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A Review on Physical Properties and Wide-Ranging Applications of Conductive Polymers

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Abstract: *Polymer science was developed by industrial laboratories of international renown in order to produce and comprehend novel plastics, rubber, adhesives, fibers, and coatings. Polymer-nanoparticle composites are highly regarded by researchers due to their hybrid and synergistic characteristics. These substances demonstrate unique mechanical, electrical, optical, and thermodynamic characteristics whether in solution or in bulk. It is improved by nanoparticles, polymer-particle interaction, and dispersion. Additions of nanoparticles and polymers require less dosing than conventional additives. Light scattering caused by the reinforcement of microparticles diminishes optical clarity. Dispersion of nanoparticles and interfacial adhesion of polymers and particles serve to reduce scattering and produce films, coatings, and membranes that are both transparent and robust. The classification of polymers is based on their dimensions and physical composition. Size has a significant effect on the properties of polymers. Polymers, as opposed to metals and ceramics, consist of macromolecules. The weight average molecular weight of covalently bonded, long chain macromolecules governs their spin, blast, deep draw, and melt-formability. As an active material, nanostructured substances can produce superior devices. Currently, engineering, physics, chemistry, and biology conduct research into nanoscience and nanotechnology. Scientific and technological attention has been directed towards semiconductor nanoparticles due to their adjustable optical and electrical characteristics, as well as their potential applications in solar cells, light-emitting diodes, and bio-labels. This article discusses the properties and applications of polymer thin films.*

Keywords: Nanoparticles, Green Polymers, and Polymers

I. INTRODUCTION

Polymers are macromolecules made of several monomers, tiny molecules that may form lengthy chains. Polymers are mostly connected similar or identical elements. Polymerization is the process of small molecules becoming big ones. Most polymers have tens of thousands of monomers. Polymers are macromolecules due of their size. Polymers have long been used to make lubricants, oils, tars, and resins. The industrial revolution sparked the contemporary polymer industry. Charles Goodyear developed vulcanized natural rubber in the late 1830s. Celluloid did well commercially 40 years later. However, polymer research made little headway until the 1930s, when vinyl, neoprene, polystyrene, and nylon were invented. These groundbreaking materials spurred a polymer research frenzy. Most industries use polymers like rubber, cotton, wool, Teflon, and all plastics, which have unmatched qualities. Natural and synthetic polymers have various features, including stiffness, strength, heat resistance, density, and cost. Polymers' research and use are increasing their social importance. Polymer science was born in industrial labs worldwide to develop new plastics, rubber, adhesives, fibers, and coatings. Polymer science became academically interesting later. Polymer science, which combines chemistry, chemical engineering, and material science, may be multidisciplinary due to its youth (2). Trade magazines sometimes call polymers resins, an old word that predates understanding the chemical nature of long chains. Polymers start from cotton, cellulose, proteins, and fiber. The 21st century produces synthetic polymers (3). The polymer chain is shown in Figure 1.

Ex: $n\,(H2C = CH2) \rightarrow -CH2 - CH2 - CH2 - CH2 -$

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Ethene (Monomer) Polythene (Polymer)

Due to its synergistic and hybrid features from several components, polymer–nanoparticle composite materials have excited many researchers in recent years. These materials have unique mechanical, electrical, optical, and thermal characteristics in solution or bulk. The presence of the nanoparticle, polymer-particle interaction, and dispersion cause such improvements. Compared to typical additives, nanoparticles and polymer additives have reduced loading needs. Microparticle reinforcing agents scatter light, diminishing optical clarity. Effective nanoparticle dispersion and polymer-particle interfacial adhesion reduce scattering and enable strong, clear films, coatings, and membranes.5. Polymer composites combine polymer resins like polyester, vinyl ester, and epoxy with fillers and reinforcing fibers to create a bulk material with greater qualities than the basic materials. Fillers are used to add bulk, reduced cost, density, or aesthetics. Polymers are reinforced with fibres to increase stiffness and strength. High-strength glass, aramid, and carbon fibres bear weight, while polymer resin protects and bonds them. Such materials are termed fibre composites.6.

