials due to their wide applications in optoelectronic devices [2]. One of the most prominent optical properties is what is known as the optical constants, which are represented by the absorption factor, the extinction and refraction coefficients, the electrical dielectric constants, and the optical conductivity. They are of great importance in optical applications such as solar cells, transistors, photodetectors, sensors, etc., and they have an important role in electronic applications [3]. The optical properties of any material depend on the ability of the material to absorb the rays falling on it the amount of transmittance of those rays and their reflection on the surface of the material [4-5].

In 2015 PANI- $NiFe_2O_4$ nanocomposites were successfully prepared by in situ polymerization with excellent, optical properties By M-Khairy and M.E.Gouda. New optical absorption band due to plasmon exciton interaction was observed in near IR of absorption spectra with E 1.0 eV for the direct band transition. The results observed refer to that specific properties can be tailored in the nanocomposites by mixing different proportions of PANI and $NiFe_2O4$ nanoparticles [6]. In the year (2018), researcher [S.Asiri] and his group studied the optical properties of $BaCr_y\ Fe_{12}\ O_{19}$ compounds ($0.0 \leq y \leq 1.0$). The study showed that the value of the energy gap decreases from 2.0 eV to 1.84 eV with the increase in the percentage of chromium [7]. In (2018), the researcher [B.S.Homlinsworth] studied the optical properties of thin films of high-temperature magnetic ferrite. He found that the energy gap is large with increasing temperature, and there is a direct energy gap of 2.7eV and an indirect energy gap of 1.2eV. This series of energy gaps has a strong overlap. With the solar spectrum, optical conductivity results showed that these states of the minority range can carry a current, and this current can be generated by light that depends on the magnetic field [8]. In (2019) Abdullah and others prepared Polycrystalline compounds of $La_{0.75}Ba_{0.25-x}SrFeO_3$ containing different amounts of Sr (x=0.00, 0.05, 0.10, and 0.15) were synthesized by the sol-gel method. Using the Tauc plot methodology, the optical band gap values have been evaluated from the UV-Vis measurements. These values increase with Sr content. The obtained results show that the structural, and optical properties are strongly affected by the strontium content [9] . In 2022, K. Parvathi enhanced the optical properties of nanocomposites made of chlorinated natural rubber and zinc ferrite ($ZnFe_2O$/(Cl-NR)) . The introduction of $ZnFe_2O$ into Cl-NR showed a decrease in the band gap energy detected by UV spectroscopy [10] .

2-Experimental Work

2-1 Materials used: hexagonal ferrite compounds($Ba_{1-x}Sr_xFe_{12}O_{19}$) , natural rubber(T484) , synthetic rubber(CQR) , mixed rubber(EGI) , formic acid CH_2O_2, rhodamine B dye.

2-2 Method preparing films:

In this research, films were prepared by casting method.

The method of preparing films for FRCs was done by dissolving a certain amount of these compounds in 20ml of formic acid, then placing the solutions on a magnetic stirrer as shown in Figure (1a) at a temperature of 150°C for four hours until they dissolved well. After that, the impurities were removed using filter papers, then the solutions were poured using a medical dropper (pipette) onto bases made of glass that had previously been cleaned to get rid of impurities whose presence affects the accuracy of the measurements. These bases were placed horizontally to ensure homogeneous distribution of the solution. The bases were then left for 48 h's. An hour until the films formed in the desired shape. The models were processed at a temperature of (50°C◦)

for a period of (30 minutes) to complete the solidification process of the material. The thickness of the films was also measured using the electronic micrometer device shown in Figure (1b) by measuring the thickness of the glass before pouring by taking several Readings for a number of locations on the glass surface, then taking the average of these readings and measuring the thickness of the film after pouring, and knowing the difference between the two readings, the thickness of the film is determined. In this way, the models are ready for optical measurements.

