Silicon
https://doi.org/10.1007/s12633-024-03121-6

RESEARCH

Ameliorating and Tailoring The Morphological, Structural, and Dielectric Characteristics of SiO_2 /NiO Futuristic Nanocomposites Doped PVA-PEG for Nanoelectronic and Energy Storage Applications

Waleed Khalid Kadhim[1] · **Majeed Ali Habeeb**[2]

Received: 13 June 2024 / Accepted: 10 August 2024

Abstract
The current investigation inquiry involves silicon dioxide (SiO_2) and nickel oxide (NiO) nanoparticles to enhance the structural and dielectric properties of a polyvinyl alcohol (PVA) with polyethylene glycol (PEG) combination for use in flexible pressure sensors and nanoelectrical devices. Solution casting was used to fabricate PVA-PEG-SiO_2/NiO nanocomposites at various weight percentages of (SiO_2/NiO) N.Ps (0, 2, 4, 6 and 8) wt%. The structural properties of PVA-PEG-SiO_2/NiO nanocomposites were studied by X-ray diffraction (XRD), and the amorphous state of the mixture consisting of polyvinyl alcohol (PVA) and polyethylene glycol (PEG) was revealed. Furthermore, the characteristic peak of the original polymers was much smaller at higher doping concentrations. According to field emission scanning electron microscopy (FE-SEM), when the weight percentage approaches 8%, the top surface of the (PVA-PEG-SiO_2/NiO) N.Cs films exhibits homogenous and cohesive clumps or fragments dispersed randomly. Optical microscopy made it possible to observe that nanoparticles (SiO_2/NiO) generate an integrated network inside the matrix of polymers, unlike the pure film of (PVA-PEG). The electrical properties of alternating current illustrate that as the frequency of the applied electrical field increases, the dielectric constant and dielectric loss of nanocomposites decline. Also, on the contrary, these values increase in conjunction with the increase in the concentration of nanoparticles, and the highest value is at a frequency of 100 Hz at a concentration of 8%. The (PVA-PEG) blend's dielectric constant and A.C. electrical conductivity were improved by almost 300% and 112%, respectively, at the highest addition rate (8 wt.%). The findings obtained revealed that the structural and AC electrical conductivity were enhanced by doping (PVA-PEG) with (SiO_2/NiO) NPs. Findings indicated that the (PVA-PEG-SiO_2/NiO) nanostructures would be excellent materials for a range of nanoelectronics industries. The results obtained showed an increase in parallel capacity. It reached 400 pf with an increase in applied pressure, as well as an increase in sensitivity to pressure of about 77.2 with the biggest percentage of weight addition of nanoparticles.

Keywords Structural properties · Dielectric properties · Pressure sensor · SiO_2/NiO nanoparticles · Sensitivity

1 Introduction

The quantity of plastic garbage that is everywhere these days is getting to the point that it is polluting the entire planet. There are an infinite amount of applications for polymers, thus finding ecologically and human-friendly polymers is imperative [1, 2]. One of the various methods available today for producing polymeric materials is mixing polymers. This procedure combines at least two different kinds of polymers to produce a novel sort of polymeric matrix [3, 4]. Two methods to increase the AC conductivity of polymeric materials are plasticizers and polymer mixing. It is easy to produce polymer blend complexes from PVA and PEG because of their tunable chemical and physical characteristics. Toughness, non-toxic, biodegradable, and heat stability are some of these characteristics [5, 6]. Over the past many years, polymer nanocomposites have garnered significant interest from both academia and industry. They are now an essential

✉ Majeed Ali Habeeb
pure.majeed.ali@uobabylon.edu.iq

Waleed Khalid Kadhim
welidkalid37@gmail.com

[1] Education Babylon, Ministry of Education, Hillah, Iraq

[2] Department of Physics, College of Education for Pure Sciences, University of Babylon, Hillah, Iraq

Published online: 21 August 2024

part of creating new, cutting-edge materials for a variety of uses, notably electrical engineering [7, 8]. There are several options within the field of nanotechnology to evolve nanomaterials with better qualities; this will allow to be utilized across a range of sectors. The general definition of nanotechnology is the manipulation of materials at the atomic or molecular level through procedures including consolidation, deformation, and separation [9, 10]. Our way of life may be enhanced by nanotechnology in many ways, including quicker electronics, massive memory, and more affordable energy through more efficient transformation of energy, and heightened safety with the creation of nanoscale [11, 12]. Despite all technological specialties, nanotechnology is one of the newest favored fields for study and advancement. With the use of nanotechnology, innovative materials will be created that may be used to construct and create new structures and properties with greater functioning, decreased upkeep expenses, and increased performance [13, 14]. Given that they are considered to be essential technologies for the 21st-century, a large sum of research has been done in this area. The particular chemical, biological, and physical features of nanoscale structures in relation to their macroscopic counterparts may soon lead to new uses [15, 16]. An innovative method for producing materials made from polymer is to profit from polymer blends, which merge two or more different polymers to create composite materials. One of the blend's most notable qualities is its adaptability to many uses [17, 18]. Due to their remarkable effectiveness and variety of features, which are achieved by adding a small plenty of nanoparticles to the polymer mixture / polymer nanocomposites have generated a lot of curiosity. When nanoparticles and polymer are combined, nanocomposites perform noticeably better at far lower loadings than when polymer is used alone [19, 20]. Polymer electrolytes are used in sensors, electrochemical devices, and rechargeable batteries; they have attracted a lot of interest lately. A number of beneficial characteristics of biopolymer materials include their affordability, non-toxicity, natural availability, biodegradability, and ecological advantages [21, 22]. Polyvinyl alcohol, or PVA, is widely used in many important uses and fields and is recognized as one of the most important polymers. Batteries, electro chromic, detectors, and the medical sectors are a few instances of these industries and uses. PVA has superior durability, resistance to corrosion, and high thermal properties compared to other kinds of polymers [23, 24]. Because of its exceptional electrical characteristics, high dielectric strength, and remarkable storage capacity, PVA shows great promise as a material. This adaptable material has several important uses; including medicine systems for distribution, packing, and polymer reuse [25].

Polyethylene glycol (PEG) is an additional artificial polymer with a broad molecule weight range that is solvent in water. Blending it with stiff polymers to create novel materials with specific qualities is a suitable option because of its elastic chain [26]. Due to its special physicochemical characteristics, polyethylene glycol (PEG) is a polyether compound that finds use in a wide range of scientific fields and enterprises. PEG is widely used in biomedicine, pharmacology, and other sectors because of its chemical solubility in water and organic solvents, as well as its non-toxic nature [27]. Nanoparticles of silicon dioxide (SiO_2) are utilized as reinforcements in electronic packaging and thermoplastic polymers. Known for its substantial particular area of surface, strong thermal properties, and developed mechanical properties, silica is a white powder that may be found in nature. SiO_2 is environmentally friendly, amorphous, and may be molded into an optoelectronic nanocomposite material by filling it with polymers that have nanopores [28]. The SiO_2 particles serve as a solid plasticizer, enhancing the mechanical, chemical, and dimensional integrity of the composite polymer. in the field of materials science, SiO_2 NPs are employed as fillers or reinforcements in composite materials for bettering mechanical properties, such as strength and toughness, their small size and huge surface area enable effective dispersion within matrices, leading to boosted material performance [29]. Amidst the plethora of available nanomaterials, nickel oxide (NiO) nanoparticles have garnered significant attention mainly because of their remarkable stability and excellent magnetic, electrical, optical, and catalytic properties. These properties also account for their many applications, including gas detectors, electro chromic components, fuel cells, batteries, solar cells sensitive to dyes, solar energy absorbers, and magnetic cameras [30]. In addition, compared to other metal oxide nanoparticles, NiO nanoparticles are incredibly affordable, environmentally friendly, and highly fixed conductive materials. Among the medical applications for these nanoparticles were biological identification, imaging, drug delivery, and antibacterial. Apart from their previously mentioned applications, (NiO) NPs have the ability to effectively remove both organic and inorganic pollutants; hence, they are crucial for maintaining the integrity of the environment [31]. Furthermore, the drugs, catalysis, and dye manufacturing sectors are more possible uses for silica nanoparticles. Likewise, silica may be used to reinforce polymer combinations in thermoplastic polymers, volatile flavorings, compound polymer gel solutions, coatings for preventing corrosion, and plastic containers [32]. The most common materials employed by pressure sensors contain silicon, sputtered thin films, polysilicon thin films, bonded metal foils, and inkjet-printed films. Piezoresistive pressure sensors are the most widely utilized technique within the

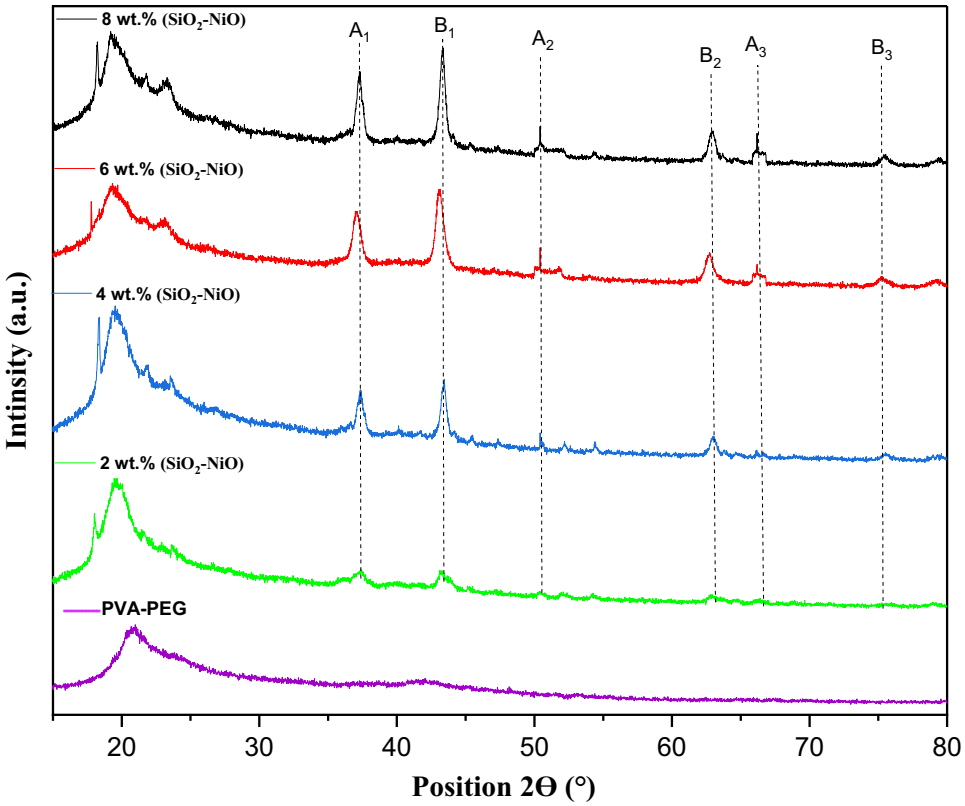

Fig. 1 Depicts the XRD patterns of (PVA-PEG -SiO_2-NiO) NCs with varying amounts of (SiO_2-NiO) NPs where (**A**) represents the SiO_2 phase and (**B**) represents the NiO phase