Proteins, polysaccharides, and nucleic acids are essential to live organisms. To fulfill commercial and scientific needs, synthetic polymers that imitate biopolymers have been created into various functional forms. Synthetic polymers are categorized by chemical characteristics. Some of these polymers have unique chemical characteristics and are used in many fields. Based on their physical or chemical features, these polymers are called stimuli-responsive, smart, intelligent, or environmental-sensitive7. This review will refer to such polymer systems as smart polymers. Their smarts come from their capacity to adapt to little environmental changes. Fast macroscopic changes in structure and reversible transitions make these materials special. Changes in shape, surface properties, solubility, complicated molecular assembly, sol-to-gel transition, and others are seen. Temperature or pH shift, ionic strength rise, metabolic chemicals, oppositely charged polymer addition, and polycation-polyanion complex formation may cause these transitions8. Recently, electric and magnetic field, light, and radiation forces have been described as stimuli for these polymers. Temperature, electric or magnetic fields, and mechanical stress impact energy sources and molecular interactions at crucial onset points. They change microstructure quickly and reversibly from hydrophilic to hydrophobic. Macroscopic alterations include precipitate development from a solution or order-of-magnitude changes in stimuli-responsive hydro gel size and water content. The phase transition may need a polymer molecular structure with the right balance of hydrophobicity and hydrophilicity9-11.

Laser ablation of polymers was originally described in 198212, 13 and quickly became a research concern14. Laser ablation was once considered a viable alternative to photolithography due to its fewer processing steps, but commercially available polymers like PMMA, PI, and PC have prevented its use.15. Low sensitivity, carbonization upon irradiation, and ablation debris fouling the surface and optics are major downsides of these polymers. Thus, innovative photopolymers were created to address these limitations16. Polymers are designed using photochemical concerns. They were developed for 308 nm irradiation since not all photolithographic procedures need sub-micrometer precision and photo chemically active groups may be separated from other polymer structure absorption. This notion may be utilized to examine if photochemically active groups in polymer chains enhance ablation. The extended lifespan of gas fills and laser optics makes the XeClexcimer laser (308 nm) fascinating technically. Adding the photochemically active chromophore to the main polymer chain is the most promising way to build ‘laser ablation polymers’17.

Properties of Polymers

Polymer properties can be classified into various groups according to their physical foundation and the scale at which they are defined (18). The identity of its constituent monomers is the most fundamental characteristic of a polymer. An additional category of characteristics, referred to as microstructure, pertains to the configuration of these monomers along a single chain within the polymer. The fundamental structural characteristics significantly influence the overall physical characteristics of the polymer. The physical characteristics of a substance are significantly influenced by its dimensions. The size of a polymer can also be quantified using its molecular weight. The chemical characteristics of polymer chains significantly influence the properties of the polymer. Due to the extremely long length of polymer chains, these exchange forces are significantly stronger than the attractive forces between conventional molecules. The presence of distinct side groups on a polymer can facilitate ionic or hydrogen bonding between its molecules. As a consequence of these more formidable forces, tensile strengths and crystalline melting points are generally elevated.

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A number of researchers have become intrigued by polymer-nanoparticle composite materials in recent years on account of the hybrid and synergistic properties that result from the combination of multiple components. Whether present in bulk or in solution, these substances possess distinctive mechanical, electrical, optical, and thermal characteristics. The aforementioned improvements are stimulated through the interaction between the polymer and the nanoparticle, the physical presence of the particle, and the state of dispersion. One apparent benefit of nanoparticles as polymer additives is that loading requirements are considerably lower than those of conventional additives. Light is scattered by microparticles employed as reinforcing agents, resulting in a decrease in both light transmittance and optical clarity. The integration of effective nanoparticle dispersion and favorable interfacial adhesion between particles and polymers eliminates scattering and presents a promising opportunity to fabricate films, coatings, and membranes that are both transparent and durable (20).

Physical properties

Optical glass density: Hundreds of varieties. Catalogs provide a variety of optical, physical, thermal, and chemical glass varieties. These materials have 2.3 to 6.3 g/cm3 densities. The heaviest optically viable polymer weighs 1.4 g/cm3, while the lightest floats in water at 0.83 g/cm3. Non-spherical surfaces may lower the element count of an optical system, everything else being equal. Overall, polymeric optical systems may be made lighter than glass ones, particularly if aspheric technology is used on the optical trains21.

