Enhanced structural, optical, electrical properties and antibacterial activity of PEO/CMC doped ZnO nanorods for energy storage and food packaging applications

A. E. Tarabiah1 · Hisham A. Alhadlaq2 · ZabnAllah M. Alaizeri2 · Abdullah A. A. Ahmed3 · G. M. Asnag4 · Maqusood Ahamed2

Received: 9 March 2022 / Accepted: 1 April 2022 / Published online: 14 April 2022 © The Polymer Society, Taipei 2022

Abstract
The zinc oxide nanorods (ZnONRs) have been successfully prepared via sol–gel way. A series of Poly(ethylene oxide) and Carboxymethyl cellulose (PEO/CMC) blend samples filled with different concentration of ZnONRs were prepared using casting method. Transmission electron microscopic (TEM) image showed that the synthesized ZnONPs had a diameter in the range of 29.29 to 59.09 nm. These samples were characterized by different analytical techniques. On the basis of results obtained from XRD and FT-IR analysis, blends are miscible. Fourier transform infrared (FT-IR) spectroscopy exhibited the complexation between PEO/CMC blend and ZnONRs. The optical energy gap was calculated using the UV/vis. data. The maximum value of AC conductivity for the pure blend was $1.98 \times 10^{-7}$ S.cm$^{-1}$, and by raising the filling of ZnONRs increased to $3.26 \times 10^{-6}$ S.cm$^{-1}$ at highest concentration. After the added of ZnONRs, an improvement for the dielectric constant ($\varepsilon'$) and dielectric loss ($\varepsilon''$) of PEO/CMC are detected. These samples can be employment in the semiconductor industries and portable electrochemical batteries, electric vehicles and grid energy storage, due to the noticed enhancements in optical, and AC conductivity. PEO/CMC/ZnONRs films were screened for their in vitro antibacterial activity against S. aureus and E. coli bacteria have been tested. The excellent antimicrobial activity of these films provides a novel and simple way for the synthesis nanocomposites as functional biomaterials and has the possibility for usage in food packaging applications.

Keywords ZnONRs · PEO · CMC · AC conductivity · Dielectric properties · Antibacterial activity

Introduction
A polymeric matrix of suitable physicochemical and electrical features which are required for develop of flexible devices can be appropriately designed via the green synthesis of mixing two or more biopolymers with their difference compositional ratios [1, 2]. Polymer solid electrolytes are remarkable materials for electro-chemical usage in many energy storage applications include fuel cells, super-capacitors and lithium batteries, also can be used in photovoltaic electrochemical solar cell and photovoltaic display. Solid polymer batteries, based on metals salts, have gained great attention due to their good unique properties such as no leakage, flexibility, good flexibility, superior thermal stability and high performance. Polymeric electrolytes are generated via a polymeric host that includes inorganic solid electrolytes, solid polymer electrolytes, and organic and inorganic hybrid composite electrolytes with alkali metal salts without organic liquid solvents [1, 3]. Polymer electrolytes (Polymer membranes) can be enhance lithium batteries by replacing the liquids electrolytes currently in use and thereby enabling the manufacture of flexible, compact, laminated solid state structures free from leaks and available in diverse...
A polymer electrolyte system [5, 6]. Polyethylene oxide (PEO) is a semicrystalline polymer, has good properties such as thermal stability, high viscosity, soluble in water, heat-deciseivity, and has the ability for solvating different inorganic salts because of the presence of the ether group (COC) within its structure, which is helps in support the transport of ions charges [5, 6]. Carboxymethyl cellulose (CMC) has large applications such as medicinal, beauty products and foods industry due its exceptional features such as nontoxic, suspension, flexibility, emulsification and easy process Ability. The biodegradable and nontoxic PEO/CMC blend matrix of enhanced thermal properties remain the choice of several scientist in developing ecofriendly nanodielectric and advanced materials [7, 8]. The anionic CMC polymer, a derivative, was chosen as the partner polymer due to its cost effectiveness, good bio-compatibility and bio-degradability and nontoxicity. The CMC structure consists of OH and C=O groups which supply interactions between the different fillers in the polymeric matrix. CMC is a noncrystalline polymer, which cause reduces degree of crystallinity of PEO, which can allow easier ionic movability compare with other semi crystalline polymeric material having low scattering loss for different application. Also, CMC reduces PEO brittleness and largely improve the thermal and mechanical stability of PEO [9, 10]. Furthermore PEO and CMC polymers are soluble in several common solvents such as water, and their heterogeneous solution invariably [11]. ZnO is n-type semiconductor material with a tunable direct energy gap of 3.37 eV at room temperature. ZnO is a nontoxic material with an excellent photocatalytic activity. Different physical and chemical ways were used for the synthesis of various structures of ZnO, such as nanorods, nanotubes, nanorods and nanospheres, with different properties which makes them suitable for an assortment of applications. Due to these new physical and chemical properties of ZnONPs, they have gained increasing importance for enhancing the performance of photovoltaic cells, some semiconductor industry, catalysis, and next generation lithium-ion batteries [11, 12]. In this work, the PEO/CMC blend as a host blend and ZnONRs as filler are used for the development of nanocomposite samples. These PEO/CMC/ZnO samples can be used as UV-mask and as anti-reflective coating in solar cells to decrease reflection from absorber layers.

