RESEARCH PAPER

Study of Optical properties of Poly (O- Toluidine)-MWCNT Films Prepared via the Spin Coating Method

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ABSTRACT

This study aimed to investigate the structural, optical, and electrical properties of poly (O-Toluidine)-MWCNT films. The spin-coating method was used to deposit the solution on glass substrates, and different ratios of poly (O-Toluidine)- to MWCNT were used, specifically 99:1, 98:2, 97:3, 96:4 and 95:5. Characterization techniques including X-ray diffraction (XRD) and UV-Visible spectrophotometer were used to analyze the crystalline nature and optical properties of the deposited films. The XRD results revealed an amorphous structure for all the samples. The optical properties of poly (O-Toluidine)-MWCNT films varied with wavelength and doping ratio. It was observed that as the wavelength decreased in the high-energy region, absorbance increased and reflectivity decreased. Conversely, as the doping ratio increased, transmittance decreased. The absorption coefficient and extinction coefficient also varied with wavelength, both decreasing as the wavelength decreased. The refractive index exhibited a decrease as the wavelength increased. Furthermore, the optical conductivity increased with both the energy of the incident photon and the increase of MWCNT concentrations. Also, the optical energy gap values for poly (O-Toluidine) films decrease with the increasing ratio of doping concentrations.

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INTRODUCTION

Polymeric materials, due to their affordability, ease of manufacture, and desirable properties, are widely used. Polymers, in particular, have garnered significant interest for photovoltaic applications. These materials are not only inexpensive and abundant but can also be easily processed at low temperatures. Their wide range of colors and unique interaction with light make them promising for use in solar cells [1,2]. One specific polymer, ortho-toluidine (o-toluidine), is a light-yellow liquid at room temperature. It has moderate to low acute toxicity and can cause minimal skin irritation and mild eye irritation. Its primary uses are in the manufacture of dyestuffs and rubber production. Incorporating nanoparticles into a biopolymeric matrix can enhance its electrical conductivity, barrier properties, and consistency. Furthermore, the strong interaction between biopolymers and the functional groups of nanoparticles increases the strength of bio nanocomposites [3,4]. The study of the electronic and optical characteristics of electrically conductive polymers, such as Poly (O-Toluidine) (POT), is of significant importance. These polymers have tunable electrical properties, unique optical properties, are easy to synthesize,

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and exhibit high environmental stability [5,6].

POT has potential applications in rechargeable microelectronic devices due to its unique properties [7–9]. POT can be used in the development of rechargeable batteries. The tunable electrical properties and unique optical characteristics of POT make it a suitable material for use in these devices. Constant-potential molecular dynamics simulation methods have been developed to truly represent the electrified electrochemical interface, which is crucial in rechargeable batteries. These methods can be used to elucidate interfacial phenomena including the structure of the electric double layer, the growth of the solid electrolyte interphase, and the occurrence of metallic dendrites. POT can also be used in the development of biosensors [10–12]. Biosensors are analytical devices that use a combination of a biological detection element and a sensor system to investigate or detect molecules. POT's unique properties make it a suitable material for use in these devices. The applications of biosensors include checking ecological pollution control, in the agriculture field, and food industries. They are advanced in terms of selectivity and sensitivity. POT can be used in the development of electrochromic displays [13–15]. Electrochromic devices operate by changing their optical properties in response to an electric charge. The most common applications of these devices are electrochromic mirrors and windows. Other applications include energy-saving electronic price tags, flashy billboards, rearview mirrors, augmented virtual reality, and even artificial irises.

Polymers like POT have a principal disadvantage of being insoluble in the majority of organic solvents. This is primarily due to their non-polar nature [16]. Organic solvents are typically polar, and the principle of "like dissolves like" applies, meaning that polar substances tend to dissolve in polar solvents, and non-polar substances dissolve in non-polar solvents. The insolubility of POT in organic solvents can pose challenges in various applications [17]. It can make it difficult to process and synthesize the polymer into desired forms or incorporate it into composite materials. In the fabrication of devices like biosensors and electrochromic displays, the insolubility of POT can pose challenges in depositing thin and uniform layers of the polymer. In pharmaceutical applications, the insolubility of POT in organic solvents can affect the delivery and release of drugs. The insolubility of POT in organic solvents can also pose challenges in the recycling and disposal of POT-based materials. Despite these challenges, researchers are exploring various strategies to overcome this limitation, such as the use of co-solvents, surfactants, or functionalization of the polymer to enhance its solubility. These strategies aim to expand the range of applications for POT and other similar polymers.