Hardness: Cosmetic flaws seldom affect picture quality, but optical surfaces should be clear of scratches and pits. Normal use, including cleaning, might cause scratching over time. Most optical glasses are hard enough to avoid damage with a little care. However, polymeric optical materials are soft enough to permanently imprint with a thumbnail. Polymeric optics hardness is material- and processing-dependent, making it challenging to define. Handling practices that would not harm a glass element may cause significant abrasion on a polymeric surface, especially a thermoplastic. Because most thermoplastic polymers shrink, hard surface coating support is low enough to defend against just superficial abrasion. These issues are irrelevant if the dubious surfaces are internal and inaccessible.

Rigidity: Young's modulus, or elastic modulus, is connected to hardness. This number and the yield elongation factor determine impact resistance, where polymers outperform glasses. Again, these attributes rely on the polymeric alloy, additives, and manufacturing history and cannot be cited. Torsion or compressive stress may degrade impact resistance in optical parts. Since optical surface profiles must typically be subwavelength accurate, poor thickness/diameter ratios or severe retaining ring compression may cause optical figure deformations. Avoid discussing polymer optics with polymer chemistry, which is complicated. However, several chemical subgroups have been added to carbon-based polymers. Unfortunately, few of these materials are regularly produced and just a few have imaging-friendly optical properties22, 23.

Additives: Polymers are normally available in a variety of melt flow grades, each of which possesses viscosity properties best suited to use in parts having specific form factors. A number of additives are commonly present in these materials. Such additives may or may not be appropriate in an optical application. Additives for such things as flame retardancy, lubricants, lubrication and mold release are best avoided if not included to address a specific requirement. Frequently, colorants are added for the purpose of neutralizing the naturally occurring coloration of the material. These additives create an artificial, but clear, appearance. The colorants must, of course, absorb energy to accomplish this, resulting in a net reduction in total spectral transmission.

Radiation Resistance: If exposed to extreme high-energy radiation, most optical polymers glow. High-energy UV and ionizing radiation produces different quantities of polymer chain cross linking depending on polymer chemistry. Cross connecting usually causes discolouration and uneven energy absorption. Cross linking can be prevented by adding inhibitors to polymers, however interestingly, polymers most vulnerable to UV-induced discolouration are least susceptible to ionizing radiation and vice versa.

Optical properties

Variations: Since most polymers were designed for different purposes, their optical properties are a lucky accident. Eyeglass and optical information storage materials may be exceptions. When citing optical parameters for polymeric materials, be careful since melt flow grades may have somewhat differing refractive index qualities. Lubricity, color, and other additives may modify spectral transmission somewhat.

Spectral Transmission: Visible-wavelength carbon-based optical polymers absorb heavily in the ultraviolet and infrared. However, absorption spectra in many publications do not show this. For chemical structure identification, spectroscopists produce such data from thin samples. This suggests that polymers transmit effectively over a broad spectral range. Although described in the lab, most of these polymers are not commercially accessible. Transmission data from thick samples is essential for optical design and imaging. Some poly-methylmethacrylate formulations transmit down to 300 nm. Most optical polymers absorb in the blue area of the visible spectrum and have further absorption zones at 900, 1150, and 1350 nm before becoming opaque at 2100 nm. The chemical structure that creates these absorption zones is typical to most carbon-based polymers, therefore their internal transmittance properties are identical, except for the blue and near-UV regions. Few polymers show discontinuous narrowband transmission leakage in the far-infrared, but only in filter thicknesses24-26.

Homogeneity: It must be remembered that polymeric optics are molded, not machined. Thus, optical characteristics cannot be measured before element production. The bulk material's optical characteristics in an optical element are almost always a result of both the material and the manufacturing process. Crystalline materials like styrene and butyrate resins are birefringent. Birefringence may arise in amorphous materials if the injection mold and process parameters are not adjusted. The bulk scatter qualities of a molded optical element depend on the material's intrinsic properties, plus the manufacturing cleanliness and heat history of the completed component.

Electrical properties

Electrically conductive polymer composites (CPCs) are often made by adding metal particles, carbon black, graphite, or carbon nanotubes to the polymer27. Conductive polymers were also projected to have several uses in the recent decade. Conductive polymers may replace inorganic materials because their conjugated double-bond chain structure gives them excellent electrical characteristics and a broad color range. They are insoluble, infusible, and unprocessable owing to strong intermolecular interactions. Thus, melt mixing or solution casting of high-quality conducting mixes with standard polymers is still under development28. Polyaniline (PANI) and polypyrrole (PPy), conjugated conducting polymers with excellent conductivities and environmental, thermal, and chemical stability, are of great interest globally. whereas doped, these polymers have electrical conductivities between 10-5 S/cm and 102 S/cm, whereas conventional insulators have conductivities below 10-12 S/cm. PANI and PPy29 may be protonated to increase nanometer-scale solubility in organic solvents and compatibility with matrix polymers.

