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Impact of Alpha Rays on the Optoelectronic Properties of Epoxy Resin Thick Films

Zahraa S. Rasheed,* Lamyaa Mohammed Raoof and Muhanad Alrakabi

Department of Physics, College of Science, Mustansiriyah University, P. O. Box 14022, Palastine St, Baghdad, Iraq

*Corresponding author: sci.phy.zsr@uomustansiriyah.edu.iq

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ABSTRACT: *Irradiated epoxy thick films are important for optical properties and may be used in many optical applications. This study aims to evaluate the effect of alpha irradiation on the optical and structural properties of epoxy thick films. Epoxy resin films were prepared by mixing epoxy resin (A) with hardener (B) at a mixing ratio of 3:1. Thus, specific thick films with thicknesses of 0.7 mm,0.8 mm and 1 mm were manufactured. Using visible and ultraviolet spectroscopy is one of the most important methods for studying polymers band gaps and electrical properties. The absorbance and transmittance spectra were used to investigate the optical properties of epoxy coatings of different thicknesses over a wavelength range of 300 nm–900 nm. Optical properties, such as absorption coefficient, refractive index, extinction coefficient, real dielectric constant, imaginary dielectric and optical band gap, were measured. The results show that the epoxy thick films have good optical transparency in the low-wavelength region. The results showed that increasing the thickness of the resin films decreased the optical energy gap and refractive index while increasing the absorption and extinction coefficients. In comparison, the effect of irradiation on an epoxy film of thickness 1 mm leads to an increase in the transmittance spectrum and energy gap and a decrease in the optical constants. The Fourier-transform infrared (FTIR) spectrum of the films was examined and showed the types of chemical bonds of the epoxy films before and after irradiation.*

Keywords: absorption coefficient, alpha radiation, epoxy, energy gap, irradiation

1. INTRODUCTION

Epoxy resin is one of the most crucial polymers in terms of hardness and resistance to chemicals to a large selection of dilute acids and solvents, good adherence and exceptional electrical insulating properties.[1] As technology and science improve, high-molecular-weight materials have emerged as one of the most tempting resources for advanced applications, and epoxy resin has good thermal stability characteristics, excellent high durability and impressive performance at extreme heat, among many other characteristics.[2,3] It is low-priced, safe and flexible in operations.[4] Much work has gone into defining and comprehending polymer mechanical and physical characteristics. Because of their usefulness in optical systems, studies on the optical properties of polymers have received much interest in recent years. Thermoplastic composites have exceptional properties such as low weight and recyclability. The increasing use of resin composites in esthetic restorative dentistry can be ascribed to their superior biocompatibility.[5] Manufacturing thermoplastic materials in the form of fibers was used as a simple approach to solving this issue.[6] In both amorphous and crystalline materials, optical absorption spectra in solids provide critical information about energy gaps and band structure. The fundamental absorption edge is a sudden increase in absorptivity when the absorbed energy radiation is nearly equal to the band energy gap. As a result, the basic absorption edge is represented by the difference in energy between the upper and lower valence band points. The absorption regions are divided into three categories: (1) high absorption, (2) exponential absorption and (3) low absorption. High absorption region, where the magnitude of the absorption coefficient ($\alpha \geq 10^4$ cm^{-1}). The Exponential Region ($1 < \alpha < 10^4$ cm^{-1}) is defined as the amplitude of the forbidden optical energy gap (E_g opt) and corresponds to the transition between the elongated level valence band (VB) and the local conduction band (CB). In addition, from the highest local levels of V.B. to the bottom extended levels of CB.[7] Low absorption region: the value of (α) is very small, approximately ($\alpha < 1$ cm^{-1}), and transitions occur between both regions VB to CB.[8] The density of the state inside space causes structural motion. Irradiation's consequences on optical absorption, especially at the absorption edge, have proven to be quite beneficial in explaining the electronic structure of materials. Optical absorption spectra were used to determine the indirect and direct band gap transitions.[9] Optical constants such as reflectance, refractive index, absorption coefficient and dielectric constant were determined using data on absorption and transmittance. Because it is strongly connected to the electronic polarisation ability of ions and the local field inside the material, the refractive index is one of the fundamental features of a material. Evaluating optical materials' refractive indices is critical for applications in integrated optics devices such as switches, fillers and modulators.[10] Ionising radiation, on the other hand, is commonly used to cause structural and optical changes

