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Recent review on metal oxides nanostructures doped polystyrene for biological and industrial applications

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Abstract

Polymers have many applications in various medical and industrial approaches. One of these polymers is polystyrene which has special properties to be considered as promising material in different optics, biomedical, and electronics fields. The addition of metal oxides nanoparticles to polystyrene have huge applications in different approaches. This article includes a recent review on metal oxide NPs doped polymer (such as polystyrene). The previous studies demonstrated the polystyrene nanocomposites comprised numerous applications in the electronics, sensors, optical optoelectronics, and biomedical fields.

Keywords: PS; Nanostructure; Metal oxide; Optoelectronics; Optical approaches

1. Introduction

Researchers in science and technology have been interested in polymeric materials for their numerous uses. This is primarily caused by the materials' low weight, excellent mechanical strength, and optical qualities, which make them multipurpose materials. In light of its use in electronic and optical devices, research on the polymer's electrical and optical characteristics has recently garnered much attention[1]. To better understand the nature of the charge transport that occurs in these materials, electrical properties are one of the most practical and sensitive ways to study the physical mechanisms that determine this prop-polymer structure. In contrast, optical properties focus on improving reflection, antireflection, interface, and polarization properties[2].Polymers are used as insulators because of their high resistivity and dielectric characteristics in a variety of products, such as printed circuit boards, corrosion-resistant electronics, and cable wrapping materials. Electrical gadgets employ polymer-based insulators to separate conductors without allowing current to flow through them. Numerous benefits exist for polymers, including low cost, simple production, adaptability, superior mechanical qualities, and great strength. It is employed in the nanolithography procedure utilized in the microelectronic manufacturing sector. Polymeric nanocomposites, a type of material that has generated a lot of interest recently, are made up of organic polymers with inorganic nanoparticles. Applications for nanocomposites in microelectronic packaging, healthcare, cars, , medication save , injection-molded goods, sensors, membranes, aerospace packaging materials, coatings, fire-retardant, adhesives, consumer goods… etc are extremely promising[3].

2. Polymer structure

The process of continuous connections to a chain or network structure of one or more molecules is known as polymerization. These huge molecules are categorized as monomers, which are the fundamental constituents of all other molecules[4] .Each molecule is composed of a large number of atoms bound together by covalent chemical bonds. The forces that draw molecules in polymers together vary on the kind of polymer. Because polymers are made up of enormous, coupled molecules that are difficult to manage, only a few crystal connections can be observed in polymers

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at low temperatures. A linear chain of molecules can only assemble itself in specific locations in an orderly manner. Polymers have crystalline and non-crystalline areas in their solid form[5].According to their chemical compositions, polymers are divided into three primary types (linear, branched, and cross-linking Polymers). Linear polymers these polymers have a linear structure and are generally thermoplastic polymers. The basic structure of these polymers is a single molecular chain of a certain length connected to each other in a linear form. They are soluble in solvents except for materials with extremely high molecular weight[6]. In the case of branching polymers, some branches form the primary polymer chain. Branching can change the physical characteristics of a polymer, such as its solubility in solvents, softening point, and thermoplastic qualities. The last type is crosslinked polymers. These polymers have a three-dimensional network structure in which chemical linkages are intricately entangled[7].

2.1. Classification of polymers based on source

Polymers may be divided into two types[8]:

2.1.1. Natural polymer

It generally consists of proteins, carbohydrates, cellulose and rubber found in plants and animals, which primarily serve as structural support.

2.1.2. Synthetic polymer

Which constitutes the great majority of industrially necessary polymers including rubber, plastics, and synthetic leather, is created from straightforward chemical components. Other qualities offered by synthetic polymers include thermal stability, mechanical, and physical characteristics.

2.2. Classification of polymers based on thermal response

The following three types of polymers can be categorized based on how temperature affects them:

2.2.1. Thermoplastic Polymers

When the temperature rises, the molecules in thermoplastic polymers become elastic and sticky because they are held together by relatively weak intermolecular interactions (Vander - Waals forces), and when the temperature falls, they revert to their former condition. As with polyvinyl alcohol, polyethylene, polypropylene, and polystyrene, these molecules move across one another when heated[9].

