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# Fabrication of Polydimethylsiloxane Composites with Nickel Nanoparticles: Unification and Current–Voltage Relationship

Ashish Kumar[1],*, Pankaj Kumar Modi[2]

**_Abstract_**

*Polydimethylsiloxane (PDMS)–nickel nanoparticle (NiNPs) nanocomposite films were fabricated and systematically investigated to understand their electrical transport behavior through current–voltage (I–V) characterization. Nanocomposite films with varying Ni nanoparticle filler concentrations (14.88 wt%, 15.77 wt%, and 16.65 wt%) were prepared using a solution-mixing and spin-coating technique, followed by controlled thermal curing. The electrical properties of both pristine PDMS and PDMS–NiNPs nanocomposites were examined over a wide voltage range (up to 800 V) and across a temperature interval of 313 K to 363 K. The I–V characteristics of all prepared samples exhibited pronounced non-linear behavior, confirming non-Ohmic conduction mechanisms. Incorporation of nickel nanoparticles significantly enhanced the electrical conductivity of PDMS, with the maximum current observed for the 16.65 wt% NiNPs-loaded film. At a fixed temperature of 313 K and an applied voltage of 200 V, the current increased markedly with increasing NiNP concentration, attributed to the higher density of charge carriers and improved formation of conductive pathways within the polymer matrix. However, at lower filler content (14.88 wt%), a reduction in current was observed, likely due to the absence of a continuous conductive network. Temperature-dependent current measurements revealed two distinct conduction regions separated near 343 K, close to the glass transition temperature of PDMS. Above this temperature, a sharp increase in current was observed, associated with polymer softening and enhanced connectivity of conducting networks. The temperature dependence of resistance followed the Mott variable range hopping model, indicating thermally assisted charge transport. These findings demonstrate that NiNP concentration and temperature play crucial roles in tailoring the electrical behavior of PDMS-based nanocomposites, highlighting their potential for applications in flexible electronics, sensors, and dielectric devices.*

**Keywords:** Conductivity, current–voltage relationship, electrical properties, I–V characterization, NiNPs–PDMS nanocomposite film, resistive behavior

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## INTRODUCTION

I–V Characterization of *NiNPs–PDMS*: – I–V characterization refers to the process of measuring and analyzing the current–voltage (I–V) relationship of a material or device [1, 2]. In this article, we will focus on the I–V characterization of nickel nanoparticles *(NiNPs)* embedded in polydimethylsiloxane *(PDMS)*, a commonly used elastomer [3, 4]. This characterization technique provides valuable insights into the electrical behavior and performance of *NiNPs–PDMS* composites, which find applications in various fields such as electronics, sensors, and energy storage. *NiNPs–PDMS* composites are fabricated by dispersing nickel nanoparticles within a *PDMS* matrix [5–9]. The dispersion can be achieved through various methods, including solution mixing, sonication, or in situ synthesis. The resulting composite exhibits unique electrical properties due to the presence of conductive *NiNPs* within an insulating *PDMS* matrix. To perform I–V characterization on NiNPs–PDMS composites, a typical setup involves applying a known voltage across the sample and measuring the resulting current flowing through it [10–13]. The voltage is usually varied over a range to obtain multiple data points for constructing a I–V curve [14–16]. This curve represents the relationship between the applied voltage and the resulting current. The I–V curve provides valuable information about the electrical behavior of the *NiNPs–PDMS* composite [17–21]. It allows researchers to determine important parameters such as conductivity, resistivity, and threshold voltage. These parameters are crucial for understanding the performance and potential applications of the composite material. The conductivity of *NiNPs–PDMS* composites can be calculated from the slope of the linear region of the I–V curve using Ohm's law $(V = IR)$ [22–23]. The resistivity is then obtained by taking the reciprocal of the conductivity. These values provide insights into the overall electrical conductivity of the composite material. Furthermore, the I–V curve can reveal important characteristics such as nonlinearity and hysteresis [24, 25]. Nonlinearity refers to the deviation from Ohm's law, indicating the presence of additional electrical effects such as tunneling or contact resistance. Hysteresis, on the other hand, occurs when the I–V curve exhibits different behavior depending on the direction of voltage sweep. These characteristics can provide insights into the underlying mechanisms governing the electrical behavior of *NiNPs–PDMS* composites. In addition to providing information about electrical properties, I–V characterization can also be used to evaluate the performance of *NiNPs–PDMS* composites in specific applications. For example, in sensor applications, the I–V curve can be used to determine the sensitivity and response time of the composite material to external stimuli such as temperature or strain. To summarize, we can say that I–V characterization is a valuable technique for understanding the electrical behavior and performance of *NiNPs–PDMS* composites. It provides insights into parameters such as conductivity, resistivity, nonlinearity, and hysteresis. This information is crucial for optimizing the design and application of these composites in various fields [26, 27].