The spin-coating synthesis of films of POT with MWCNT is highly relevant to the field of nanomaterials and nanotechnology [18]. Spin coating allows for the precise control of the thickness of the films at the nanoscale. This is crucial in nanotechnology, where the properties of materials can change dramatically at the nanoscale. The spin coating technique is versatile and can be used with a wide range of materials, including polymers like POT and nanomaterials like MWCNT. This makes it a valuable tool in the synthesis of nanocomposites and other advanced materials. Films produced by spin coating are used in the fabrication of various devices, including biosensors, electrochromic displays, and solar cells. These are all areas where nanotechnology is making significant contributions. Spin coating is a cost-effective and efficient method for depositing uniform films. This is particularly important in nanotechnology, where the production of nanomaterials can often be expensive and time-consuming. Khan and Shaheen focused on the ion exchange capacity (IEC) of poly-o-toluidine (POT)/multiwalled carbon nanotubes (MWCNTs)/Sn(IV) tungstate (ST) thin films. The IEC of the POT/MWCNTs/ST thin film was found to be better than that of pure POT and POT/MWCNTs [19]. Nagaraja et.al investigated the improved third-order nonlinear optical properties of polyaniline and poly (o-toluidine) with different doping concentrations of multi walled carbon nano tube (MWCNTs) composite thin films [18]. The films exhibited reverse saturable absorption and self-defocusing nonlinearity. Ganash examined the use of poly(o-toluidine) (POT) coatings and poly(o-toluidine)/oxidized multi-walled carbon nanotubes (POT-MWCNT) composite on 304 stainless steel for corrosion protection [20]. The coatings were synthesized on steel substrates under cyclic voltametric conditions. Singh et.al reported the synthesis of a hybrid nanocomposite containing poly o-toluidine, copper nanocomposite (CuONC), and multiwalled carbon nanotubes (MWCNT) [21].

The electrochemical performance of the hybrid composite was inspected as a supercapacitor material.

In this research, we embark on a detailed examination of the optical properties of POT films, specifically focusing on the implications of introducing MWCNT. We investigate how these properties alter with different doping ratios; an area that has not been thoroughly investigated in the existing body of literature. We utilize the spin-coating method to deposit the solution onto glass substrates, which guarantees a uniform and high-quality film, a critical aspect for the properties we are studying. This research highlights the promising potential of POT in various industries and technologies, and emphasizes the need for additional studies to fully exploit this potential. The findings from this study are expected to lay the groundwork for the development of advanced applications of POT in various fields.

MATERIALS AND METHODS

The preparation of the poly (O-Toluidine)-MWCNT blend involved a series of steps. Initially, 25 mg of poly (O-T) granules were dissolved in 25 mL of chloroform solvent. The solution was then placed in an ultrasonic bath with 40 kHz ultrasonic agitation for 30 minutes to ensure uniform dispersion of the polymer in the solvent. This was further facilitated by using a magnetic stirrer at room temperature. In the next step, 25 mg of MWCNT granules were dissolved in 25 mL of chloroform solvent. Similar to the previous step, the solution was placed in an ultrasonic bath for 30 minutes to ensure uniform dispersion in the solvent. This method, known as indirect ultrasonication, was carried out in an ultrasonic bath filled with water. The solution was then stirred magnetically to ensure uniform dispersion of the nano material in the solvent at room temperature. After achieving a good solvent MWCNT solution, it was mixed in different volumetric proportions (1, 2, 3, 4, and 5%) to POT volumetric proportions (99, 98, 97, 96 and 95%) respectively. The films were then prepared using the spin coating method. The schematic representation of the film fabrication process is illustrated in Fig. 1. Finally, the layers were analyzed using X-ray diffraction (XRD) to study their crystalline nature, and UV-Visible spectrophotometry, within a wavelength range of 200 nm to 1100 nm, to examine their optical properties.

RESULTS AND DISCUSSION

The absorbance measurements of POT films created on glass bases, as shown in Fig. 2. We observed that the absorbance value tends to increase with decreasing wavelength in the high-energy region and decrease slightly with increasing wavelength in the low-energy region. This can be attributed to the energy of incoming photons, which is inversely proportional to their wavelength, as per the Planck-Einstein relation [22]. Hence, photons with shorter wavelengths (higher energies) have a higher probability of being absorbed by the POT films.

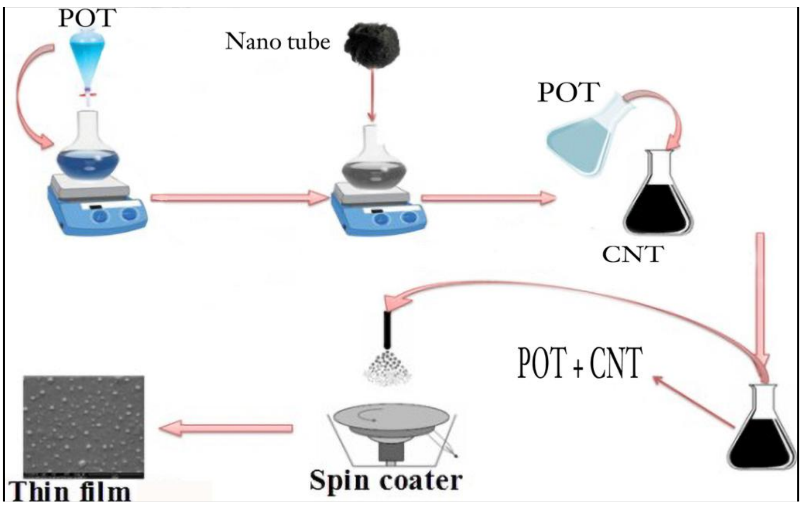

Fig. 1. Schematic representation of the film fabrication process for poly (O-Toluidine)-MWCNT films using the spin coating method

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Fig. 3 show the transmittance spectrum of POT-MWCNT films produced on glass substrates. The transmittance spectrum displays a behavior that is opposite of the absorbance behavior. As the doping ratio increases, the transmittance decreases. This can be explained by the fact that as the doping ratio increases, the number of charge carriers in the thin film also increases [15]. These additional charge carriers can absorb more photons, thereby reducing the transmittance. Moreover, the value of transmittance increases with the wavelengths. This is because photons with longer wavelengths (lower energies) are less likely to be absorbed by the POT films, resulting in higher transmittance [15]. This demonstrates that the energy of the incident photon determines the spectrum of absorption and transmittance. These findings have significant implications for potential applications of the films. For instance, the ability to control the transmittance of the films by adjusting the doping ratio could be useful in the development of smart windows and other optoelectronic devices. Furthermore, understanding the relationship between transmittance and doping ratio could also aid in the optimization of thin film solar cells and other photovoltaic devices.