2.2.2. Elastomers Polymers

Elastomers are a type of network polymer that is weakly cross-linked and may be reversibly expanded to extraordinary lengths. When not under stress, their molecules are incredibly tightly and randomly coiled before expanding. Stretching polymers causes them to bend. As a result, the chains are less random, which lowers the material's entropy. This entropy drop is caused by the retroactive force that has been seen. Cross-links prohibit molecules from passing one another when a material is expanded. As the rubbers cool, they get glassy or crystal transparent (partially). They don't flow when heated because of cross-links in the conventional sense[10].

2.2.3. Thermosetting Polymers

When heated, a type of synthetic polymer known as thermosetting polymer undergoes chemical processes to generate a three-dimensional networked structure. This procedure produces a material that is insoluble and infusible; these properties are a direct outcome of the 3D network composed of covalent bonds. Because of this, thermosets cannot be reformed or remolded using heat or solvents as thermoplastics can. Thermosets include some kinds of crucial polymers for technology[11].

2.3. Classification of polymers based on homogeneity

Polymers are classified based on the homogeneity of the repeater units to:

2.3.1. Homo polymers

Polymers made from a single monomer species called the homo polymer ,example for this is polyvinyl chloride(PVC)(monomer is vinyl chloride)[12].

2.3.2. Copolymers

Copolymers are made up of two units of duplicating units of different monomers. It is classified as random, alternative, block, and graft copolymers. An example of this is polyethene-vinyl acetate. (PEVA) [13].

2.3.3. Composite polymers

It is The process of modifying the characteristics of homogenous polymers by including new materials and formulas.[14].