For film, fiber, and coating applications, these conducting blends or composites offer several intriguing features. Conducting polymers may be used in EMI shielding, transparent packaging of electronic components, solar batteries, nonlinear optical display systems, ‘smart’ textiles and recording, and more. Cambridge Display Technologies (CDT) detected conjugated polymer electroluminescence, which might expand OLED markets30. This light-emitting polymer (LEP) technology might provide flexible, full-color screens with excellent luminescence, low power consumption, and cheap cost. However, Clemson, Furman, and Ga. Tech. labs are studying chameleon fibers that change substrate color when electrically charged. These intelligent textiles made of conductive materials were direct surface coated or in-situ polymerized on textile substrates31.

Polymers are widely used in electrical and electronic areas because they are electrical insulators. However, material designers have tried to integrate polymers' manufacturing adaptability with metals' electrical characteristics. In applications including antistatic materials, low-temperature heaters, electromagnetic radiation shielding, and electric field grading, polymers with higher conductivity or permittivity are needed. The extrinsic technique of combining an insulating polymer with a conductive addition is most typically used to dramatically modify its electrical characteristics. The conducting component is added to polymers at levels that keep the composite electrically insulative and at higher levels that make it (semi)conductive32. Many engineering disciplines are interested in metal-filled polymer composites. Because such composites have electrical properties similar to metals but mechanical qualities and manufacturing processes like plastics33, they are of interest. Many variables affect the metallic properties of such composites, and managing their electrical and physical qualities dictates their application range. In the heterogeneous polymer-filler system, where scattered metallic or carbon filler forms the conductive phase, electric charge and heat flow conditions dictate electrical and thermal conductivity. Many studies have examined how polymer matrix and filler affect composite electrical properties34, 35.

Thermal conductivity

An important material feature is thermal conductivity, which measures how easily warmth is transported. Low thermal conductivity materials are insulators while high conductivity materials are conductors. Solid conductors like metals have thermal conductivities of 10–400 W/°C m, whereas insulators like polymers, glasses, and ceramics have 0.1–2 W/°C m. Thermal conductivity is a weak function of temperature and seldom varies by 10 in a wide class of materials. Thermal conductivity is crucial to assessing a material's suitability. In many situations, a textbook number or one measurement near the usage temperature is enough to decide. However, certain materials' compositions vary substantially enough to demand frequent thermal conductivity measurements36.

Classification of Polymers

Different types of polymers exist. Polymer categorization is in Fig. 2.

Classification on the basis of source

1. Natural polymers are present in nature.

Starch, cellulose, proteins, nucleic acids, natural rubber

2. Synthetic polymers are man-made.

Polyethylene, Bakelite, PVA, Terylene

Classification on the basis of structure

Linear Polymers: Monomeric units create long straight chains in Linear Polymers. Examples: HDPE, Nylons, Polyester

Branched chain Polymers: Branched chain polymers are mainly linear in nature, but also possess some branches along the main chain.

Ex: Low Density Polythene (LDPE), Glycogen, Amylopectin

Three-dimensional network Polymers: Three-dimensional network polymers have solely covalent connections between monomer monomers. They are huge molecules with strong cross-links that impede monomeric unit mobility.

Ex: Bakelite, Urea-formaldehyde, Melamine formaldehyde

Classification on the basis of their methods of synthesis

Based on the modes of synthesis, the polymers have been classified into two groups.

Addition Polymers: Addition Addition polymerization produces lengthy chains of polymers by repeatedly adding monomers.

Ex: Polyethylene, Polypropylene, Polystyrene, etc.

Condensation Polymers: Using two monomers, condensation reactions produce polymers.

Ex: Nylon-6, Bakelite, Polyester, etc.

Classification on the basis of their growth polymer chain

Chain growth polymers: Monomer units are added to the reactive intermediate-carrying developing chain to generate chain growth polymers.

Ex: Polyethene, Polypropylene, Polystyrene, etc…

Step-growth Polymers: Step-growth Polymers are formed through a series of independent reactions involving bond formation between two different monomers with loss of small molecules like H_2O, HCl, and NH_3etc.