Table 1 The mean crystallite size for "SiO_2/NiO" nanoparticles determined from patterns of XRD utilizing the Scherer equation

Material	2Θ(°)	hkl	FWHM (rad)	Crystallite size (nm)
SiO_2				
A_1	37.2463	110	0.3023	28.98
A_2	50.4078	210	0.501	18.31
A_3	66.2561	310	0.5821	17.03
NiO				
B_1	43.3726	200	0.285	31.34
B_2	62.872	220	0.5334	18.24
B_3	75.4065	311	0.7246	14.48

pressure sensor industry because of its high sensitivity and inexpensive cost [7]. Based on whether behavior is more suited in a particular case, the piezoresistive or pseudocapacitive behavior of the nanocomposite pressure sensors drives their operation. Important performance parameters like pressure sensitivity, pressure range, ability to detect small pressures, and endurance of larger forces set apart various types of pressure sensors [33]. This study addresses the manufacturing of (PVA-PEG-SiO_2-NiO) nanocomposites (NCs) for optoelectronics applications, with an aim of offering a low-cost and straightforward process.

2 Experimental Part

The casting approach was utilized to create nanocomposites from polyvinyl alcohol (PVA)/Polyethylene glycol (PEG) and silicon dioxide (SiO_2), nickel oxide (NiO) NPs. It involved creating a more homogenous solution by dissolving pure PVA and PEG in 45 ml of water distillation for 50 min while stirring with a magnetic stirrer at seventy degrees Celsius. Silicon dioxide (SiO_2) and nickel oxide (NiO) NPs were included to the polymer mixture at weight percentages of 2%; 4%; 6%; and 8%, respectively. After casting it, it was left to dry for 6 days at room temperature and the polymer nanocomposites were formed. Square pieces of (PVA-PEG-SiO_2/NiO) nanocomposites were taken for different measurements. Using field emission scanning electron microscopy (fesem), (model/ InspectTM F50—DETAILS\1.2 nm at 10 kV; pressure 3.11e-3 par country/ Holland), was used to examine the structural properties of nanocomposites. Olympus offers the Optical Microscope (OM) (Top View Model Number: Nikon-73346) with a camera for microscopic images with a magnification of 20x, in alongside employing a diffract meter with a radiation wavelength of 1.5418 Å to measure X-ray diffraction (XRD). Utilizing an LCR meter (HIOKI; 3532–50; LCR HI TESTER), the dielectric properties of nanocomposites were examined between

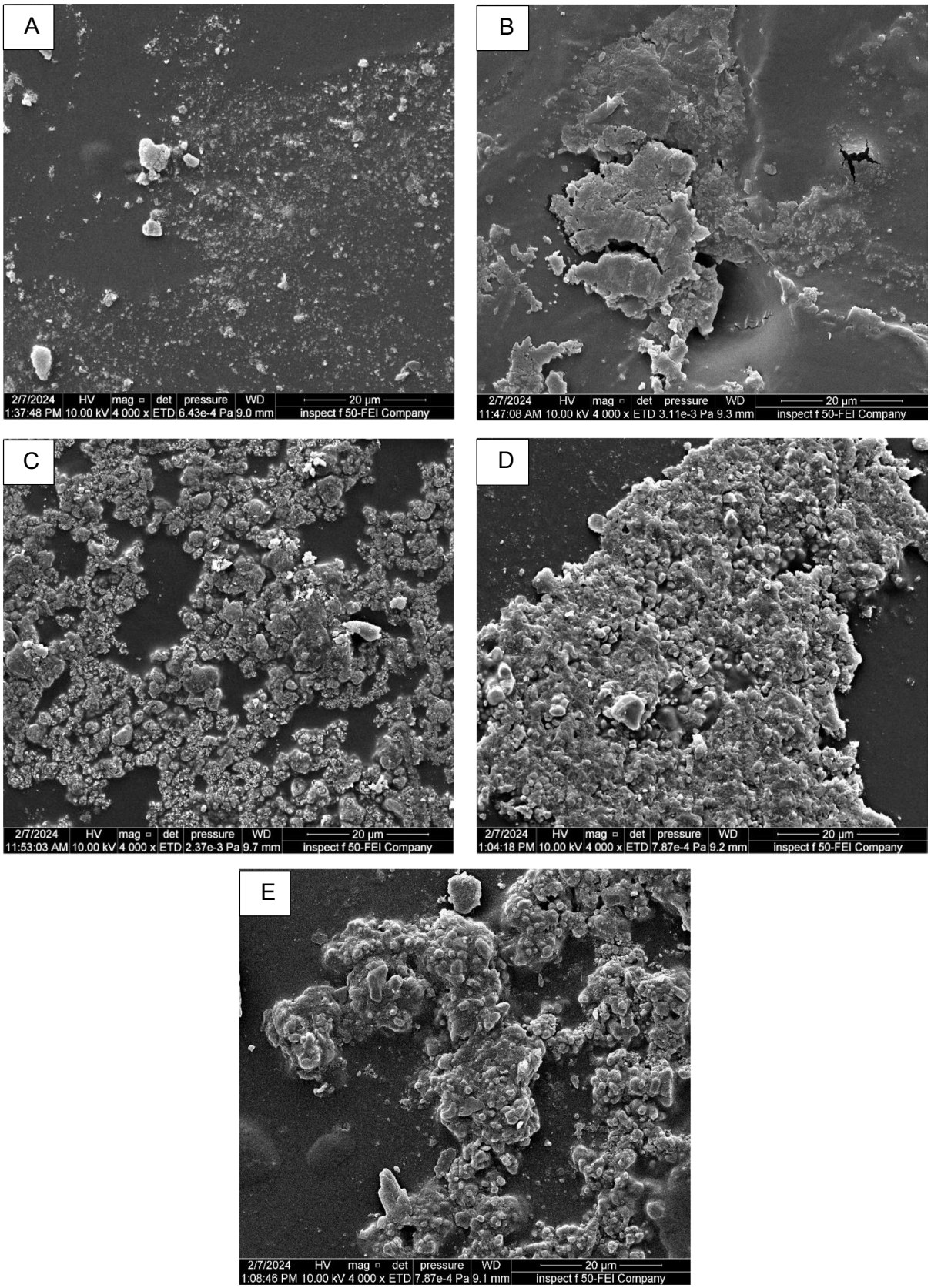

Fig. 2 FE-SEM photographs of (PVA-PEG-SiO_2-NiO) NCs: (**A**) for (PVA-PEG), (**B**) for 2 wt.% (SiO_2/NiO), (**C**)for 4 wt.% (SiO_2/NiO), (**D**) for 6 wt% (SiO_2/NiO), (**E**) for 8wt% (SiO_2/NiO)