3. Nanocomposites and some Applications

Generally speaking, nanocomposites outperform traditional composites in a variety of ways, including by enhancing the physical, electrical, optical, and thermal properties, among others[15].In addition to being light in both weight and size, a nanometer (nm) is one billionth of a meter. As a result, nanomaterials are substances whose smallest unit has a size between (1-100) nanometers[16,17].Their powers are so promising that they might be employed in a variety of applications ranging from packaging to healthcare. These high-performance materials have exceptional property combinations and unique design options. Their potential is so promising that they are useful in various applications, from packaging to biomedical. Materials may show new properties, such as electrical conductivity, insulating properties, elasticity, improved strength, a different colour, and enhanced reactivity, with just a reduction in size and no alteration to the material itself.[18]. However, polymer nanocomposites are at the forefront of applications due to their more advanced stage of research[19].Additionally, nanomaterial-based composites can offer a variety of multifunctional qualities, including stability thermal, electronic qualities, field emission, optical quality, increased material durability, impact resistance, absorb energy and others [20]. There are many studies on properties of composites and nanocomposies included optical properties[21-34], electrical and dielectric properties[35-40], to employ in various applications involved sensors and piezoelectric[41-57], biomedical[58-64], radiation shielding and environmental[65-77], electronic and optoelectronics[78-100], and energy storage[101-104].In (2015), M. Awad *et. al* [105], studied the antibacterial activity of a silver/polystyrene nanocomposite against both bacteria(positive and negative) grams. This suggests that the nanocomposite might be used in pharmaceutical, biological, and industrial domains, such as bandages, wound dressings, and dental instruments. Furthermore, the uses include food and water storage, as well as wastewater treatment. In (2016),M. Al-Saleh and J. Abdul[106],prepared the Graphene nanoplatelet–polystyrene (GNP–PS) nanocomposites using melt-mixing. Used the microstructure, direct current electrical percolation behaviour, and dielectric properties for studied the frequency. The electrical percolation curve demonstrated a constant change from insulation to conduct. The nanocomposite showed exceptional storing capacities at high frequencies. In (2016),H.Shanshool, *et. al*[107], omposed polymer matrix(PMMA-PVDF-PVA-PS), while the filler is of ZnO nanoparticles in various concentrations.transmittance is low inThe UV regions, as seen in UV-visible transmittance spectra, which are inversely proportional to ZnO nanoparticle concentration. . As the weight % of ZnO nanoparticles in nanocomposites increased, the energy gap values decreased for all samples. In (2017), X. Zhang, *et. al*[108], studied the $SrTiO_3$/epoxy nanocomposites created by adding $SrTiO_3$ nanoparticles of various weight fractions to the epoxy resin host, the shape of the nanoparticles and composites, and their electrical and thermal conductivity qualities. As the weight fractions increased, the dielectric constant also and the frequency dropped. The tests revealed substantial improvements in the composites' thermal and electrical characteristics. In (2017),S. Moharana, *et. al* [109], used solution casting techniques to prepare the three-phase PS-BFO-GNP nanocomposite films with GNP acting as a conductive filler. It was discovered that adding GNP to the matrix of PS-BFO nanocomposites may significantly increase their dielectric constant.The improvement in dielectric and ferroelectric characteristics supports the prospect of end-use usability as a new class of polymer-based materials for electronic device applications. In (2018), G.Soni*et. al*[110] ,used the solution casting process to create thin films of PMMA polymer doped with SiO_2 with a thickness of 60 microns, and then they examined the addition of nanoparticles to the electrical and structural characteristics of the thin films. The optical bandgap decreased as the quantity of SiO_2 nanoparticles increased. In (2020), L. Weng, *et. al*[111].studied the PVDF/Ag-SiO_2 nanocomposite's high dielectric properties. This resulted in the Ag-SiO_2 having a rise in dielectric constant and low electrical conductivity dependent on frequency. They can get Ag-SiO_2/PVDF composites of frequency constant in electrical conductivity by the concentration of nanoparticles.Ag-SiO_2/PVDF composite materials may be used as material for energy storage. In (2020), G. Soni, *et. al*[112] ,studied the impact of a mixture of ZnO and SiO_2 nanoparticles on the optical properties of a solution-cast composite thin film PMMA/ZnO/SiO_2, with a thickness of 50 μm, and discovered that the optical bandgap of the composite thin films decreases with increasing concentrations of zinc oxide and silica. In (2021), L. Gaabour[113], studied the impact of adding titanium oxide nanoparticles (TiO_2) to a polymer mix of polystyrene (PS) and polyvinyl chloride (PVC) with a composition of 50/50 wt.%. Using new methods, the produced polymer nanocomposite films' structural, optical, and dielectric characteristics are examined. Refractive index, optical dielectric (constant and loss), and other optical characteristics including absorbance, reflection, bandgap energy, and others are examined. These findings demonstrated that interband between the valence and conduction bands are produced by TiO_2.Because of charge carrier accumulation and improved polymeric chain motion inside the polymeric matrix, adding TiO_2 to the PS/PVC increase the PS/PVC electrical conductivity. In (2022) , M. Meteab ,*et .al*[114] , studied the structural and dielectric characteristics of (PS-PC/Co_2O_3-SiC) nanocomposites. The FTIR measurements demonstrated that the polymer matrix and (Co_2O_3/SiC) NPs do not interact chemically. The dielectric characteristics were investigated at frequencies ranging from 100Hz to 5×10^6Hz. According to the results of the dielectric characteristics, the dielectric constant and dielectric loss of (PS-PC/Co_2O_3-SiC) nanocomposites as the concentration of (Co_2O_3/SiC) NPs increased. However, they dropped as the frequency increased. The frequency and concentration of (Co_2O_3/SiC) NPs increase with the A.C conductivity of (PS-PC/Co_2O_3-SiC) nanocomposite.