Optical measurements were carried out using the electromagnetic spectrometer [UV-vis(1800)] shown in Figure (1c) for films prepared from (Ferrite/T484, CQR, EGI) within the wavelength range (300-800) nm and at different weight percentages, respectively.

a) b)

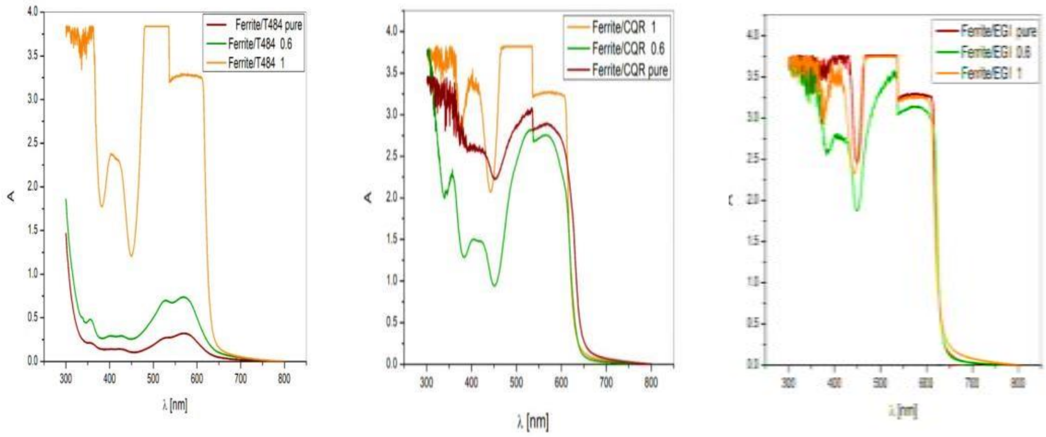
c)

Fig **1**. shows the devices used to measure optical properties , (a) thermal magnetic stirrer device, (b) an electronic micrometer, (c) an ultraviolet electromagnetic spectrometer.

3-Results and Discussion

3-1 Absorptance Spectrum (A)

Absorbance spectrum measurements were carried out within the wavelength range (300-800)nm for all films prepared from Ferrite/T484, CQR, EGI, and Figure (2a, b, c) shows the relationship of absorbance with wavelength. We note from the figure that the absorbance for all films decreases with... Increasing the wavelength is greatest at short wavelengths. This is due to the fact that the energy of the incident photon is less than the value of the energy gap of the semiconductor, so the incident photon does not have enough energy to excite the electron and move it from the valence band to the conduction band. Therefore, the absorbance decreases with increasing wavelength [11].

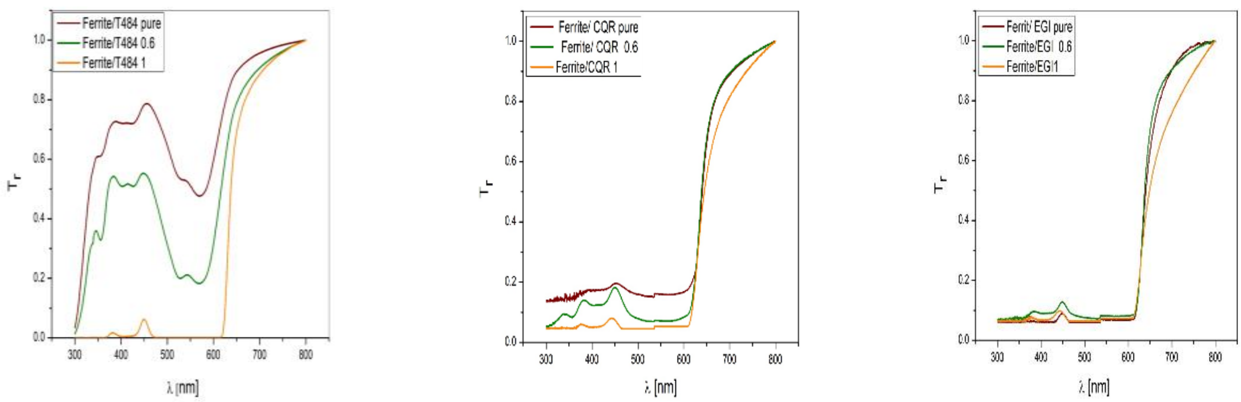


a) b) c)

Fig .2abc. The relationship between absorbance and wavelength for films prepared from (Ferrite/ T484, CQR, EGI)

3-2 Transmittance Spectrum (T_r)

We notice from Figure (3a, b, c) that the transmittance spectrum has an opposite behavior to absorbance, as it increases with increasing wavelength, as well as with decreasing mixing ratio, for all membranes. This is due to the small percentage of ferrite meaning the presence of materials that are less effective in absorbing and transmitting electromagnetic waves, which reduces of permeability in general.