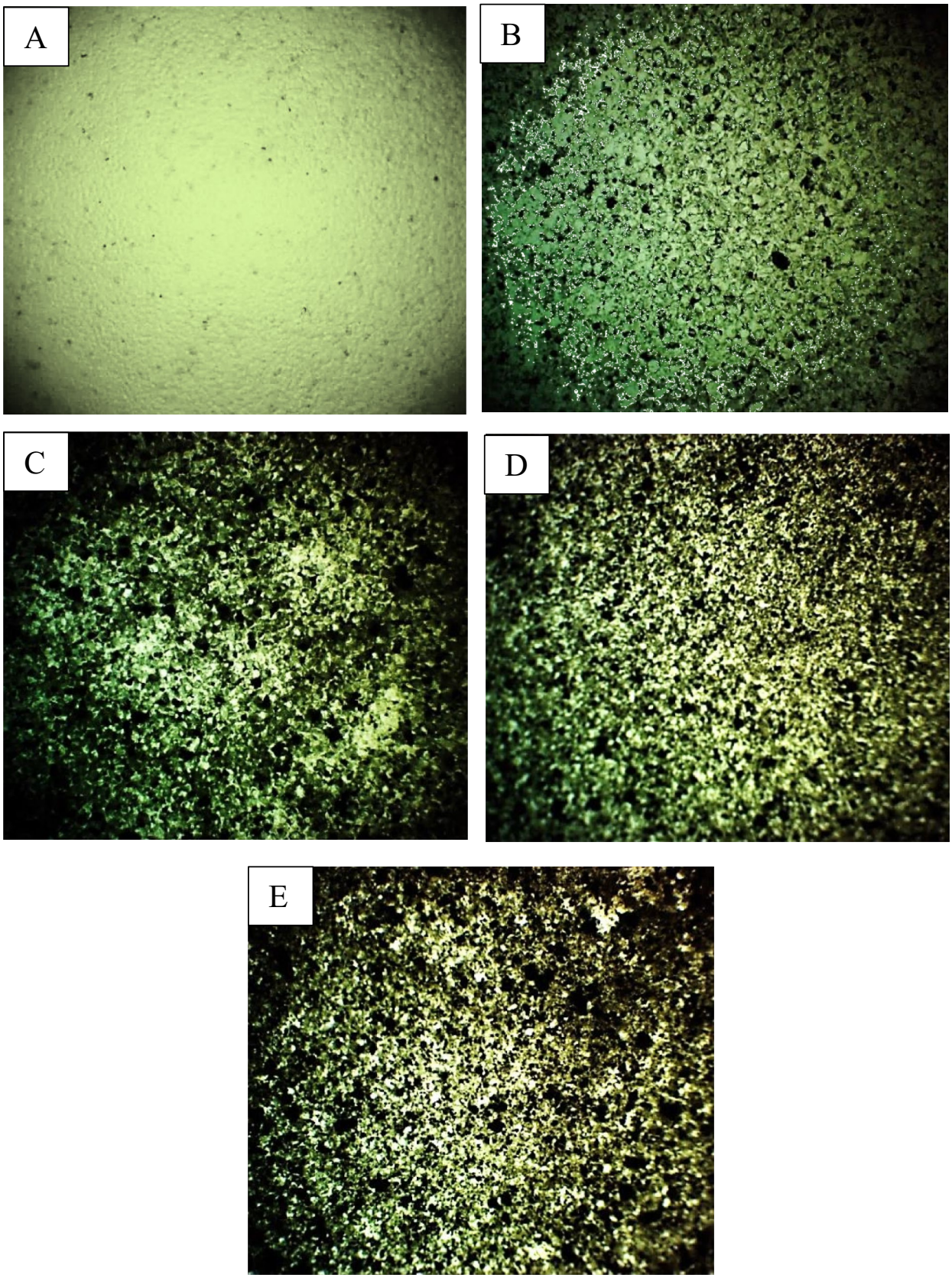

Fig. 3 Optical microscope photographs of (PVA-PEG-SiO_2-NiO) NCs at a magnification (10x):- **A** (PVA-PEG); **B** 2 wt.% (SiO_2/NiO); **C** 4 wt.% (SiO_2/NiO); **D** 6 wt.% (SiO_2/NiO); **E** 8 wt.% (SiO_2/NiO)

100 Hz and 5 MHz. By means of LCR meter to calculate the parallel capacitance between both poles above and below the test piece over a range of pressures (80–160 bar), the effectiveness of the pressure sensor of (N.Cs) was determined.

The dielectric constant (ϵ') is calculated from the following function [34]:

$$\epsilon' = C_P/C_0 \tag{1}$$

Capacitance is indicated by C_p, while a vacuum capacitor is indicated by (C_o). We find the dielectric loss (ϵ") using [35]:

$$\epsilon'' = \epsilon' D \tag{2}$$

(D) is displacement. Here is the formula for calculating AC electrical conductivity [36]:

$$\sigma_{a.c} = \omega\epsilon''\epsilon_0 \tag{3}$$

where (ω) is the angular frequency. The following is a definition of pressure sensor sensitivity [37, 38]:

$$S_{AP}(\%) = \left(1 - C_b/C_n\right) \times 100\% \tag{4}$$

When blends and nanocomposites' capacitances are represented by the symbols C_b and C_n, respectively.

3 Results and Discussions

3.1 XRD Analysis

The XRD of the PVA-PEG mixture and nanocomposites is displayed in Fig. 1. The structure of PVA-PEG blends and nanocomposites with different concentrations of nanoparticles (SiO_2/NiO) was investigated using X-ray diffraction (XRD). The nanocomposites and (PVA-PEG)

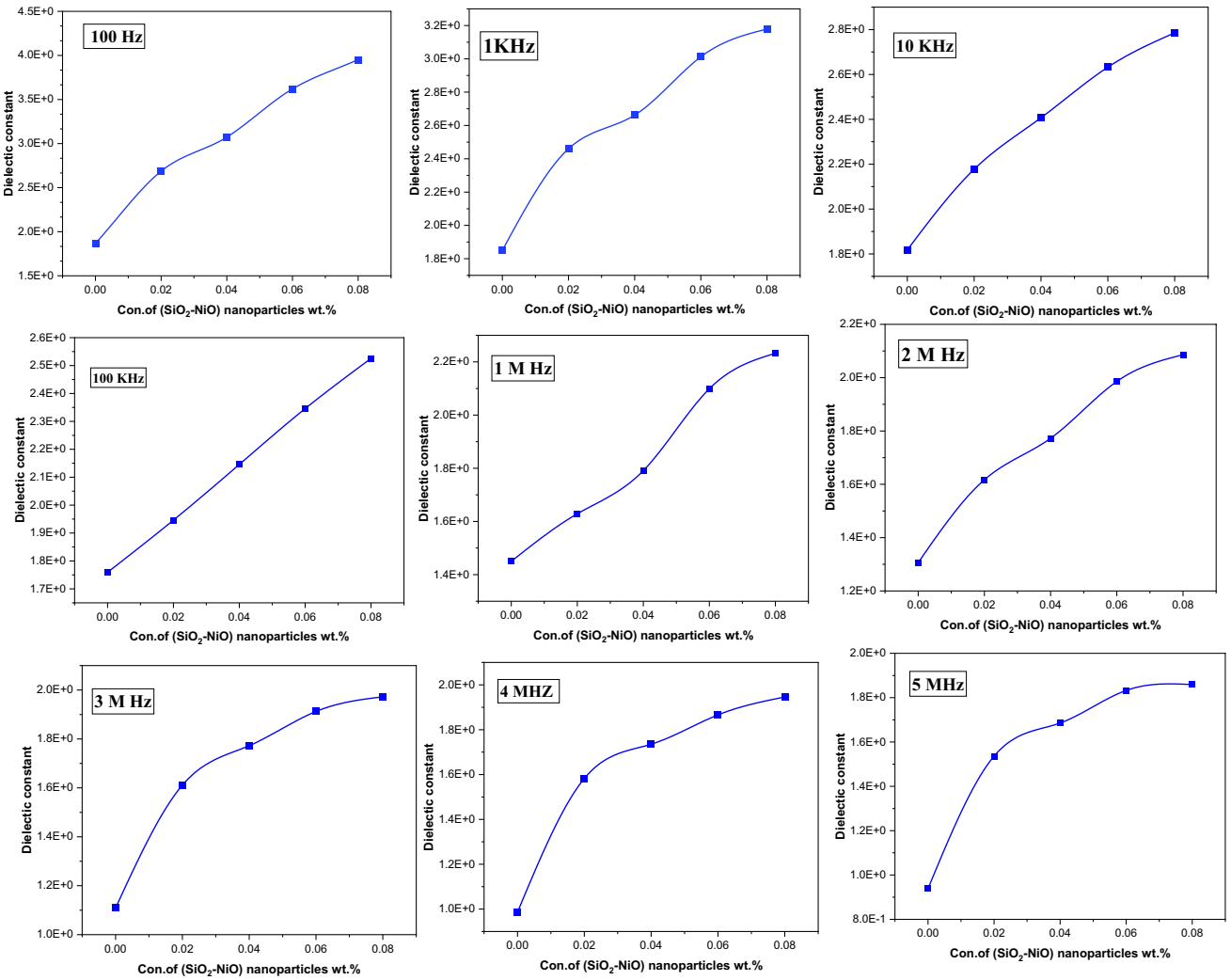

Fig. 4 Impact of (SiO_2/NiO) NPs ration on dielectric constant of PVA-PEG blend at different frequencies

