RESEARCH PAPER

Tailoring Electrical Performance of PVA-PVP-SiC Composites Using CuO Nanofiller

Zainab H.Wetwet [1,2]*, Bahaa H. Rabee [2], Huda Bukheet Hassan [2]

[1] *Ministry of Education, Director of Education, Babylon, Iraq*

[2] *Department of Physics, Faculty of Education for Pure Science, University of Babylon, Babylon, Iraq*

ARTICLE INFO

Article History:
Received 05 April 2026
Accepted 13 July 2026
Published 01 October 2026

Keywords:
CuO Nanofiller
Electrical properties
FE-SEM
Nanocomposite

ABSTRACT

This study examined the morphological, structural, and insulating effects of incorporating CuO nanoparticles into PVA-PVP-SiC-based polymer composites. Casting was used to create PVA/PVP/SiC/CuO composites in varying concentrations (0.0, 0.3, 0.7, and 1 percent by weight). Additionally, the addition of nanobubbles using an ultrasonic instrument demonstrated that these compounds had unique features in comparison to other nanocomposites and that they significantly improved insulation because the nanoparticles improved polarization and increased the number of charge carriers in the polymer system.. Due to the buildup of charges at the particle-polymer interfaces, the dielectric constant and electrical conductivity dramatically increased by 47% and 82%, respectively, when the compound content reached 1%wt. CuO compounds demonstrated a consistent improvement due to their semiconducting nature. The compounds' structural properties were examined using optical microscopy (OM) and FE-SEM methods. Furthermore, the dielectric properties were examined in the 100 Hz–5 MHz frequency range. These results imply that CuO compounds are more successful at improving electrical insulation and can be used in a range of nanodielectrics.

How to cite this article
Wetwet Z., Rabee B., Hassan H. Tailoring Electrical Performance of PVA-PVP-SiC Composites Using CuO Nanofiller. J Nanostruct, 2026; 16(4):4612-4618. DOI: 10.22052/JNS.2026.04.011

INTRODUCTION

Due to their exceptional potential for a wide range of applications, polymeric nanocomposites have attracted significant scientific and industrial interest. Nanotechnology is a fascinating science with the potential to improve our quality of life. Polymeric nanocomposites consist of copolymers or polymers with nanoparticles or nanofillers dispersed in polymer matrices [1] [2]. One of the fundamental aspects of nanotechnology in the use of polymers is the composition of polymer-based nanocomposites. A new approach that differs from the traditional addition of plastics is the use of inorganic nanomaterials as nanofillers in polymer-based nanocomposites [3]. When compared to other materials, such as clay and most metals, the properties of polymers do not particularly improve, which limits their use in the production of goods and construction [1,4]. Improvements in the properties of polymers lead to a wide range of applications. The inorganic filler present within the polymers is what defines them. Solvent casting techniques are considered the simplest and most time-efficient method for synthesizing polymer nanocomposites, which are the most important

* *Corresponding Author Email: edu770.zanab.hadiar@student.uobabylon.edu.iq*

in enhancing the properties of nanocomposites if successful. [5,6]. Polyvinyl alcohol (PVA), one of the original and most popular polymers, is widely used in semiconductor applications for several reasons. Polyvinyl alcohol (PVA) dissolves easily in water and in chemical compounds containing hydroxyl groups [7,8]. Polyvinylpyrrolidone (PVP), a commonly used water-soluble synthetic polymer, is well-known for its exceptional film-forming properties, which make it a popular choice for electrospun nanofibers. [9] Copper oxide holds a prominent position among metal oxides. The simplest copper molecule is CuO, although it possesses a number of desirable properties such as electrical conductivity, high-temperature superconductivity, and non-toxicity. Its narrow bandgap energy of approximately 1.2 electron volts at room temperature enables it to function as both a solar cell and a photodetector. [10,11]. However, the structural properties of polymers are significantly enhanced by metal oxides (MO). It is also used in optoelectronics, composite reinforcement, and catalytic supports due to its strong mechanical and thermal properties [12]. The toxicity of organic materials used in sterilization procedures is one of their drawbacks, which has sparked interest in inorganic disinfectants such as metal oxide nanoparticles (NPs) [13]. Nanoparticles of high-ion metal oxides are considered particularly important antimicrobial agents due to their ability to be prepared in unusual crystalline forms and their very high surface areas [14]. Although metal oxide particles such as ZnO, CuO, and NiO possess antibacterial properties, they are not very effective against foodborne diseases [15]. The purpose of this work is to study the potential uses of silicon carbide (SiC) nanoparticles and their effect on the alternating current (A.C.) electrical properties. For PVA–NiO–SiC nano-composites. The creation of nanocomposites of PVA-PVP-SIC-CuO for use in a variety of optical and electronic applications is the aim of this work.