The reflectance spectra for POT-MWCNT coatings are shown in Fig. 4, with UV wavelengths exhibiting the maximum reflectivity. Reflectivity decreases in the high energy region and somewhat increases in the low energy zone as the wavelength increases [23]. This behavior can be explained using equation (1) which connects reflectivity (R), absorbance (A), and transmittance (T):

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

In this equation, A represents the fraction of incident light that is absorbed by the material, T represents the fraction that is transmitted through the material, and R represents the fraction that is reflected by the material. This relationship is a fundamental principle of optics and is based on the conservation of energy. The observed behavior of reflectivity in POT-MWCNT films has significant implications. For instance, the decrease in reflectivity in the high energy region suggests that the films are absorbing more of the high-energy (short-wavelength) light. This could be beneficial in applications such as solar cells, where maximizing the absorption of high-energy light can improve efficiency. On the other hand, the increase in reflectivity in the low energy region could be useful in applications such as optical filters or mirrors, where high reflectivity is desired

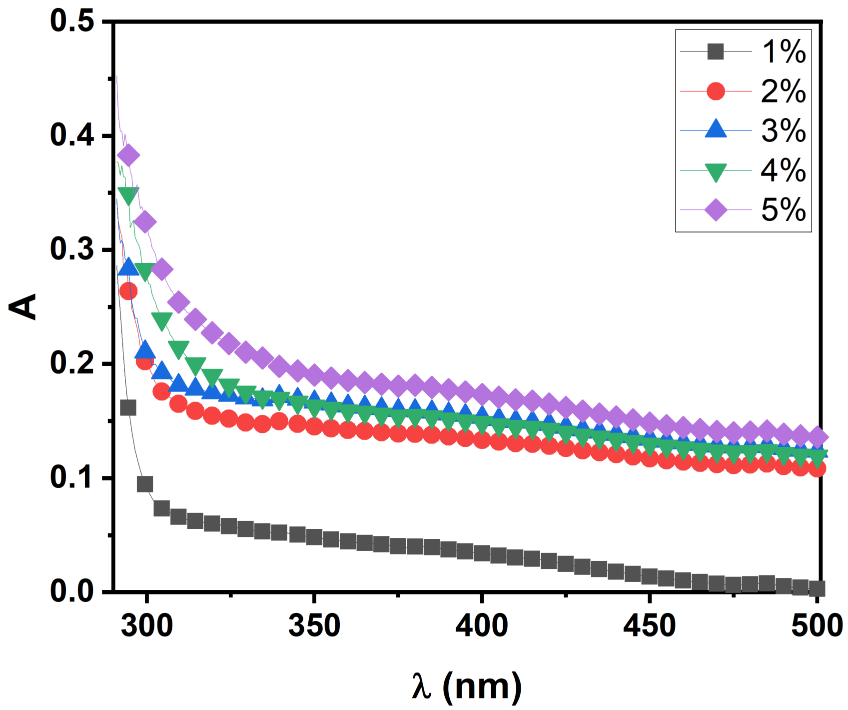

Fig. 2. The absorbance spectra of POT-MWCNT films with different amount of MWCNT

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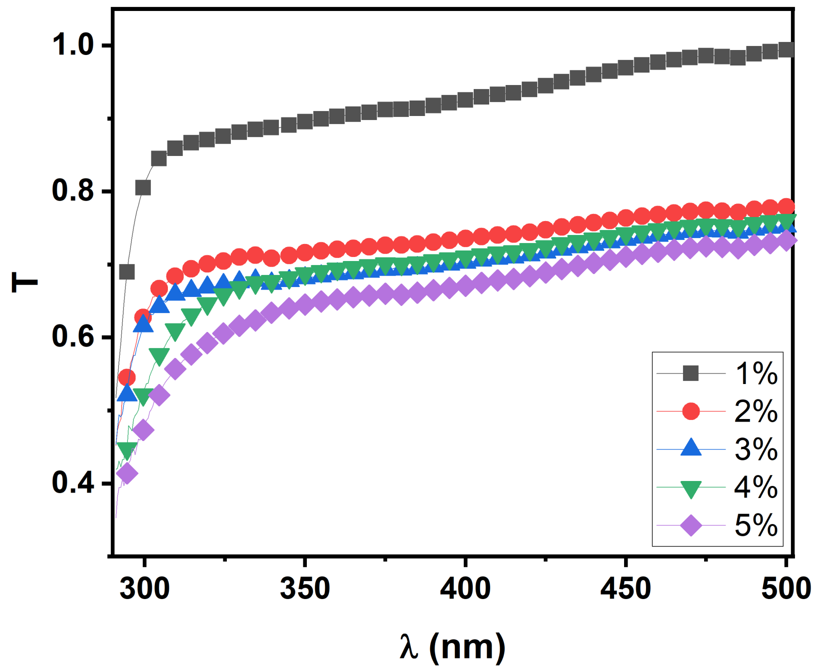