a) b) c)

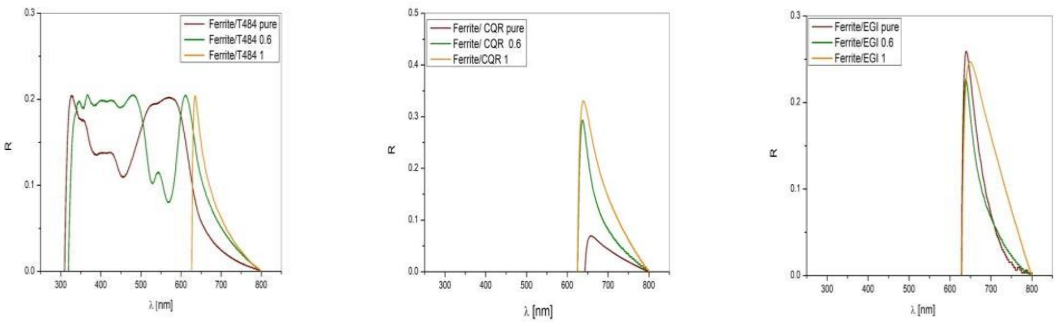
Fig .3abc. The relationship between the transmittance spectrum and the wavelength of films prepared from (Ferrite/T484, CQR, EGI)

3-3 Reflection Spectrum (R)

The reflectivity spectrum of films prepared from Ferrite/T484, CQR, EGI was calculated from the following relationship:(Req.)

$$A+T+R=1 \qquad (1)$$

Figure (4, a, b, c) shows the change in the reflectivity spectrum as a function of wavelength for films prepared from (Ferrite, T484, CQR, EGI), where the absorbance increases with increasing wavelength and with increasing mixing ratio in Figure (4a, b) and in Figure (4c) The greatest reflectivity appears at the mixing ratio (1) in the compound (Ferrite/CQR), where its value is (0.35). We also note that the reflectivity spectrum is similar to the absorbance spectrum.



a) b) c)

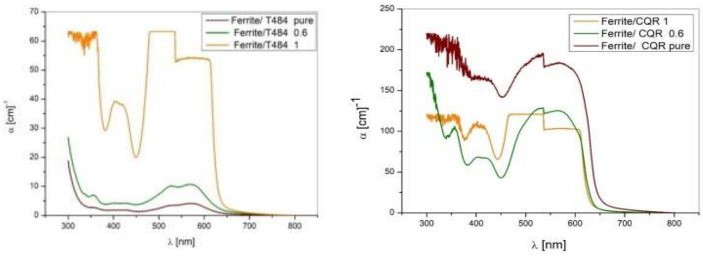
Fig .4abc. The relationship between the reflectivity spectrum and the wavelength of films prepared from (Ferrite/T484, CQR, EGI)

3-4 Absorption Coefficient (α)

The absorption coefficient is defined as the portion of the incident light beam that is absorbed per unit thickness of the light-absorbing material (absorbed photons). The absorption coefficient was calculated from the equation:(Req.)

$$\alpha = \frac{2.303A}{d} \qquad (2)$$

Figure (5a, b, c) shows the relationship between the absorption coefficient (α) as a function of wavelength, where the value of the absorption coefficient was less than (10^4 cm^{-1}). This indicates the nature of indirect electronic transfers. It was also found that the values of the absorption edge change with the mixing ratios between... The connection and equivalence bands are due to the presence of additional energy generated from mixing, and as the mixing ratio increases, the energy levels generated increase [12].



a) b) c)