MATERIALS AND METHODS

Preparation and purification of nanocomposites

Using solution casting, PVA-PVP-SiC-CuO nanocomposites were produced. To create a homogeneous solution and improve the homogeneity of the nanocomposite, 75% of polyvinyl alcohol (PVA) was dissolved in 60 milliliters of water using a magnetic stirrer. Then, 25% of PVP was added and left to dissolve for 20 minutes at 75 degrees Celsius. After that, SiC and CuO nanoparticles were added to the mixture in weight ratios of (0.3, 0.7, and 1) %wt. To create nanobubbles inside the nanocomposite, air bubbles are injected into it. The mixture is put in an ultrasonic processor (ul-ultrasonic) mixer (FS-1200N) at room temperature with a frequency of 20 kHz once its homogeneity has been confirmed. We can presume that ultrasound is used to create nanobubbles. Controlling the power and timing

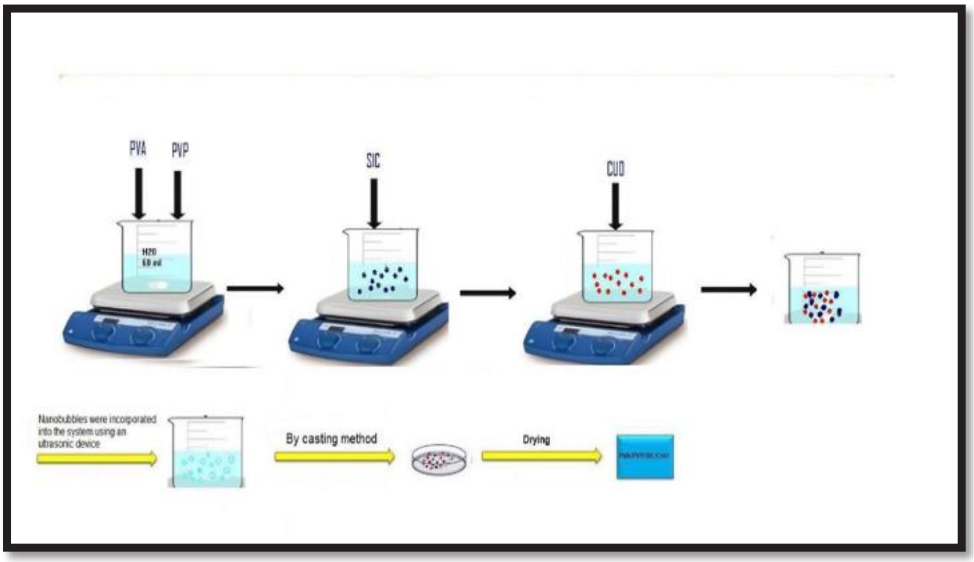

Fig. 1. Scheme of experimental work.

determines the right amount and size [16]. Use a tube that is attached to an air compressor and inserted into the solution beaker to produce tiny bubbles that gradually vanish, leaving just nanobubbles behind. Then, they were placed in a 10 cm diameter Petri dish and left to dry at room temperature for seven days, resulting in composites with a thickness of 110 micrometers. Fig. 1. shows the experimental workflow.