Fig. 3. The transmittance spectra of POT-MWCNT films with different amount of MWCNT

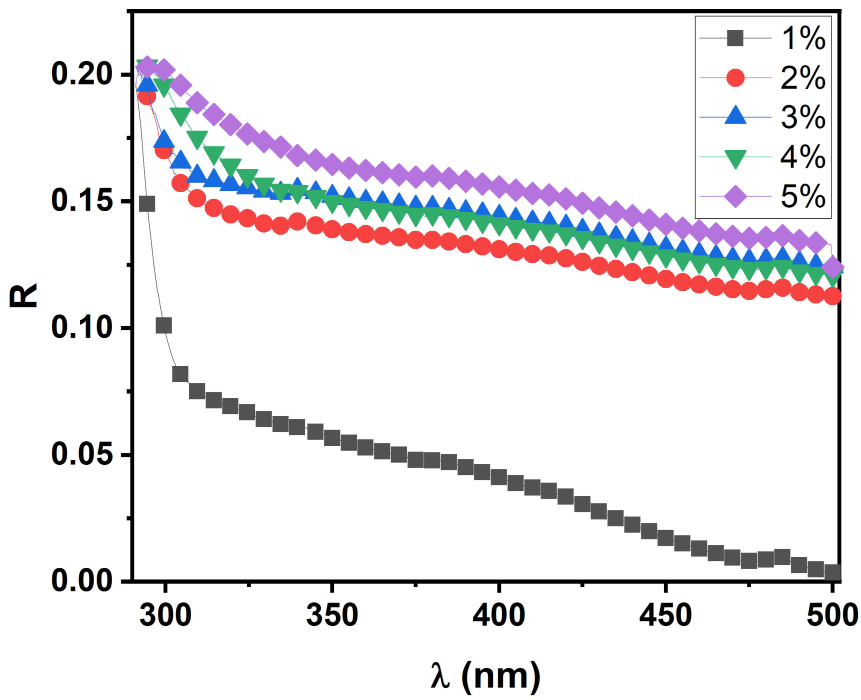

Fig. 4. The Reflectance spectra of POT-MWCNT films with different amount of MWCNT

[18].

The absorption coefficient (α) of POT-MWCNT films varies with wavelength, as shown in Fig. 5. The absorption coefficient is a crucial parameter in determining the optical energy gap of a material. It determines how far into a material light of a

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particular wavelength can penetrate before it is absorbed. In a material with a low absorption coefficient, light is only poorly absorbed, and if the material is thin enough, it will appear transparent to that wavelength. The changes in the absorption coefficient with wavelength in POT-MWCNT films can be attributed to the fact that the absorption of light is dependent on the energy of the incoming photons, which is inversely proportional to their wavelength [15]. Therefore, photons with shorter wavelengths (higher energies) have a higher probability of being absorbed by the POT-MWCNT films, resulting in a higher absorption coefficient. The absorption coefficient and the absorbance spectrum exhibit similar behavior, which is owing to the relationship between them as given in equation (2):

$$\alpha = (2.303 * A) / t \qquad (2)$$

Where α is absorption coefficient, A is absorbance and t is thickness of the material. This equation is derived from the Beer-Lambert Law, which states that the absorbance of a material is directly proportional to its absorption coefficient and the path length (in this case, the thickness of the material). Therefore, the observed changes in the absorption coefficient with wavelength are reflected in the absorbance spectrum.

The extinction coefficient (K_o) represents how much energy has been absorbed by the thin layer and the inactivity of the Electromagnetic wave within it. The extinction coefficient is a measure of the damping of the electromagnetic wave as it passes into a medium. It is related to the absorption coefficient (α) by the equation:

$$K_0 = \frac{\alpha\lambda}{4\pi} \qquad (3)$$

In POT-MWCNT films, as shown in Fig. 6, the extinction coefficient declines with decreasing wavelength. This decrease in the extinction coefficient results from a decrease in the absorption coefficient [24]. The absorption coefficient allows us to measure how much light is absorbed and is related to the extinction coefficient. The observed changes in the extinction coefficient with wavelength have significant implications. For instance, a decrease in the extinction coefficient at shorter wavelengths (higher energies) suggests that the films are less effective at absorbing high-energy light. This could be beneficial in applications such as anti-reflective coatings or optical filters, where low absorption at certain wavelengths is desired.

The refractive index is a fundamental property that determines how much a light wave is refracted,

