

Unification and DC Conductivity of PDMS/NiNPs Nanocomposite

Ashish Kumar^{1,*}, Pankaj Kumar Modi²

Abstract

The DC conductivity of nickel nanoparticles–polydimethylsiloxane (NiNPs–PDMS) composite materials has attracted considerable attention due to their promising applications in flexible electronics, sensors, and energy storage devices. The electrical performance of these composites is largely governed by the formation of conductive networks within the insulating polymer matrix. Incorporating nickel nanoparticles into PDMS introduces conductive pathways that significantly enhance DC conductivity once a critical percolation threshold is reached. Several key factors influence the DC conductivity of NiNPs–PDMS composites. The size and morphology of nickel nanoparticles play a crucial role, as smaller particles with higher surface area-to-volume ratios facilitate better particle–particle contact and more efficient conductive networks. Equally important is the uniform dispersion of nanoparticles within the PDMS matrix, as poor dispersion or agglomeration can disrupt conductive pathways and limit charge transport. The loading fraction of nickel nanoparticles strongly affects conductivity. Increasing filler concentration generally leads to higher conductivity due to the increased number of conductive paths. However, excessive nanoparticle loading may cause agglomeration, which can reduce effective conductivity and compromise mechanical flexibility. Interfacial interactions between NiNPs and the PDMS matrix also significantly impact electrical behavior. Surface functionalization of nanoparticles can improve compatibility with PDMS, enhance dispersion, and promote efficient charge transfer across interfaces. Temperature dependence is another critical aspect of DC conductivity in NiNPs–PDMS composites. Elevated temperatures typically increase conductivity by enhancing electron mobility and hopping mechanisms. Nevertheless, at excessively high temperatures, polymer degradation or nanoparticle aggregation may occur, leading to a decline in electrical performance. Understanding these factors is essential for optimizing NiNPs–PDMS composites for practical applications. In this present study, we prepared a polymer nanocomposite using Polydimethylsiloxane (PDMS) as the polymer network and Ni nanoparticles as a dopant. The PDMS nanocomposites were loaded with different weight percentages (wt%) of NiNPs filler. The electrical properties of these nanocomposites over a wide temperature range were analyzed by our team. Our findings indicate that the electrical conductivity of the nanocomposites strongly depends on weight percentage of the Ni nanoparticles. Understanding these factors is crucial for tailoring the electrical properties of these composites for specific applications.

*Author for Correspondence

Ashish Kumar

E-mail: anishkr43@gmail.com

¹Research Scholar, Department of Physics, College of Commerce Arts & Science, Patliputra University, Patna, Bihar, India

²Assistant Professor, Department of Physics, College of Commerce Arts & Science, Patliputra University, Patna, Bihar, India

Received Date: December 29, 2025

Accepted Date: January 21, 2026

Published Date: January 27, 2026

Citation: Ashish Kumar, Pankaj Kumar Modi. Unification and DC Conductivity of PDMS/NiNPs Nanocomposite. Research & Reviews: Journal of Physics. 2026; 15(1): 28–37p.

Keywords: Composite materials, DC conductivity, Nickel nanoparticles, NiNPs–PDMS, Polydimethylsiloxane

INTRODUCTION

Polymer nanocomposites are the active combination of polymer and nanomaterials. The presence of nanomaterials in polymer improves its mechanical, thermal, electrical, and gas barrier properties [1–5]. Recently, Ni nanoparticles have attracted great attention due to their unique properties and wide applications [6–8]. NiNPs properties include small size, high surface area,

magnetic properties, catalytic activity, biomedical applications, excellent electrical conductivity, and tunable properties [9–13]. While the special features of PDMS that make it useful for the semiconductor industry include its thermal stability, low surface energy, excellent electrical insulation properties, optical transparency, and flexibility [14, 15]. In the presence of chemical catalysts, when heated together, PET is produced [16, 17]. The main mechanism for electron transport in disordered systems, especially conductive materials dispersed in nonconductive networks, is the Efros–Shklovskii variable-range hopping (VRH) model [1–4] in a low concentration and low temperature regime and the Mott model in a high concentration and high temperature regime [18–20]. For both models, the conductivity can be expressed as follows:

$$\sigma = A \exp [-(T_0/T)^a] \quad (1)$$

Where σ is the electrical conductivity, A is a constant, T_0 is the characteristic temperature, T is the measurement temperature, and a is $1/2$ for the ES model and $1/4$ for the Mott model. The aim of this work is to study the influence of the NiNPs content on the DC conductivity of nanocomposite films.

TO PREPARE THE FILM BODY

Of NiNPs–PDMS (nickel nanoparticles–polydimethylsiloxane) for different weight percentages of NiNPs [5, 6]. The following steps were performed:

Materials and Equipment

- Nickel nanoparticles (NiNPs)
- Polydimethylsiloxane (PDMS)
- Solvent (Hexane)
- Glass substrate
- Spin coater
- Oven

Preparation of NiNPs–PDMS Solution

- Desired amount of PDMS [8–10] was weighed and placed in a clean container.
- Appropriate amount of Hexane (solvent) was added to the PDMS and mixed well until a homogeneous solution was obtained.
- NiNPs were dispersed in the PDMS solution while stirring gently. The weight percentage of NiNPs was adjusted according to the desired concentration.