### Experimental section

#### Materials

PEO was purchased from Acros Organics, U.S.A. with molecular weight ≈ 60,000 g/mol. CMC with molecular weight ≈ 90,000 g/mol and sodium hydroxide were purchased from Sigma Aldrich (U.S.A.). Zinc nitrate (Zn(NO₃)₂) was supplied from Merck. Sodium hydroxide (NaOH) was obtained from El-Nasr Co. (Egypt). The distilled water was used as a solvent.

#### Synthesis of ZnONRs

The alkali solution of zinc was synthesized via dissolving 15 g of zinc nitrate and 4 g of NaOH in distilled water. Then the NaOH solution was heated to specific temperature. Under constant stirring, the Zn(NO₃)₂ solution was slowly dropped into the NaOH. After 90 min reaction, the white precipitate deposited in the bottom of the bottle was collected by filtration and rinsed three times with high purity water and ethanol, respectively. At last, the ZnONRs were acquired by centrifugation and dried of the precipitate in a vacuum at 450 °C for 3 h.

#### Synthesis of PEO/CMC/ZnO nanocomposite samples

The PEO/CMC blend (70/30 wt.%) were prepared by casting route, each component of blend was dissolved alone in the water with continuous stirring, for 8 h at room temperature, until complete dissolution. After that, the solution was mixed at 40°C using magnetic stirrer for 10 h, and then the ZnO was added into the polymeric solution with various concentrations (0.0, 0.1, 0.2, 0.4 and 0.6 wt. %) with stirring for other 3 h to obtain the nanocomposites solutions. The solutions were exposed to ultrasonic waves for 10 min and were cast on to a Petri dish. Finally, the solutions were dried in an oven at 40 °C for 72 h. The thickness of the films was in the range from 55 to 87 μm. The obtained films were kept in vacuum desiccators, until use.

#### Measurements

DIANO Corporation X-ray diffractometer was used to examine the XRD patterns with scan rate 1°.min⁻¹ using CuKα radiation (λ = 1.5412 Å) of the TiO₂ NPs and the nanocomposite samples. TEM micrograph of TiO₂ NPs was conducted using a JEM-1011/JEOL/Japan. The FT-IR spectra of the nanocomposite samples were obtained on a Nicolet iS10 spectrometer at wavenumber range from 4000 to 400 cm⁻¹. The UV/vis. spectra were carried out using a PerkinElmer Lambda 20 UV-vis. spectrometer with scanning range was
from 190 to 800 nm. Scanning electron micrographs was carried out via SEM (JEOL/JSM 6100) at 30,000 V. For AC impedance measurements were obtained in a dry nitrogen atmosphere at room temperature with a frequency range of 0.1 Hz to $2 \times 10^7$ Hz via broadband dielectric spectroscopy with the use of the concept of Novocontrol turnkey idea 40 System. Staphylococcus aureus and Escherichia coli were selected to examination the antimicrobial activity as representatives of gram +ve bacteria, gram -ve bacteria, using disc diffusion method using inoculums containing 106 bacterial spread on Mueller Hinton agar plates. The samples discs were placed on the surface of agar plates seeded with the test organisms. The plates were incubated at 37 °C. Inhibition zone diameters (mm) were measured after 24 h for bacteria.