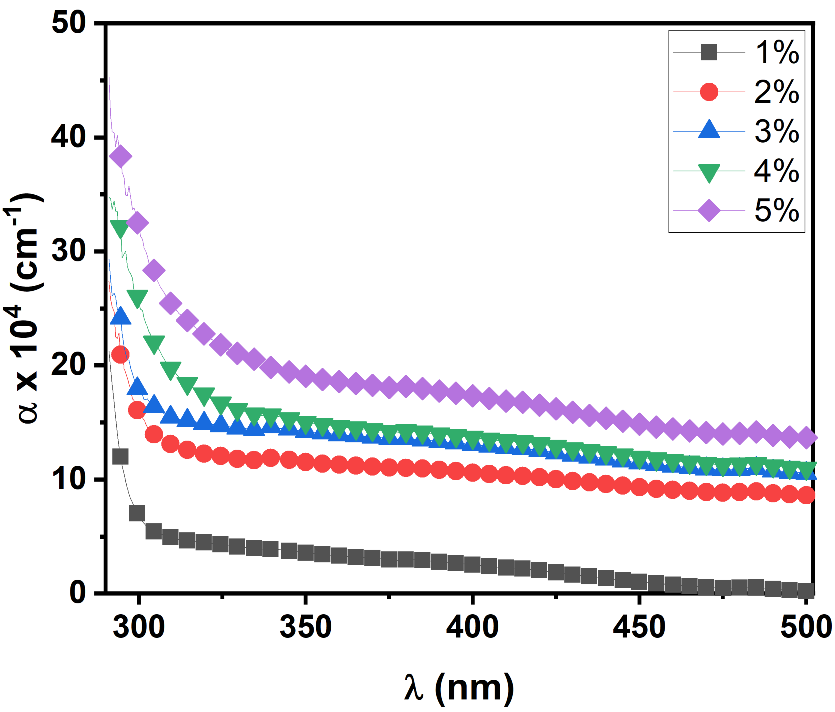

Fig. 5. Absorption coefficient of POT-MWCNT films with different amount of MWCNT

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or bent, when moving between different mediums. It is crucial in determining the optical properties of materials. The refractive index of a material can provide information about how the material interacts with light of different wavelengths and frequencies. In the case of POT-MWCNT films,

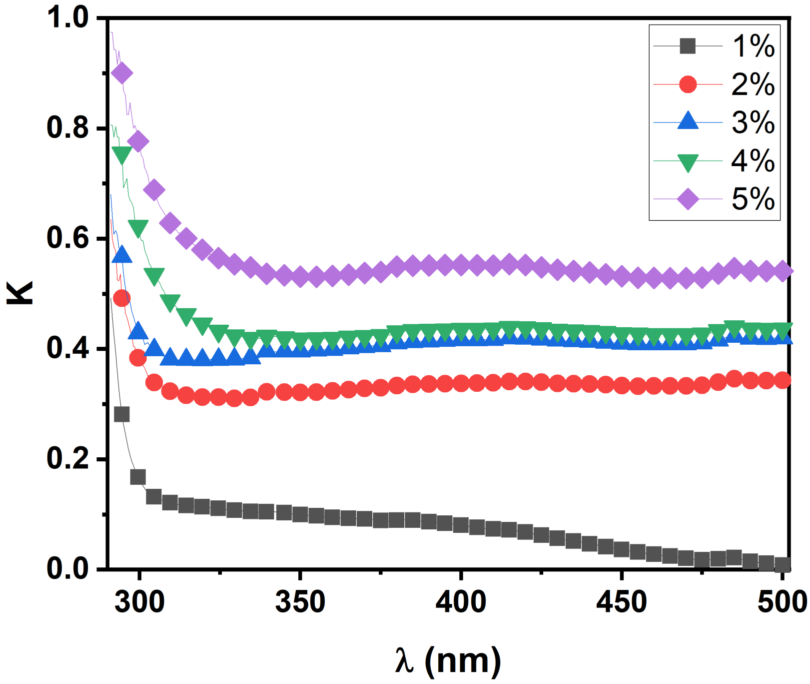

Fig. 6. The extinction coefficient of POT-MWCNT films with different amount of MWCNT

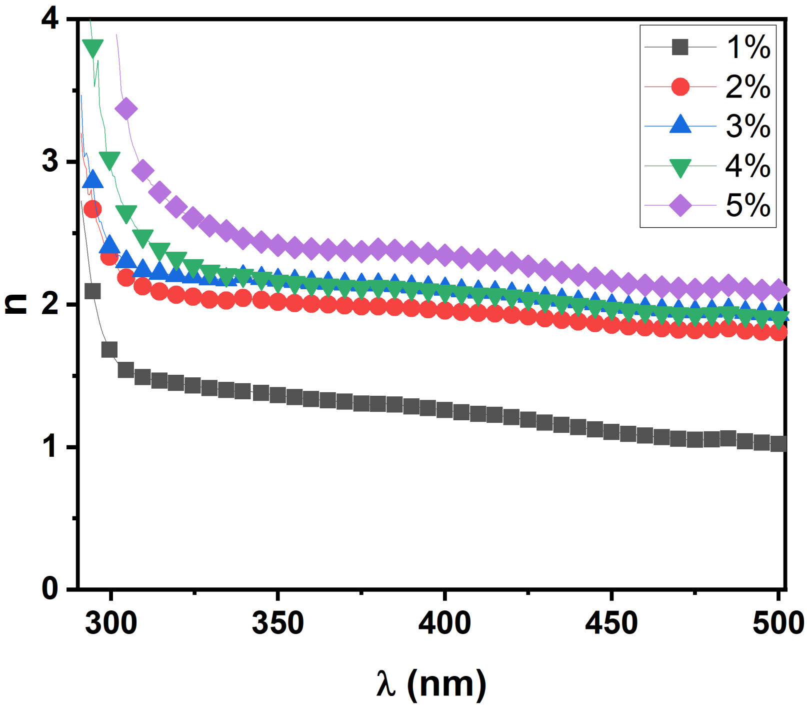

Fig. 7. The refractive index for POT-MWCNT films with different amount of MWCNT

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the refractive index values were calculated using Equation (4), before and after doping.