in exposed polymers.[11] Depending on the polymer structure, ionising radiation and absorbed dose, ionising radiation can cause a cross-link or rupture in the molecular bonds of polymers.[12,13] Irradiation, in particular, has been effectively employed to cure epoxy resins to create advanced composites, allowing them to operate at room temperature and in less time than thermal procedures.[14]

This research evaluates the effect of alpha irradiation on epoxy thick films' optical and structural properties. Technical characteristics have been exploited because of its good attenuation capabilities, low material cost and low processing (molding, machining, etc.) expenses.

2. EXPERIMENTAL

2.1 Tools and Materials

The tools used in this study were (UV-Vis) spectrophotometer (T70), UK, Perkin Elmer spectrum one Fourier-transform infrared (FTIR) spectrometer, USA and Isotrak the americium-241 Demo Source, Germany. The material used was epoxy resin Company Don Construction Products (DCP) manufactures it (type Quickmast 105), Jordan.

2.2 Preparation of the Epoxy Films

An epoxy resin system is mixed with a hardener and then solidified to form a strong permanent bond. The epoxy-thick film was created by mixing different amounts of hardener for 3 min and then transferring them to various molds for 24 h. The samples were obtained from the de-molded and investigated. The thickness of the deposited films was examined with a thickness monitor and confirmed to be 0.7 mm, 0.8 mm and 1 mm.

2.3 Irradiation of the Epoxy Films

The americium-241 radioactive source was placed on top of a thick epoxy film, and the material was exposed to alpha irradiation, as shown in Table 1.[15]

Table 1: Information for the irradiated source.

Isotope	Activity	Date of manufacture	$T_{1/2}$	E(Kev)	I(%)	Notes
$^{241}Am_{146}$	9 μCi	1,976	432.2Y	59.54	Iα = 84.5	Manmade
				5,485.6	Iα = 13.0	Q[α (100%)=5637.8Kev] v+S.F.
				5,442.8	Ir = 35.9	Neutron Activation

3. RESULT AND DISCUSSION

3.1 Optical Measurements

A (UV-Vis) spectrophotometer was used to gather the optical transmission and absorbance spectra of the epoxy films at room temperature in the wavelength range of 300 nm–900 nm. The transmission spectra of the epoxy thick films before and after irradiation are shown in Figure 1. The transmittance spectrum in the range of 310 nm–396 nm is sharply reduced. Its intensity decreases as the thickness of the layer increases. When the epoxy film is at a thickness of 1 mm under irradiation, we notice an increase in transmittance. Because Alpha irradiation has changed the optical characteristics of materials, atomic electrons may be ionised or excited, and atoms may be displaced from their lattice locations due to the radiation. The photogenerated electrons formed loose bonds with some trapping centers in the material structure. Because of these novel electronic structures, the optical properties of the films change.[16]

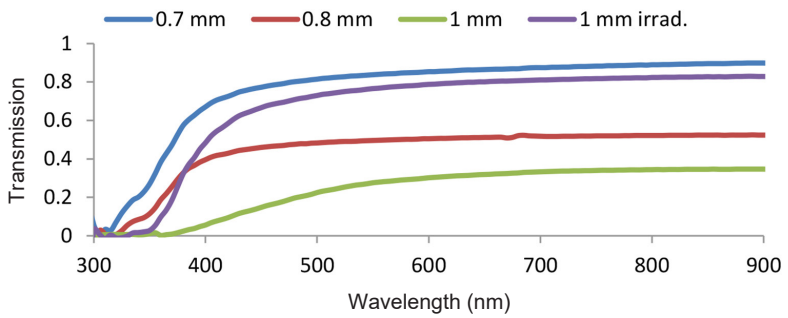

Figure 1: Transmission spectrum before and after irradiation of epoxy thick films of varying thicknesses.