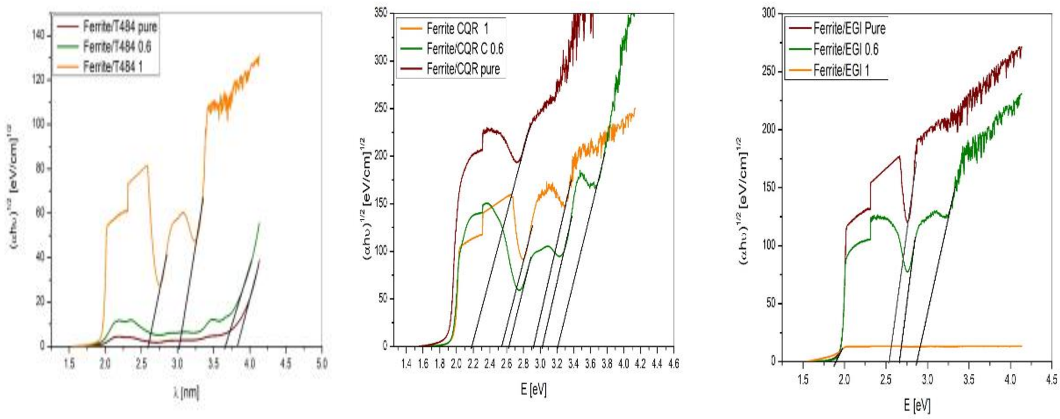
Fig .5abc. The relationship between the absorption coefficient and the wavelength of films prepared from (Ferrite/T484, CQR, EGI)

3-5 Optical energy gap (E_g)

To find the value of the energy gap for the films used, the relationship was use(Req.)

$$\alpha h\nu = A(h\nu - E_g)^r \qquad (3)$$

We notice from Figure (6a) that the optical energy gap increases with a decrease in the concentration ratio. The reason for this is that with increasing concentration, new levels are generated near the valence band within the energy gap, which leads to the generation of bridges to cross the electrons transferred between the conduction and valence bands, so the number of electronic transitions increases. In Figure (6b, c), the energy gap increases at concentration (0.6) as a result of the increase in density at this concentration, as well as as a result of defects in the crystal structure created by the increase in strontium atoms, which created difficulty in the transfer of electrons between the conduction and valence bands, leading to an increase in the value of the energy gap. [13].



a) b) c)

Fig .6abc. The relationship between $(\alpha h\nu)^{1/2}$ and hv for films prepared from (Ferrite/T484, CQR,EGI)

Table 2- shows the optical energy gap values for films prepared from (Ferrite/T484, CQR, EGI)

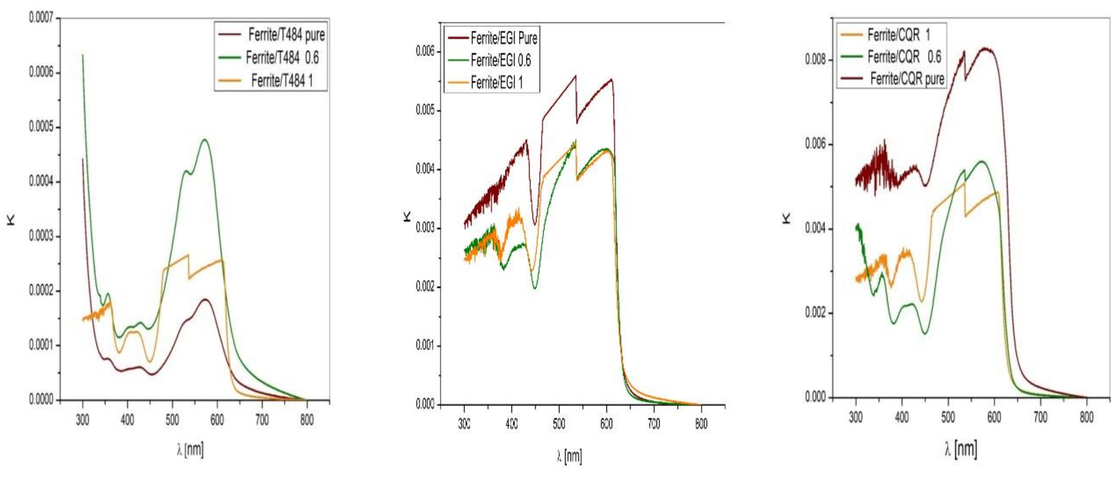
Sample	**Energy gap (E_g)**
Ferrite/T484 pure	(3.83) ev
Ferrite/T484 0.6	(3.67) ev
Ferrite/T484 1	(2.59,3.03) ev
Ferrite/CQR pure	(2.18) ev
Ferrite/CQR 0.6	(2.63,3.02,3.22) ev
Ferrite/CQR 1	(2.54,2.92) ev
Ferrite/EGI pure	(2.54) ev
Ferrite/EGI 0.6	(2.66,2.87) ev
Ferrite/EGI 1	(1.79)ev