Film Deposition

- Glass substrate was cleaned thoroughly to remove any contaminants.
- Sufficient amount of the NiNPs–PDMS solution was poured onto the glass substrate.
- Spin coater was used to spread the solution evenly across the substrate surface. The rotation speed and time were adjusted based on the desired film thickness.
- Coated substrate was allowed to dry using an oven.

Film Characterization

- Once the film was completely dry, it was characterized using techniques of scanning electron microscopy (SEM), Grazing Incidence X-ray Diffraction (GIXD), and Transmission Electron (TEM) to analyze its morphology, structure, and composition [16].

Repeat Steps for Different Weight Percentages

- To prepare films with different weight percentages of NiNPs, steps 2–4 were repeated while varying the amount of NiNPs added to the PDMS solution.

Through the aforementioned process, we prepared nanocomposite films with varying filler amounts of

Ni nanoparticles (14.88 wt%, 15.77 wt%, and 16.65 wt%).

METHOD OF INVESTIGATION

We sandwiched the prepared nanocomposite film between the two disc-shaped copper electrodes of a sample holder. The samples with the holder were put inside an electrical furnace where the temperature was measured by a thermometer. We applied a DC voltage and measured the current; the measured current was used for the conductivity measurements at a given temperature [11]. The DC conductivity of the films was calculated using the well-known relation $\sigma = J/E = Id/AV$; where d is the sample thickness, I is current drawn at applied voltage V , and A is the cross-sectional area [15].

Our Findings and Detailed Discussion of the Observed Results

What we observed, we shall try to illustrate it here with the help of graphical representations, so as to give a better understanding of it to the readers in Figures 1–4.

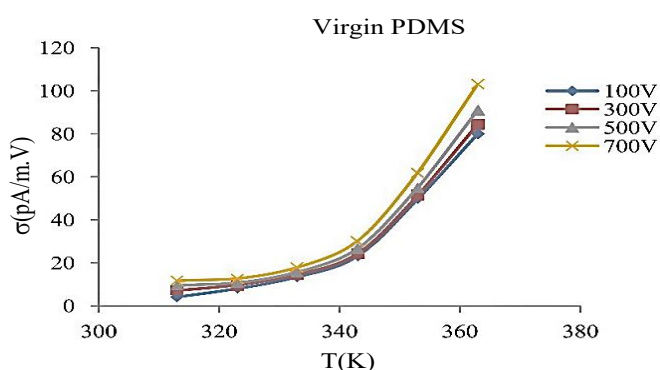


Figure 1. Plot of conductivity vs. temperature for virgin PDMS at different applied voltages.

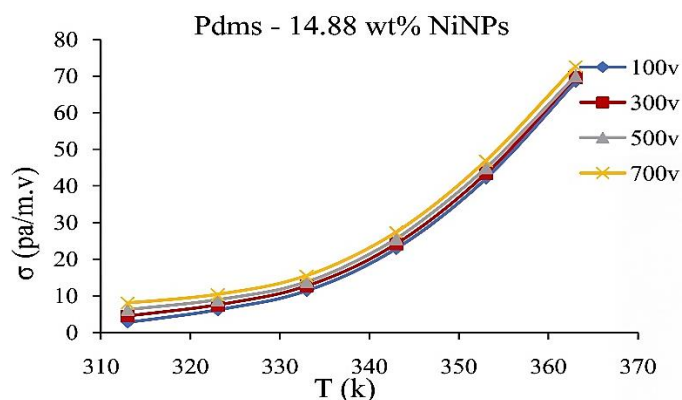


Figure 2. Plot of conductivity vs. temperature for PDMS–14.88 wt% NiNPs nanocomposite film at different applied voltages.

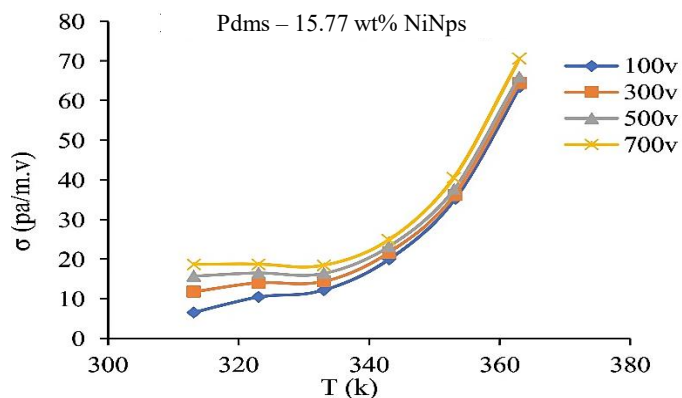


Figure 3. Plot of conductivity vs. temperature for PDMS–15.77 wt% NiNPs nanocomposite film at different applied voltages.

different applied voltages.

Variation of $\ln(\sigma)$ with $E^{1/2}$

The above-tailed variation of $\ln(\sigma)$ with $E^{1/2}$, at different temperatures, is illustrated through Figures 5–8. It can be evidently observed that there is a linear dependency of $\ln(\sigma)$ on $E^{1/2}$.