Figure 2 displays the absorption spectra of epoxy films, which have opposite performance to the transmission spectrum. The epoxy thick film has an absorption band of approximately 310 nm–396 nm in its absorption spectra. When increasing thickness, the absorption edge shifts towards a longer wavelength (redshift) and increases absorption intensity.[15] The use of photon energy (hυ) to drive electrons from VB to CB is the course of UV-absorption in such materials.[17] As for the effect of irradiation, we notice that the absorbance decreases after irradiation, and the reason is that the radiation leads to the cleavage of the chains, which means that the energy absorbed by the polymer molecules leads to the breaking of the chains.

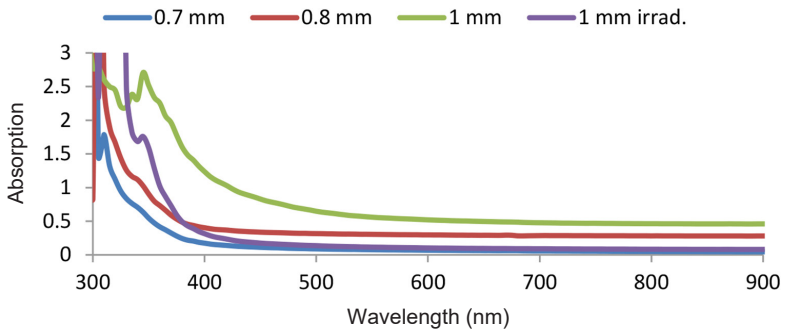

Figure 2: Absorption spectrum before and after irradiation of epoxy thick films of varying thicknesses.

Figure 3 shows the absorption coefficient (α) of epoxy films. The reason for the increase in the absorption coefficient when the thickness is increased is the improvement of the internal structure of the polymer, which increased its response to the absorption of photon energy higher than it was previously. The decrease in the values of the absorption coefficient after irradiation is due to the cleavage of the polymer chains and, thus, the lack of the absorption coefficient.[18] Absorption is determined using the coefficient, referred to as the rate during which light intensity reduces, and can be calculated using Beer Lambert's Equation.[19,20]

$$I = I_o \exp(-\alpha x) \quad (1)$$

Hence,

$$\alpha = (2.303 / x) \log (I_o / I) = (2.303 / x)\ A \quad (2)$$

where,
I_o = the incident intensity sample
A = absorbance
x = thickness of the films
I = the transmitted intensity.

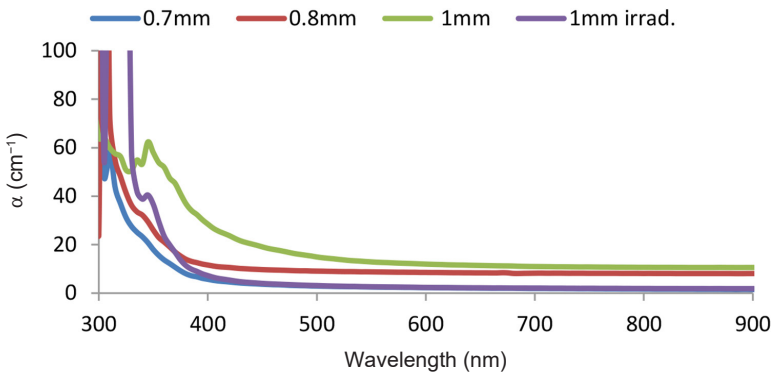

Figure 3: Absorption coefficient spectrum before and after irradiation of epoxy thick films of varying thicknesses.

The absorption coefficient (α) for thin films can be linked to the incident photon energy (hν) using Equation 3:

$$\alpha\, h\nu = B(h\nu - E_g)^r \quad (3)$$

where,

B = a constant

E_g = energy gap

r = an index based on the type of electron transfer that generated the optical absorption, with values of 2, 3 for indirect transitions and 1/2, 3/2 for direct transitions[21]

The parameter $(h\nu)^{1/r}$ is displayed against the photon energy (hν) in Figure 4. The best straight lines produced experimentally for the films, which provide a value of r = 2 by Equation 3, support the occurrence of indirect transitions.

