Study on the Prospects of the Application of Inorganic Material Doped PMMA in Photoelectronic Structure

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Abstract: This article investigates the impact of inorganic material doping on the electronic and optical properties of polymethyl methacrylate (PMMA) in order to obtain widespread application in electronic and optical fields. The effects of the addition of nanoparticles in PMMA materials on optimized geometric parameters, electronic, and spectral properties are explored. The electronic and structural properties involve bandgap, Fermi energy, and chemical potential), and most of the studied nanocomposites have direct electronic transitions from the valence band to the conduction band, with wavelengths within the solar spectrum range. Finally, the studied nanocomposites can be applied in numerous photoelectronic fields.
***Keywords*:** Polymethyl methacrylate, inorganic materials, structural design, electronic fields

1. Introduction

Polymers have attracted widespread interest in device manufacturing due to their unique inherent properties, such as processability, flexibility, and high mechanical strength[1]. Furthermore, polymers doped with noble metal nanoparticles combine the inherent properties of polymers with the novel properties of nanoparticles, presenting novel and unique characteristics. The modification of materials to enhance performance in various potential fields has opened new doors by controlling the doping materials and optimizing the doping ratio[2]. The study of absorption processes is the study of light and electron interaction, where if the frequency of photons matches that of the excited electron, the photon is absorbed; otherwise, the material is transparent to this radiation[3]. To make the performance of a medium as excellent as that of a conductor, the doping method can be used, and the addition of dopants can change the optical properties of these materials[4].

Photoelectron spectroscopy is a method of measuring photoelectrons generated by the photoelectric effect when irradiating a sample with ultraviolet or X-ray radiation (10-1400 eV) in the sample. Due to momentum conservation, the angle of the emitted photoelectrons is proportional to the electron's momentum. If we can accurately measure the motion and emission angle of electrons, we can know the relationship between electron motion and momentum, i.e., the electronic band structure. So far, lasers have been extracted from over 200 different dyes. By selecting the appropriate dye, coherent radiation can be obtained from almost any given wavelength. The search for new active medium dyes is related to solving chemical and photochemical problems. Using dye instability, as well as selecting suitable solvents. It is noted that solvents include water, ethanol, methanol, cyclosporine, toluene, glycerol, benzene, acetone, and other liquids. The position of the laser-generated wavelength within the emission linewidth range can be stably changed, and the oscillation wavelength can be stably recombined at around 0.1 m. Lasers on dyes have successfully competed with parametric light generators in the visible and near-infrared regions.

Polymethyl methacrylate (PMMA) is an excellent organic optical material, generally used for manufacturing various optical devices such as optical lenses. Laser damage in transparent optical materials, including polymers, is caused by the coupling of laser radiation heating, nano, and microwave. Ethanol and methyl methacrylate (MMA) will increase the energy threshold by tens of times by slowly clearing these organic liquids from these compounds through multiple slow distillations. The sampling threshold of the polymer extracted from MMA polymers (PMMA) has increased several times. The polymer sampling threshold is lower because the same clearing method is smaller in solid polymers than in liquid monomers, including heating to higher temperatures in solid polymers than in liquid monomers. In a liquid environment, the main role of heat released from heat is the kinetic energy produced by the surrounding liquid and the evaporative heat generated by microbubbles.

2. Current Status of PMMA Optoelectronics Applications

2.1 Factors Affecting Polymers

Polymers and their primary hybrid composite materials (organic-inorganic) are attracting increasing attention from researchers due to their applications in multiple industrial fields. Information on the electronic structure of crystalline and amorphous semiconductors mainly comes from the study of optical properties over a wide frequency range. As the particle size decreases, the surface-to-volume ratio increases, making surface properties critically important. The smaller the particles, the more important the surface properties, which affect interfacial properties, aggregation behavior, and the physical properties of the particles.