The electrical conductivity of insulators/semiconductors for the Poole–Frenkel process, according to which these plots of $\ln(\sigma)$ vs. $E^{1/2}$ should be linear, was also observed to be satisfied through Figures 5–8.

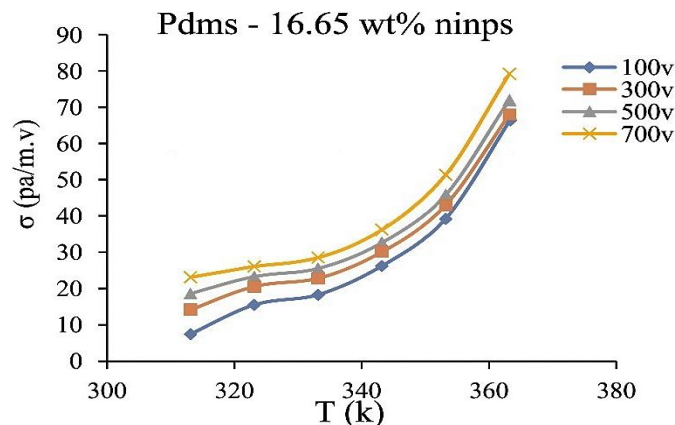


Figure 4. Plot of conductivity vs. temperature for PDMS–16.65 wt% NiNPs nanocomposite film at different applied voltages.

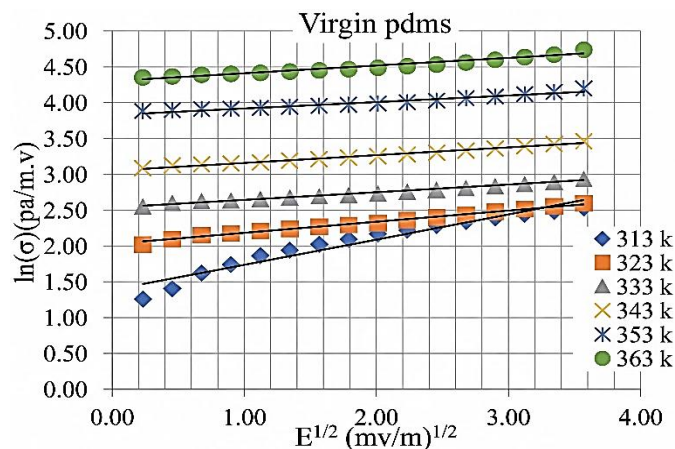


Figure 5. Plot of $\ln(\sigma)$ vs. $E^{1/2}$ for virgin PDMS at different temperatures.

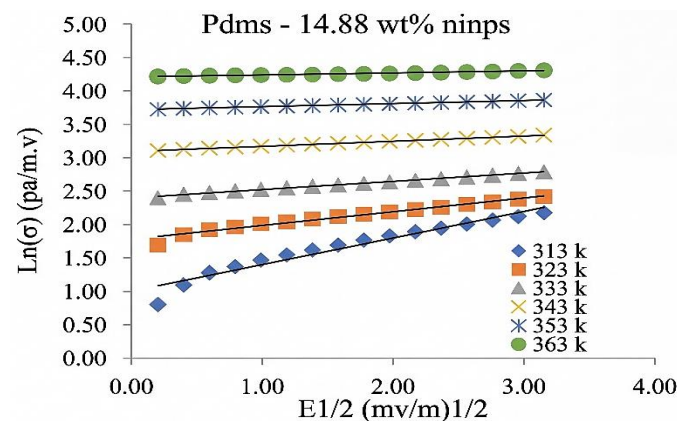


Figure 6. Plot of $\ln(\sigma)$ vs. $E^{1/2}$ for PDMS–14.88 wt% NiNPs at different temperatures.

DISCUSSION

Dependence of Conductivity on Temperature

The variation of DC conductivity with temperature in the case of virgin PDMS and PDMS–NiNPs nanocomposite films is demonstrated by Figures 1–4. Here, electrical conductivity is seen to increase with rising temperature, but it is observed from these plots that this increasing tendency of conductivity is sharper at higher temperatures. An increase in conductivity with an increase in temperature is the characteristic behavior of semiconductors. Figures 9–12 show the $\ln(\sigma)$ vs. $10^3 \times T^{-1}$ plots [11–14]. From these $\ln(\sigma)$ vs. $10^3 \times T^{-1}$ plots, the activation energy of the samples was computed. This activation energy was calculated by the equation below:

$$\sigma = \sigma_o \exp(-E_a/KT) \quad (2)$$

Where σ_o = Pre-exponential factor and K = Boltzmann constant.

Mott's (1968) concept of variable-range hopping conduction, Mott's theory, relates the conductivity with the temperature through a simple mathematical relation:

$$n\sigma = \ln\sigma_o - \left(\frac{T_o}{T}\right)^{1/4} \quad (3)$$

Equation (3) suggests that the plot of $\ln(\sigma)$ vs. $T^{-1/4}$ should be linear.

The $\ln(\sigma)$ vs. $T^{-1/4}$ plots for virgin PDMS and PDMS–NiNPs nanocomposite sample films at different applied voltages are shown in Figures 13–16. It is evident from these plots that $\ln(\sigma)$ varies linearly with $T^{-1/4}$, as suggested by Mott's theory Figure 2 [17–20].