## EXPERIMENTAL DETAILS

### Required Materials and Equipment

Nickel nanoparticles (NiNPs), Polydimethylsiloxane (PDMS), Solvent (Hexane), Glass Substrate, Spin Coater, Oven.

### Synthesis of Nickel Nanoparticles (NiNPs) and Polydimethylsiloxane PDMS Composites

The desired amount of *PDMS* was weighed and placed in a clean container. An 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. The deposition of the film glass substrate was cleaned thoroughly to remove any contaminants. A sufficient amount of the *NiNPs–PDMS* solution was poured onto the glass substrate. A 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. The coated substrate was allowed to dry using oven. 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. We prepared nanocomposite films with varying filler amounts of Ni nanoparticles (14.88 wt%, 15.77 wt%, and 16.65 wt%) using the identical procedure.

### Method Followed for Investigation

To obtain I–V characteristic curves, the film sample was positioned between two disc-shaped electrodes within a sample holder. The experimental temperature was controlled by placing the sample holder inside a thermostat *U*-10. The electrodes of the sample holder were connected in series with an external resistance *(R)* and an adjustable *DC* voltage power supply (High Voltage Power Supply Model: *EHT*-11) using a wire. A digital multimeter was employed to measure the potential drop (V) across the external resistance (R). The current (I) flowing through the circuit was determined using the equation $I = V/R$. The I–V curves were plotted at various temperatures (40°C–90°C) with regular increments of 10°C by adjusting the temperature of thermostat *U*-10.

**RESULT AND DISCUSSIONS**

The I–V characteristics of the *NiNPs–PDMS* nanocomposites were investigated across a wide voltage range, typically below 800 V. The prepared film sample had a thickness of approximately 130 µm, resulting in a maximum electric field of around 6 x $10^6$ V/m when subjected to biased voltage. Figures 1–4 illustrate the current–voltage characteristics of the prepared film samples at temperatures ranging from 313 K to 363 K, with a regular interval of 10 K.