Classification based on molecular forces

On the basis of magnitude of inter molecular forces present in polymers, they are classified into four categories.

Thermoplastics: Thermoplastics soften when heated and harden when cooled due to weak intermolecular interactions. Most linear, somewhat branched polymers are thermoplastic. Every major thermoplastic is made using chain polymerization. Food packaging, insulation, bumpers, and credit cards are examples.

Thermosets: Heat cannot form thermosets. Most thermosets are three-dimensional networked polymers with substantial cross-linking. Thermosets are robust and lasting because cross-linking stiffens the chains. These are mostly utilized in cars and construction. Make toys, varnishes, boat hulls, and glues using them.

Elastomers: Elastomers are rubbery polymers that stretch readily to many times their unstretched length and quickly return to their original proportions when tension is relieved. Low cross-link density elastomers are cross-linked. Low crystallinity and above Tg are required for elastomers. Rubber bands and elastics are elastomers37.

Fibers: Numerous synthetic fiber polymers are comparable to plastic polymers. Fibers often have an aspect ratio of 100. Denier measures fiber thickness. Denier measures fiber linear mass density. Definition: mass in grams per 9000m. Kevlar, carbon, PE, PTFE, and nylon are synthetic fibers; silk, cotton, wool, and wood pulp are natural38, 39.

Structure of Polymers

Their macromolecular nature distinguishes polymers from ceramics and metals. Covalently bound, long chain macromolecules have a weight averaged molecular weight that influences their processability, such as spin, blow, deep draw, and melt-formability. The average molecular weight influences mechanical strength, and greater molecular weights improve strain to break, impact resistance, wear, etc. Since large molecular weights cause high shear and elongational viscosities that render polymers unprocessable, natural limitations are reached. In addition to rubbish bags, polyethylene is used to make high-performance fibers42 and bulletproof vests. These high-performance fibers, with moduli of 150 GPa and strengths of up to 4 GPa, maximize the potential of polymers' molecular structure and low density. Considering polymers, it becomes evident why living nature employed them to create its structures, not only in high-strength materials like wood, silk, or spiderwebs43.

Nano Polymers

Nanostructured materials may be used to make better active devices. Nano science and nanotechnology, which includes physics, chemistry, biology, and engineering, have become prominent fields of study. The term nano comes from Greek "dwarf". 10-9 units are prefixed with it. Nano science studies nanoscale matter characteristics and utilizes them to produce new structures, technologies, and systems. Particles under 100 nm are termed nanoparticles. They offer unique features owing to their tiny size and are valuable in various applications. Nanometer-level measurement and manipulation are enabling novel materials with improved mechanical, optical, transport, and magnetic capabilities. Polymers or copolymers with nanoparticles are polymer nanocomposites (PNC). These may vary in form, but one dimension must be 1–50 nm. PNCs are multi-phase systems that use 95% of plastics manufacture. Controlled mixing, stability, orientation, and compounding procedures are identical for all multi-phase systems, including PNC. Changing from micro to nano particles changes their physical and chemical characteristics. Increased particle size and surface area-to-volume ratio are key effects. As particles become smaller, the surface area-to-volume ratio rises, making atoms on the particle's surface more dominant than those within. When particles react, this modifies their characteristics. Nanoparticles' increased surface area promotes interaction with other particles in the mixture, increasing strength, heat resistance, and other factors44. Silicon nanospheres, a nanopolymer, are 40–100 nm in size and considerably harder than silicon, between sapphire and diamond45.