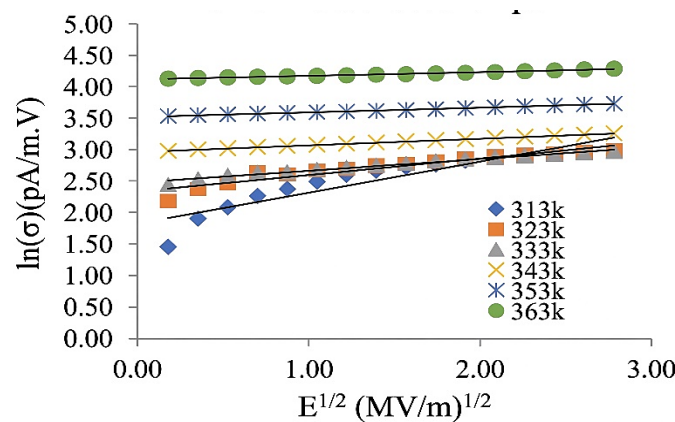


Figure 7. Plot of $\ln(\sigma)$ vs. $E^{1/2}$ for PDMS–15.77 wt% NiNPs at different temperatures.

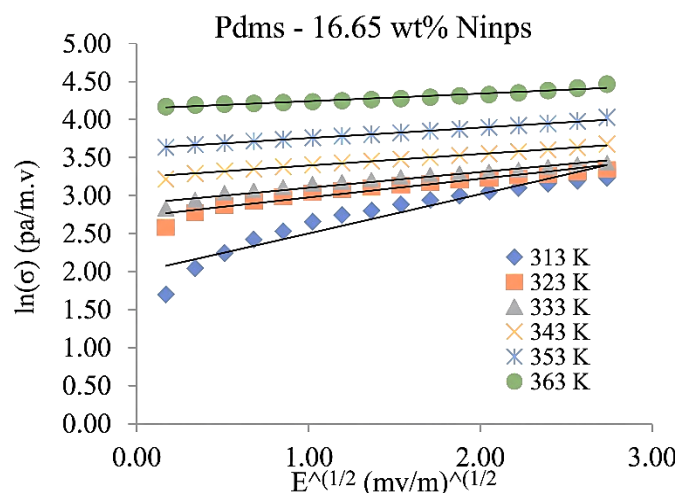


Figure 8. Plot of $\ln(\sigma)$ vs. $E^{1/2}$ for PDMS–16.65 wt% NiNPs at different temperatures.
Virgin PDMS

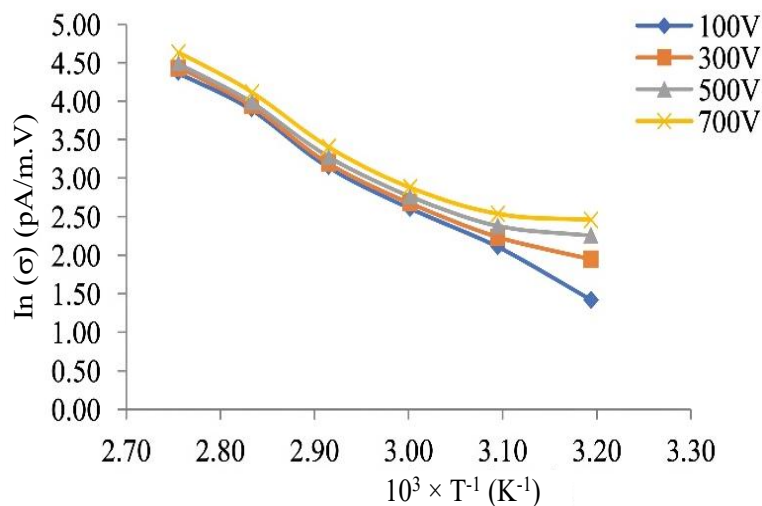


Figure 9. Plot of $\ln(\sigma)$ vs. $10^3 \times T^{-1}$ for virgin PDMS at different applied voltages.

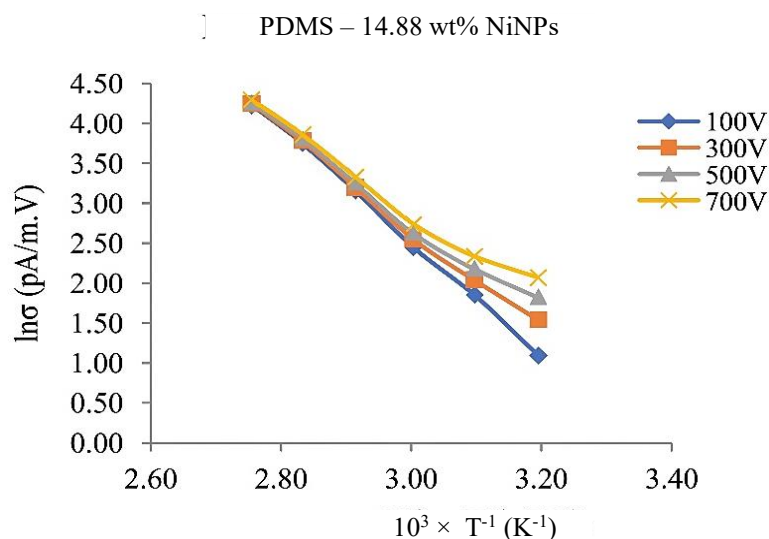


Figure 10. Plot of $\ln(\sigma)$ vs. $10^3 \times T^{-1}$ for PDMS–14.88 wt% NiNPs nanocomposite film at different applied voltages.

