REVIEW ON POLYMER NANOCOMPOSITES AND THEIR PHOTOVOLTAIC PROPERTIES

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Abstract
The increasing global demand for sustainable energy sources has encouraged extensive research into advanced nanocomposite materials for solar energy convert into electrical energy directly. Polymer nanocomposites have emerged as promising candidates because they combine the flexibility and processability of polymers with the superior electrical, optical, and thermal properties of nanomaterials. These hybrid materials have shown significant potential in photovoltaic technologies by improving light absorption, charge transport, and device stability. This review discusses the fundamentals of polymer nanocomposites, fabrication methods, photovoltaic behavior, applications in various solar cell technologies, current limitations, and future research directions.
Keywords: *Polymer, Nanocomposites, Photovoltaic Properties.*

Introduction

The depletion of fossil fuel (non-renewable energy) resources and increasing environmental concerns have intensified interest in renewable energy technologies which can reduce the fuel requirement of the world. Solar energy is considered one of the most abundant and environmentally friendly energy sources available on the earth surface. Conventional silicon-based photovoltaic devices offer high energy conversion efficiencies; however, they are expensive and require energy-intensive manufacturing processes as compared to the solar energy [1-5].

Polymer nanocomposites provide an alternative approach by integrating polymer matrices with nanoscale fillers to produce lightweight and flexible energy-conversion devices as compared to other energy conversion equipment's [6]. Their tunable physical and chemical properties enable improved solar cell performance while reducing production costs as compared to other energies [7].

Discussion

Polymer Matrix Materials: which are commonly used polymers such as Poly(3-hexylthiophene) (P3HT), Polyvinylidene fluoride (PVDF), Polyaniline (PANI), PEDOT:PSS, Polyvinylcarbazole (PVK), etc. These polymers possess semiconducting characteristics suitable for photovoltaic applications [9].

Nanomaterials: which can be frequently used nanofillers like Graphene, Graphene oxide, Carbon nanotubes, Titanium dioxide (TiO_2), Zinc oxide (ZnO), Quantum dots, etc. These fillers increase interfacial surface area and facilitate efficient charge transport of the developed nanocomposite materials [10].

Preparation Methods: The fabrication process strongly influences photovoltaic performance of the synthesized materials [11].

Solution Mixing: Both polymer and nanoparticles are dissolved or dispersed in a common solvent it should be organic media or aqueous media. This method is simple, easy and low cost [12].

Melt Blending: The polymer is heated above its melting temperature and mixed with nanoparticles. This technique is suitable for industrial-scale production [8].

In-Situ Polymerization: Polymerization occurs in the presence of dispersed nanoparticles, resulting in strong interfacial bonding and improved electrical properties [13].

Layer-by-Layer Assembly: Thin layers are deposited sequentially, allowing precise control over thickness and composition [14].

Photovoltaic Properties

1. Enhanced Light Absorption: Nanofillers extend the spectral absorption range, increasing photon harvesting and exciton generation [3].
2. Improved Electrical Conductivity: Graphene and carbon nanotubes create conductive pathways that facilitate electron transport and reduce energy losses [15].
3. Efficient Charge Separation: Polymer nanocomposites suppress electron-hole recombination, thereby improving photocurrent generation [16].
4. Thermal Stability: Nanoparticles improve heat resistance and protect devices from thermal degradation [17].
5. Mechanical Flexibility: Unlike silicon-based devices, polymer nanocomposites can be bent and stretched without significant loss of performance [5].

Applications in Solar Cells

There are various types of solar cells classified below with their advantages;

1. Organic Solar Cells: Polymer nanocomposites enhance charge transport and improve power conversion efficiency [18].
2. Perovskite Solar Cells: These materials are employed as electron and hole transport layers to improve operational stability [19].
3. Dye-Sensitized Solar Cells: Polymer nanocomposites improve ionic conductivity and mechanical durability [20].

Challenges

Despite their advantages, several limitations remain in solar cells materials such as, Nanoparticle agglomeration [13], Moisture sensitivity [17], Oxygen degradation [17], Manufacturing scalability [18], Reduced long-term stability compared to silicon technologies [5].

Future Perspectives

Future research of Polymer Nanocomposites should focus on; Sustainable and biodegradable polymers [2], Improved nanoparticle dispersion [13], Stable perovskite interfaces [19], Roll-to-roll manufacturing technologies [18], Artificial intelligence-assisted materials discovery [2]

Conclusion

Polymer nanocomposites are promising materials for future photovoltaic systems because they combine flexibility, low weight, and enhanced electrical properties. Although challenges remain, ongoing research may enable the commercialization of efficient and affordable flexible solar energy devices.

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