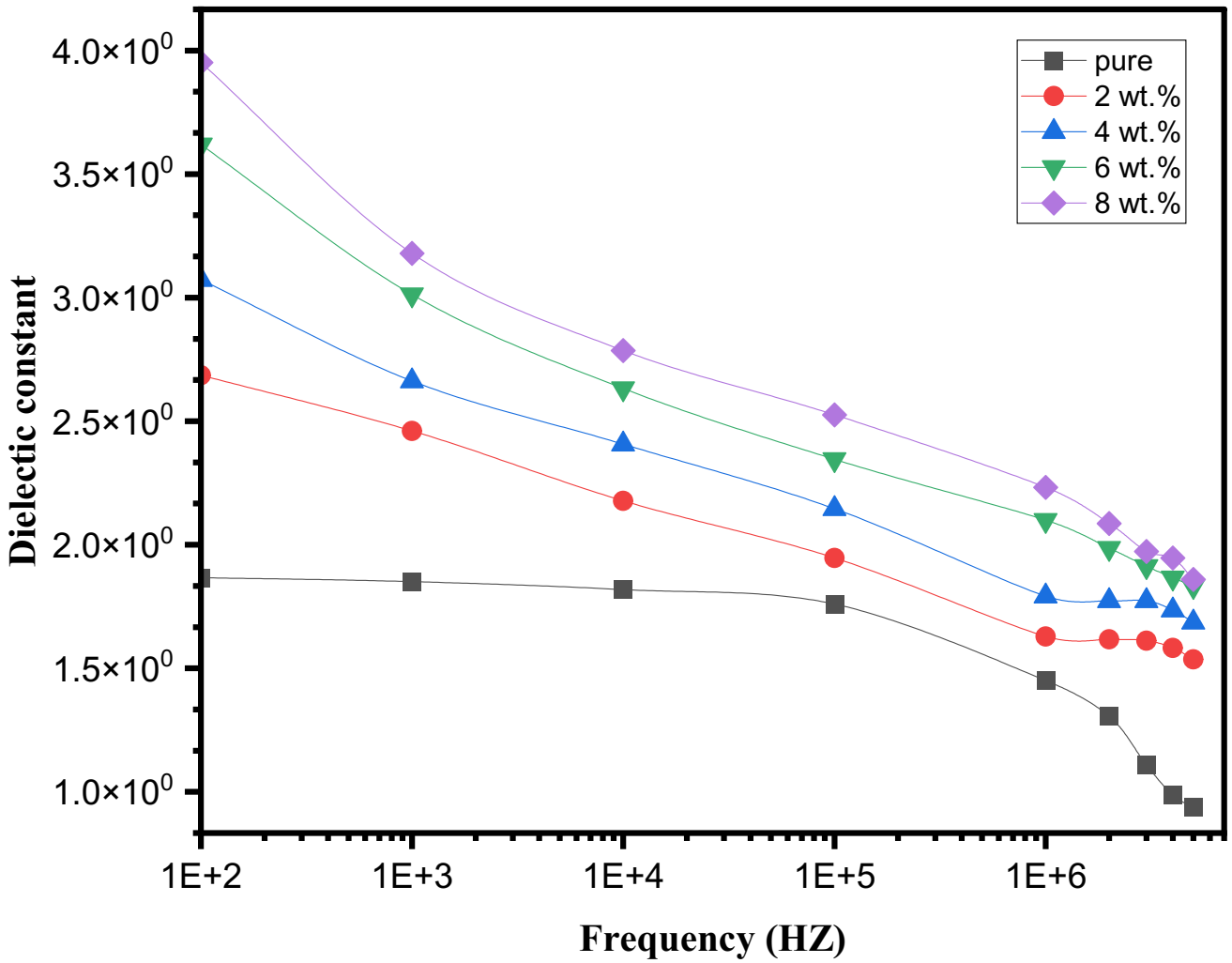

Fig. 5 Change of ϵ' with a frequency of (PVA-PEG-SiO_2/NiO) NCs

blend display a broad band located at 2θ = 20.26°, indicating the amorphous nature of PVA and PEG, according to XRD analysis [7]. The primary mechanism responsible for the preservation of PVA and PEG amorphous nature is between molecules hydrogen bonding, different monomer structures and the molecules inside each component form this link [39]. A reduction in the polymer blend's degree of amorphous form was seen upon insertion of (SiO_2/NiO) nanoparticles. The results confirm that there is variation in the electrostatic forces that occur between (SiO_2/NiO) NPs and the polymer blend. As the (SiO_2-NiO) concentration in the polymer nanocomposite samples varies as a result of this change, the polymer blend's structures vary as well, eventually raising the degree of crystallization of the nanocomposites. Ion mobility is accelerated and conductivity is raised in the absence of a well-defined structure. The crystalline state of nanoparticles (SiO_2/NiO) is responsible for the steep peaks seen at (2θ = 37°, 43°, 63° and 75°) which are linked to the increasing concentration of nanoparticles (SiO_2/NiO) in the nanocomposites. The findings demonstrate that the specimen's structural features may be altered by the addition of (SiO_2/NiO) nanoparticles [40, 41], as indicated in Table 1.

3.2 Field Emission Scanning Electron Microscopy (FE-SEM) Measurements of (PVA-PEG-SiO_2/NiO) NCs

Representative (FE-SEM) photographs of (PVA-PEG-SiO_2/NiO) films with and without varying SiO_2 and NiO nanoparticle concentrations are shown in Fig. 1, which provides a good idea of their size and shape. It is discovered that the polymer picture (A) is more coherence and homogeneous. The surface morphology of (PVA-PEG-SiO_2/NiO) nanocomposites alters noticeably when (SiO_2/NiO) nanoparticles are introduced (see figures B; C; D;

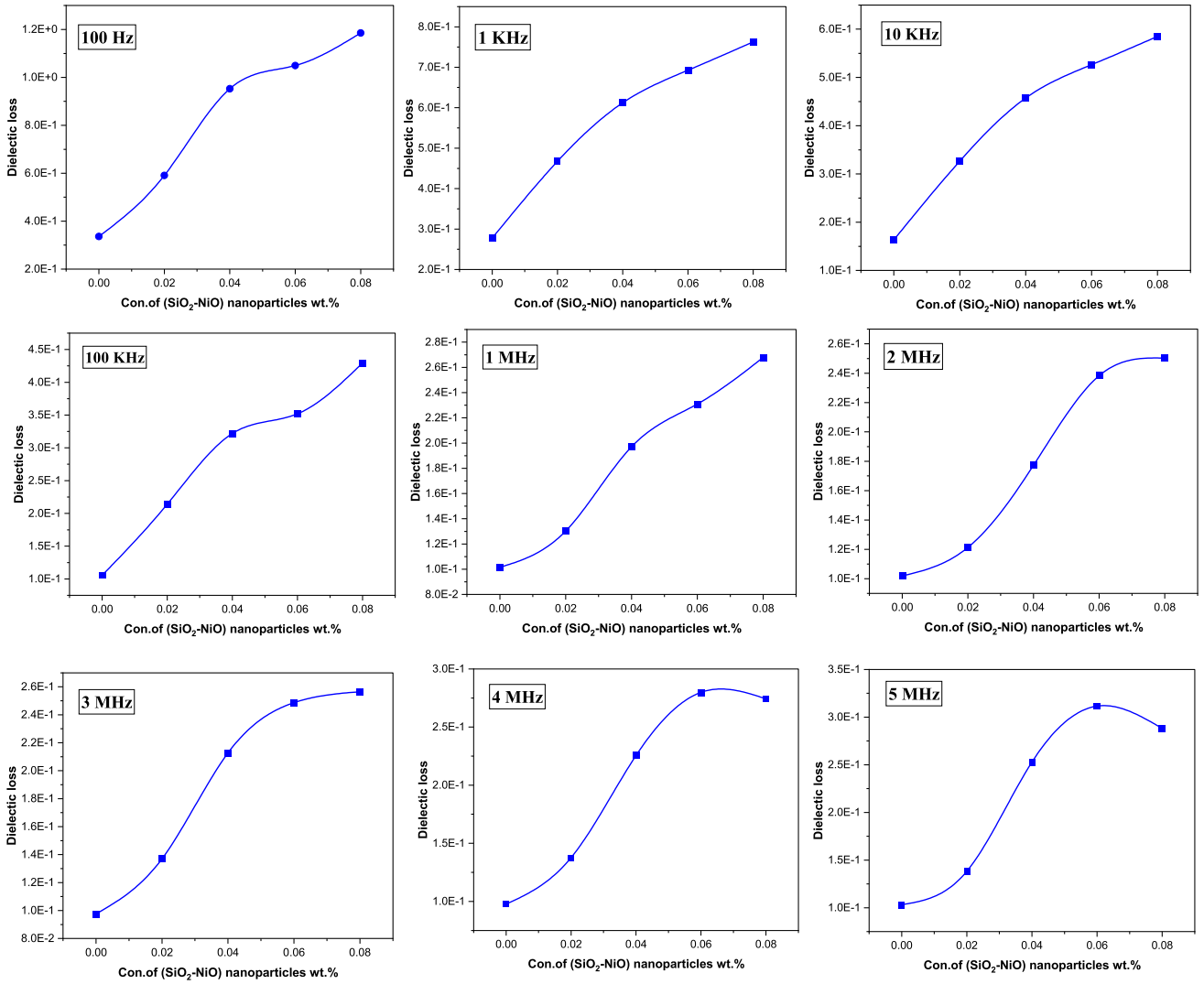

Fig. 6 Impact of (SiO_2/NiO) NPs ration on dielectric loss of PVA-PEG blend at different frequencies

and E). The photographs also demonstrate that the granules particles' (SiO_2/NiO) nanoparticle concentration is increasing. The upper surface of (PVA-PEG-SiO_2/NiO) nanocomposites has a lot of clumps or particles dispersed on the uppermost surface. Nanoparticles in (PVA-PEG-SiO_2/NiO) nanocomposite films are uniformly dispersed and have a tendency to cluster; the (FE-SEM) images also show the formation of paths and a connected network within the nanocomposites that allow the passage of charge carriers [42, 43] (Fig. 2).

By comparing the results of XRD and SEM, it was clear from the X-ray examination that PVA and PEG are in amorphous form and the degree of amorphous decreases with the increase of nanoparticles in the polymer blend. Also, the crystalline state of the nanoparticles (SiO_2/NiO) is responsible for the appearance of sharp peaks. As a result, the structural properties of the models change. As for the SEM examination, it showed the presence of clusters and aggregates on the surface of the nanocomposites when adding the filler, they tend to aggregate and show paths for the charge carriers to move through them, unlike the image of the more cohesive polymer blend.

3.3 The Optical Microscope of (PVA-PEG-SiO_2/NiO) N.Cs

The microscopic image of PVA-PEG-SiO_2/NiO nanocomposites (at magnification 10×) is displayed in Fig. 3. A distinct variance among the samples can be seen in microscopic pictures as the amounts of (SiO_2/NiO) nanoparticles climb. As can be seen in the photos (A-B-C-D and E), the lack of any discernible holes or fractures, demonstrates the efficient interfacial contact between the

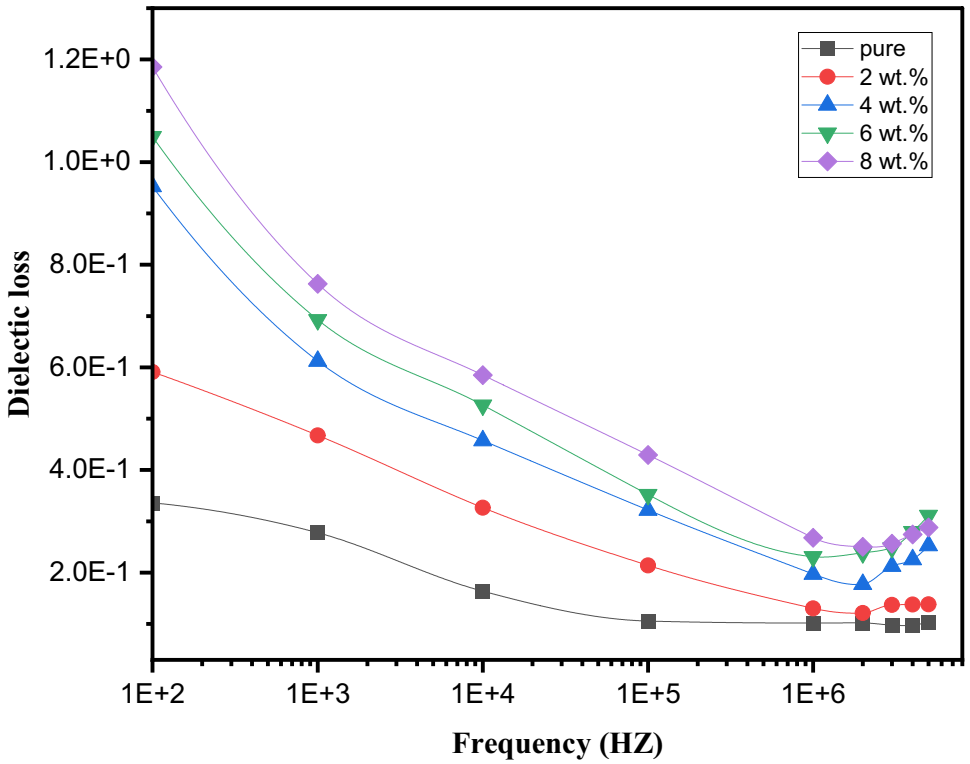

Fig. 7 Change of ϵ'' with a frequency of (PVA-PEG-SiO_2/NiO) NCs

blending matrix and the (SiO_2/NiO) nanoparticle composition. Nanocomposites have noticeable form uniqueness. At a percentage of 8% by weight for (SiO_2/NiO) nanoparticles, an ongoing network of nanoparticles forms. When multiple spherical particle pieces or clusters create on the surface of nanocomposites, it means that a homogeneous growth process is present. During which the well-dispersed and aggregating nanoparticles in the PVA-PEG blend establish an ongoing network inside the polymers. As the quantities of (SiO_2/NiO) nanoparticles increase, microscopy results clearly demonstrate the distinction among the samples, as seen in the photos (A-B-C-D and E). Hence, charge carriers are permitted to pass through specific channels in this network, which lowers the composite material's resistance (PVA-PEG) [44, 45].