**Results and discussion**

**X-ray diffraction (XRD) scans**

To obtain some information about the structural and the crystallite of the prepared samples under investigations, X-ray diffraction scans were studied. Figure 1a represent the XRD patterns for pure PEO, CMC and blend. The PEO spectrum displays the semicrystalline nature of PEO and reveal three main sharp peaks at $2\theta = 18.9^\circ$, $23.0^\circ$ and $25.9^\circ$. The planes (112), (120) and (222) [PCPDF Filenos. 49-2200 and 49-2201] are related to these three peaks [3, 13]. While the spectrum of CMC give the wide peak at $2\theta = 21.7^\circ$ which is indicate to as the amorphous structure of CMC. The XRD scans of pure blend show the semi-crystalline structure of PEO/CMC blend and exhibited two main diffraction peaks at the positions around $18.9^\circ$ and $23.0^\circ$ which were arisen from the crystalline phases of PEO. Other diffraction peaks with lower intensity were found at 25.9°, 36.0°, and 39.6° [14]. Figure 1b represents the X-ray diffraction scans of pure ZnONRs and PEO/CMC/ZnONRs nanocomposites. The pattern of ZnONRs shows the diffraction peaks at $2\theta = 31.6^\circ$, 34.2°, 36.1°, 47.4°, 56.4°, 62.7°, and 67.8° which are referred to (100), (002), (101), (102), (110), (311) and (312) planes, respectively [15, 16]. The diffraction patterns of filled samples showed decrease in the degree of crystallization. This enhancement in the amorphous structure caused to greater ionic mobility and high ionic conductivity [17]. Also this spectra showed the appearance of new (312) planes, respectively [15, 16]. The diffraction patterns are referred to (100), (002), (101), (102), (110), (311) and (312) planes, respectively [14].

**TEM micrograph of ZnONRs**

TEM was used to investigate the sizes, crystallinity and shapes of the nanosize material. Figure 2 exhibited TEM image with its corresponding size distribution (both diameter and length) histogram of ZnONRs. The micrograph clearly illustrates rod-shaped of ZnO, which having the diameters in the range 29.29 to 59.09 nm, while the length of the ZnO nanorods were in the range between 34.85 to 135.92 nm. The variation in nanorods size is possibly due to the fact that it is being synthesized at various times [17]. The average size of nanorods from a TEM micrograph agrees fairly well with the size estimated by XRD results [18].

**FT-IR analysis**

FT-IR spectra for pure PEO, CMC and PEO/CMC blend in the range of 4000–400 cm$^{-1}$ are exhibited in Fig. 3. The spectrum of PEO shows sharp band at 2886 cm$^{-1}$ was attributed as asymmetric stretching of the CH$_2$, the bands at 1465, 1348 and 1110 cm$^{-1}$ were attributed to CH$_2$ scissoring, CH$_2$ asymmetric bending, and C-O-C stretching vibration [5, 19–22], respectively. From the pure CMC spectrum, main characteristic peaks were noticed. The broad peak noticed at 3397 cm$^{-1}$ was assigned to O-H stretching [23, 24], while the small peak at 2922 cm$^{-1}$ was attributed to CH$_3$ asymmetric stretching [24]. The peak at 1596 cm$^{-1}$ was due to the carbonyl (C=O) stretching of the protonated carboxylic acid group (–COOH) [24, 26]. The peaks at 1421, 1325 and 1064 cm$^{-1}$ which are assigned to the CH$_2$ scissoring, C–O bending and C–O–C glycosidic ether, respectively [25, 26]. The FT-IR spectrum of pure PEO/CMC confirms the existence of OH and C=O groups of CMC and CH$_2$ and C–O–C groups of PEO, which confirm the good miscibility between blend components (PEO and CMC). Consequently, the quasi hydrogen bonds occur between the H atoms of CH$_2$ of PEO and the O atoms of C=O of CMC.