Experimental

Using the casting technique, PVA-PVP-SiC-CuO nanocomposites were produced, mixed with different weight ratios of silicon carbide nanoparticles, which are 0.3%, 0.7%, and 1% wt. When the electron distributions around the constituent atoms or molecules are polarized by an external electric field, insulating materials can be used to store electrical energy in the form of charge separation. The complex permittivity of the material can be expressed as Eq. 1 [17]:

$$\varepsilon^* = \varepsilon_a - j\varepsilon_b \quad (1)$$

Here, j = √-1 and ε_a and ε_b stand for the real and imaginary components of the complex permittivity, respectively. [17] provides the permittivity's true portion.

$$\varepsilon_a = \varepsilon_0 \bar{\varepsilon} \quad (2)$$

The dielectric constant, or ε_a, of a material indicates how much energy it can store from an applied electric field. The capacitance of a capacitor with two parallel plates can be found using the Eq. 3 [18].

$$C = \bar{\varepsilon}\varepsilon_0 \frac{A}{t} \quad (3)$$

where t is the sample thickness, ε is the vacuum permittivity, and ε^- is the dielectric constant. [19] provides the dielectric constant:

$$\bar{\varepsilon} = \frac{C_p}{C_0} \quad (4)$$

In this case, vacuum capacitance is indicated by Co and parallel capacitance by Cp. Because of conversion into heat energy (molecular vibration) or charge migration (conduction), a portion of the applied electric field energy dissipates as a material's polarization changes. For a long time, ceramic capacitors made of highly polarizable inorganic materials have been utilized to satisfy applications requiring pulse power [20]. The dielectric loss (ε″) can be found using Eq. 5 [21]:

$$\varepsilon'' = \varepsilon' D \quad (5)$$

D represents the dispersion factor. The quantity of electrical energy that is transformed into thermal energy within the sample and lost from the applied field is described by this. What defines the dissipated power in the insulator is the existence of alternating potential as a function of alternating conductivity, which is described as Eq. 6 [21]:

$$\sigma_{ac} = \omega\, \varepsilon''\, \varepsilon_0 \quad (6)$$

where ω is the angular frequency.

RESULTS AND DISCUSSION

The effects of the frequency range from 100 Hz to 5 MHz on the dielectric constant (ε′), dielectric loss (ε′′), and alternating electrical conductivity ($\sigma_{A.C}$) are shown in Fig. 2.

At low frequencies, the PVA/PVP/SiC/CuO composites show significantly high dielectric constant (ε′) values. The concentration of charge carriers near the electrodes causes space charge effects, which can explain the high dielectric constant values at low frequencies.

It has been observed that the dielectric constant values (ε′) at high frequencies approach a constant value. The dielectric constant decreases because charge carriers cannot rearrange themselves in the direction of the field due to the rapid periodic reversal of the electric field. At all concentrations, dielectric relaxation processes are also responsible for the decrease in (ε′) with increasing frequency. When the component ratio reached 1% by weight, the dielectric constant of the (PVA/PVP/SiC/CuO) compound increased from 0.87 to 1.557 at a frequency of 100 Hz [22]. For many electronic applications, including pressure sensors, these dielectric constant results are crucial. With the increase in frequency of the (PVA/PVP/SiC/CuO) compounds, the dielectric loss (ε′′) decreases. Under the influence of different electric fields, it is believed that the energy density of the polymeric material is significantly affected by the dielectric loss, as shown in the Fig. 3. Dielectric loss is the result of loss due to vibration, conduction, and dipole [23]. At low frequencies, the movement of charges within the polymer matrix is the reason for the high values of dielectric loss. In addition to electrical conductivity losses, the high energy