3.4 The A.C electrical Properties of (PVA-PEG-SiO_2/NiO) NCs

At room temperature, Fig. 4 illustrates the alteration in the real dielectric constant with nanoparticles concentration at frequencies ranging from 100 Hz to 5 MHz. The dielectric constant of the nanocomposites (PVA-PEG-SiO_2/NiO) is high at low frequencies, as the Fig. 5 shows, since the electric dipoles have enough relaxation time to be maintained by the field. Consequently, the dielectric constant is large. Nevertheless, by increasing the frequency, the dipoles are not given enough time to be maintained by the field, resulting in a decrease in relaxation time and dielectric constant, as seen in Fig. 5.

We notice that the behavior of the dielectric constant increases with increasing proportions of (SiO_2/NiO) nanoparticles for all frequencies, as is clear in Fig. 4 [46, 47].

There is a group of polarizations that occur in nanocomposites, including: directional polarization, which results from the effect of the applied electric field that makes the dipoles align with their direction, and ionic polarization, which occurs due to an exterritorial electric field that affects the ions and is opposite, and these polarizations determine the behavior of the dielectric constant by altering added nanoparticles and their concentration [48, 49].

At ambient temperature, Fig. 6 illustrates the alteration in the dielectric loss with nanoparticle concentration at frequencies ranging from 100 Hz to 5 MHz. The graph displays that when the amount of nanoparticles increases, dielectric loss rises as well. Dielectric loss depends on the electrical conductivity, as well as the distance and internal polarization factors of the (PVA-PEG-SiO_2/NiO) nanocomposites. Also the nanocomposite forms an ongoing network of particles when the concentration of these nanoparticles approaches 8 weight percent. Then the dielectric loss becomes the highest possible [50, 51]. Polarization causes a change in dielectric loss, including: interfacial polarization resulting from the non-homogeneity of materials, and dipole polarization. The fluctuation of (PVA-PEG-SiO_2/NiO) nanocomposites dielectric loss with frequency at room temperature is demonstrated

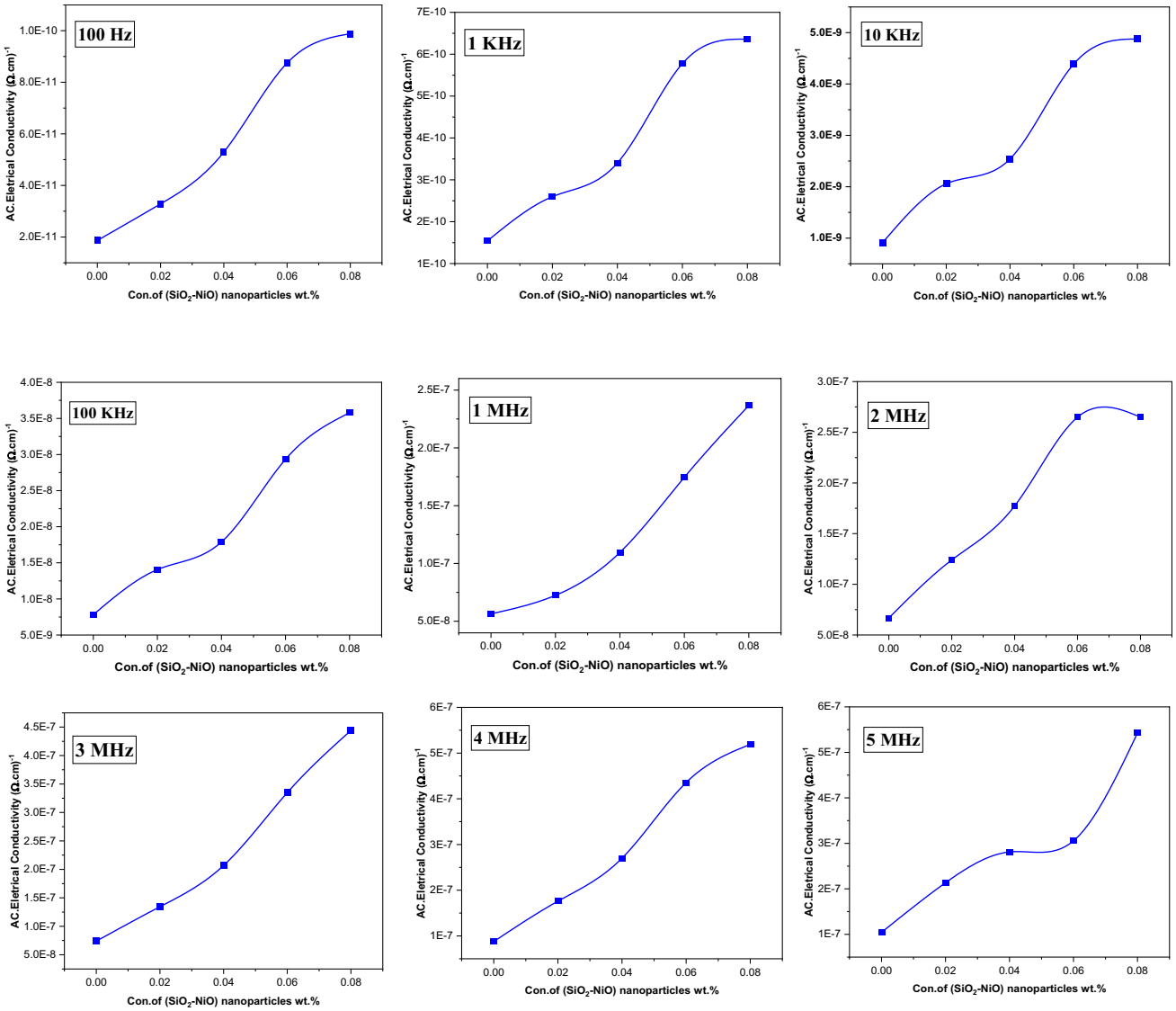

Fig. 8 Impact of the percentage of (SiO_2-NiO) NPs on ($\sigma_{a.c}$) of the PVA/PEG blend at different frequencies

in Fig. 7. The graph displays that dielectric loss lowers with increasing frequency. This phenomenon can be explained by a failure of dipoles made of composite molecules to rotate in parallel, which causes an interval between the dipole's frequency and the electric field's frequency. In other words, dipoles cannot keep up with the frequency of the applied electric field. As a result, neither charge accumulation nor ion dispersion occurs [52, 53].

Figure 8 illustrates the alteration in the A.C electrical conductivity with nanoparticle concentration at frequencies ranging from 1×10^2 Hz to 5×10^6 Hz. SiO_2/NiO nanoparticle concentrations rise are accompanied by a growth in conductivity, as indicated in Fig. 8. A rise in electric charge results from to configure of saturated nanoparticles. The findings may be explained by the effect of space charge brought about by the increase in charge carriers and their even distribution throughout the polymer matrix [54, 55].

The A.C. electrical conductivity efficiency of the (PVA-PEG-SiO_2/NiO) NCs as an indicator of frequency is depicted in Fig. 9. The electrical conductivity of (PVA-PEG-SiO_2/NiO) nanocomposite samples is found to increase with a rise in the applied electric field frequency. The polarization of free charge, which happens at extremely low frequencies in combination with the jumping mobility of charge carriers, is responsible for the aforementioned phenomena [56, 57]. Table 2 shows the sample values of (ε', ε", and σ a.c) for (PVA-PEG-SiO_2/NiO) NCs at 1kHz.

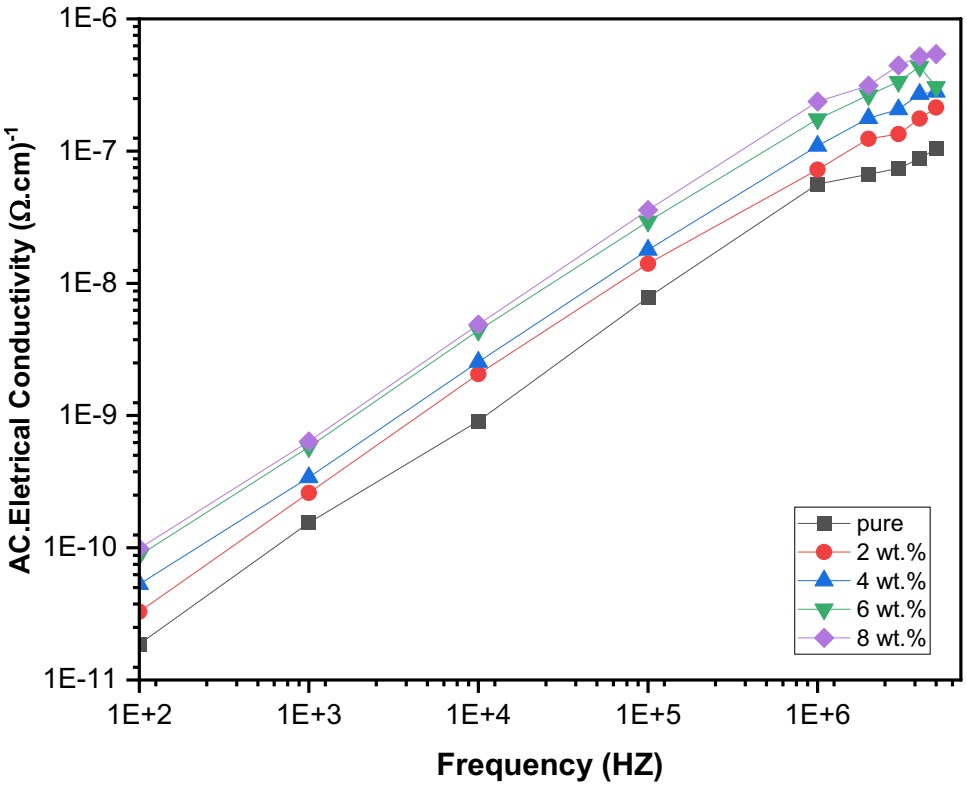

Fig. 9 Change of $\sigma_{a.c}$ with a frequency of (PVA-PEG-SiO_2/NiO) NCs

Table 2 Values of dielectric [constant—loss] and A.C. electrical conductivity ($\sigma_{a.c}$) for (PVA-PEG-SiO_2/NiO) N.Cs at 10^3 Hz