Semiconducting Nanopolymers

Due to their size-tunable optical and electrical characteristics and possible uses in solar cells, LEDs, and bio-labels, semiconductor nanoparticles (NPs) have garnered scientific and technical attention46. These particles' production and characterization are crucial for optical device improvement. In quantum dot applications and research, zinc selenide (ZnSe) is a common and significant crystalline material47. Wide band gap (2.69 eV) semiconductor ZnSe has a significant binding energy and a tiny exciton (3.8 nm Bohr radius at ambient temperature). ZnSe, having a higher energy valence band-edge than ZnS48, should perform better. Thus, ZnSe is an effective host for doping transition-metal ions to change characteristics. Doped semiconductor nanoparticles are a novel family of materials with several uses in sensors, displays, electrical devices, lasers, and nonlinear optical devices.49. Due to their high surface-to-volume ratio, semiconductor nanoparticles' characteristics rely on shape and size. Stabilizer polymers are used to make semiconductive nanoparticles. The semi-crystalline, water-soluble, low-electrical conductivity polymer50 is poly vinyl alcohol (PVA). PVA is an odorless, tasteless, transparent white or cream granular powder with outstanding film-forming, emulsifying, and adhesive characteristics. Nontoxic polymer stabilizes CdSe nanoparticles51. In light-emitting diodes, photo detectors, and full-color displays, CdSe, an II-VI, n-type direct band gap semiconductor, has garnered attention52. CdSe is an ideal host for doped Nanoparticles53 and an inorganic passivation for stability because to its broad band gap (2.6 eV). Cadmium selenide, a semiconductor, has few industrial uses. Due of their optical and electrical characteristics, CdSe nanoparticles are popular54.

Green polymer

Biodegradable and renewable materials are green. Green composites are eco-friendly, biodegradable, and sustainable, making them appealing. It's easy to dispose of or compost them after use without affecting the environment. The issue with green composites is finding green polymers for the matrix. Green polymer has renewable and degradable characteristics.

Biodegradation of a polymer in nature involves chemical structure changes, mechanical and structural property loss, and conversion into environmentally friendly compounds55. Starch, lignin, cellulose acetate, poly-lactic acid (PLA), polyhydroxylalkanoates (PHA), polyhydroxylbutyrate (PHB), and other degradable synthetic polymers are biopolymers56. Synthetic materials are not renewable and consequently not degradable57. PLA schematic is in Fig. 3.

Applications of Polymers

Agriculture and Agribusiness: Aeration, plant development, and health are improved by polymeric compounds in and on soil.

Medicine: Biomaterials like heart valve replacements and blood vessels are constructed of Dacron, Teflon, and Polyurethane.

Consumer Science: Plastic containers of all sizes are lightweight and cheaper than conventional containers. Other polymer uses include clothing, floor coverings, waste bags, and packaging.

Industry: Industrial polymer uses include automobile components, fighter jet windshields, pipelines, tanks, packaging materials, insulation, wood replacements, adhesives, composite matrix, and elastomers.

Sports: Playground equipment, various balls, golf clubs, swimming pools and protective helmets are often produced from polymers.

Transparent and Optical Materials: Windows, optical fibers, lenses, reflectors, and transparent film applications employ polymers58.

Nanocomposites are employed in mirror housings, door handles, door panels, trunk liners, instrument panels, parcel shelves, head rests, roofs, upholstery, engine covers, intake manifolds, and timing belt covers. Vacuum cleaner impellers and blades, power tool housings, mower hoods, and mobile phone and pager covers are also being explored. Its barrier qualities, chemical resistance, and surface attractiveness make it ideal for beer and fizzy drink bottles and fruit juice and dairy paperboard. Nanocomposites' reduced weight makes them promising for aeronautical applications59.

II. CONCLUSION

Due to its synergistic and hybrid features from several components, polymer–nanoparticle composite materials have excited many researchers in recent years. These materials have unique mechanical, electrical, optical, and thermal characteristics in solution or bulk. The presence of the nanoparticle, polymer-particle interaction, and dispersion cause such improvements. Compared to typical additives, nanoparticles and polymer additives have reduced loading needs. Polymers' monomers' identities are their most fundamental properties. Microstructure describes the arrangement of these monomers inside the polymer at the chain level. The polymer's bulk physical characteristics depend on these fundamental structural features. Nanostructured materials may be used to make better active devices. Nano science and nanotechnology, which includes physics, chemistry, biology, and engineering, have become prominent fields of study. The II–VI group semiconductor zinc selenide is a common and significant crystalline material for quantum dot applications and research. ZnSe has a broad band gap, high binding energy, and a tiny exciton with a Bohr radius of 3.8 nm at ambient temperature ZnSe, having a higher energy valence band-edge than ZnS, should perform better. Thus, ZnSe is an effective host for doping transition-metal ions to change characteristics. Nanocomposites are employed in mirror housings, door handles, door panels, trunk liners, instrument panels, parcel shelves, head rests, roofs, upholstery, engine covers, intake manifolds, and timing belt covers. Vacuum cleaner impellers and blades, power tool housings, mower hoods, and mobile phone and pager covers are also being explored.

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