The wavenumbers and bands assignments of the PEO, CMC and pure blend were reported in Table 1. From the FT-IR spectra for PEO/CMC/ZnO samples, the embedding of ZnONRs was largely effect on the functional groups for PEO/CMC blend as a result from the complexation or interaction between blend and ZnONRs.

The effect of ZnONRs on the modes of vibrations were found in terms of reduce or increase in the intensity, broadness of the peaks with ZnONRs concentrations which resulted from the formations of cross-links between Zn and CH$_2$ and C=O groups, and coordination between ZnO as shown in Fig. 4. The peak of OH
group at 3397 cm$^{-1}$ was largely increase after embedded of ZnONRs. The absorbance for CH$_2$ and C=O groups of blend are greatly raised, which assigned to the strong interactions between PEO/CMC and ZnONRs by making coordination with these functional group [20, 25]. This is an index for the formations of hydrogen bonds between ZnO and the pure PEO/CMC. The appearance of the variation of the intensity reveals the existence of interactions between ZnONRs and functional groups existing in components of polymeric blend [26]. The obtained results describe that there is an interactions between the PEO/CMC blend and ZnONRs.
Fig. 2 TEM micrograph and the corresponding histogram of diameter and length distribution of ZnONRs.
**Optical properties (UV/vis.)**

Figure 5 shows the absorption spectra of pure PEO/CMC blend, PEO/CMC blend filled with various contents of synthesized ZnONRs in the range from 190 to 800 nm. The UV/vis. spectrum of pure sample shows the only peak that appears at 206 nm at the UV region, that mainly can be assigned to $n \rightarrow \pi^*$ electronic transition [27, 28] that proves its semicrystalline nature. After the addition with ZnO nanorods, UV/vis. spectra of PEO/CMC/ZnONRs nanocomposite samples show a red shifts in the peak positions at about 206 nm of pure samples to 214 nm for sample doped with 0.60 wt. % ZnO. This red-shift denotes that within the PEO/CMC there is a decrease in optical energy gaps that proved the complexation and interactions between ZnONRs and PEO/CMC matrix. Additionally, the UV/vis. spectra of PEO/CMC/ZnONRs nanocomposite samples achieved a manifest characteristic peak at 380 nm. The presence of this peak was due to interband transitions of zinc electrons from valance level and also known as Surface Plasmon Resonance (SPR) of ZnONRs [30] that proved the successes formations of ZnONRs in the PEO/CMC matrix. SPR peak starts with shifts to longer wavelength and the intensity continuously increasing with rising concentration of ZnONRs. This red-shift denotes that the nanorods diameters increase with increasing concentration of the ZnONRs. As a red-shift is occurred this shows the effect of quantum confinement. To evaluate the optical energy gap of the PEO/CMC and the PEO/CMC/ ZnONRs nanocomposite samples were calculated via Tuac’s equation [29]:

$$\alpha_{\nu} = A(\hbar\nu - E_g)^m$$  \hspace{1cm} (1)

where A represent a constant, $\hbar\nu$ represent a photons energy and m take the value of 2 for allowed indirect transition, 0.5 for allowed indirect transition. Figures 6 and 7 show the relation of both $\alpha_{\nu}^{1/2}$ and $\alpha_{\nu}^{2}$ on $\hbar\nu$ at higher photon energy which exhibited that, both indirect and direct optical transition are possible for present samples. The straight-line portion of the curve is extrapolated to zero to give indirect/ direct optical transition. That is clear, from Figs. 6 and 7, the indirect/direct optical energy gap value decrease with ZnO filling that is related to the fact that the ZnO contents significantly decrease the $E_g$ in the mean of producing some defects in the nanocomposite films. The indirect optical energy gap of the pure PEO/CMC blend is 4.49 eV, this value was significantly reduced via rising the ZnO until reaches 1.88 eV in PEO/CMC/ZnO samples, while the direct optical energy gap of the pure blend is 4.97 eV and reached 3.62 eV at highest concentration, as shown in Table 2. These defects generate the localized states that reflect the decrease in the crystallinity degree in polymeric films [23, 30].