Con. Of SiO_2/NiO (wt.%)	ε'	ε''	$\sigma_{a.c}$ (S/ cm)
0	1.84992	1.866	1.54222E-10
2	2.46034	2.685	2.59807E-10
4	2.66204	3.346	3.40286E-10
6	3.01212	3.945	5.77556E-10
8	3.17872	4.518	6.36E-10

3.5 Utilizing (PVA-PEG-SiO_2-NiO) NCs for Pressure Sensor Applications

The parallel capacitance fluctuation in (PVA-PEG-SiO_2/NiO) nanocomposites at various proportions of weight of (SiO_2/NiO) nanoparticles during applied pressure is displayed in Fig. 10. There is a direct correlation between the value of capacitance and the load pressure's scale, as pressure rises, the capacitance increases because of the crystal's several interconnecting domains that contain both positive and negative charges, as the graph depicts [58, 59]. These symmetric regions inside the crystal structure lead to the absence of any net charge in the crystal. This symmetry is disrupted when the crystal is under stress. To bring symmetry back, these domains reposition, generating a current and raising the capacitance in this step [60].

Figure 11 illustrates the effect of (SiO_2/NiO) nanoparticles on the electrical capacitance (Cp) for (PVA-PEG-SiO_2/NiO) NCs at 80 bars. This graph makes it evident that when the concentration of (SiO_2/NiO) nanoparticles rises, so does the electrical capacitance of nanocomposites. This might be caused by the increase in charge carriers density in nanocomposites [61]. The effectiveness of the nanostructures (PVA-PEG-SiO_2/NiO) is strongly influenced by the concentration of (SiO_2/NiO) nanoparticles, establishes the pressure sensing range, leading to a range of applications that call for greater forces. The impact of (SiO_2/NiO) nanoparticles on (PVA-PEG-SiO_2/NiO) NCs sensitivity is seen in Fig. 12 and Table 3. This graph makes it evident that when the concentration of (SiO_2/NiO) nanoparticles climbs, so does the sensitivity of nanocomposites. This is due to an internal dipole moment [62].

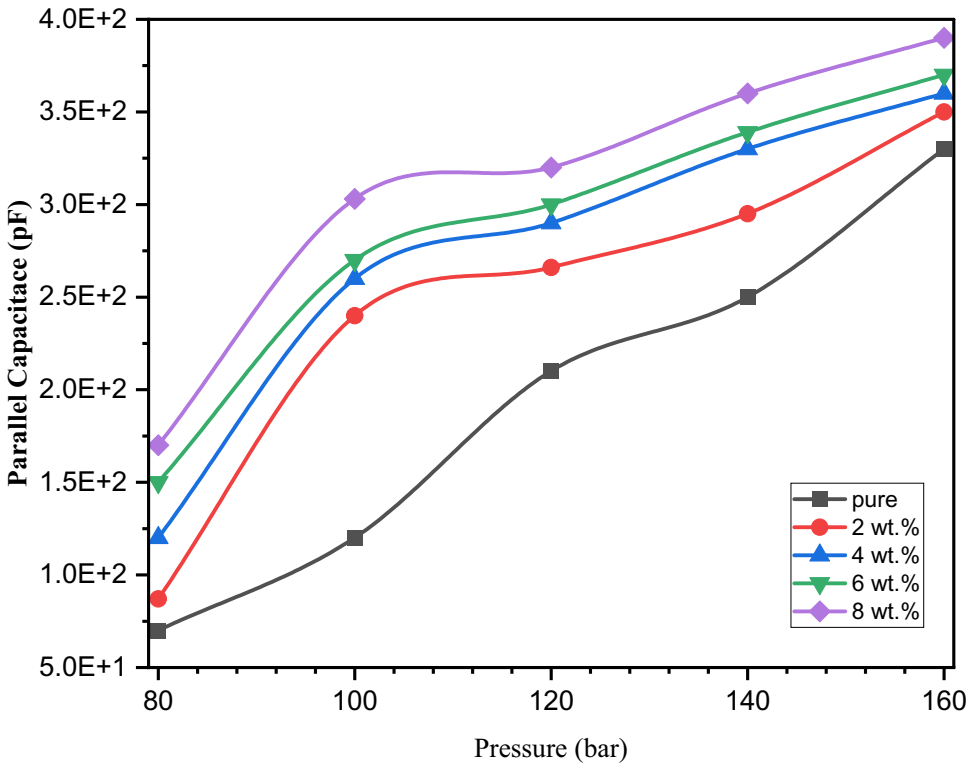

Fig. 10 Adjustment in parallel capacitance for (PVA-PEG-SiO_2/NiO) NCs under pressure

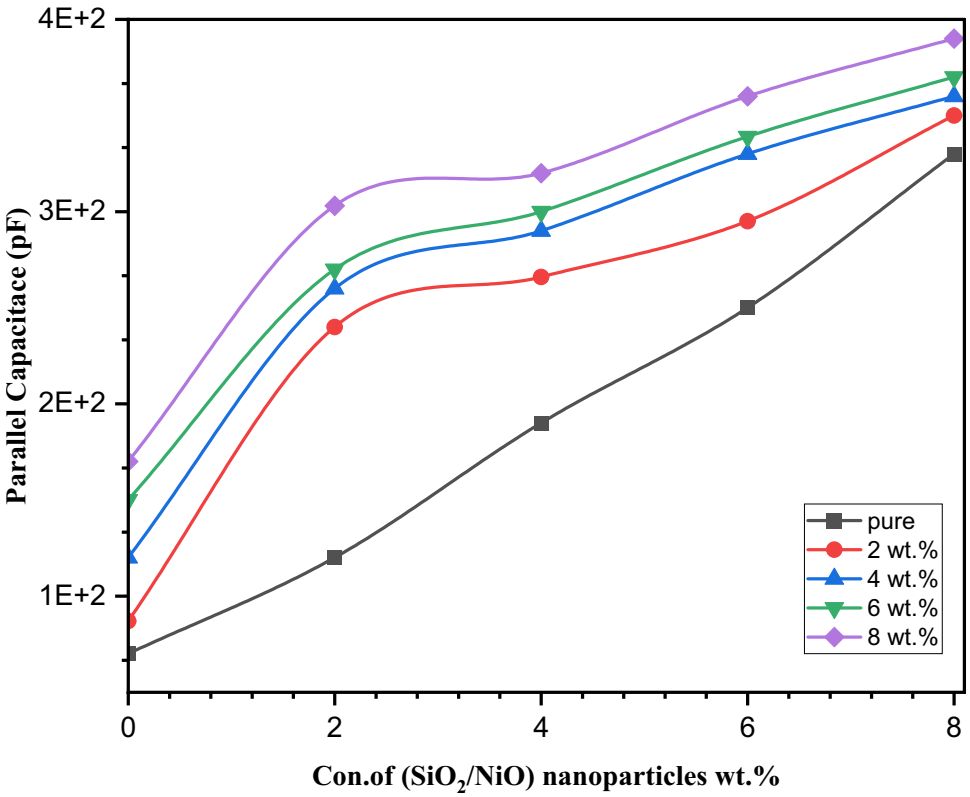

Fig. 11 The impact of concentration of (SiO_2/NiO) NPs on parallel capacitance for (PVA-PEG-SiO_2/NiO) NCs at 80 bar

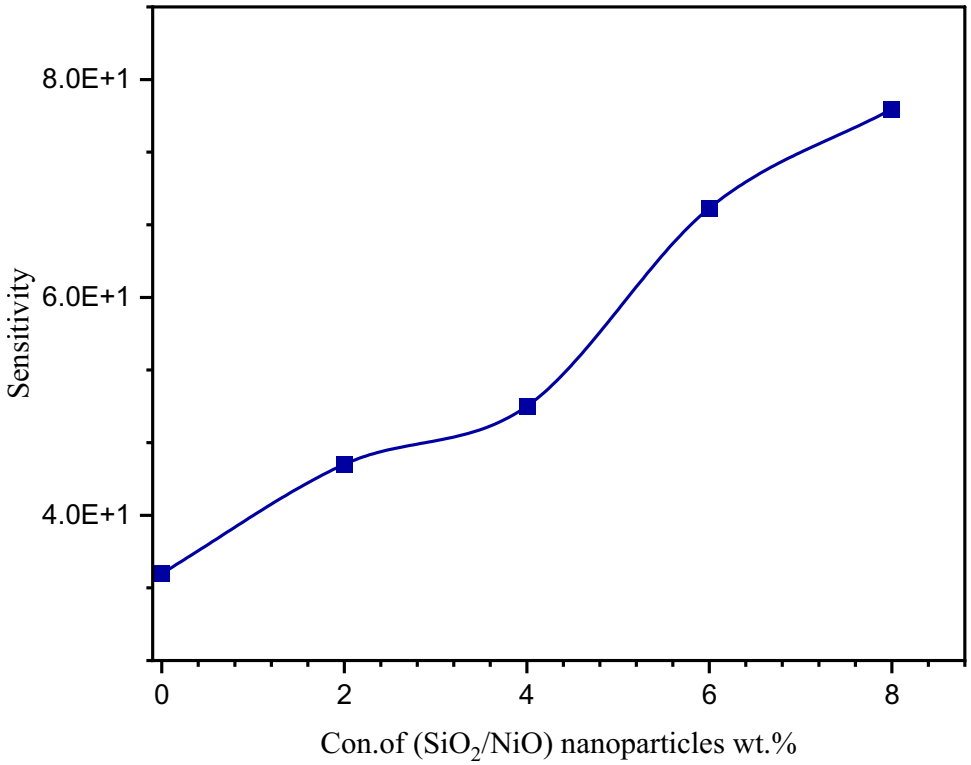

Fig. 12 The impact of (SiO_2/NiO) NPs concentration on sensitivity for (PVA-PEG-SiO_2/NiO) NCs

