Charge Transport and Relaxation Dynamics In PVC–PMMA Polymer Composite Thin Films

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doi.org/10.64643/IJIRTV12I9-195737-459

Abstract—Thin films of polyvinyl chloride (PVC)–polymethyl methacrylate (PMMA) polymer composites doped with iodine and cinnamic acid were fabricated using an isothermal evaporation technique. The electrical relaxation behavior of the composites was investigated through current–time (I–t) measurements under sequential forward and reverse DC polarities. The relaxation time (τ) was evaluated from the time required for the conduction current to attain its peak value. Drift mobility (μ) and charge carrier density (n) were estimated using established theoretical models. The obtained relaxation times are in good agreement with previously reported values for similar polymer composite systems. Results indicate that increasing dopant concentration leads to a reduction in carrier mobility due to enhanced trapping and scattering, while simultaneously increasing charge carrier density owing to dopant-induced charge generation. These findings provide insight into charge transport and dielectric relaxation mechanisms in doped polymer composite thin films.

Index Terms—Polyvinyl chloride (PVC); Polymethyl methacrylate (PMMA); Polymer composites; Relaxation time; Dielectric relaxation.

I. INTRODUCTION

Polymer composites have attracted significant attention due to their wide applications in electronic, optoelectronic, and dielectric devices. Among them, PVC and PMMA are widely used because of their excellent film-forming ability, mechanical strength, and chemical stability. Blending PVC with PMMA improves thermal and electrical characteristics while maintaining structural integrity.

Electrical relaxation phenomena in polymer composites provide important insight into charge transport, trapping, and polarization mechanisms. When an external electric field is applied, charge carriers migrate and gradually attain equilibrium, giving rise to time-dependent current behavior known as dielectric or electrical relaxation. Doping polymer blends with additives such as iodine and cinnamic acid modifies their electronic structure, introducing localized states and altering charge transport.

The present work focuses on investigating relaxation mechanisms in PVC–MMA composite thin films by analyzing current–time characteristics, relaxation time, charge carrier mobility, and carrier density as functions of dopant concentration.

II. EXPERIMENTAL DETAILS

2.1 Materials

Polyvinyl chloride (PVC) and polymethyl methacrylate (PMMA) of analytical grade were used as host polymers. Iodine and cinnamic acid were used as dopants without further purification. Suitable solvents were employed to ensure homogeneous mixing.

2.2 Film Preparation

Thin films of PVC–PMMA composites were prepared using the isothermal evaporation technique. The polymer solutions were cast on cleaned glass *substrates and allowed to evaporate under controlled temperature conditions to ensure uniform thickness. Dopant concentration was varied systematically.*

2.3 Electrical Measurements
Aluminum electrodes were deposited on both sides of the films to form a sandwich configuration. Current–time (I–t) characteristics were recorded by applying a DC voltage across the samples. Measurements were taken under both forward and reverse polarities until steady-state conduction was achieved.

III. THEORETICAL BACKGROUND

3.1 Relaxation Time
The relaxation time (τ) is defined as the time required for the current to reach its maximum or steady value after the application of an electric field:

$$\tau = t_{max}$$

3.2 Drift Mobility
The drift mobility (μ) of charge carriers is given by:

$$\mu = \frac{d^2}{V_\tau}$$

were
d = thickness of the film,
V = applied voltage,
τ = relaxation time.
3.3 Charge Carrier Density
The charge carrier density (n) is calculated using:

$$n = \frac{J}{q\mu E}$$

were
J = current density,
e = electronic charge,
μ = mobility,
E= electric field.

IV. RESULT AND DISCUSSION

4.1 Current–Time Relaxation Behavior
Figure 1 shows a typical current–time response of the PVC–PMMA composite film under DC bias. The current increases rapidly at short times due to the movement of free charge carriers and gradually approaches a steady state as trapping and polarization effects dominate.

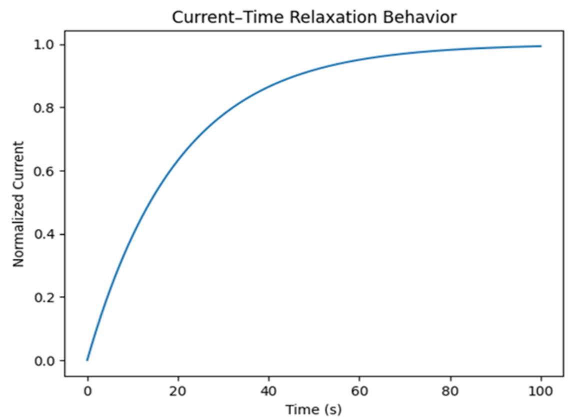

Figure 1. Current–time relaxation behavior of PVC–PMMA composite thin film.