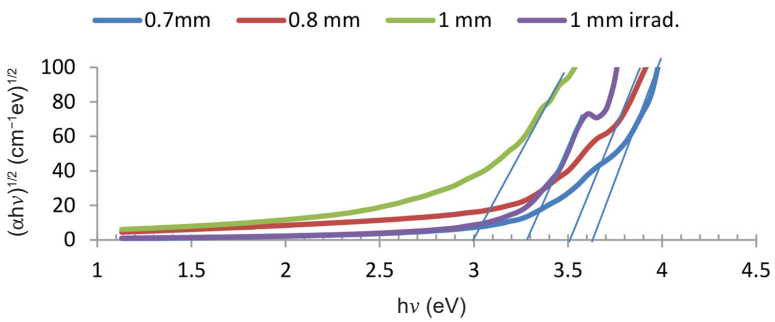

Figure 4: Energy gap before and after irradiation of epoxy thick films of varying thicknesses.

E_g reduces from 3.6 eV to 3 eV as the thickness increases. This effect is caused by increased grain size, film homogeneity, bond creation and decreased concentration of other bonds in the glass polymer. E_g for the epoxy film at 1 mm with Alpha irradiation equals 3.3 eV.[16] The reason is that irradiation leads to a disturbance in the system, causing the mobility gap's valence and conduction band edges to widen. The optical gap in amorphous polymers is intimately related to the characteristics of short-chemical organisations. Equation 4 calculates the reflectionspectrum (R) from the transmission (T) and absorption spectra (A).

$$R + A + T = 1 \tag{4}$$

Figure 5 depicts the reflection spectrum of epoxy films of varying thicknesses under irradiation. Films with increased thickness result in increased reflection. The decrease in reflectivity after irradiation indicates an increase in the size of the crystals of the polymer material, which affects the surface. Since the reflectivity occurs only at the surface, the increase in the size of the crystals increases the amount of diffuse reflective compound. The reflectivity is completely dependent on the density. The figure shows that the reflectivity values decrease after irradiation because of the dissolution process between the particles, which leads to a decrease in the amount of rays reflected by the polymer particles.[22]

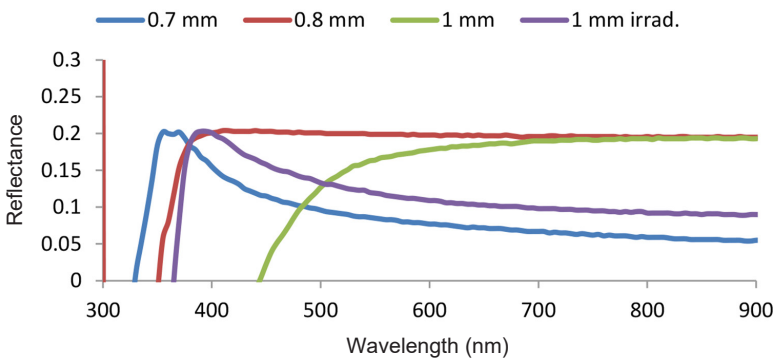

Figure 5: Reflection spectrum before and after irradiation of epoxy thick films of varying thicknesses.

The extinction coefficient (K), which is related to wavelength (λ) and the absorption coefficient (α) by Equation 5: [23]

$$K = \alpha\lambda / 4\pi \tag{5}$$

The samples' refractive index (n) can be calculated using Equation 6: [22]

$$n = \left[\left(\frac{1+R}{1-R}\right)^2 - (K^2+1)\right]^{1/2} + \frac{1+R}{1-R} \quad (6)$$

Figures 6 and 7 show the dispersion behaviour of the epoxy films' extinction coefficient and refractive index, respectively. The similarity, like the change in the extinction coefficient with the energy of the photon, due to the nature of the change in the absorption coefficient with the energy of the photon is due to the direct relationship between them. The refraction index (n) increased with the thickness of the epoxy films.