Table 3 Sensitivity values with concentrations of (SiO_2/NiO) NPs for (PVA-PEG-SiO_2/NiO) NCs

Con.of (SiO_2-NiO) NPs (wt. %)	Sensitivity (%)
0	34.65347
2	44.66667
4	50
6	68.18182
8	77.27273

4 Conclusions

In this work, (PVA-PEG-SiO_2/NiO) NCs were created by the solution casting approach. X-ray diffraction (XRD) revealed that the structure of the PVA/PEG mixture is amorphous, mainly due to the hydrogen bond between the molecules. Sharp peaks appear when nanoparticles are added, due to the crystalline state of the nanoparticles and the change in the structural properties of the samples. FE-SEM has been used to examine the surface morphology of the films formed from (PVA-PEG-SiO_2/NiO) NCs. The findings show that a wide variety of aggregates or pieces are present and are dispersed randomly over the top surface. The combination of silicon dioxide (SiO_2) and nickel oxide (NiO) nanoparticles at a concentration of 8% weight percent leads to the creation of an integrated network inside the polymer mix, according to optical microscope (O.M.) photographs. The dielectric properties of (PVA-PEG-SiO_2/NiO) nanocomposites were investigated, and the outcomes showed that a rise in the concentration of (SiO_2/NiO) NPs was associated with an increase in the dielectric constant, dielectric loss, and A.C. electrical conductivity of the (PVA-PEG) blend to (3.17872, 4.518, and 6.36E-10 S/ cm)respectively. Even though the A.C. electrical conductivity rises, the dielectric constant and dielectric loss decline in proportion to an increase in the frequency of the electric signal. The (PVA-PEG-SiO_2/NiO) nanostructures are well-suited for use in a variety of nanoelectronics technologies that value flexibility, cost-effectiveness, high energy storage, as well as low loss due to their advantageous structure and dielectric characteristics. The (PVA-PEG-SiO_2/NiO) nanocomposites are lightweight, malleable, and very efficient, but they also show great pressure sensitivity. The highest reported sensitivity of nanocomposites is 77.27% at 8 w.t % concentration.

Acknowledgements Acknowledgements to University of Babylon.

Author Contributions All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by Majeed Ali Habeeb, Waleed Khalid Kadhim. The first draft of the manuscript was written by Majeed Ali Habeeb and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding No funding.

Data Availability No datasets were generated or analysed during the current study.

Declarations

Ethics Approval The research is not involving the studies on human or their data.

Consent to Participate Consent.

Consent for Publication Consent.

Competing Interests The authors declare no competing interests.

References

1. Kanoun O, Bouhamed A, Ramalingame R, Bautista-Quijano JR, Rajendran D, Al-Hamry A (2021) Review on conductive polymer/CNTs nanocomposites based flexible and stretchable strain and pressure sensors. Sensors 21(2):341. https://doi.org/10.3390/s21020341
2. Hadi AH, Habeeb MA (2021) Effect of CdS nanoparticles on the optical properties of (PVA-PVP) blends. J Mech Eng Res Dev 44(3):265–274
3. Al-Sharifi NK, Habeeb MA (2023) Synthesis and exploring structural and optical properties of ternary PS/SiC/Sb2O3 nanocomposites for optoelectronic and antimicrobial applications. Silicon. https://doi.org/10.1007/s12633-023-02418-2
4. Mohammed AA, Habeeb MA (2023) Modification and development of the structural, optical and antibacterial characteristics of PMMA/Si3N4/TaC nanostructures. Silicon. https://doi.org/10.1007/s12633-023-02426-2
5. Alhussain H, Alghamdi AM, Elamin NY, Rajeh A (2024) "Recent progress in enhanced optical, mechanical, thermal properties, and antibacterial activity of the Chitosan/Polyvinylalcohol/Co3O4 nanocomposites for optoelectronics and biological applications. J Polym Environ. https://doi.org/10.1007/s10924-024-03191-y
6. Dwech MH, Habeeb MA, Mohammed AH (2022) Fabrication and evaluation of optical characterstic of (PVA-MnO2–ZrO2) nanocomposites for nanodevices in optics and photonics. Ukr J Phys 67(10):757–762. https://doi.org/10.15407/ujpe67.10.757
7. Mahdi SM, Habeeb MA (2023) Influence of ZrC nanofiler on the structural, dielectric and optical features of the PVA–PVP blend for electronic and optical nanodevices, Optical and Quantum Electronics, 55. Issu 9:1076. https://doi.org/10.1007/s11082-023-05426-z
8. Habeeb MA, Abdul Hamza RS, Oreibi I, Sabur DA (2024) Fabrication and evaluation the optical and dielectric characteristics of promising PVA-ZrC-SiO2 nanocompsites films. Silicon 16(7):2839–2851. https://doi.org/10.1007/s12633-024-02903-2
9. Cha J, Kim J, Ryu S, Hong SH (2019) Comparison to mechanical properties of epoxy nanocomposites reinforced by functionalized carbon nanotubes and graphene nanoplatelets. Compos B Eng 162:283–288. https://doi.org/10.1016/j.compositesb.2018.11.011
10. Habeeb MA, Abdul Hamza RS, Oreibi I (2024) Polymer nanocomposites comprising PVA matrix and Ag–BaTiO3 nanofillers a comparative study of structural, dielectric and optical characteristics for optics and quantum nanoelectronic applications. Opt Quantum Electron 56(1):119. https://doi.org/10.1007/s11082-023-05685-w
11. Hamid LA, Dwech MH, Aadim KA (2020) Influence of laser energy on the optical properties of AG2s ito thin films prepared by the PLD technique. Ukr J Phys 65(2):179–183
12. Habeeb MA, Mahdi WS (2019) Characterization of (CMC-PVP-Fe_2O_3) nanocomposites for gamma shielding application. Int J Emerg Trends Eng Res 7(9):247–255. https://doi.org/10.30534/ijeter/2019/06792019
13. Habeeb MA, Jaber ZS (2022) Enhancement of Structural and Optical Properties of CMC/PAA Blend by Addition of Zirconium Carbide Nanoparticles for Optics and Photonics Applications. East Eur J Phys 4:176–182. https://doi.org/10.26565/2312-4334-2022-4-18
14. Abutalib MM, Rajeh A (2021) Enhanced structural, electrical, mechanical properties and antibacterial activity of Cs/PEO doped mixed nanoparticles (Ag/TiO_2) for food packaging applications. Polym Testing 93:107013. https://doi.org/10.1016/j.polymertesting.2020.107013
15. Alharbi EM, Rajeh A (2022) Tailoring the structural, optical, dielectric, and electrical properties of PEO/PVA blend using graphene nanoplates for energy storage devices. J Mater Sci Mater Electron 33:22196–22207. https://doi.org/10.1007/s10854-022-08999-9
16. Mahdi SM, Habeeb MA (2023) Tailoring the structural and optical features of (PEO–PVA)/(SrTiO3–CoO) polymeric nanocomposites for optical and biological applications. Polym Bull. https://doi.org/10.1007/s00289-023-04676-x
17. Hashim A, Habeeb MA (2018) Structural and optical properties of (Biopolymer Blend-Metal Oxide) bionanocomposites for humidity sensors. J Bionanosci 12(5):660–663. https://doi.org/10.1166/jbns.2018.1578
18. Habeeb MA, Kadhim WK (2014) Study the optical properties of (PVA-PVAC-Ti) nanocomposites. J Eng Appl Sci 9(4):109–113. https://doi.org/10.36478/jeasci.2014.109.113
19. Al-Attafi K, Dwech MH, Mezher HA, Nattestad A, Kim JH (2023) A Comparative study of organic Dye-Sensitized solar cells based on Anatase TiO2 and Amorphous free mixed phase's Anatase/Rutile P25 TiO2 Photoanodes. Coatings 13(1):121. https://doi.org/10.3390/coatings13010121
20. Obaid HN, Habeeb MA, Rashid FL, Hashim A (2013) Thermal energy storage by nanofluids. J Eng Appl Sci 8(5):143–145. https://doi.org/10.36478/jeasci.2013.143.145
21. Habeeb MA (2011) Effect of rate of deposition on the optical parameters of GaAs films. Eur J Sci Res 57(3):478–484
22. Habeeb MA, Hashim A, Hayder N (2020) Structural and optical properties of novel (PS-Cr_2O_3/$ZnCoFe_2O_4$) nanocomposites for UV and microwave shielding. Egyptian Journal of Chemistry 63:697–708. https://doi.org/10.21608/ejchem.2019.12439.1774
23. Zhao X, Jingxing Si, Huang D, Li Ke, Xin Y, Sui M (2020) Application of star poly(ethylene glycol) derivatives in drug delivery and controlled release. J Control Release 323:565–577. https://doi.org/10.1016/j.jconrel.2020.04.039
24. Al-Sharifi NK, Habeeb MA (2023) Improvement structural and dielectric properties of PS/SiC/Sb2O3 Nanostructures for Nanoelectronics Devices. East Eur J Phys 2:341–347. https://doi.org/10.26565/2312-4334-2023-2-40
25. Abdul Hamza RS, Habeeb MA (2024) Reinforcement of morphological, structural, optical, and antibacterial characteristics of PVA/CMC bioblend filled with SiO2/Cr2O3 hybrid nanoparticles for optical nanodevices and food packing industries. Polym Bull 81(5):4427–4448. https://doi.org/10.1007/s00289-023-04913-3
26. Phukan P, Saikia D (2013) Optical and structural investigation of CdSe quantum dots dispersed in PVA matrix and photovoltaic applications. Int J Photoenergy 2013:1–5
27. Habeeb MA, Hamza RSA (2018) Synthesis of (polymer blend –MgO) nanocomposites and studying electrical properties for