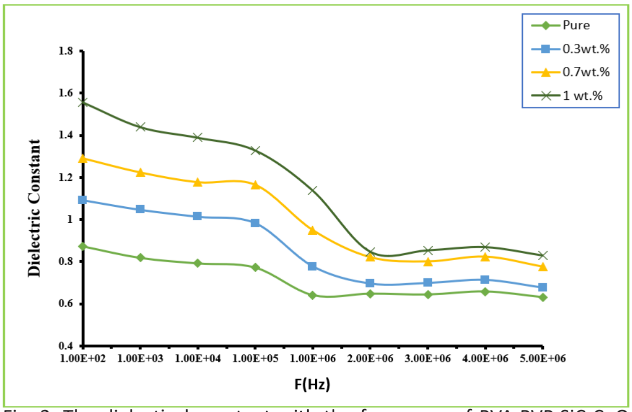

Fig. 2. The dialectical constant with the frequency of PVA-PVP-SiC-CuO nanocomposites.

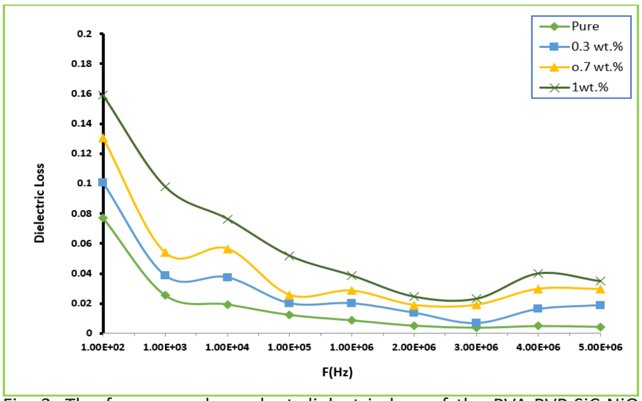

Fig. 3. The frequency-dependent dielectric loss of the PVA-PVP-SiC-NiO nanocomposite.

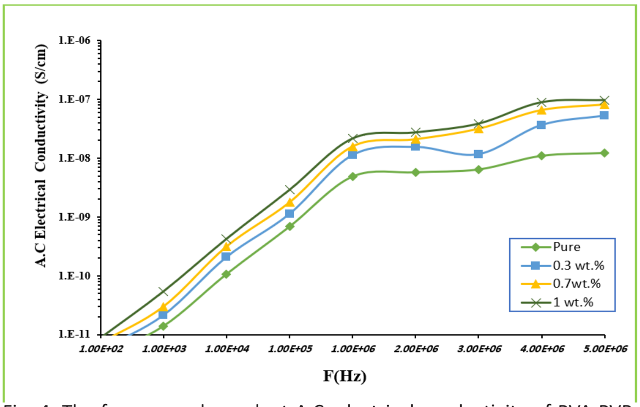

Fig. 4. The frequency-dependent A.C. electrical conductivity of PVA-PVP-SiC-CuO nanocomposites.

barrier for polarity switching and significant polar hysteresis may be responsible for the noticeable loss at low frequencies. The frequency increases the alternating electrical conductivity ($\sigma_{A.C}$) of the (PVA/PVP/SiC/CuO) compounds. The ion exchange mechanism is effective in the high-frequency region due to the increase in conductivity resulting from the movement of charge carriers and ionic jumps within the infinite network, as shown in Fig. 4. There are fewer moving ions, and as a result, the electrical conductivity is lower at low frequencies when the frequency decreases because charges accumulate more at the poles and the surfaces that separate them [24].

SEM was used to study the effect of introducing nanobubbles through ultrasound on the structure of pure polymer films (PVA-PVP) and nanocomposites (PVA-PVP-SiC-CuO). In Fig. 5, the pure sample (A) showed the presence of nano and micro bubbles dispersed within the polymer matrix, giving the surface porosity and a homogeneous texture.For the sample with a concentration of 0.3 wt%, the bubbles contributed to the good distribution of particles, with some minor agglomerations remaining. At a concentration of 0.7 wt%, particle aggregates began to appear, while at 1 wt%, the

agglomerations increased and a clear roughness appeared on the surface [25,26].