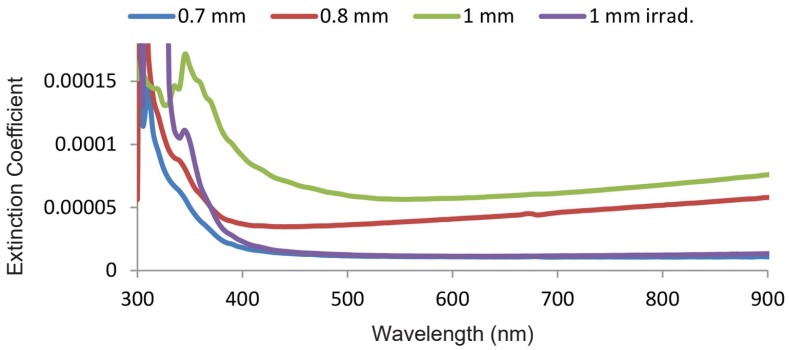

Figure 6: Extinction Coefficient before and after irradiation of epoxy thick films of varying thicknesses.

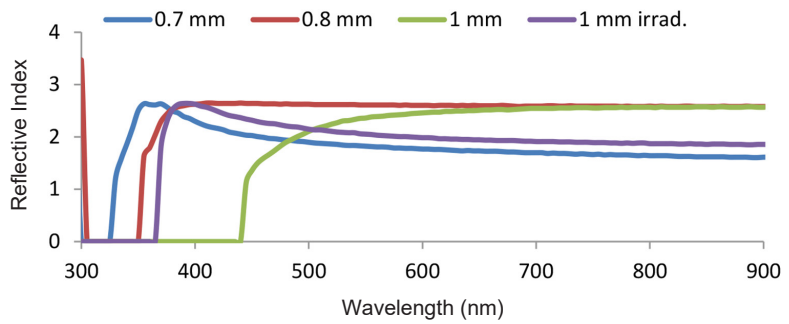

Figure 7: The refractive index before and after irradiation of epoxy thick films with different thicknesses.

For all films in the UV wavelength range, values (n) are high, whereas they are low in the zone of light. With increasing thickness, the refractive index increases. If the refractive index and extinction coefficient are known, the complicated dielectric constants of the film can be calculated. They are expressed by Maxwell's Equations 7 and 8: [24]

$$\varepsilon_r = n^2 - k^2 \quad (7)$$

$$\varepsilon_i = 2nk \quad (8)$$

Figures 8 and 9 show the epoxy films and the complicated dielectric constants' dependency on incident light. They both follow a similar pattern, and their values increase as the thickness increases and decrease at a thickness of 1 mm with irradiation. When alpha particles interact with thick films, a Coulomb force is created between the charged alpha particle and the electrons of the thick film.

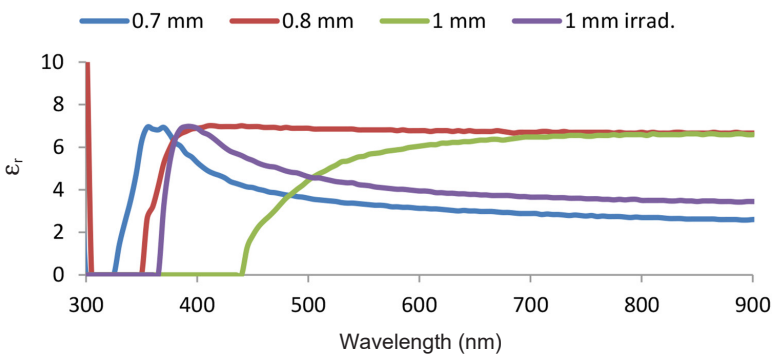

Figure 8: Real part dielectric (ε_r) constant before and after irradiation of epoxy thick films of varying thicknesses.