**Morphological studies of PEO/CMC/ ZnO nanocomposites samples**

SEM micrographs of PEO/CMC/ZnO nanocomposites are shown in Fig. 8. The SEM image of surface of pure PEO/
CMC blend (Fig. 8a) exhibits smooth surface with some cracks confirming the formation of the appropriate miscible blend of these components (PEO and CMC). The SEM micrograph given in Fig. 8b–e of doped samples reveal that the white parts which indicate ZnONRs presence in the form of agglomerate that are at random dispersion on the nano-composite samples surfaces [29]. When the nano inclusions increase to 0.40 wt. % and then to 0.60 wt. %, relatively large variations in the morphological of the samples surface were observed. The morphological properties of polymeric films exhibited variations with raised the ZnONRs content which produced from cluster formations within the nano-composite samples. The clusters sizes increased with raised the ZnONRs contents due to the existence of oxygen atom in the structure of samples which is the essential factor for the bonding of ZnONRs to the polymeric chains cause to stability of the PEO/CMC/ZnONRs samples [31, 32].

**AC conductivity (σ<sub>ac</sub>)**

In this part, the AC electrical conductivity and the dielectric parameters of the present PEO/CMC blend and PEO/CMC/ZnONRs films at various concentration (0.10, 0.20, 0.40 and 0.60 wt. %) related with the frequencies in the range 10<sup>-1</sup> Hz to 2 × 10<sup>7</sup> Hz at room temperature (RT) were examined as represent in Figs. 9–13. The conductivity of prepared samples was calculated using this equation [33]:

\[
\sigma_{ac} = \frac{L}{RA}
\]  

(2)
where $R$ is the bulk resistance, $L$ is thickness in cm of the samples and $A$ is the electrode area (cm$^2$). As shown in Fig. 9, the value of conductivity increase linearly with raising frequency which has two slope values due to the semi-crystalline nature of samples [34]. The value of $\sigma_{ac}$ has been enhanced with the ZnONRs contents. At low frequency ($f$), the frequency independent conductivity is dc conductivity and under the influence of an applied electric field, the dc conductivity emerges from the drift of the charges carrier over extended distance. The average distance of the charges carrier decrease with the rise of the frequencies and causing to an increased in the conductivity exponentially with the relation $\sigma_{ac} = A(2\pi f)^s$, where $s$ is a frequency dependent exponent have ($1 < s > 0$) and $A$ represent a constant [35].
It is found that the value of the S was in the range of 0.588 to 0.410; these data are according to Elliot’s, general feature of amorphous semiconductor nature [35]. The charges immigration via the hopping mechanism is behavior and general feature in amorphous and heterogeneous solids. At high frequency, the ac conductivity increased due to the excess charges carriers produced which are assigned to the trapped charge activation in the polymeric material that undergoes localized motion. The AC conductivity obeys the behavior of Jonscher universal law represents by the following equation [36]:

$$\sigma_{ac} = \sigma_{dc} + A\omega^s$$  \hspace{1cm} (3)

It is clear that the improvement in the conductivity of the polymeric samples as compared with pristine blend due to the increase of charges mobility. The highest value of
conductive networks are created when ZnONRs loading in polymeric matrix according to the electronic and impurities contributions arising from the ZnONRs [37]. At higher ZnONRs concentration, the molecules start to bridge gap separated between two localized states and potential barrier between them, and therefore support of charge carrier transfer.

### Dielectric properties

The dielectric properties, dielectric constant ($\varepsilon'$) and dielectric loss ($\varepsilon''$), at room temperature for PEO/CMC/ZnO nanocomposites with frequencies, are shown in Figs. 10 and 11. The $\varepsilon'$ is the energy storage ability, which can be considered as a gauge of the polarization of present dielectric matrix. So, it is found that the value of $\varepsilon'$ is decrease monotonically with raising frequency until reached to a constant value at higher frequency (Fig. 10). In the high frequency region, the contribution of charges carrier to the $\varepsilon'$ is reducing with raising frequency due to the high periodic reversal of the applied fields at the interfaces of sample [36, 37]. The Figure exhibits the increase in $\varepsilon'$ of the films as a function of ZnONRs concentration. The PEO/CMC/ZnO samples had dielectric relaxation peak in $\varepsilon''$ at low frequencies which is assigned to its structural dynamics as showed in Fig. 11. The dielectric loss increase with rising ZnONRs concentration, this improvement denotes that the charge carrying capacity of doped samples become higher compared with the pure PEO/CMC sample. Furthermore, the high value of $\varepsilon''$ shown at low frequency being caused by the mobile charges in the PEO/CMC samples. In higher frequency, while, the increase in mobile charges concentration at high filler level of ZnONRs results in a reduction of $\varepsilon''$ values [38, 39].