Fig. 6 show images of nanofilms of PVA-

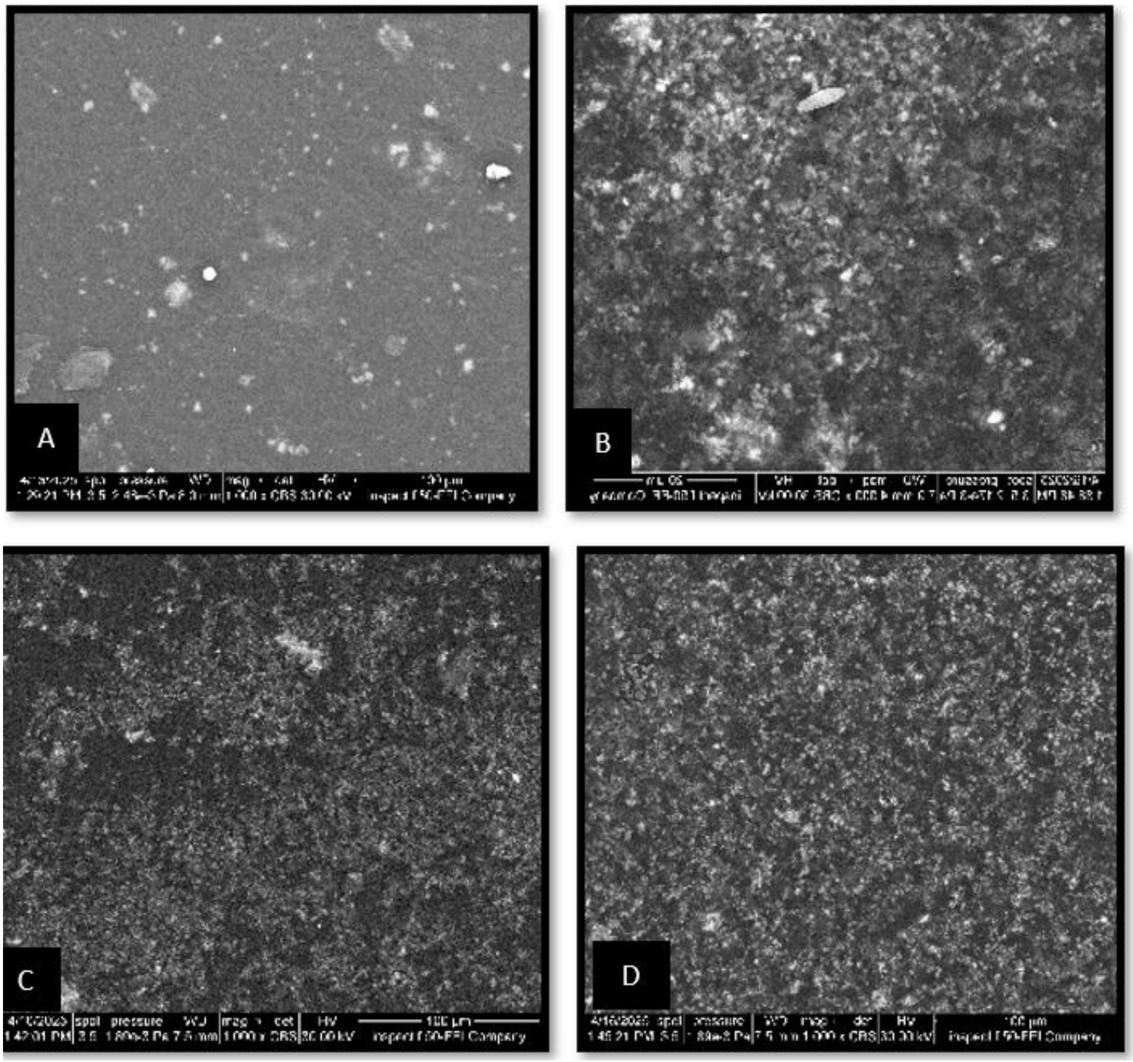

Fig. 5. SEM pictures of (PVA-PVP-SiC-PVP) nanocomposites (A) for the blend of PVA and PVP, (B) for 0.3 weight percent SiC-CuO, (C) for 0.7 weight percent SiC-CuO, and (D) for 1 weight percent SiC-CuO.