2.2 Structural Features of PMMA

PMMA has many advantages, including excellent optical and insulating qualities. Due to its high rigidity and transparency, low molecular weight, high light transmittance, and chemical resistance, PMMA has also been widely used in industrial applications. With its high impact strength, light weight, shatter resistance, and ideal manufacturing conditions, PMMA is often used as a substitute for inorganic glass. The transparency of some organic glass is equal to the transparency of optical glass. The weight of organic glass is 2.5 times the size of silicate glass. Low density, high impact resistance, and relatively low cost are undeniable benefits of polymer products compared to inorganic glass products. Organic glass has excellent dielectric properties and, unlike silicate glass, has significant sound and thermal insulation performance. Therefore, a 2 mm thick organic glass is comparable to a 10 mm thick silicate glass. Two notable features are weather resistance and scratch resistance. The presence of nearby methyl (CH3) groups in the polymer structure prevents it from crystallizing firmly and allows for free movement around the C-C bonds.

3. Prospects of Inorganic Material Doping in PMMA Optoelectronics Applications

3.1 Structural Features of PMMA in Optoelectronic Applications

PMMA is an amorphous polymer belonging to the family of acrylic polymers. It is a colorless and transparent polymer, and due to its minimal fluctuation under ultraviolet radiation, it is one of the sunlight-resistant polymers. PMMA has a high Young's modulus and a low elongation at break. Therefore, it is one of the toughest thermoplastic plastics, with high scratch resistance and does not shatter upon breaking. This polymer has chemical corrosion resistance as it is unaffected by other laboratory chemical aqueous solutions. On the other hand, it is sensitive to halogenated hydrocarbons, aromatic hydrocarbons, esters, and ketones. Broadband can be produced in the spectral range from ultraviolet to near-infrared. In the range generated by organic compounds, up to 100 nm of regenerative lasers can be rearranged by multiple selective elements, obtaining narrowband radiation from 0.001 nm width. The characteristics of organic compound lasers make them valuable in various scientific and technological fields because it is possible to generate different selective stimulations such as atmosphere, ocean, biological objects, laser isotope separation, etc. However, these lasers have a weakness – their active medium is a solution of organic molecules, usually organic solvents, toxic, flammable, and so on. All these have prompted researchers to create solid active media based on organic compounds. Sol-gel glasses produced by hydrolysis and alcoholic condensation of silicon or titanium were tested as solid laser elements, followed by subsequent polymerization and integration into tetraethyl silane hydrate reaction glass. Although sol-gel glasses have a higher spectral range and intensity, they are not the best substrates for many organic molecules. Moreover, the synthesis method of this type of glass seems simple. In fact, the subtleties that may lead to failure are unknown. Research on solid laser active media has been conducted based on the synthesis of materials using microporous quartz glass, followed by polymerization and integration into tetraethyl silane hydrate reaction glass. These media combine high mechanical strength and excellent optical properties.

3.2 Structural Composition of PMMA in Optoelectronic Applications

Plastic chip electrodes (PCEs) are manufactured using PMMA and graphite through a simple solution casting method. The materials are characterized by microscopy (SEM and AFM), thermal properties (TGA), and mechanical and electrical properties. The fabricated electrodes are low-cost and reusable in various applications. The combination of covalent and non-covalent interactions has been found to be a breakthrough approach for utilizing nanocomposites.

The influence of SiO2 nanoparticles on the modification of SiO2/PMMA composites was studied. SiO2/PMMA nanocomposites were prepared using a two-step process: non-covalent modification of SiO2 nanoparticles with tetraoctylammonium bromide to help disperse them in the solvent, and covalent modification of SiO2 nanoparticles with MMA monomers to prepare silica/PMMA nanocomposites. The purpose is to utilize SiO2 to improve the mechanical properties of PMMA for a broader range of applications. Compared to pure PMMA, tensile and bending strengths were found to increase by 80.6%

and 127.3%, respectively. The two-step method was found to be direct, efficient, and economical. However, the surface functionalization of nanoparticles through polymer grafting plays a crucial role in the development of organic-inorganic nanocomposites.

The most attractive solid-state lasers are optically transparent polymers in which dyes are introduced. Compared to other optical materials, polymers have a decisive advantage: dyes can be introduced at sufficiently high concentrations, providing high optical density at low thicknesses. The synthesis of organic polymers made from laser dyes is straightforward. In the chosen laser dyes, our efficiency is determined by the chemical structure and polymer composition. It is the matrix that defines the basic thermal, optical, and mechanical characteristics of the solid active media. The main requirement of the polymer environment is the stability of the pump laser. The laser intensity of polymers largely depends on the material's optical cleanliness, as well as the length of the irradiated area, radiation frequency, exposure pattern, and other factors.

