

Future Prospects of Polymer Dielectric Nano-Composite & its Applications

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Polymer Nanocomposites are polymers in which small amounts of nanometer-size fillers have been mixed either by chemical mixing or physical mixing. Nanotechnology is used in many different fields as it gives us many advantages in miniaturization techniques in all fields (instruments). Nano-materials are more effective fillers for the preparation of polymer composites because of their surface properties and high aspect ratio. By integrating two or more Nano-materials with different properties, polymer composites improve performance [1-4].

Because of their robust mechanical properties and high surface-to-volume ratio, nano-composites can be used in a wide range of industries. Compared to traditional composites, nano-composites provide superior performance enhancement in terms of electrical, thermal, and superior mechanical characteristics and barriers. The capacity of a dielectric polymer to sustain an electrostatic field is a crucial characteristic. The remarkable electrical, mechanical, and thermal capabilities of polymer dielectric nanocomposites have drawn a lot of interest recently [5-8].

This review paper is based on earlier research and expects the future scope of practical knowledge. The present work aimed to design various Nano-composite materials that will be guidelines for the scientific and technological communities. The work will also emphasize various devices for characterization techniques with mechanical, optical & dielectric Properties using XRD, SEM, TEM, AFM, FTIR, XPS (ESCA), DSC, TGA, DTA, etc.

Keywords: polymer, nano-composite, dielectric

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1. Introduction of Polymer

1.1 Polymers

A polymer is a large molecule (macromolecule) resistant to Chemicals composed of many repeating units. A polymer is built up by the repetition of small units that can be atoms or small molecules. Polymers are found in nature and are also made by humans. A polymer molecule's number of repeating units can be thousands or even millions [9-10].

1.2 Natural Polymers

Natural polymers include cellulose, proteins, and DNA. Cellulose is the main component of plant cell walls. Proteins are essential for life and are found in all living things. DNA is the genetic material that contains the instructions for building and maintaining life.

1.3 Synthetic Polymers

Humans create synthetic polymers, which are utilized in many different products. Polyester, polyethylene, polypropylene, and polyvinyl chloride are a few examples of typical synthetic polymers. These polymers are used to make plastics, fibers, films, and other materials. Biological Polymers form foundation of Life & Intelligence, which provides food to us.

1.4 Properties of Polymers

The properties of polymers depend on the type of polymer and the structure of the polymer chains. Some common properties of polymers include:

- **Strength:** Polymers can be very strong, especially when they are cross-linked.
- **Elasticity:** Polymers can be elastic, meaning that they can be stretched and deformed without breaking.
- **Durability:** Polymers can be very durable and can withstand a wide range of environmental conditions.
- **Low density:** Polymers are typically low in density, which makes them lightweight.
- **Low cost:** Polymers are typically low in cost, which makes them affordable.

Polymers are classified into three main types: thermoplastics, thermosets, and elastomers.

- Thermoplastics can be melted and reshaped repeatedly. Examples of thermoplastics include polyethylene, polypropylene, polyvinyl chloride, and polystyrene.
- Thermosets can be molded or shaped once, but they cannot be melted and reshaped. Examples of thermosets include epoxy resin, polyurethane, and bakelite.
- Elastomers are elastic polymers that can be stretched and deformed without breaking. Examples of elastomers include natural rubber, synthetic rubber, and silicone rubber.

Polymers are an important class of materials with a wide range of properties. They are used in a variety of products, from clothing and food packaging to cars and medical devices.

1.5 Applications of Polymers

Polymers are used in a wide variety of products, from clothing and food packaging to cars and medical devices. Some common applications of polymers include:

- **Plastics:** Polymers are used to make a wide variety of plastics, including polyethylene, polypropylene, polyvinyl chloride, and polystyrene. Numerous items, such as bottles, bags, toys, and furniture, are made of plastic.
- **Fibers:** A vast range of fibers, such as nylon, polyester, and acrylic, are made from polymers. Fibers are used to make clothing, carpets, and other textiles.
- **Films:** Polymers are used to make a wide variety of films, including polyethylene terephthalate (PET) film and polyvinyl chloride (PVC) film. Films are used to package food, beverages, and other products.
- **Elastomers:** Polymers are used to make a wide variety of elastomers, including natural rubber and synthetic rubber. Elastomers are used to make tires, gaskets, and other products that require elasticity.
- **Composite Materials:** Polymers are used to make a wide variety of composite materials, which are materials that are made from a combination of two or more materials. Composite materials are used to make aircraft, boats, and other products that require strength and durability.