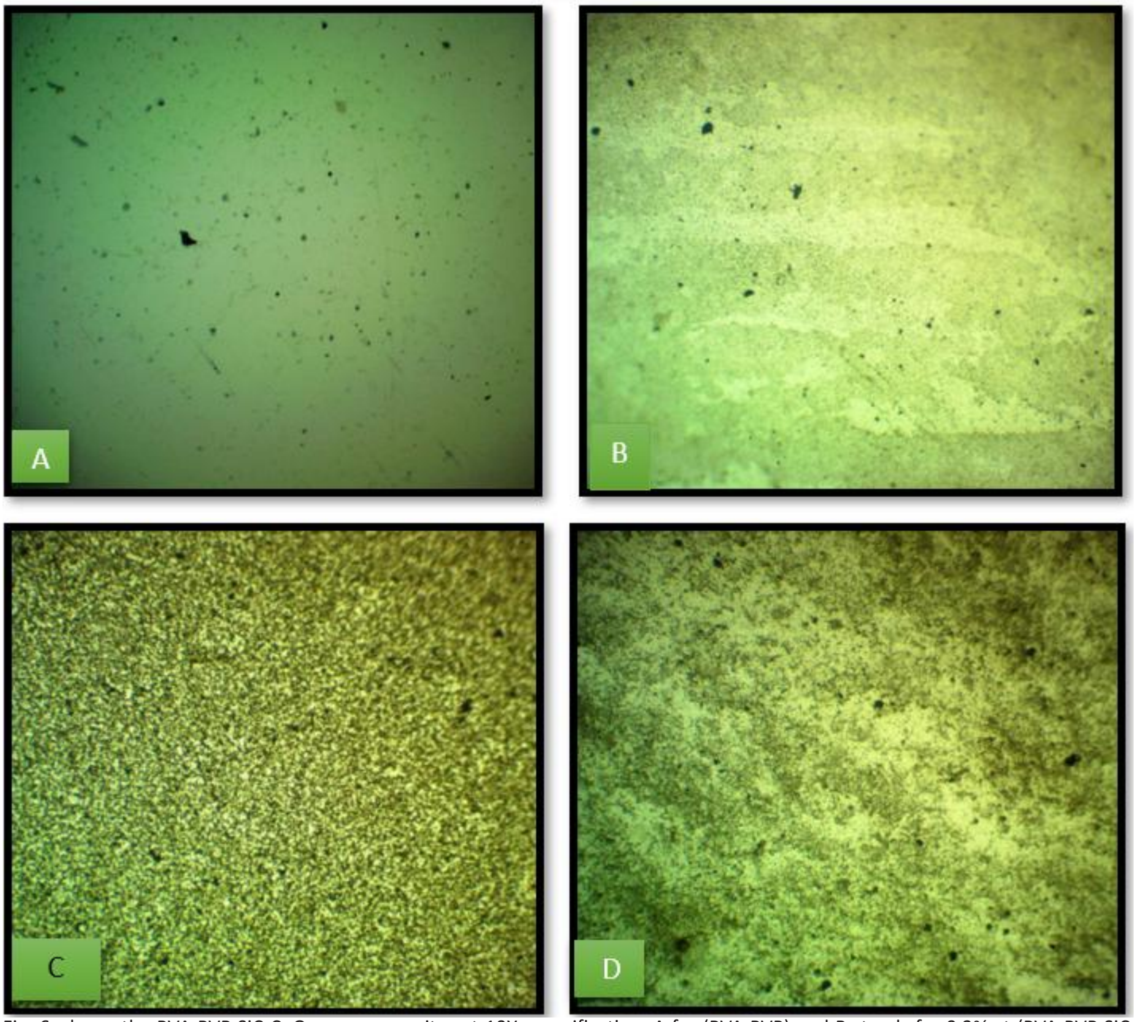

Fig. 6. shows the PVA-PVP-SiC-CuO nanocomposites at 10X magnification. A for (PVA-PVP) and B stands for 0.3%wt (PVA-PVP-SiC-CuO), C for 0.7%wt (PVA-PVP-SiC-CuO), D for 1% wt (PVA-PVP-SiC-CuO).