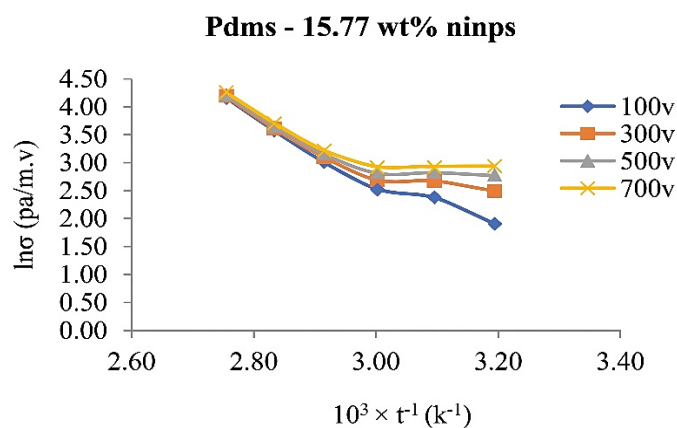


Figure 11. Plot of $\ln(\sigma)$ vs. $10^3 \times T^{-1}$ for PDMS–15.77 wt% NiNPs nanocomposite film at different

applied voltages.

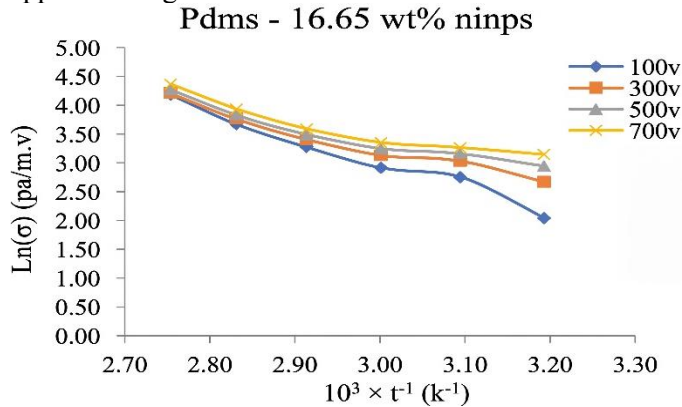


Figure 12. Plot of $\ln(\sigma)$ vs. $10^3 \times T^{-1}$ for PDMS-16.65 wt% NiNPs nanocomposite film at different applied voltages.

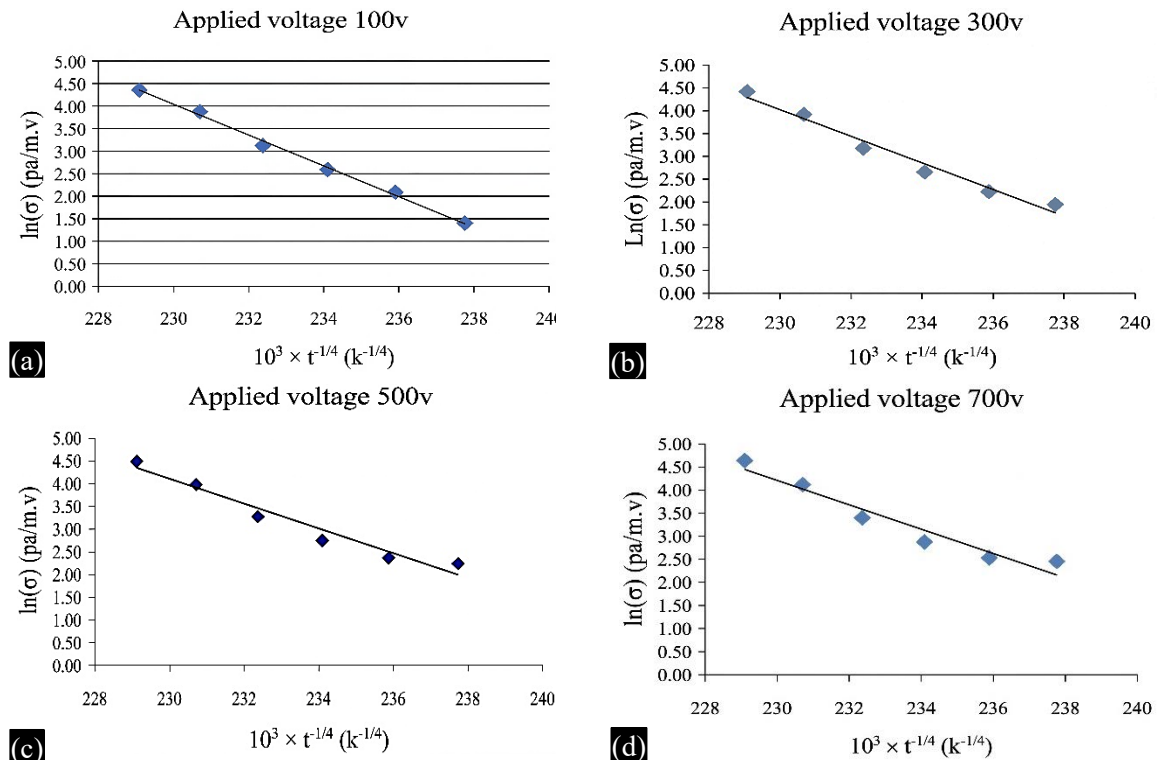


Figure 13 [(a–d)]. Linear plotting of $\ln(\sigma)$ vs. $10^3 \times T^{-1/4}$ for virgin PDMS at different applied voltages (V).