3.3 Optical Properties of Inorganic Materials Doped PMMA

An appropriate polymer material is required as the main matrix in the composite material for the production of quasi-solid-state dye-sensitized solar cells (DSSC) using highly conductive polymer gel electrolytes. A polymer gel electrolyte was prepared using PMMA, ethylene carbonate, 1,2-propylene carbonate, dimethyl carbonate, and sodium iodide/iodine as the I/I3 source. Quasi-solid-state dye-sensitized solar cells with good long-term stability and a 4.78% photoelectric conversion efficiency were fabricated using this electrolyte.

Fluorescent PMMA films embedded with commercial coumarin dye (MACROLEX Fluorescent Red G) were prepared using a flow spin-coating process. For greenhouse applications, films with the highest dye concentration were utilized and their emission was adjusted to match the chlorophyll absorption bands (650-680 nm). Due to their excellent weather resistance, they can be used for commercial plant growth chambers.

The advantage of solid matrices for laser dyes over liquid solvents is their lower thermo-optical distortion, which is related to a lower expansion coefficient. This is a particularly significant advantage in the case of polymer-impregnated porous silicate glasses. It is worth noting that this advantage is only applicable to dye lasers with electron tube pumping, as thermo-optical distortions can develop within a single pulse due to the long duration of the pulse. In the case of laser pumping, the circulation of the liquid allows for high optical uniformity to be maintained in the generation area. Considering the use of solid matrices for electron tube pumped dye lasers is quite difficult, the discussed advantage is only important in rare cases.

Another benefit of solid matrices compared to most organic solvents is their fire resistance. The main drawback of all solid matrices is the difficulty of replacing the active medium when the dye or matrix degrades, which can only be replaced by circulation in liquid media. In solid matrices, heat removal from the active generation area is also challenging. It limits the matrix's thermal conductivity, whereas in liquids, the circulation system releases this constraint.

3.4 Electrical Properties of Inorganic Materials Doped PMMA

Considering the characteristics of electrochemical device materials, carbon nanotube and PMMA composites or modified carbon nanotubes would be suitable materials for chemical sensors. However, current developments show that polymer materials are mainly used for temperature sensing applications in anti-counterfeit labels. The heating/ethanol response of commercial PMMA, which has been programmed for gradient pre-strain/stress fields, is studied, and the observed features suggest possible applications of PMMA in temperature sensors.

Two different types of PMMA mold cavities are employed: coin-type and those with various protruding elements on the top design mold. Compression is used to create gradient pre-strain/stress fields, and watermarks that appear only when heated to a specific temperature are used for monitoring overheating temperatures. Since most polymers exhibit shape memory effects, other common polymers can also be employed for these applications.

Polymers, which can be fabricated in virtually any desired shape and size, allow for addressing challenges within a certain range by transferring large samples, such as through the generation area. A primary drawback of polymer matrices is their low radiation intensity, i.e., their stability against strong light radiation. The use of polymers as alternatives to traditional optical materials is continuously expanding.

An important driving factor in this direction is the processing of glass elements, particularly non-spherical elements, and their assembly and adjustment. Organic polymers possess thermoplasticity, the ability to transform into a viscous state upon heating and maintain their shape upon cooling. Thus, transparent thermoplastic polymers can be used for manufacturing optical components using high-performance methods, such as injection molding, which is a promising direction for enhancing optical production. The cost-effectiveness of polymers as optical media is based on reducing material and processing costs.

Polymer materials can be used for large-scale production of optical components with complex surface contours and mounting grooves, which are difficult or nearly impossible to create with inorganic glass.

4. Conclusion

This article provides an overview of the current state of research in the fields of solar energy devices, sensors, energy harvesting applications, drug delivery carriers, and polymer nanocomposite materials applications. This analysis can offer researchers an opportunity to advance polymer science and technology, as well as help researchers and industrialists understand the real experimental facts and translate them into large-scale production and deeper understanding of polymers.

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