The electric modulus ($M^*$) illustrated the relaxation mechanism in the PEO/CMC/ZnONRs samples. The follows equation depicted the electric modulus:

$$M^* = M' + M''$$

where $M'$ and $M''$ represent the real and the imaginary part of the electric modulus.

The frequency dependence of $M'$ for various concentrations of ZnO is depicted in Fig. 12. It is clear that $M'$ reached highest values at highest frequencies. This is attributed to the fact that at high frequencies the dielectric constant reduced to a minimum values as showed in Fig. 10 and consequently $M'$ becomes maximum ($M'^\infty = 1/e''\infty$). The highest value of $M'$, at highest concentration of ZnO can be attributed to its low dielectric constant compare to others samples. These remarkable result reveal that $M'$ and $M^*$ analysis are important to investigate the ionic conducting of PEO/CMC nanocomposites [38, 40]. The Fig. 13 a showed $M''$ with log f for polymeric matrix with different content of ZnONRs. It is found that the shape of all curves are peaks, where showed a peaks at the relaxation frequencies, with a tails extension in the area of lower relaxation time is due to interfacial polarization effect that appear the basic source of dielectric relaxation at ZnONRs interface. At low frequency, charge carriers can move more easily, while at higher frequencies, they perform local movement and are limited to a potential gap [41–43]. Also, can be found that the shape of the curves was asymmetric and the peak frequency moves toward the higher frequency with increase ZnONRs content.

### Antibacterial activity

The in vitro antibacterial activity of the PEO/CMC/ZnO nanocomposites is display in Fig. 14. The samples discs were placed on the surface of agar plates seeded with the test organisms. The plates were incubated at 37 °C. The data exhibited of that the polymeric samples antibacterial activity orderly increases with the content of ZnONRs increasing the diameters of the clear zone on all strains raised with increasing ZnONRs concentration as displayed in Table 3 and Fig. 14. Also, it can be noticed that the antibacterial activity of gram +ve is more compared to that of the gram -ve bacteria.

The growing of antibacterial activity is due to the synergistic influence between polymeric matrix PEO/CMC and ZnONRs [44, 45]. The proposed mechanism of antibacterial activity of ZnO/PEO/CMC nanocomposite can be described according to reactive oxygen species (ROS) and Zn$^{2+}$ that release from ZnONRs [45]. The ROS and Zn$^{2+}$ can interact with bacterial cells wall and intra-cellular content of the cell such as protein, lipid, and carbohydrates leading to nucleic acids damage and eventually leads to bacteria death [45, 46]. The results exhibited that the PEO/CMC/ZnO nanocomposites in food packaging industries can be a potential replacement for their synthetic counterparts.
Fig. 8 SEM micrographs of the surface of (a) pure PEO/CMC blend and its complexes filled with concentrations of ZnONRs (b) 0.10, (c) 0.20, (d) 0.40, and (e) 0.60 (wt. %) at magnification 5000 times
Fig. 9 Frequency dependent AC conductivity of PEO/CMC filled with various concentrations of ZnONRs at room temperature

Fig. 10 Variation of the real part of $\varepsilon'$ with Log $f$ of PEO/CMC/ZnO nanocomposites at room temperature
Fig. 11 Variation of the real part of $\varepsilon''$ with Log $f$ of PEO/CMC/ZnO nanocomposites at room temperature

![Graph of $\varepsilon''$ vs Log $f$ for PEO/CMC/ZnO nanocomposites with different ZnONRs concentrations.]

Fig. 12 Variation of the real part of $M'$ with Log $f$ of PEO/CMC/ZnO nanocomposites at room temperature

![Graph of $M'$ vs Log $f$ for PEO/CMC/ZnO nanocomposites with different ZnONRs concentrations.]