piezoelectric application. Indones J Electr Eng Inform 6(4):428–435. https://doi.org/10.11591/ijeei.v6i1.511
28. Kadham Algidsawi AJ, Hashim A, Hadi A, Habeeb MA, Abed HH (2022) Influence of MnO2 Nanoparticles Addition on Structural, Optical and Dielectric Characteristics of PVA/PVP for Pressure Sensors. Phys Chem Solid St 23(2):353–360. https://doi.org/10.15330/pcss.23.2.353-360
29. Dwech MH, Aadim KA, Jihad GH (2020) Effect of laser fluencies on solar cell characterization of (CdO)1–x:Sbx/PSi thin films by laser induce plasma. IOP Conf Ser Mater Sci Eng 928:072153. https://doi.org/10.1088/1757-899X/928/7/072153
30. Habeeb MA, Abdul Hamza RS, Oreibi I (2024) Tailoring the structural and optical features of PVA/SiO_2-CuO polymeric nanocomposite for optical and Gamma Ray shielding applications. Silicon 16(4):1407–1419. https://doi.org/10.1007/s12633-023-02769-w
31. Hashim A, Habeeb MA, Jebur QM (2020) Structural, dielectric and optical properties for (Polyvinyl alcohol-polyethylene oxide manganese oxide) nanocomposites. Egypt J Chem 63:735–749. https://doi.org/10.21608/ejchem.2019.14849.1901
32. Hashim A, Kadham Algidsawi AJ, Ahmed H, Hadi A, Habeeb MA (2021) Synthesis of PVA/PVP/SnO2 nanocomposites Structural, optical, and dielectric characteristics for pressure sensors. Nanosistemi Nanomateriali Nanotehnologii 19(2):353–362. https://doi.org/10.15407/nnn.19.02.353
33. Hashim A, Kadham AJ, Hadi A, Habeeb MA (2021) Determination of optical parameters of polymer blend/nanoceramics for electronics applications. Nanosistemi Nanomateriali Nanotehnologii 19(2):327–336. https://doi.org/10.15407/nnn.19.02.327
34. Habeeb MA (2014) Dielectric and optical properties of (PVAc-PEG-Ber) biocomposites. J Eng Appl Sci 9(4):102–108. https://doi.org/10.36478/jeasci.2014.102.108
35. Dalven R, Gill R (1967) Electrical properties of β-Ag2Te and β-Ag2Se from 4.2° to 300° K. J Appl Phys 38(2):753–756
36. Alghamdi HM, Rajeh A (2023) Comparative analysis of the structural, optical, mechanical, and electrical properties of PMMA/PU blend-based nanocomposites with FeVO4 nanofiller for energy storage devices. Polym Adv Technol 34:3711–3721. https://doi.org/10.1002/pat.6173
37. Mahdi SM, Habeeb MA (2023) Low-cost piezoelectric sensors and gamma ray attenuation fabricated from novel polymeric nanocomposites. AIMS Mater Sci 10(2):288–300. https://doi.org/10.3934/matersci.2023015
38. Li Y, Porwal H, Huang Z, Zhang H, Bilotti E, Peijs T (2016) Enhanced thermal and electrical properties of polystyrene-graphene nanofibers via electrospinning. J Nanomater 2016:1–6
39. Alsalmah HA, Alruqi AB, Nur O, Rajeh A (2024) Developing polymer nanocomposite films of ZnO/NiFe2O4 nanohybrids, polyvinyl pyrrolidone, and chitosan for flexible electromagnetic applications and energy storage devices. Ceram Int 50:28794–28804. https://doi.org/10.1016/j.ceramint.2024.05.190
40. Habeeb MA, Abdul Hamza RS (2018) Novel of (biopolymer blend-MgO) nanocomposites: Fabrication and characterization for humidity sensors". J Bionanosci. 12(3):328–335. https://doi.org/10.1166/jbns.2018.1535
41. Abbas NK, Habeeb MA, Algidsawi AJK (2015) Preparation of chloro penta amine cobalt (III) chloride and study of its influence on the structural and some optical properties of polyvinyl acetate. Int J Polym Sci 2015:926789. https://doi.org/10.1155/2015/926789
42. Mathew CM, Kesavan K, Rajendran S (2015) Structural and electrochemical analysis of PMMA based gel electrolyte membranes. Int J Electrochem 2015:1–7
43. Elamin NY, Modwi A, Abd El-Fattah W, Rajeh A (2023) Synthesis and structural of Fe3O4 magnetic nanoparticles and its effect on the structural optical, and magnetic properties of novel Poly(methyl methacrylate)/Polyaniline composite for electromagnetic and optical applications. Opt Mater 135:113323. https://doi.org/10.1016/j.optmat.2022.113323
44. Mahdi SM, Habeeb MA (2022) Evaluation of the influence of SrTiO3 and CoO nanofillers on the structural and electrical polymer blend characteristics for electronic devices. Digest J Nanomater Biostruct 17(3):941–948. https://doi.org/10.15251/DJNB.2022.173.941
45. Alqarni LS, Alghamdi AM, Elamin NY, Rajeh A (2024) Enhancing the optical, electrical, dielectric properties and antimicrobial activity of chitosan/gelatin incorporated with Co-doped ZnO nanoparticles: Nanocomposites for use in energy storage and food packaging. J Mol Struct 1297:137011. https://doi.org/10.1016/j.molstruc.2023.137011
46. Abutalib MM, Rajeh A (2020) Preparation and characterization of polyaniline/sodium alginate-doped TiO_2 nanoparticles with promising mechanical and electrical properties and antimicrobial activity for food packaging applications. J Mater Sci Mater Electron 31:9430–9442. https://doi.org/10.1007/s10854-020-03483-8
47. Habeeb MA, Jaber ZS, Radi WH (2023) Synthesis and Characterization of (PVA-CoO-ZrO2) Nanostructures for Nanooptoelectronic Fields. East Eur J Phys 2:228–233. https://doi.org/10.26565/2312-4334-2023-2-25
48. Habeeb MA, Mohammed AH (2023) Fabrication and tailored optical and electrical characteristics of Co2O3/SiC nanostructures doped PVA for multifunctional technological applications. Opt Quant Electron 55(9):791. https://doi.org/10.1007/s11082-023-05061-8
49. Algidsawi AJK, Hashim A, Hadi A, Habeeb MA (2021) Exploring the characteristics of SnO2 nanoparticles doped organic blend for low cost nanoelectronics applications. Semicond Phys Quantum Electron Optoelectron 24(4):472–477
50. Dwech MH, Aadim KA, Hamid LA (2020) Influence of laser energy on the characteristics of Ag2S/ITO thin films solar cell prepared by PLD technique. AIP Conf Proc 2213:020147. https://doi.org/10.1063/5.0000029
51. Mahdi SM, Habeeb MA (2022) Synthesis and augmented optical characteristics of PEO–PVA–SrTiO3–NiO hybrid nanocomposites for optoelectronics and antibacterial applications. Opt Quant Electron 54(12):854. https://doi.org/10.1007/s11082-022-04267-6
52. Mohammed AA, Habeeb MA (2023) Effect of Si_3N_4/TaC nanomaterials on the structural and electrical characteristics of Poly Methyl Methacrylate for electrical and electronics applications. East Eur J Phys 2:157–164. https://doi.org/10.26565/2312-4334-2023-2-15
53. Praveenkumar K, Sankarappa T, Ashwajeet J, Ramanna R (2022) Dielectric and AC conductivity studies in PPy-Ag nanocomposites. J Polym 4:176–182. https://doi.org/10.26565/2312-4334-2022-4-18
54. Habeeb MA, Hashim A, Hayder N (2020) Fabrication of (PS-Cr_2O_3/$ZnCoFe_2O_4$) nanocomposites and studying their dielectric and fluorescence properties for IR sensors. Egypt J Chem 63:709–717. https://doi.org/10.21608/ejchem.2019.13333.1832
55. Jebur QM, Hashim A, Habeeb MA (2020) Structural, A.C electrical and optical properties of (polyvinyl alcohol-polyethylene oxide-aluminum oxide) nanocomposites for piezoelectric devices. Egypt J Chem 63:719–734. https://doi.org/10.21608/ejchem.2019.14847.1900
56. Habeeb MA, Rahdi WH (2023) Titanium carbide nanoparticles filled PVA-PAAm nanocomposites, structural and electrical characteristics for application in energy storage. Opt Quant Electron 55(4):334. https://doi.org/10.1007/s11082-023-04639-6

57. Mahdi SM, Habeeb MA (2022) Fabrication and Tailored Structural and Dielectric characteristics of (SrTiO3/ NiO) Nanostructure Doped (PEO/PVA) polymeric Blend for Electronics Fields. Physics and Chemistry of Solid State 23(4):785–792. https://doi.org/10.15330/pcss.23.4.785-792
58. Alharbi EM, Rajeh A (2024) Processing polymer film nanocomposites of poly(vinylidene fluoride)/poly(ethylene oxide) and cobalt oxide nanoparticles for flexible energy storage systems" Opt Quant Electron 56(1167). https://doi.org/10.1007/s11082-024-07134-8
59. Hadi AH, Habeeb MA (2021) The dielectric properties of (PVA-PVP-CdS) nanocomposites for gamma shielding applications. J Phys Conf Ser 1973(1):012063. https://doi.org/10.1088/1742-6596/1973/1/012063
60. Hayder N, Habeeb MA, Hashim A (2020) Structural, optical and dielectric properties of (PS-In_2O_3/$ZnCoFe_2O_4$) nanocomposites. Egypt J Chem 63:577–592. https://doi.org/10.21608/ejchem.2019.14646.1887
61. Hashim A, Kadham Algidsawi AJ, Ahmed H, Hadi A, Habeeb MA (2021) Structural, dielectric, and optical properties for (PVA/PVP/CuO) nanocomposites for pressure sensors. Nanosistemi Nanomateriali Nanotehnologii 19(1):91–102. https://doi.org/10.15407/nnn.19.01.091
62. Habeeb MA, Al-Sharifi NK, Mohammed AA (2023) Fabrication and exploring the structural, dielectric and optical features of PVA/SnO_2/Cr_2O_3 nanostructures for optoelectronic applications. Opt Quant Electron 55(11):1016