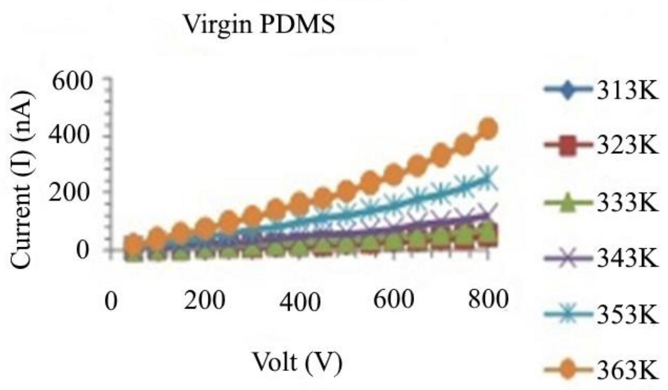


**Figure 1.** Variation of current and voltage of virgin PDMS.

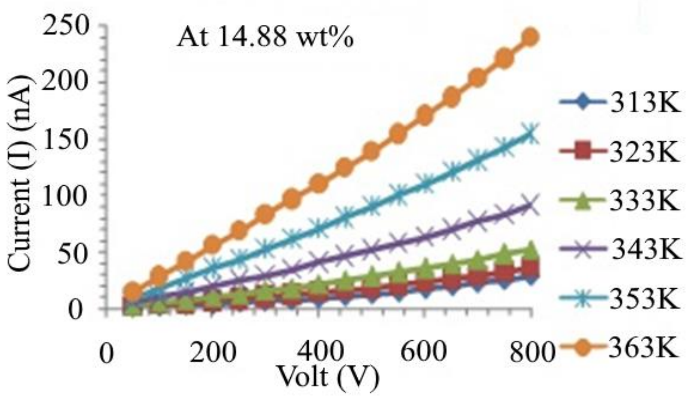


**Figure 2.** Variation of current and voltage of PDMS-Ni at 14.88 wt%.

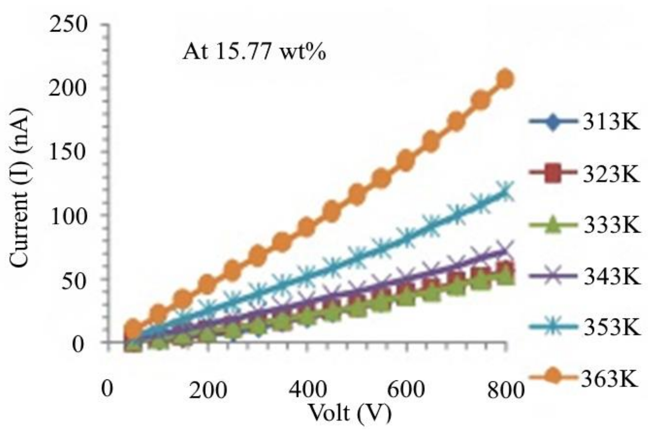


**Figure 3.** Variation of Current and Voltage of PDMS-Ni at 15.77 wt%.

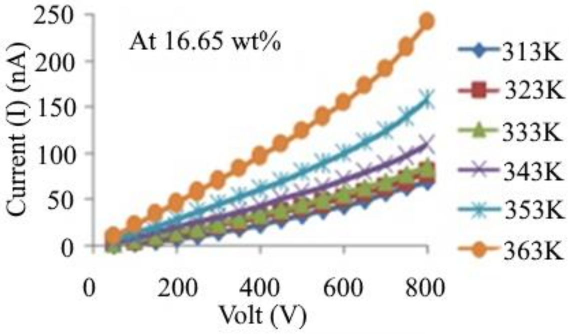


**Figure 4.** Variation of Current and Voltage of PDMS-Ni at 16.65 wt%.

The Figures clearly indicate that the I–V curves exhibit non-linear behavior, suggesting that all four samples demonstrate non-Ohmic characteristics. Figure 5 depicts the I–V characteristics curve of nanocomposite films with varying weight percentages (wt%) of NiNPs.

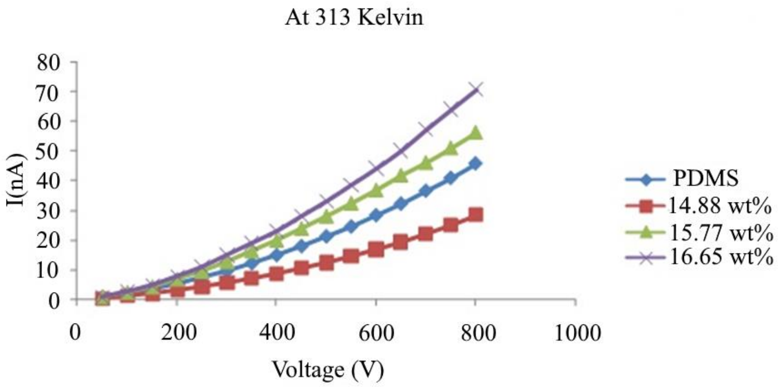


**Figure 5.** Variation of Current and Voltage of PDMS-Ni at (313 K).

The plot demonstrates a significant change in the current drawn in the film of polydimethylsiloxane (PDMS) after the introduction of nickel (Ni) nano powder doping into the pristine PDMS polymer.

At a temperature of 313 K and a biased voltage of 200 V, the current in the original PDMS film is measured at 5.2 nA. However, this value increases to 6.75 nA and 7.85 nA for samples containing 15.77 wt% and 16.65 wt% Ni nanoparticles (NiNPs), respectively. Both Ni nanoparticles and PDMS–NiNPs nanocomposites are semiconducting materials that possess free charge carriers available for conduction. Consequently, as the weight percentage of NiNPs increases in the nanocomposite, the number of free charge carriers also increases, leading to an enhancement in current. In the case of the 14.88 wt% PDMS–NiNPs sample, the current reduces to 3.15 nA, which could be attributed to the non-formation of a new conducting network within the nanocomposite film. Figures 6–9 illustrate the variation of current in virgin PDMS/PDMS–NiNPs nanocomposite sample films with temperature.