PVP-SiC-CuO at ×10 magnification for different concentrations. Differences are evident between the samples in terms of particle distribution and dispersion, as the nanoparticles contributed to the formation of a network within the polymer that helps generate nanobubbles, enhancing porosity and homogeneity. Direct ultrasonic devices are more effective than mechanical stirring in improving dispersion and preventing the agglomeration of nanofibers, thanks to the cavitation phenomenon that leads to a uniform distribution of particles at both the macro and micro levels [26].

CONCLUSION

According to the study's findings, the electrical characteristics of the PVA-PVP-SiC composite polymer are enhanced by the addition of CuO nanoparticles. CuO nanoparticles improved electrical performance stability and raised the dielectric constant. As the number of nanoparticles in the PVA/PVP/SiC/CuO nanocomposites increased, the dielectric characteristics improved. When the nanocomposite content reached 1%wt, the electrical conductivity rose by 80% and the dielectric constant by 47%. Consequently, it is recommended to utilize CuO in capacitors and insulating materials. The application of ultrasound enhanced the dispersion of nanoparticles inside the polymer matrix, according to the results of microscopic pictures like OM and SEM. This was because the photomicrographs provided sufficient structural homogeneity. Additionally, pictures captured by scanning electron microscopy revealed a decrease in aggregation and an improvement in surface homogeneity. This indicates that the selected techniques are successful in enhancing the optical and structural characteristics of nanomaterials, increasing their applicability in cutting-edge optical and electrical devices.