(a)

(b)

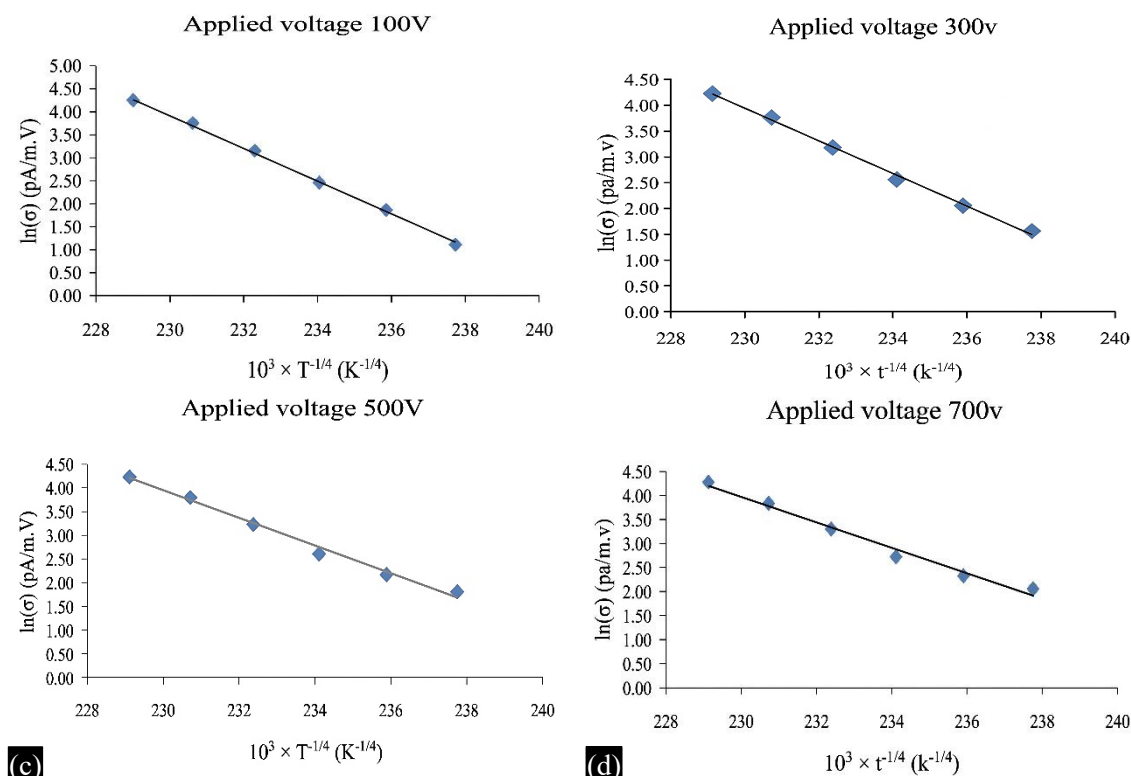


Figure 14 [(a–d)]. Linear plotting of $\ln(\sigma)$ vs. $10^3 \times T^{-1/4}$ for PDMS–14.88 wt% NiNPs at different applied voltages (V).