---

**Additional Text**: (if present)

- Any relevant additional text mentioned in the image.
The ZnONRs were added in the PEO/CMC blend samples to form a nanocomposite via casting method. TEM micrograph denoted synthesis of ZnONRs with sizes in the range 29.29 to 59.09 nm. The XRD patterns showed that the semi-crystalline nature of the blend. The FT-IR spectrum of pure PEO/CMC confirms the existence of OH and C=O groups of CMC and CH₂ and C-O-C groups of PEO, which confirm the good miscibility between blend.

### Conclusion

Table 3 Antibacterial activity of PEO/CMC filled with different concentration of ZnONPs

| Concentration of ZnONPs | S. aureus Diameter of zone (mg/ ml) | E. coli Diameter of zone (mg/ ml) |
|------------------------|-------------------------------------|----------------------------------|
| 0.00                   | -ve                                 | -ve                              |
| 0.10                   | 31                                  | 6                                |
| 0.20                   | 35                                  | 17                               |
| 0.40                   | 42                                  | 32                               |
| 0.60                   | 56                                  | 36                               |
components (PEO and CMC). FT-IR spectra confirmed the
clexpansion between PEO/CMC and ZnO nanorods via the interactions between the polar groups of the poly-
meric matrix and ZnONRs. The SEM images showed the
uniform dispersion of ZnONRs on the samples surfaces.
The AC conductivity increases with increasing frequency
and concentration of TiO2NPs in all samples. The highest
value of conductivity was at highest concentration of
ZnONRs is 3.26 × 10−6 S.cm−1. Both dielectric constant
(ε′) and dielectric loss (ε″) were reduced with increasing
frequency according to direction of dipoles toward
applied electric field until reached to constant values at
higher frequencies which attributed to dipoles orientation.
The improvement of the antimicrobial activity for
filled polymeric samples was noticed. These enhancements
in the optical and electrical properties and antimicrobial
activity of PEO/CMC blend filled with ZnONRs make it a
considerable substance for energy storage device applica-
tions and in food-packaging industry.

Author contribution A.E. Tarabiah: Methodology, Project admin-
istration, Data curation. Hisham A. Alhadda: Writing—original draft.
ZahnAllah M. Aiaizeri: Conceptualization, Investigation. Abdullah
A. A. Ahmed: Formal analysis, Resources. G.M. Asnag: Supervision,
Writing—original draft. Maqusood Ahamed: Review & editing.

Funding The authors extend their sincere appreciation to researchers
supporting project number (RSP-2021/129), King Saud University,
Riyadh, Saudi Arabia for funding this research.

Data availability The data that support the findings of this study are
available from the corresponding author upon reasonable request.

Declarations

Informed consent All the authors consent for submitting it to Journal of Journal of Polymer Research for publication.

Conflict of interest The authors declare that they have no known com-
peting financial interests or personal relationships that could have ap-
ppeared to influence the work reported in this paper.