CONFLICT OF INTEREST

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

REFERENCES

1. Life Cycle Analysis of Polymer Nanocomposites for Energy Storage. Polymer Nanocomposites for Energy Applications: Wiley; 2022. p. 235-239.
2. Paul DR, Robeson LM. Polymer nanotechnology: Nanocomposites. Polymer. 2008;49(15):3187-3204.
3. Lagashetty A, Venkataraman A. Polymer nanocomposites. Resonance. 2005;10(7):49-57.
4. Kinetic and thermodynamic study of adsorption of an industrial food dye using Iraqi clay. J Popul Ther Clin Pharmacol. 2023;30(5).
5. Gasson PC. Materials Sciences and Engineering – Eighth edition. W. D. Callister and D. G. Rethwisch John Wiley and Sons, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK. 2010. 968pp. Illustrated. £47.99. ISBN 978-0-470-50586-1. The Aeronautical Journal. 2011;115(1168):388-389.
6. Kadhim MA, Al-Bermany E. New fabricated PMMA-PVA/graphene oxide nanocomposites: Structure, optical properties and application. J Compos Mater. 2021;55(20):2793-2806.
7. Jafar HI. Study of A.C Electrical Properties of Aluminum–Epoxy Composites. Journal of Al-Nahrain University Science. 2011;14(3):77-82.
8. Hayder N, Habeeb M, Hashim A. Structural, Optical and Dielectric Properties of (PS- In_2O_3/ $ZnCoFe_2O_4$) Nanocomposites. Egyptian Journal of Chemistry. 2019;0(0):0-0.
9. Amith V, Sridhar R, Angadi G, Narashima Murthy HN. Synthesis and Characterization of Polyvinylpyrrolidone(PVP) Nanofibrous Thin Films. IOP Conference Series: Materials Science and Engineering. 2018;376:012139.
10. Hassan HB, Abduljalil HM, Hashim A. Investigating the Electronic and Optical Characteristics of New Nanocomposites for Flexible Optoelectronics Nanodevices. Physics and Chemistry of Solid State. 2022;23(3):454-460.
11. Muntaz Begum S, Rao MC, Ravikumar RVSSN. Cu^{2+} Doped PVA Passivated ZnSe Nanoparticles-Preparation, Characterization and Properties. Journal of Inorganic and Organometallic Polymers and Materials. 2012;23(2):350-356.
12. Memic A, Alhadrami HA, Hussain MA, Aldhahri M, Al Nowaiser F, Al-Hazmi F, et al. Hydrogels 2.0: improved properties with nanomaterial composites for biomedical applications. Biomedical Materials. 2015;11(1):014104.
13. Hajipour MJ, Fromm KM, Akbar Ashkarran A, Jimenez de Aberasturi D, Larramendi IRd, Rojo T, et al. Antibacterial properties of nanoparticles. Trends Biotechnol. 2012;30(10):499-511.
14. S. Khashan k, M. Sulaima G, A. Abdul Ameer F, R. Marzoog T. Synthesis, Antibacterial Activity of TiO_2 Nanoparticles Suspension Induced by Laser Ablation in Liquid. Engineering and Technology Journal. 2014;32(5B):877-884.
15. Karthik K, Dhanuskodi S, Gobinath C, Prabukumar S, Sivaramakrishnan S. Ultrasonic-assisted CdO–MgO nanocomposite for multifunctional applications. Materials Technology. 2019;34(7):403-414.
16. Mo C-R, Wang J, Fang Z, Zhou L-M, Zhang L-J, Hu J. Formation and stability of ultrasonic generated bulk nanobubbles. Chinese Physics B. 2018;27(11):118104.
17. Barber P, Balasubramanian S, Anguchamy Y, Gong S, Wibowo A, Gao H, et al. Polymer Composite and Nanocomposite Dielectric Materials for Pulse Power Energy Storage. Materials. 2009;2(4):1697-1733.
18. Swatsitang E, Putjuso T. Dielectric properties of Ni-doped $Ba_{0.5}Sr_{0.5}TiO_3$ ceramics prepared with hydrothermal synthesized nanopowders. J Sol-Gel Sci Technol. 2014;72(1):30-36.
19. Abdullah OG, Tahir DA, Jamal GM, Saeed SR. Dielectric Properties of Polyester Reinforced with Carbon Black Particles. Applied Mechanics and Materials. 2011;110-116:170-176.
20. Hule RA, Pochan DJ. Polymer Nanocomposites for Biomedical Applications. MRS Bull. 2007;32(4):354-358.
21. Kasrani S. EFFECT OF Al_2O_3 Additions on the Dielectric Properties of a Porcelain Insulator Prepared from Economical Natural Raw Materials. Ceram Silik. 2024:1-6.
22. Kadhim MA, Al-Bermany E. Structural and DC-electrical properties of novel PMMA-PVA nanocomposites reinforced with graphene nanosheets. IOP Conference Series: Materials Science and Engineering. 2021;1067(1):012120.
23. Reddy MO, Chandra Babu B. Structural, Optical, Electrical, and Magnetic Properties of PVA:Gd^{3+} and PVA:Ho^{3+} Polymer Films. Indian Journal of Materials Science. 2015;2015:1-8.
24. Mallakpour S, Motirasoul F. Ultrasonication synthesis of PVA/PVP/α-MnO_2-stearic acid blend nanocomposites for adsorbing CdII ion. Ultrason Sonochem. 2018;40:410-418.
25. El-Kader MFHA, Elabbasy MT, Adeboye AA, Menazea AA. Nanocomposite of PVA/PVP blend incorporated by copper oxide nanoparticles via nanosecond laser ablation for antibacterial activity enhancement. Polym Bull. 2021;79(11):9779-9795.
26. Al-Aaraji NA-H, Hashim A, Hadi A, Abduljalil HM. Effect of Silicon Carbide Nanoparticles Addition on Structural and Dielectric Characteristics of PVA/CuO Nanostructures for Electronics Devices. Silicon. 2021;14(9):4699-4705.