3-6 Extinction coefficient (K)

The extinction coefficient was calculated from the relationship (Req.)

$$K = \frac{\alpha\lambda}{4\pi} \quad (4)$$

Figure (7a, b, c) shows the relationship of the extinction coefficient with wavelength. We notice from the figure that the extinction coefficient is greatest at wavelengths in the range (450-650). We also notice that there is a similarity between the extinction coefficient curve with the absorption coefficient curve, because The values of the extinction coefficient depend on the values of the absorption coefficient according to the relationship (4).



a) b) c)

Fig .7abc. The relationship between the extinction coefficient and the wavelength of films prepared from Ferrite/T484, CQR, EGI).

3-7 Refractive index (n)

The index of refraction is defined as the ratio between the speed of light in a vacuum to its speed in a medium for a given wavelength.

The index of refraction (n) was calculated for all films prepared from Ferrite/T484, CQR, and EGI using the following equation [14].

$$n = \sqrt{\frac{4R}{(1-R)^2} - K^2} + \frac{1+R}{1-R} \quad (5)$$

Figure (8a, b, c) shows the change in refractive index as a function of wavelength for films prepared from (Ferrite, T484, CQR, EGI). We notice from the figure that the nature of the refractive index curve is almost similar to the nature of the reflectivity index curve, because the refractive index is related to reflectivity according to the relationship (5) As it increases with increasing wavelength and with increasing mixing ratio in Figure (8c), we obtain the largest value of the refractive index with decreasing mixing ratio for the compound (Ferrite/EGI Pure), where its value reaches (2).

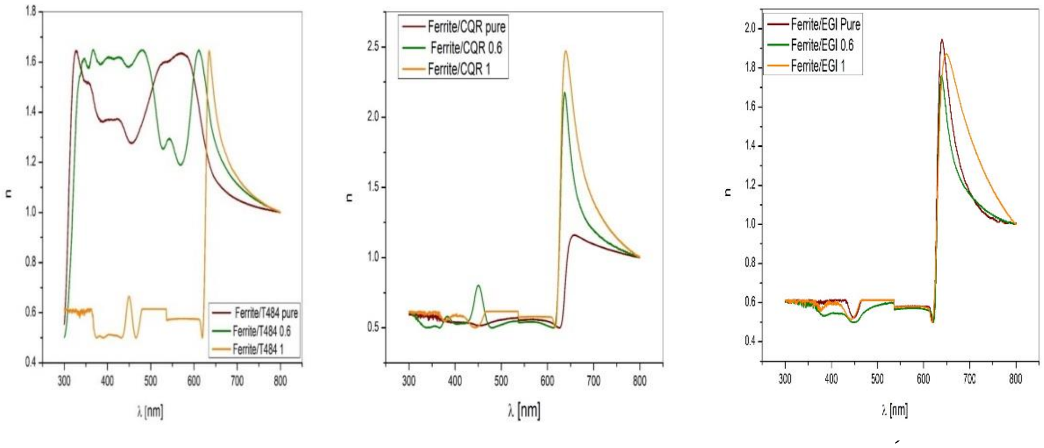


Fig .8abc. The relationship between the refractive index and wavelength of films prepared from Ferrite/T484, CQR, EGI)

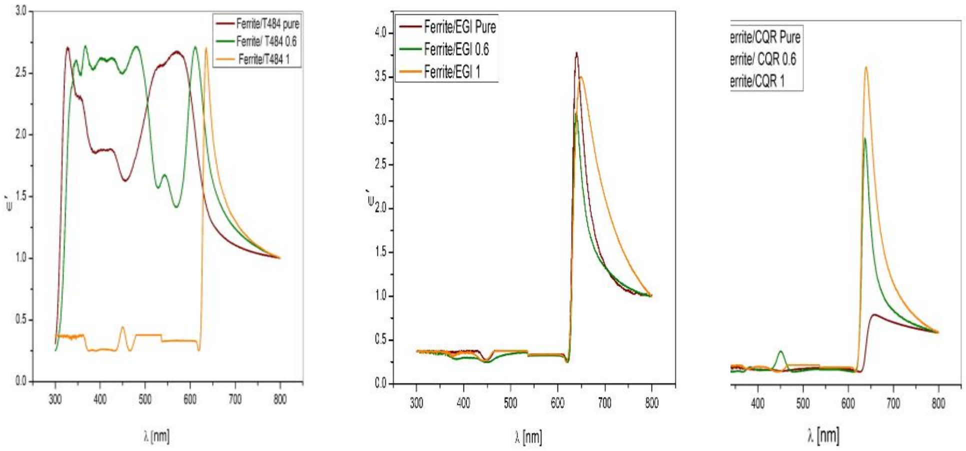
3-8 Dielectric Constant (€)