References
1. Yuan S, Shen F, Chua CK, Zhou K (2019) Prog Polym Sci 91:141–168
2. Patrick A, Glasme L, Latham R, Linford R (1986) Solid State
Ionics 18–19:1063–1067
3. Alshehari AM, Salim E, Oraby AH (2021) J Market Res
15:5615–5622
4. Morsi MA, Asnag GM, Rajeh A, Awwad NS (2021) Compos
Commun 24:100662
5. Abdellhany AM, Oraby AH, Asnag GM (2019) J Mol Struct
1180:15–25
6. Tominaga Y, Ohno H (2000) Electrochim Acta 45:3081–3086
7. Jinisha B, Anilkumar KM, Manoj M, Pradeep VS, Jayalekshmi S
(2017) Electrochim Acta 235:210–222
8. Kumar KN, Vijayalakshmi L, Choi J (2019) Optik 183:805–812
9. Dhatwar P, Sengwa RJ (2021) Compos Interfaces 28(8):827–842
10. Asnag GM, Oraby AH, Abdellhany AM (2019) Compos B
172:436–446
11. Abutalib MM (2019) Physica B 557:108–116
12. Dhatwar P, Sengwa RJ (2021) Optik - Int J Light Electron
Optics 233:166594
13. Abdellrazek EM, Abdellhany AM, Badr SL, Morsi MA (2016) Res
J Pharm Biol Chem Sci 7:1877–1890
14. Hea J-R, Zha J-J, Yina S-W, Yang X-Q (2022) Food Hydrocoll
122:107076
15. Qiao F, Sun K, Liu W, Xie Y, Chu H (2022) Vacuum 196:110787
16. Karpuraranjith M, Thambidurai S (2017) Int J Biol Macromol
104:1753–1761
17. Asnag GM, Awad NS, Ibrahim HA, Moustapha ME, Alqahtani
MS, Menazzea AA (2022) J Inorg Organomet Polym Mater 1–9
18. Zagal-Padilla CK, Garcia-Sandoval J, Gamboa SA (2022) J Alloys
Compd 891:162087
19. Gondaliya N, Kanchan D, Sharma P, Joge P (2011) Mater Sci
Appl 2:1639–1643
20. Xu Y, Li J, Li W (2022) Coll Surf A: Physicochem Eng Aspects
632:127773
21. Meikhail MS, Oraby AH, Farea MO, Abdellhany AM (2014) Biol
Chem Sci 5:976–983
22. Patel G, Sureshkumar MB, Patel P (2015) Sci Res Pub 4:9–24
23. EI Sayed AM, Saber S (2022) J Phys Chem Solids 163:110590
24. Hameed ST, Qahtan TF, Abdellhany AM, Oraby AH (2022) Phys
B: Condens Matter 633:413171
25. Ezati P, Riahi Z, Rhim JW (2022) Food Hydrocoll 122:107104
26. Huang J, Yang H, Chen M, Ji T, Hou Z, Wu M (2017) Polym
Testing 59:212–219
27. Atta MR, Alsalumia QA, Asnag GM, Rajeh A (2021) J Mater Sci:
Mater Electron 32(8):10443–10457
28. Abdellrazek EM, Asnag GM, Oraby AH, Abdellhany AM, Alshehri
AM, Gumaan MS (2020) J Electron Mater 49:6107–6122
29. Abutalib MM, Rajeh A (2020) J Mater Sci: Mater Electron
31:9430–9442
30. Atta MR, Algethami N, Farea MO, Alsalumia QA, Rajeh A (2022).
Int J Energy Res. https://doi.org/10.1002/er.7703
31. Frade T, Bouzon V, Gomes A, da Silva Pereira MI (2010) Surf
Coat Technol 204:3592–3598
32. Manshad AK, Alib J, Haighomi GM, Sajadid SM, Keshavarz A
(2022) Fuel 307(1):121927
33. Awwad NS, Abd El-Kader MFH, Ibrahim HA, Asnag GM, Morsi
MA (2021) Compos Commun 24:100678
34. Abdutalib MM, Rajeh A (2020) J Organomet Chem 918:121309
35. Demirezen S, Çetinkaya HG, Altundal Ş (2022) Silicon 1–11
36. Mathew S (2022) J Non Cryst Solids 577:12132f
37. Abdellhany AM, Farea MO, Oraby AH (2021) J Mater Sci: Mater
Electron 32:6538–6549
38. Enachi M, Lupan O, Braniste TT, Saraua A, Chow L, Mishra
VK et al (2015) Phys Status Solidi (RRL)–Rapid Res Lett
9(3):171–174
39. Morsi MA, Abdelaziz M, Oraby AH, Mokhles I (2019) J Phys
Chem Solids 125:103–114
40. Abdellhamied MM, Abdelleheem AM, Atta A (2022) Plast Rubber
Comp 51(1):1–12
41. Agrawal SL, Singh M, Asthana N, Dwivedi MM, Pandey K (2011)
Int J Polym Mater Polym Biomater 60:276–289
42. Ayesh AS (2008) J Thermoplast Compos Mater 21(4):309–322
43. Aziz SB (2015) Bull Mater Sci 38(6):1597–1602
44. Farea MO, Abdellhany AM, Meikhail MS, Oraby AH (2020) J
Market Res 9(2):1530–1538

© Springer
45. Abdeen ZI, El-Farargy AF, Negm NA (2018) J Mol Liq 250:335–343
46. Tekin D, Birhan D, Kiziltas H (2020) Mater Chem Phys 251:123067

Publisher’s Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.