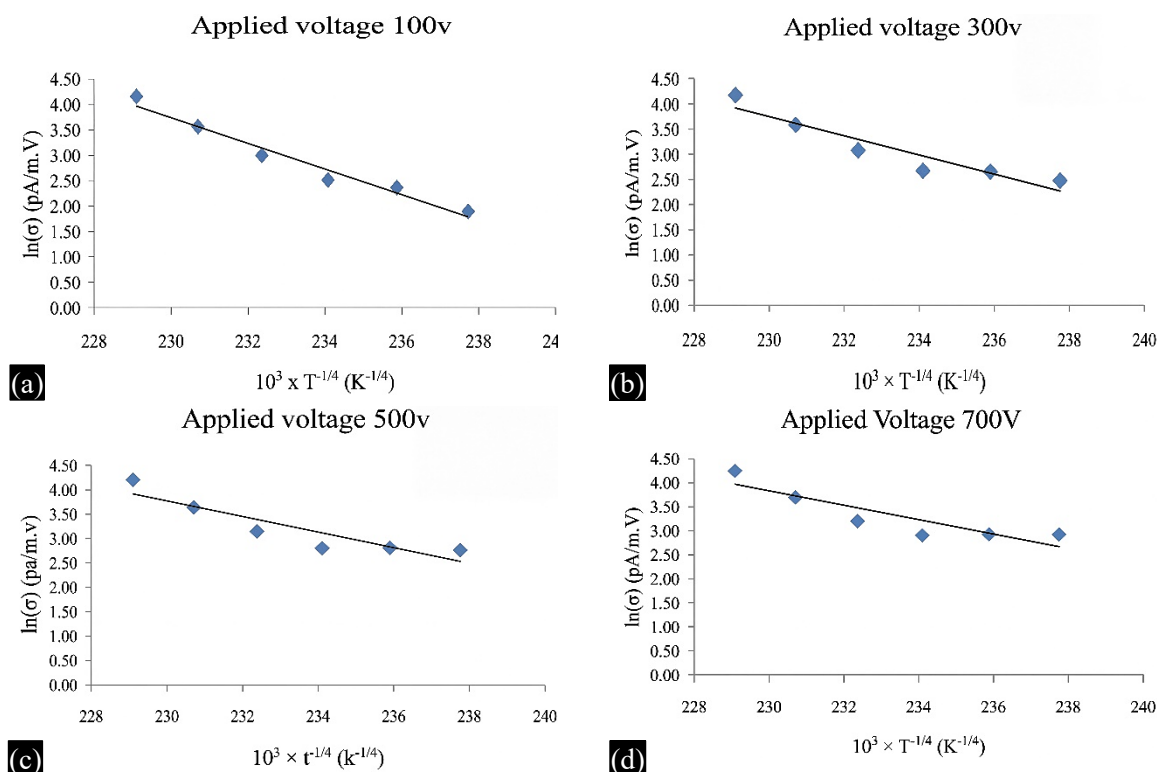


Figure 15 [(a–d)]. Linear plotting of $\ln(\sigma)$ vs. $10^3 \times T^{-1/4}$ for PDMS–15.77 wt% NiNPs at different applied voltages (V).

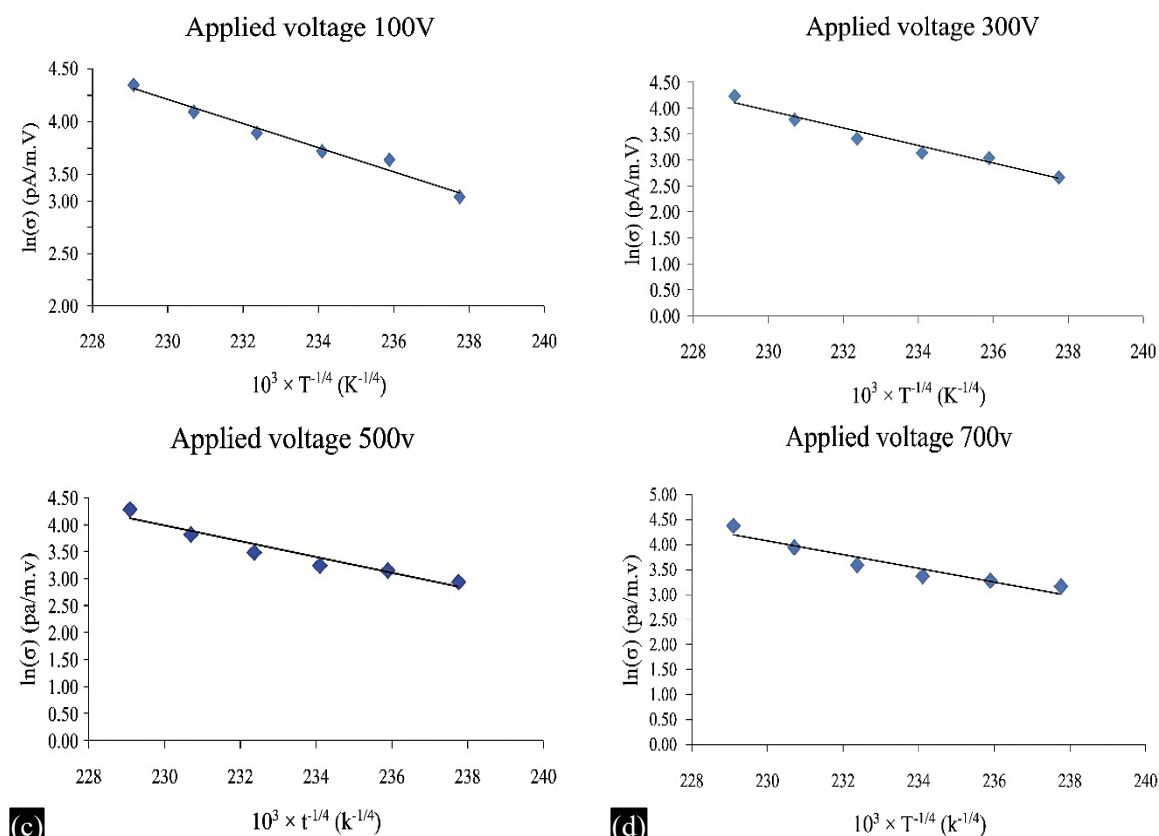


Figure 16 [(a–d)]. Linear plotting of $\ln(\sigma)$ vs. $10^3 \times T^{-1/4}$ for PDMS–16.65 wt% NiNPs at different applied voltages (V).