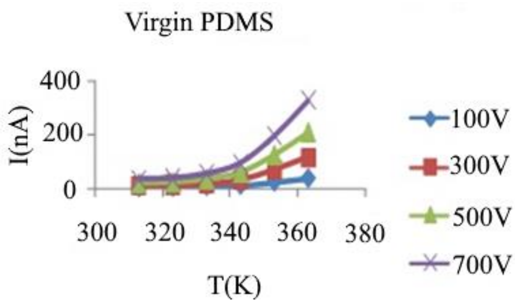


**Figure 6.** Variation of current and temperature for Virgin PDMS.

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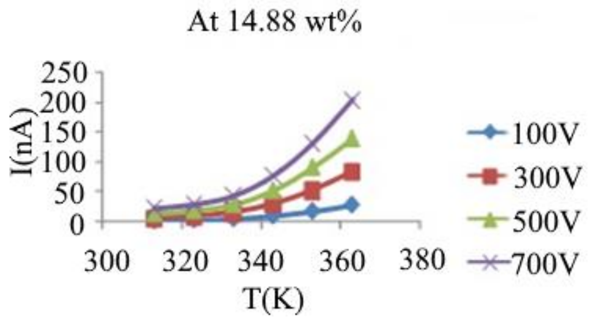


**Figure 7.** Variation of current and temperature of PDMS-Ni at 14.88 wt%.

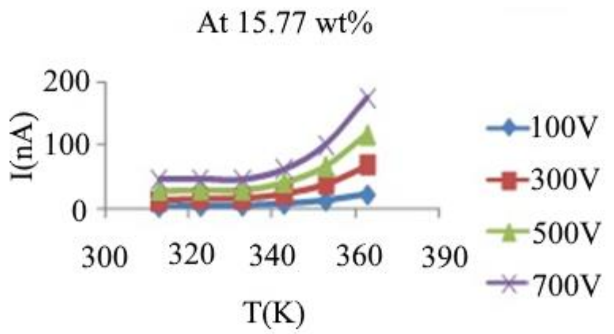


**Figure 8.** Variation of current and temperature of PDMS-Ni at 15.77 wt%.

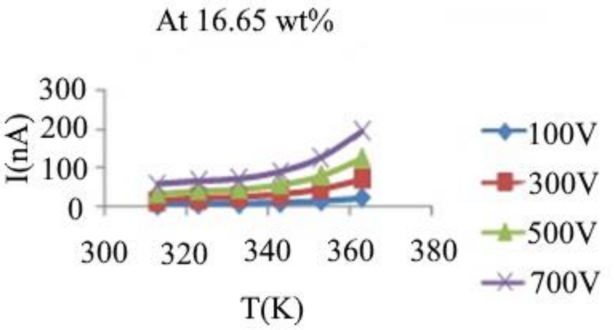


**Figure 9.** Variation of current and temperature of PDMS-Ni at 16.65 wt%.

The current–temperature (I–T) curves exhibit a distinct behavior that suggests the existence of two main regions in the current (I) curve. The first region spans from 313 K to 343 K, where the increase in current with temperature is relatively small. The second region extends from 343 K to 363 K, characterized by a sharp increase in current. In Figures 6–9, the temperature point of 343 K separates these two regions. It is noteworthy that the glass transition temperature (Tg) of Polydimethylsiloxane (PDMS) is 348 K, which is close to the temperature point of 343 K. Above the glass transition temperature (Tg), PDMS undergoes a structural change, becoming softer. This change enables small conducting networks within PDMS to combine and form larger ones. The temperature dependence of electrical conductivity σ(T) in PDMS can be described by the Mott Variable Range Hopping model.

$$\sigma(T) = \sigma_0 \exp[-(T_0 / T)^{1/4}] \quad (1)$$

where σ and T represent conductivity and temperature, respectively. $\sigma_0$ is the conductivity at characteristic temperature $T_0$. Equation (1) sets clear that ln(σ) Vs $T^{1/4}$ plot be a straight line with the Mott Variable Range Hopping model. Because conductance and resistance are reciprocal to each other, hence for simplicity we can use resistance (*R*) in place of conductivity for the purpose of plotting. Figures 10–13 illustrate ln(R) Vs $T^{1/4}$. The straight line observed indicates that the Mott model is suitable for the explanation of electrical conduction.