2. Overview of Polymer Dielectric Nanocomposites

Nanocomposites are materials that are composed of a polymer matrix and a small amount of nanoscale filler. The filler can be a metal, ceramic, or other material with high dielectric properties. The addition of a small amount of filler can significantly improve the dielectric properties of the polymer matrix. An ideal high dielectric constant material should have a high dielectric constant, low dielectric loss, good processability, and high break-down strength.

2.1 Importance and Applications Polymer Dielectric Nanocomposites

It found applications in various fields, including energy storage devices, capacitors, high-voltage insulation systems, and flexible electronics. The improved dielectric properties make them desirable for these applications due to their high dielectric constant, low dielectric loss, and enhanced breakdown strength [5-8].

2.2 Objectives of the Review

This review aims to provide an in-depth understanding of the synthesis methods, characterization techniques, properties, and potential applications of polymer dielectric nanocomposites. It also discusses the challenges faced in large-scale production and provides future perspectives in this rapidly evolving field [11-12].

2.3 Properties of Polymer Dielectric Nanocomposites

Adding small amounts of fillers to polymer dielectric nanocomposites can significantly enhance their properties. Improvements include a higher dielectric constant, lower loss tangent, better thermal stability, and increased mechanical strength. These enhancements make the materials more efficient and durable for advanced applications.

3. Materials, Nano-fillers & Methodology

3.1 Basics

Nanoparticles, such as metal oxides (e.g., TiO₂, ZnO), metal nanoparticles (e.g., Ag, Cu), and organic nanoparticles (e.g., carbon black, silica), have been widely investigated as Nano-fillers in polymer matrices.

They offer a large interfacial area and can enhance the dielectric constant and breakdown strength of the nanocomposites. Nanotubes Carbon nanotubes (CNTs) and other nanotubes, such as boron nitride nanotubes (BNNTs) [13-14].

The most recent and ongoing state-of-the-art developments in the creation and preparation of high-k polymer Nano-composites using core-shell Nano-architecture strategies are outlined. Their benefits over conventional melt-mixing and solution-mixing techniques are highlighted in particular. First, even in highly loaded nano-composites, uniform dispersion of nanoparticles is easily achievable. Second, the dielectric constant of nano-composites can be successfully raised while maintaining the high breakdown strength. Third, nano-composites containing electrically conductive nanoparticles can successfully minimize dielectric loss [15-17].

BaTiO₃ (Dielectric ceramics) have giant dielectric constants ranging from several hundred to tens of thousands, have low breakdown strength and high dielectric loss. Small size of the nanoparticles makes it possible to reduce the dimensions of polymer nanocomposites that helps to miniaturization of various electronic devices [18-22].

The inorganic compound barium titanate has the chemical formula BaTiO₃. When formed as big crystals, Barium titanate is clear and has a white powdery appearance. The photorefractive effect is shown by a ceramic substance that is ferroelectric, pyroelectric and piezoelectric. It is utilized in nonlinear optics, electromechanical transducers, and capacitors [23-27].

4. Theory & Applications

Nanotechnology is used for many different things and in many different fields, like computer, biology, medicine, physiology, industry, and any mechanical or chemical field. Another such area is where the use of nanotechnology has recently been introduced and is consistently demonstrated as a means of maximum success. Nano-composite materials are multiphase solids with one, two, or three phases that are less than 100 nm in size, or structures with nanoscale repeat distances between the various phases. In order to design and produce novel materials with previously unheard-of flexibility and physical property improvements, building blocks are utilized[28-30].