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

The refractive index changes as a function of wavelengths, as shown in Fig. 7. This change in refractive index with wavelength can be attributed to the fact that the refractive index of most materials varies with wavelength [5]. As the wavelength increases, the refractive index decreases. This is because the energy of the incoming photons, which is inversely proportional to their wavelength, affects the interaction of the material with the light. It's important to note that the maximum refractive index (2.5) generally correlates to the optical energy gap and that it decreases with increasing wavelength due to the increase in charge carriers.

Optical conductivity is a property of a material that describes the relationship between the induced current density in the material and the magnitude of the inducing electric field for arbitrary frequencies. It is a measure of how much a material can conduct electricity when it is illuminated by light. The energy of the incident photons, which is inversely proportional to their wavelength, affects the interaction of the material with the light. Therefore, the optical conductivity of a material can changes with the energy of the incident photons. In the case of POT-MWCNT films, the optical conductivity was calculated using the equation:

$$\sigma = \varepsilon_i \varepsilon_o \qquad (5)$$

where σ is Optical conduction, ε_j is dielectric constant (imaginary) and ε_o is permittivity of the space. The measured values of optical conductivity for POT-MWCNT films after doping show that the optical conductivity increases with the energy of the incident photon. This is because photons with higher energies (shorter wavelengths) are more likely to be absorbed by the POT-MWCNT films, resulting in a higher optical conductivity. Furthermore, the optical conductivity also increases with the increase of MWCNT concentrations. This can be attributed to the fact that as the doping ratio increases, the number of charge carriers in the thin film also increases [25]. These additional charge carriers can absorb more photons, thereby increasing the optical conductivity.

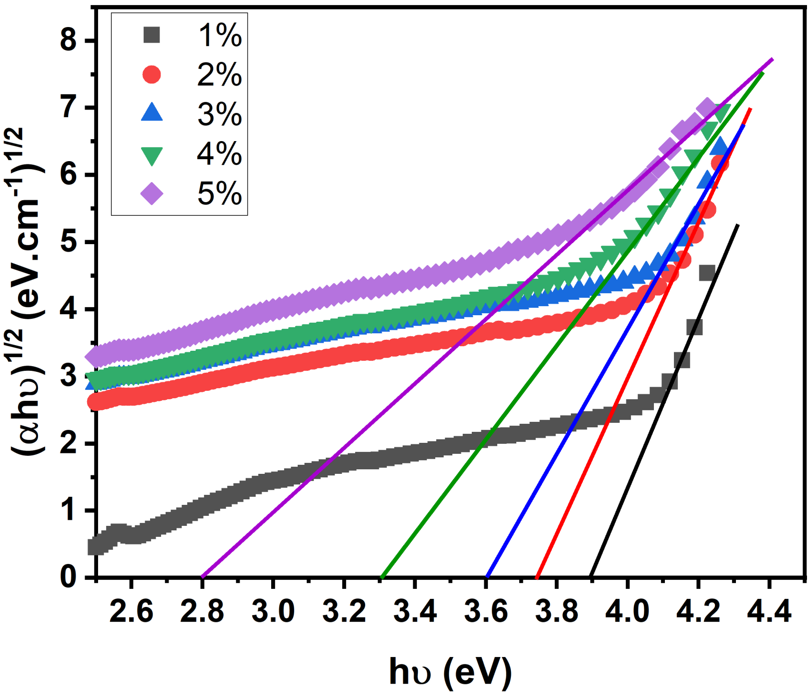

Fig. 8. The indirect energy gap in POT-MWCNT films with respect to the incident photon energy for different quantities of MWCNT

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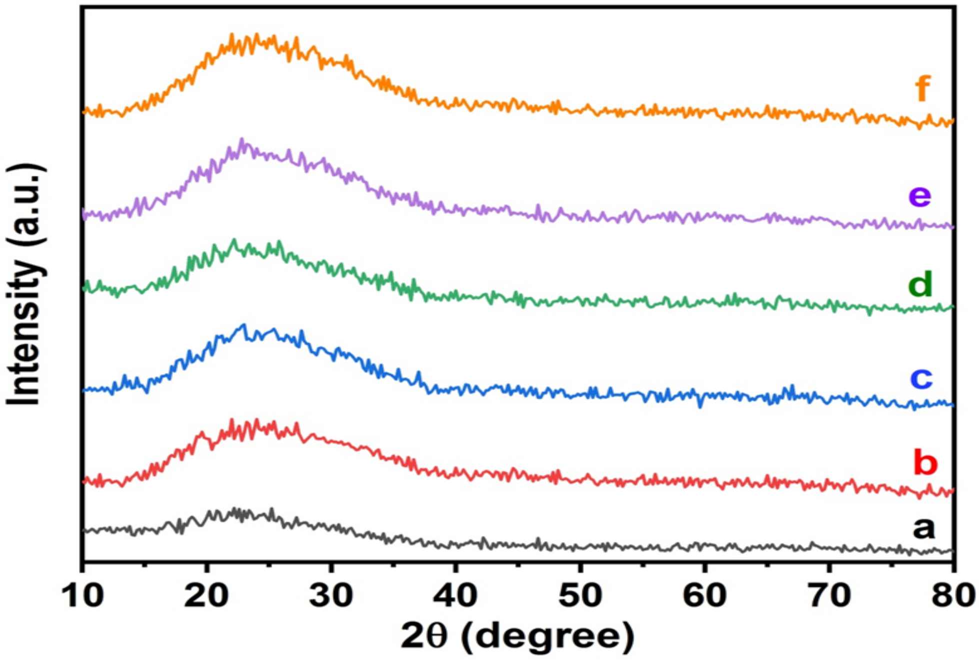

Fig. 9. The XRD patterns of POT and POT/MWCNT films: (a) POT, (b) MWCNT (1%), (c) MWCNT (2%), (d) MWCNT (3%), (e) MWCNT (4%) and (f) MWCNT (5%).