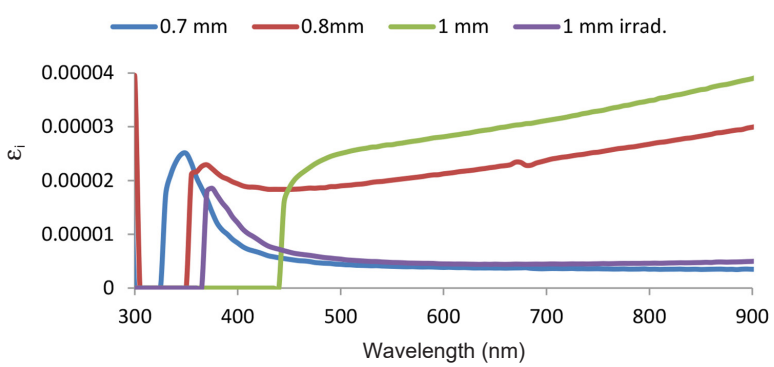

Figure 9: Imaginary part dielectric (ε_i) constant before and after irradiation of epoxy thick films of varying thicknesses.

Furthermore, matter absorbs charged alpha particles and when this charged particle loses energy due to atom ionisation, the molecules' bonds change and break. As a result, the kinetic energy is gradually depleted until it loses all of its energy continuously and not in lots throughout the matter.[25]

3.2 FTIR Measurements

The primary purpose of FTIR spectroscopy is to determine the key distinctive peaks of epoxy resin in the wavenumber range 370 cm^{-1}–7,800 cm^{-1}. Figure 10 depicts the compared epoxy resin before and after the effect of irradiation on the FTIR spectrum. The spectral data of the epoxy thick film samples are shown in Table 2, and there was a substantial difference between the epoxy resin thick film and the impact of irradiation.