This behavior is characteristic of dielectric relaxation in polymer systems and indicates the presence of space charge polarization and trap-controlled conduction.

4.2 Effect of Dopant Concentration on Mobility
Figure 2 illustrates the variation of normalized charge carrier mobility with dopant concentration. Mobility decreases with increasing dopant content, which can be attributed to enhanced scattering of charge carriers and increased trap density introduced by dopant molecules.

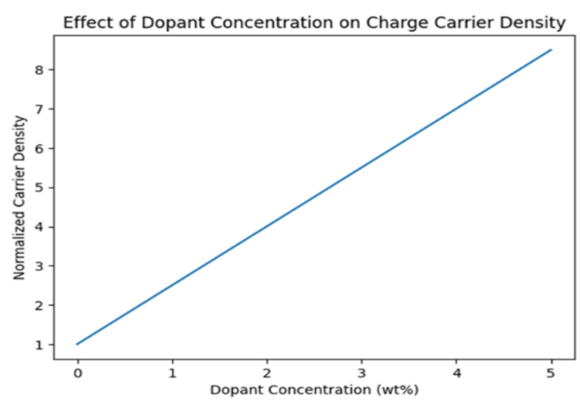

Figure 2. Effect of dopant concentration on normalized charge carrier mobility.

This trend suggests that although dopants introduce additional charge carriers, they also create localized states that hinder carrier transport.

4.3 Charge Carrier Density Variation
Figure 3 shows the dependence of charge carrier density on dopant concentration. An almost linear

increase in carrier density is observed with increasing dopant content.

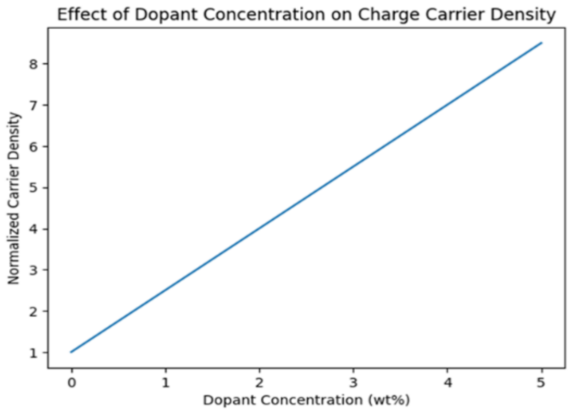

Figure 3. Effect of dopant concentration on normalized charge carrier density.

The increase in carrier density is due to charge transfer interactions between the polymer matrix and dopant molecules, leading to the generation of additional free carriers.

4.4 Relaxation Mechanism

The relaxation process in PVC–PMMA composites is governed by a combination of dipolar orientation, space charge polarization, and trapping–de-trapping phenomena. The obtained relaxation times are consistent with reported values for similar polymer blend systems, confirming the validity of the experimental approach.

V. CONCLUSION

Electrical relaxation studies of iodine- and cinnamic-acid-doped PVC–PMMA composite thin films reveal that:

1) The current–time characteristics exhibit typical dielectric relaxation behavior.
2) Relaxation time values are in good agreement with existing literature.
3) Increasing dopant concentration decreases charge carrier mobility due to enhanced trapping effects.
4) Charge carrier density increases with dopant concentration due to dopant-induced charge generation.

These results demonstrate that dopant concentration plays a crucial role in tailoring the electrical properties of PVC–PMMA polymer composites for potential electronic and dielectric applications.

ACKNOWLEDGMENT

The authors express their sincere gratitude to the Department of Physics and the Department of Chemistry, Mahatma Fule Arts, Commerce and Sitaramji Chaudhari Science Mahavidyalaya, Warud, for providing the necessary laboratory facilities and support to carry out this research work. The authors are also thankful to the Kavikulguru Institute of Technology and Science, Ramtek, and Shri Shivaji Education Society Amravati, Science College, Nagpur, for their cooperation and encouragement during the experimental and analysis stages of this study. Valuable discussions with colleagues and technical staff are gratefully acknowledged.

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