In semiconductor physics, the energy gap, also known as the band gap, is a crucial parameter. It represents the minimum energy difference between the top of the valence band and the bottom of the conduction band. The indirect-energy-gap is determined by knowing the absorption coefficient and the energy of the incident photon. The absorption coefficient is proportional to the square root of the photon energy in the indirect band gap. Therefore, photons with higher energies (shorter wavelengths) have a higher probability of being absorbed by the semiconductor, resulting in a higher absorption coefficient. The optical energy gap values for POT-MWCNT films decrease with the increasing ratio of doping concentrations, as depicted in Fig. 8. This can be seen in the provided table, where the energy gap for pure POT films was 3.9 eV, and this value decreased with the increasing doping ratio to 2.8 eV at the ratio of 5%. This decrease can be explained by the fact that the impurities led to the creation of donor levels inside the energy gap near the conduction band, which shifted the Fermi level towards the conduction band. The implications of the observed decrease in the energy gap with increasing doping ratio are significant [26]. Doping of semiconductors with various elements increases their photocatalytic activity due to the formation of new energy levels near the conduction band. Furthermore, the decrease in the energy gap of the film after doping can be attributed to the creation of additional energy levels in the film's energy gap, which results in the broadening of the band of the film and hence decreases its energy gap. This could potentially enhance the efficiency of devices such as solar cells and other photovoltaic devices.

The X-ray diffraction patterns of POT and POT-MWCNT films prepared with different [MWCNT]/[POT] volume ratios of 1%, 2%, 3%, 4%, and 5% are shown in Fig. 9. XRD is an indispensable tool for characterizing films of materials1. The XRD patterns of both POT and POT-MWCNT films exhibit a single broad peak at around 25°, indicating that all the films have an amorphous structure. This is because there were no sharp peaks in the XRD patterns, which are characteristic of crystalline structures. Amorphous structures are characterized by a lack of long-range order that is usually seen in crystalline materials. They often have unique properties that can be advantageous in certain applications. For instance, some amorphous materials have been shown to offer higher bioavailability than their crystalline counterparts due to their higher solubility. In the case of POT-MWCNT films, the addition of MWCNT does not affect the crystallinity of the films [27,28],

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Table 1. The indirect energy gap values for POT MWCNT films

Sample	E_g (ev)
POT=99 %, MWCNT=1 %	3.9
POT=98 %, MWCNT=2 %	3.74
POT=97 %, MWCNT=3 %	3.6
POT=96 %, MWCNT=4 %	3.3
POT=95 %, MWCNT=5 %	2.8

as shown in Figs. 9(a) – 9(f). This suggests that the MWCNT are well-dispersed within the POT matrix, maintaining the amorphous nature of the POT films even after doping.

CONCLUSION

This study successfully prepared and characterized poly (O-Toluidine)-MWCNT films using the spin-coating method, which was chosen for its precision, versatility, and cost-effectiveness. The addition of MWCNT to POT enhanced the optical characteristics of the films, specifically increasing absorbance and transmittance. The study also found that the optical energy gap decreased with an increase in the doping ratio, suggesting that the doped films are more efficient at absorbing high-energy light. The XRD tests showed that all the films have an amorphous structure, indicating that the MWCNT are well-dispersed within the POT matrix. However, the insolubility of POT in organic solvents poses challenges in processing and synthesizing the polymer. Future research should focus on further exploring these strategies to expand the range of applications for POT and other similar polymers. Additionally, more research is needed to fully realize the potential of POT in various applications, including rechargeable microelectronic devices, biosensors, and electrochromic displays. The findings of this study provide a solid foundation for future research in this area.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