The dielectric constant, with its real and imaginary parts, represents the response of electrons to the electromagnetic field and is given by equation [15-20].

$$\epsilon = {}^{\prime}\epsilon\ (n^2 - K^2) \qquad (6)$$

$$\epsilon^{\prime\prime} = (2nk) \qquad (7)$$

We notice from Figures (9a, b, c) and (10a, b, c), which represent the relationship between the real and imaginary dielectric constants as a function of wavelength, that the behavior of the real dielectric constant is similar to the behavior of the refractive index curve, which increases with increasing wavelength, and that the behavior The imaginary dielectric constant curve is similar to the behavior of the extinction index curve, and here the effect of the refractive index curve is negligible.



a) b) c)

Fig .9abc. The relationship between wavelength and the real dielectric constant for films prepared from (Ferrite/T484, CQR, EGI)

a) b) c)

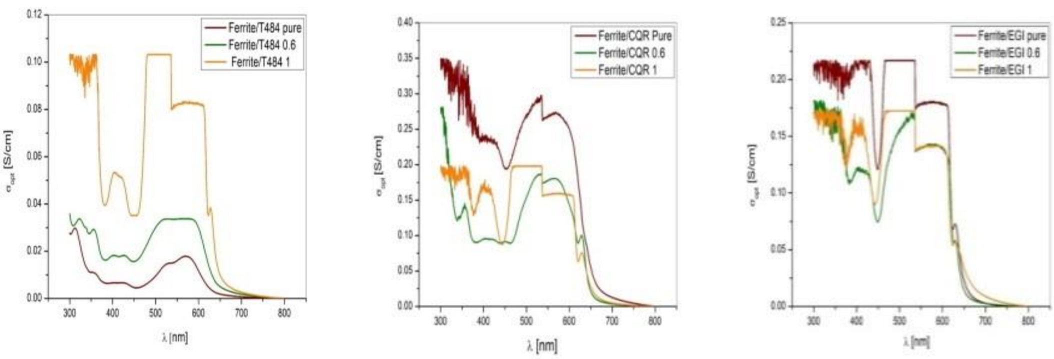
Fig.10abc.The relationship between wavelength and the imaginary dielectric constant for films prepared from (Ferrite/ T484,CQR,EGI)

The Optical Conductivity (σ_{opt}) 3-9

Optical conductivity (σ_{opt}) was calculated from the following equation:(Req.)

$$\sigma_{opt} = \alpha\, n\, c/4\pi \qquad (8)$$

Figure (11a, b, c) represents the relationship between the optical conductivity and the wavelength of the films prepared from (Ferrite/T484, CQR, EGI). It is noted from the figure that the conductivity increases with a decrease in wavelength. In its calculations, the optical conductivity depends on the refractive index and the absorption coefficient according to The equatin(8).



a) b) c)

Fig .11abc. The relationship between optical conductivity and wavelength for films prepared from (Ferrite/T484, CQR, EGI)

4- Conclusion

After preparing the films through the casting process and measuring the optical properties using an electromagnetic spectrometer, we concluded that the absorbance increases with decreasing wavelength because at short wavelengths the energy of the photons is high and their absorption rate by the material is large, but at long wavelengths the energy of the photons is low and their absorption by the material is also low. The transmittance spectrum increases. As the wavelength increases, due to the interaction between the electromagnetic properties of the material and the structural composition, which in turn leads to an increase in permeability as the wavelength increases. It was also found that the absorption coefficient (α) is less than (10^4 cm^{-1}), and through it indirect electronic transfers were identified and that the values The energy gap ranges between (1.786-3.28) eV. The large value of the energy gap for pure (Ferrite/T484) compounds indicates that the electrons need a lot of energy to move from the valence band to the conduction band, and therefore these materials are not good conductors of electricity.

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