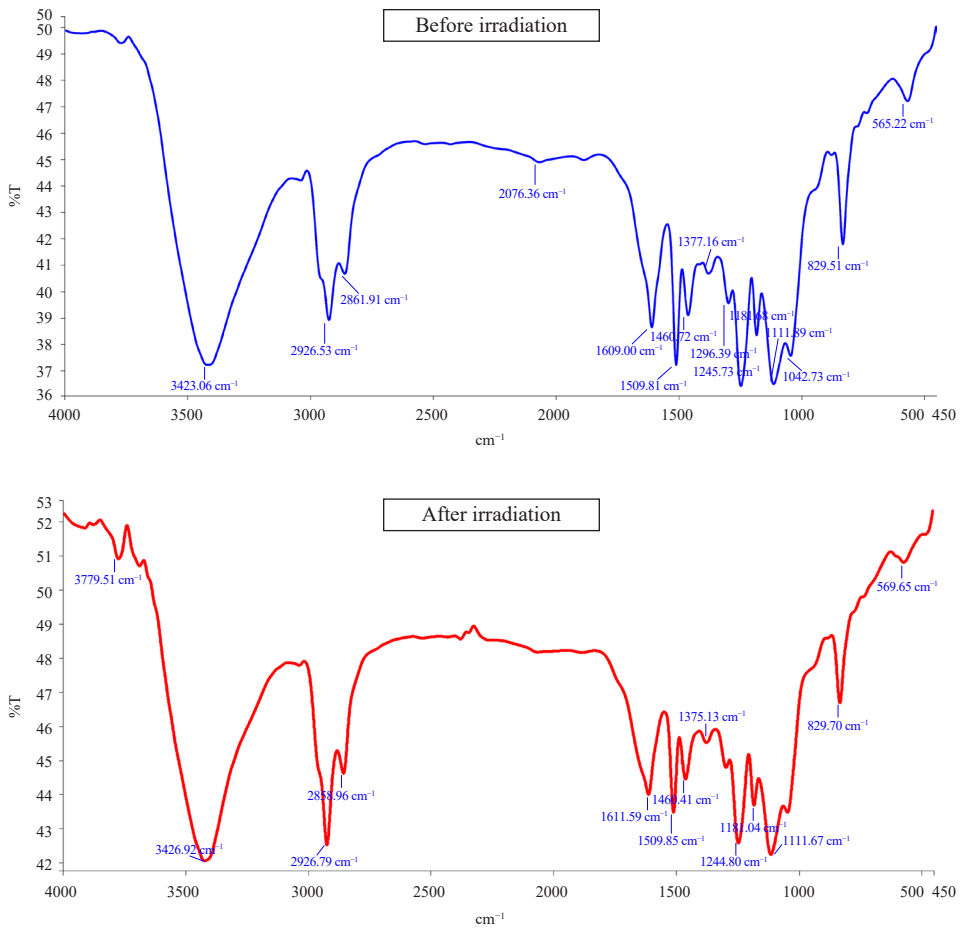

Figure 10: FTIR spectra of epoxy thick films before and after irradiation.

Table 2: Bands of (FTIR) for epoxy resin thick film before and after irradiation.

Active band	Not irradiated thick film		Irradiated thick film	
	Wavenumber (cm^{-1})	(%T)	Wavenumber (cm^{-1})	(%T)
O-H	–	–	3,779.51	50.94
(3,200–3,600) cm^{-1}	3,423.06	37.21	3,426.92	42.02
C-H aliphatic	2,926.53	38.91	2,926.79	42.49
(2,800–3,200) cm^{-1}	2,861.91	40.67	2,858.96	44.61
C=C	1,609.00	38.63	1,611.59	43.99
aromatic rings	1,509.81	37.21	1,509.85	43.45
(1,500–1,610) cm^{-1}				
$C\text{-}CH_2$	1,460.72	39.10	1,460.41	44.44
$C\text{-}CH_3$	1,377.16	40.68	1,375.13	45.51
C-O-C ethers	1,296.39	39.55	–	–
(1,000–1,300) cm^{-1}	1,245.73	36.40	1,244.80	42.55
	1,181.68	38.33	1,181.04	43.67
	1,111.89	36.47	1,111.67	42.21
	1,042.73	37.55	–	–
C-H aromatic	829.51	41.80	829.70	46.69
(625–870) cm^{-1}	565.22	47.24	569.65	50.84

The FTIR spectra of the epoxy thick film before irradiation in Figure 10 shows that the peak (829.51 cm^{-1} and 565.22 cm^{-1}) corresponds to the (C-H) aromatic, that the peaks (1,296.39 cm^{-1}, 1,245.73 cm^{-1}, 1,181.68 cm^{-1}, 1,111.89 cm^{-1} and 1,042.73 cm^{-1}) correspond to the (C-O-C) of ether groups, and that the transmission around (1,460.72 cm^{-1} and 1,377.16 cm^{-1}) characterise the asymmetric bending vibrations of ($C\text{-}CH_3$).[26] This is similar to the findings of previous studies. Figure 10 depicts the impact of irradiation on epoxy resin on the FTIR spectrum at a thickness of 1 mm.[27] As shown in Table 2, there was shifting disappearance and appearance of new bands after irradiation by Alpha rays.

4. CONCLUSION

In this study, we explain the influence of different thicknesses and alpha irradiation doses by considering the optical UV area:

1. Epoxy resin thick films were prepared by adding hardener to cure epoxy at room temperature and then exposing them to alpha irradiation.
2. The optical properties of epoxy thick films of varying thicknesses were measured before and after alpha irradiation.

3. For thicknesses of 0.7 mm, the epoxy thick film is transparent.
4. Because of their UV absorption peak, these films are suitable for use foundation solar cell plates and paints for various porous surfaces.
5. The results reveal that as the thickness increases, the reflectance, absorption and extinction coefficients increase, whereas the refractive index, real dielectric constant and band gap decrease.
6. Increase the transmittance of a 1mm thick epoxy film after irradiation so that irradiation may increase the transmittance of an epoxy coating in a greenhouse.
7. The FTIR spectrum reveals a significant difference between the epoxy resin thick film before and after irradiation.

5. AKNOWLEDGEMENTS

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