REFERENCES

1. Hou W, Xiao Y, Han G, Lin J-Y. The Applications of Polymers in Solar Cells: A Review. Polymers. 2019;11(1):143.
2. Gnida P, Amin MF, Pająk AK, Jarząbek B. Polymers in High-Efficiency Solar Cells: The Latest Reports. Polymers. 2022;14(10):1946.
3. Jafarzadeh S, Nooshkam M, Zargar M, Garavand F, Ghosh S, Hadidi M, et al. Green synthesis of nanomaterials for smart biopolymer packaging: challenges and outlooks. Journal of Nanostructure in Chemistry. 2023;14(2):113-136.
4. Ramesh M, Balaji D, Rajeshkumar L, Bhuvaneswari V. Manufacturing methods of elastomer blends and composites. Elastomer Blends and Composites: Elsevier; 2022. p. 11-32.
5. Bajpai M, Srivastava R, Dhar R, Tiwari RS. Review on Optical and Electrical Properties of Conducting Polymers. Indian Journal of Materials Science. 2016;2016:1-8.
6. K N, Rout CS. Conducting polymers: a comprehensive review on recent advances in synthesis, properties and applications. RSC Advances. 2021;11(10):5659-5697.
7. Islam S, Sehrawat P, Khan H, Hashmi SA, Zulfequar M. Poly(o-toluidine)/multiwalled carbon nanotube-based nanocomposites: An efficient electrode material for supercapacitors. J Mater Res. 2021;36(17):3472-3483.
8. Weber E, Richter E, Holze R. o-Toluidine in electrochemistry – an overview. J Solid State Electrochem. 2022;26(4):1097-1114.
9. Akhtar K, Gul M, Haq IU, Shah SSA, Khan ZU. Effect of calcination temperature on the morphological and dielectric properties of phase-pure $MnCrFeO_4$ nanoparticles. Inorganic and Nano-Metal Chemistry. 2017;47(12):1722-1727.
10. Zhou T, Xie X, Cai J, Yin L, Ruan W. Preparation of poly(o-toluidine)/TiO_2 nanocomposite films and application for humidity sensing. Polym Bull. 2015;73(3):621-630.
11. Ekinci E. Preparation and sensor properties of poly (o -toluidine) film. Polym Bull. 1999;42(6):693-699.
12. Alqarni SA, Hussein MA, Ganash AA, Khan A. Composite Material–Based Conducting Polymers for Electrochemical Sensor Applications: a Mini Review. BioNanoScience. 2020;10(1):351-364.
13. Mortimer RJ. Spectroelectrochemistry of electrochromic poly(o–toluidine) and poly(m-toluidine) films. J Mater

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Chem. 1995;5(7):969-973.
14. Ganash AA, Alhebshi NA, Alyoubi NH. Fabrication of a poly(o-toluidine-co-aniline)/SiO2 nanocomposite for an electrochemical supercapacitor application. J Appl Electrochem. 2020;50(10):1019-1035.
15. Elmansouri A, Outzourhit A, Oueriagli A, Lachkar A, Hadik N, Achour ME, et al. Spectroscopic Characterization of Electrodeposited Poly(o-toluidine) Thin Films and Electrical Properties of ITO/Poly(o-toluidine)/Aluminum Schottky Diodes. Active and Passive Electronic Components. 2007;2007:1-7.
16. Siddhanta SK, Garg AB, Mittal R, Mukhopadhyay R. Organosoluble Poly(o-toluidine). AIP Conf Proc: AIP; 2011.
17. Aksimentyeva OI, Konopelnyk OI, Horbenko YY, Martyniuk GV. Nanofabrication of conducting polymer fillers in polymer matrix: Polystyrene-poly-o-toluidine composites. Mol Cryst Liq Cryst. 2022;751(1):73-82.
18. Nagaraja KK, Pramodini S, Poornesh P, Telenkov MP, Kityk IV. Nonlinear optical properties of polyaniline and poly (o -toluidine) composite thin films with multi walled carbon nano tubes. Physica B: Condensed Matter. 2017;512:45-53.
19. Khan AA, Shaheen S. Preparations and characterizations of poly-o-toluidine/multiwalled carbon nanotubes/ Sn(iv) tungstate composite ion exchange thin films and their application as a Pb(ii) selective electrode. RSC Adv. 2014;4(45):23456-23463.
20. Ganash AA. Effect of conducting composite carbon nanotube-poly(o-toluidine) coatings on the corrosion resistance of stainless steel material. Polym Compos. 2013;34(7):1180-1185.
21. Singh KK, Sharma AK, Kaushal I, Saharan P, Kumar V. Hybrid poly (o-toluidine)/mwcnt/copper oxide nano composite electrode for electrochemical supercapacitor. Rasayan Journal of Chemistry. 2020;13(04):2114-2122.
22. Talib RA, Thbayh DK, Ziadan KM. Optical properties of incorporating of ZnO nano-particles on the dopant poly(o-toluidine). Materials Today: Proceedings. 2020;20:433-438.
23. Fakher Alfahed RK, Al-Asadi AS, Al-Mudhaffer MF, Badran HA. Synthesis, morphological and optical characterizations of the poly (O-toluidine)-LiCl networks thin film. Optics & Laser Technology. 2021;133:106524.
24. Wen T, Zhang H, Li X, Yu L, Ren Y, Liu H, et al. Numerical Simulation on the Oxidation of Lanthanum During the Electroslag Remelting Process. JOM. 2018;70(10):2157-2168.
25. Weiss R. Lentivirus tropism and pathogenesis. Immunol Lett. 1999;66(1-3):3-5.
26. Ashoorioon A, Chialva D, Danielsson U. Effects of nonlinear dispersion relations on non-Gaussianities. Journal of Cosmology and Astroparticle Physics. 2011;2011(06):034-034.
27. Tamilselvi D, Velmani N, Rathidevi K. Electrical conductivity studies of zinc oxide, nickel doped zinc oxide poly(o-toluidine) nanocomposite using chemical oxidative polymerization. Egyptian Journal of Chemistry. 2019;0(0):0-0.
28. Islam S, Lakshmi GBVS, Zulfequar M, Husain M, Siddiqui AM. Comparative studies of chemically synthesized and RF plasma-polymerized poly (o-toluidine). Pramana. 2014;84(4):653-665.