3.1. Polystyrene (PS)

Polystyrene is a versatile polymer with the following properties: transparency, ease of coloring and processing, and cheap cost. PS is a transparent stiff polymer that is resistant to a wide range of chemicals. PS has excellent flow properties and is hence very straightforward to process. It is valuable in optical and insulation applications due to its outstanding optical qualities, which include a high refractive index and strong dielectric properties. Packaging, housewares, toys, electronics, appliances, furniture, and building and construction insulation are among the applications of polystyrene[115]. PS is one of the greatest polymers, Its properties may be altered in a variety of ways, including physical mixing with other materials and copolymerization[116]. Because PS is amorphous, it lacks a clear melting point. This is seen by the material gradually deteriorating across a wide temperature range. While PS has a low intrinsic fire resistance and burns easily, starting flames long after the ignition source has been removed, polystyrenes respond well to high-energy radiation. PS is a superb insulator with high dielectric resistance, moderate stiffness, and a low loss factor even in wet conditions[117]. Table (1) shows some of the physical properties of PS[118], and figure (1) shows the chemical structure of polystyrene[119].

Table 1 The physical properties of (PS) [120]

Parameters	**PS**
Chemical formula	(C8H8) n
Density	(1.04 - 1.09) g/cm3
Refractive index	59.1 - 60.1
Glass transition degree (Tg)	100 C0
Melting point (Tm)	240 C0
Tensile strength	(46–60) MPa

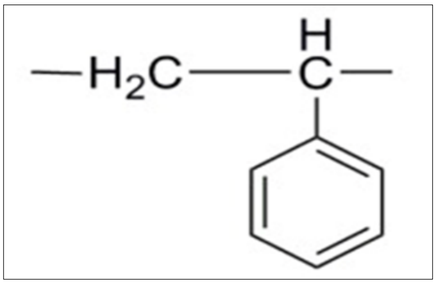

Figure 1 Chemical structure of PS[121]

3.2. Silica (SiO_2) Nanoparticles and its Properties

Silica or Silicon dioxide is a silicon oxide with the chemical formula (SiO_2).Silica nanoparticles (SiO_2) are an intriguing material because of its thermal and chemical stability, low toxicity, ability to be functionalized with a range of chemicals and polymers, biocompatibility, physiological degradability, low cost, and so on. Nano-silica may also be widely used in a variety of different environmental protection sectors, such as batteries, paints, cosmetics, glass, steel, chemical fibers, plexiglass, and many more. Rubber and polymers containing silica nanoparticles offer much higher strength, hardness, wear, and aging resistance[120]. The addition of (10nm) SiO_2 to PS increased its hardness and thermal stability[121].Table (2) shows some properties of SiO_2[122]

Table 2 Some properties of SiO_2 [122]

Chemical formula	**SiO_2**
Particles size	5–10 nm
Density	2.4 g/cm3
Color	White
Specific surface area (BET)	180 m2 /g
Purity (based on metal)	> 99.9%
Refractive index	1.544

3.3. Strontium titanate ($SrTiO_3$) Nanoparticles and its Properties

Strontium titanate ($SrTiO_3$) nanoparticles are incipient ferroelectric materials because their ferroelectricity is preserved at low temperatures by quantum functions. They are recognized for their ability to serve as high-temperature resistive oxygen sensors and transition to non-ferroelectric characteristics at lower temperatures.$SrTiO_3$ has a high dielectric constant. Their unique properties, which include high breakdown strength, low leakage current density, low dielectric loss, tuneability, and high dielectric constant[123].$SrTiO_3$ has potential use in environmental cleaning and renewable energy generation[124].has improved corrosion resistance, , and other advantages Due to its excellent properties, $SrTiO_3$ may be employed in oxygen sensors,, organic thin film transistors, dye-sensitized solar cells (DSSCs), and other applications[125].Table (3) show some properties of $SrTiO_3$[126].

Table 3 Some properties of $SrTiO_3$[126]

Chemical formula	**$SrTiO_3$**
Melting point	2080°C
Refractive index	2.31-2.38
Density	5.2 g/cm^3
Color	Gray/White off
Purity	>99.9 %

4. Conclusion

This work involved a recent review on metal oxide NPs (like $SrTiO_3$ and SiO_2) doped polymer (such as polystyrene). The previous studies showed the polystyrene nanocomposites have numerous applications in many fields included: electronics, optical optoelectronics, and biomedical fields.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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