CONCLUSION

The incorporation of nickel nanoparticles (NiNPs) into a polydimethylsiloxane (PDMS) matrix has shown promising results in enhancing the electrical conductivity of the composite. The DC conductivity of NiNPs–PDMS composites is influenced by several factors, including the concentration of NiNPs, their size and shape, and the dispersion within the PDMS matrix. The presence of NiNPs creates conductive pathways within the insulating PDMS matrix, allowing for the flow of electrons. As a result, the overall conductivity of the composite material increases. The size and shape of the NiNPs play a crucial role in determining the conductivity of the composite. Smaller nanoparticles with a higher surface area-to-volume ratio provide more contact points for electron transfer, leading to increased conductivity. Additionally, a uniform dispersion of nanoparticles within the PDMS matrix ensures efficient electron transport throughout the material.

As a summary, we can say that the DC conductivity of NiNPs–PDMS composites is a promising area of research with potential applications in various fields. The enhanced conductivity of NiNPs–PDMS opens up new possibilities for various applications, such as flexible electronics, sensors, and energy storage devices. By understanding and controlling the factors that influence conductivity, researchers can develop composite materials with tailored electrical properties for specific applications.

REFERENCES

1. Zhang Y, Guo W, Liu J. Enhanced dielectric properties of polydimethylsiloxane-based composites filled with nickel nanoparticles for energy storage applications. *J Appl Polym Sci.* 2020;137(1):47819.
2. Chen X, Li Z, Huang X. Fabrication and characterization of a flexible capacitor based on nickel nanoparticles and polydimethylsiloxane for energy storage applications. *J Nanosci Nanotechnol.* 2019;19(12):8117–22.

3. Liu J, Guo W, Zhang Y. Enhanced dielectric properties of polydimethylsiloxane-based composites filled with nickel nanoparticles for energy storage applications. *J Electron Mater.* 2019;48(6):3650–6.
4. Zhang Y, Guo W. Fabrication and characterization of a flexible capacitor based on nickel nanoparticles and polydimethylsiloxane. *J Mater Sci Mater Electron.* 2019;30(15):14242–8.
5. Li Y, Li X, Wang H. A flexible and stretchable supercapacitor based on nickel nanoparticles and polydimethylsiloxane. *J Power Sources.* 2017;342:1–7.
6. Wang L, Liang J, Xu C. Flexible supercapacitors based on nickel nanoparticles/polydimethylsiloxane composite electrodes with high capacitance and stability. *Electrochim Acta.* 2018;283:1192–9.
7. Li Y, Li X, Wang H. Fabrication and characterization of a flexible supercapacitor based on nickel nanoparticles and polydimethylsiloxane for energy storage applications. *J Mater Sci Mater Electron.* 2018;29:18568–75.
8. Liu G, Chen Y, Gong M, Liu X, Cui Z, Pei Q, et al. Enhanced dielectric performance of PDMS-based three-phase nanocomposite films. *J Mater Chem C.* 2018;6:10829–37.
9. Vakil PN, Muhammed F, Hardy D, Dickens TJ, Ramakrishnan S, Strouse GF. Dielectric properties of Ni-loaded polymer nanocomposites. *ACS Omega.* 2018;3(10):12813–23.
10. Cao L, Xi R, Zhou C, He G, Yang F, Xu L, et al. Polymer capacitor films with nanoscale coatings for dielectric energy storage: A review. *Coatings.* 2024;14(9):1193.
11. Ben Mansour R, Ouzzane M, Aidoun Z. Numerical evaluation of ejector-assisted mechanical compression systems for refrigeration applications. *Int J Refrig.* 2014.
12. Lin CC, Chen CC, Weng CM, Chu SY, Hong CS, Tsai CC. Effects of lithium doping on microstructure, electrical properties, and chemical bonds of sol-gel derived NKN films. *J Appl Phys.* 2015.
13. Campbell AJ. Bulk limited conduction in electroluminescent polymer devices. *J Appl Phys.* 1998.
14. Das SN. Hydrogen sensor based on thin film nanocrystalline n-GaN/Pd Schottky diode. *J Phys D Appl Phys.* 2007 Dec 12.
15. Khirade PP, Birajdar SD, Humbe AV, Jadhav KM. Structural, electrical and dielectrical property investigations of Fe-doped BaZrO₃ nanoceramics. *J Electron Mater.* 2016.
16. Toor A, So H, Pisano AP. Improved dielectric properties of polyvinylidene fluoride nanocomposite embedded with poly(vinylpyrrolidone)-coated gold nanoparticles. *ACS Appl Mater Interfaces.* 2017.
17. Larson C, Peele B, Li S, Robinson S, Totaro M, Beccai L, et al. Highly stretchable electroluminescent skin for optical signalling and tactile sensing. *Science.* 2016;351(6277):1071–1074.
18. Zhou Y, Cao S, Wang J, Zhu H, Wang J, Yang S, et al. Bright stretchable electroluminescent devices based on silver nanowire electrodes and high-k thermoplastic elastomers. *ACS Appl Mater Interfaces.* 2018;10(51):44760–44767.
19. Altuntas H, Ozgit-Akgun C, Donmez I, Biyikli N. Current transport mechanisms in plasma-enhanced atomic layer deposited AlN thin films. *J Appl Phys.* 2015.
20. Han ZJ. Electrical conductivity of poly(ethylene terephthalate) modified by titanium plasma. *J Appl Polym Sci.* 2008 May 3.