 

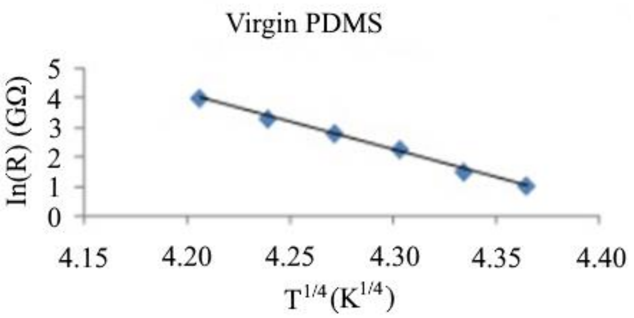


**Figure 10.** Variation of In(R) versus $T^{-1/4}$ for Virgin PDMS.Ω

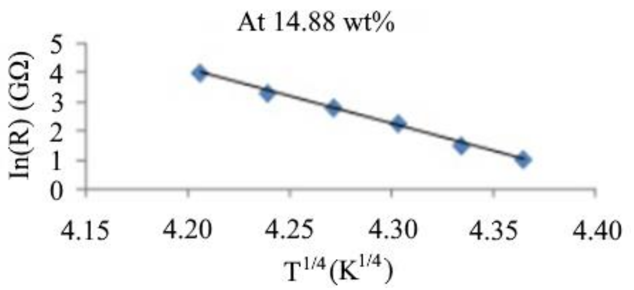


**Figure 11.** Variation of In(R) versus $T^{-1/4}$ of PDMS-Ni at 14.88 wt%.

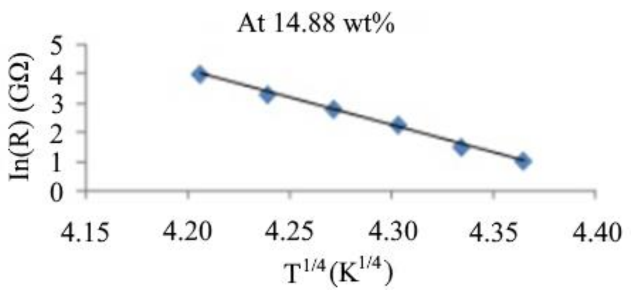


**Figure 12.** Variation of In(R) versus $T^{-1/4}$ of PDMS-Ni at 15.77 wt%.

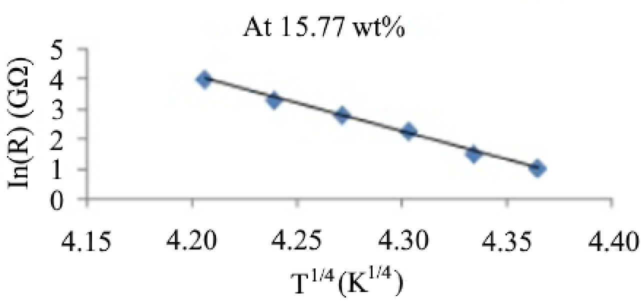


**Figure 13.** Variation of In(R) versus $T^{-1/4}$ of PDMS-Ni at 16.65 wt%.

## CONCLUSION

This study aimed to synthesize and characterize PDMS–NiNPs nanocomposite films through I–V characterization. The results indicate that both virgin and doped PDMS films exhibit non-Ohmic behavior. The current (I) demonstrates a strong correlation with the amount of NiNPs in the nanocomposite, with the maximum current observed in the 16.65 wt% NiNPs–PDMS film. Additionally, the I–V characteristic curve shows high sensitivity to temperature, as the current drawn increases with rising temperature. Notably, above the glass transition temperature (Tg), the slope of the I–T curve is greater compared to below Tg.

 

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