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Field and Temperature Effects on DC Conductivity in LDPE Nanocomposites with Varying ZnO NPs Loading

Manisha C. Golchha[1]* and Roshani N. Bhagat[2]
[1]**Department of Physics, Brijlal Biyani Science College, Amravati (MS), India.*
[2]*Department of Physics, Rajarshee Shahu Science College, Amravati (MS), India.*
[1]*E-mail: manishagolchha@gmail.com

Abstract:
Polymer inorganic nanocomposite (PINC) thin films were fabricated using the solution casting method, incorporating low-density polyethylene (LDPE) as the matrix and varying weight percentages (0, 0.5, 1, 3, 5 wt.%) of zinc oxide nanoparticles (ZnO NPs) as fillers. The influence of varying ZnO NPsfiller concentrations on the DC conductivity of LDPE nanocomposites was studied under different temperature and electric field conditions.The results revealed that the conductivity is sensitive toZnO nanoparticle concentration, temperature and electric field, and showing an increasing trend with each. This indicates that ZnO nanoparticles significantly contribute to enhancing the electrical conductivity of the nanocomposites.
Keywords: ZnO NPs, LDPE, PINCs, DC Electrical Conductivity.

Introduction:

Reinforcing agents or nanosized fillers are added to create polymer nanocomposites. Polymer matrices and trace amounts (e.g., a few weight percent of the polymer matrix) of nanometer-sized additives make up polymer nanocomposites. The goal of creating polymer nanocomposites is to enhance the mechanical, thermal, and electrical characteristics of polymers (*Kango S* et al, **2013**).

Over the past 20 years, polymer-inorganic nanocomposites (PINCs) have attracted a lot of scientific and technological attention. High-performance new materials with a wide range of applications can be produced by incorporating inorganic nanoparticles into the polymer matrix. By integrating inorganic nanoparticles into a polymer matrix, the characteristics of the polymer and the inorganic nanoparticles can be combined or improved, enabling the development of new activities for PINCs (*Li S*et al, **2010**).

Polymer inorganic nanocomposites of LDPE and ZnO NPs were prepared with a view that they can exhibit some novel properties. In the present work, ZnO/LDPE nanocomposites were prepared by adding ZnO NPs in different weight % (0, 0.5, 1, 3, 5 wt.%) in LDPE. In this paper, the effect of doping inorganic ZnO NPs on electrical properties of LDPE is reported.

Experimental:

The solution-casting method was employed to fabricate ZnO/LDPE nanocomposite thin films (*Sangawar V S* et al,**2006**). To obtain a clear and viscous solution, granular LDPE was dissolved in xylene at 100°C for two hours using a hot plate magnetic stirrer. The as synthesized zinc oxide nanoparticles (ZnO NPs), having an average crystalline size of approximately 80 nm, were incorporated as fillers in varying weight percentages (0, 0.5, 1, 3, and 5), as documented in*Golchha M C* et al, **2013**. The solution was further stirred at a constant temperature for two hours to ensure optimal dispersion.

Subsequently, the prepared solution was poured onto a sanitized, optically flat glass plate and heated at 80°C for one hour. Once the solvent had fully evaporated, the resulting film detached from the glass surface. The thickness of the samples was measured using a compound microscope and an ocular micrometer with a minimum count of 15.38 µm. All samples were maintained at a uniform thickness of approximately 61.52 µm (*Golchha M C* et al, **2011)**.

Result and Discussion:

DC Electrical Conductivity: The present study is carried out tounderstand the temperature dependence ofelectrical conduction in unfilled and ZnO NPsfilled LDPE thin films. It was also decided tostudy the role of filler molecules when added invarying concentrations to LDPE. Electrical DCconductivity measurement of thin film sampleshas been carried out in the temperature range319 K to 403 K.

Figure 1 illustrates the DC electrical conductivity thermograms, depicted as log σ vs. $10^3/T$ plots, for various samples including unfilled LDPE and LDPE filled with 0.5, 1, 3, and 5 wt. % ZnO NPs. In all these samples, conductivity rises with both temperature and ZnO NPs concentration. As the amount of ZnO filler is increased, conductivity improves. This improvement is attributed to the increase in charge carriers that occurs with the higher concentration of ZnO nanoparticles (*Shrivastava* et al, **2009**).

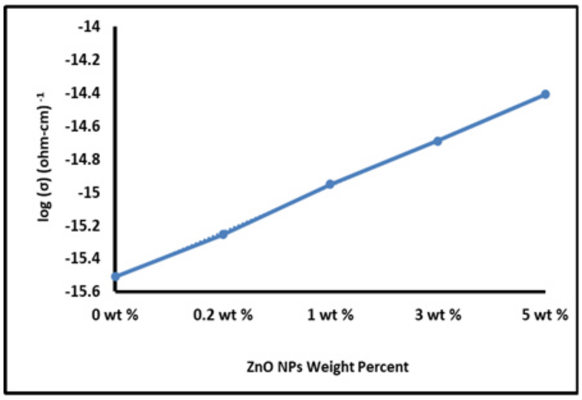

Figure 1: Effect of ZnO NPs filler on DC electrical conductivity of ZnO/LDPE.