Because of their robust mechanical properties and high surface-to-volume ratio, nano-composites can be used in the construction and automotive industries. When it comes to electrical, thermal, mechanical, and barrier qualities, nano-composites outperform traditional composites. In addition to having superior transparency, they also have less flammability. Other applications include electronic covers, power tool casings, and so on.

Applications of Polymer Dielectric Nanocomposites

Polymer dielectric nanocomposites have a wide range of potential applications. Some of the most promising applications as follows:

- **Capacitors:** The high-performance dielectric constant of the filler can increase the capacitance of the capacitor.
- **Insulators:** The high-performance dielectric constant of the filler can improve the insulation properties of the material.
- **Sensors:** The high-performance dielectric constant of the filler can improve the sensitivity of the sensor.

5. Discussion

This review paper provides an overview of the recent advancements in the field of polymer dielectric nanocomposites, highlighting their synthesis methods, characterization techniques, and potential applications. The paper discusses various types of nanofillers used in polymer matrices, such as nanoparticles, nanotubes, and nanosheets, and their effects on the dielectric properties of the composites. Additionally, the review covers the influence of processing techniques, including solution casting, melt blending, and in-situ polymerization, on the final properties of the nanocomposites. Furthermore, the paper discusses the challenges associated with the large-scale production and commercialization of polymer dielectric nanocomposites, along with potential solutions. Finally, future perspectives and emerging trends in this rapidly evolving field are also presented. This review paper aims to provide a comprehensive understanding of polymer dielectric nanocomposites, covering their synthesis, characterization, properties, and applications.

This review paper aims to provide a comprehensive understanding of polymer dielectric nanocomposites, covering their synthesis, characterization, properties, and applications. By exploring the current state of the art, challenges, and future prospects, this review contributes to the advancement and development of this promising field. Researchers, engineers, and material scientists working in the area of polymer nanocomposites will find this review valuable for their investigations and future directions. The study approach is based on earlier research and expectations of practical knowledge. Our study aimed to design various Nano-composite materials that require us in the future. Now a day there is a wide range of Applications of Polymer Nano-composite such as Insulator, Packaging Industry, Energy storage material, Automotive Industry, Medical & life science field (Drugs, Tumor, fracture, Joints), Film casting, Fiber spinning, Acrylic coating, Polyethylene, nylon, PVC pipes etc.

6. Conclusion and Future Perspective

In the current review, 2 nanomaterials generally have a high surface area used as Barium Titanate (BaTiO_3) & Boron carbonitrides have been thoroughly reviewed. Also, polymer matrices such as PEEK (Poly Ether Ether Ketone), PVDF (polyvinylidene Fluoride) & PMAA (polymethacrylic acid) will be thoroughly viewed. Polymer Nano-composite with dielectric materials has a variety of uses today in every field.

Polymer dielectric nanocomposites are a promising new class of materials with a wide range of potential applications. The addition of a small amount of filler can significantly improve the dielectric properties of a polymer matrix. This makes polymer dielectric nanocomposites attractive materials for a variety of applications, including capacitors, insulators, and sensors.

Core-shell strategies have many advantages such as powerful and versatile tools for designing and preparing high- k polymer, high over-all performance, to resolve the well-known paradoxes. The shells act as buffer layers to minimize the local electric field enhancement, to suppress the leakage currents and increase the breakdown strength of the high- k Nano-composites, high dielectric constant, low dielectric loss and acceptable breakdown strength.

There are many Applications of Nano-composites such as:- To make flexible batteries with high power output, Making tumors easier to diagnose and remove, Food Packaging, Automotive engine parts & fuel tanks, Thin film capacitors for Computer chips, Flame retardants, Light emitting diodes, Photodiodes, Photovoltaic solar cells, Medical applications, Bone tissue engineering and regenerative medicine, High-voltage insulation, Corrosion protection, Infrastructure (e.g. seismic retrofit of bridges), Improved barrier properties of membranes (e.g. gas separation or filtration), Thermal barrier coatings for electronic components, Making lightweight sensor (Gas Sensor) etc. [11].

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