Figure 2 displays how DC electrical conductivity varies with changes in the field and ZnO NPs concentration at room temperature. Conductivity increases as both the field and ZnO filler concentration rise. A polymer's side chain, molecular chain, and the border between its crystalline and amorphous regions are where charge trapping occurs. Some extra trapping sites might be created by the strong field used during electret production. Thermal excitation and molecular chain motion that lowers the trap's depth are the causes of the charge release from these traps. The released charge may discharge at the electrodes, recombine, or re-trap in trapping sites. In LDPE, the contact between the amorphous and crystalline phases serves as a charge-carrier trap (*Song S* et al, **2020**).

Both free volume and segmental mobility increase as a result of the temperature increase. These two entities then boost conductivity by allowing free charges to move between sites. Temperature dependence of the conductivity means that more ions obtained kinetic energy by thermally induced hopping of charge carriers between confined sites. (*Cheng Y* et al, **2020**, *Tominaga Y et al,* **2005)**.

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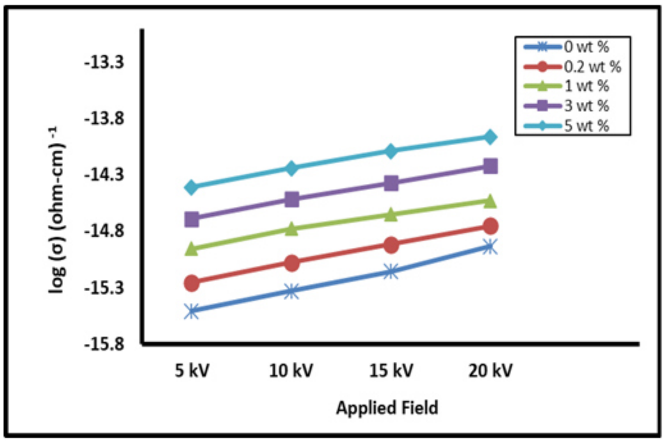

Figure 2: Variation of DC conductivity of ZnO/LDPE with varying Field and filler concentration

Figure 3 shows the effect of temperature with different filler concentrations. The DC electrical conductivity is also temperature-dependent, increasing as the temperature rises.The increase in conductivity at higher temperatures can be linked to the softening effect, which enables the injected charge carriers to move more easily throughout the sample, leading to a substantial current and improved conductivity. As the temperature rises, the LDPE chain becomes more pliable. This conduction mainly results from direct interaction with ZnO particlesas explained by *Twainsi A* et al, **1999** and *Saq-an S A* et al, **2004**.

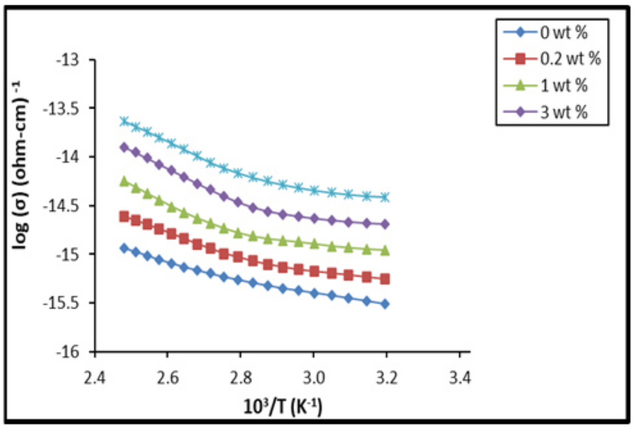

Figure 3: Variation of DC conductivity of ZnO/LDPE with varying temperature and filler concentration.

Conclusion:

The DC electrical conductivities of prepared ZnO/LDPE nanocomposites thin films were determined asa function of filler concentration, temperature and field.DC conductivity was found to increase with increasing filler concentration which may bedue to increase of charge carriers with increasing filler concentration.

The overall conduction mechanism is related to electrons transfer through the ZnO aggregations distributed in the polymeric matrix. The thermoelectrically conduction behavior of the composites is interpreted in the form of variable range hopping mechanism and on the basis of mobility of LDPE chains and to the transfer of electrons through the ZnO NPs aggregations distributed in the polymer matrix.

According to the results, the ZnO nanoparticles doped in LDPE exhibit good compatibility, which affected the material's electrical conductivity characteristics.

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