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(Review Article)

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Development of nanometal nitride doped PMMA blend for biomedicine and industrial fields: Recent review

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Abstract

PMMA has many applications in different medical, electronics, optics and industrial fields. PEG has been used in various biological and industrial applications. Nanometal nitride like Si3N4 NPs has good physical and chemical properties to use in many applications. Hence, the nanostructures of Si3N4 NPs doped PMMA/PEG blend can be considered as promising materials in different applications. This work comprised a recent review on PMMA and PEG nanocomposites NPs. The previous studies showed that the PMMA and PEG nanocomposites have numerous applications in optical, optoelectronics, biomedical, electronics fields.

Keywords: Biomedical; PMMA; PEG; Nanoparticles; Optical fields

1. Introduction

Plastics, natural and synthetic fibers, rubbers, coatings, adhesives, sealants, etc. all fall under the purview of polymer science, a relatively new field of study[1]. Polymers are distinguished by their high number of repeating units and their high molecular weight. Polymer synthesis is performed on a massive scale, and polymers can be used in a wide variety of contexts thanks to their versatile set of properties[2]. The process of polymerization converts monomers into polymers. Chemical reactions lead to the formation of two distinct types of chains from individual monomers. Both types of chains exist, but one is linear and the other is three-dimensional[3].The monomer units in polymer molecules can number in the tens, hundreds, or even thousands. Polymer composites are distinguished by their ease of formation, low density in comparison with metals, higher resistance to corrosion and better surface quality. Polymer composites are strong, lightweight, thermally stable, hard, and abrasion resistant, making them a viable alternative to metals. Aside from all advantages, the lightness of these materials gives them an advantage in many areas. Because of their intriguing properties and potential, researchers from a wide variety of fields and industries have taken an interest in polymer composites.[4].Polymers are classified as either natural that resulted from natural biosynthesis, orsynthetic[5]. Polymers, also known as plastics, have expanded into new areas of use as a result of advances in polymer science [6].Polymers have been used extensively in a variety of technological fields over the past few decades due to their chemical stability, versatility, light weight, and low cost in comparison to other classes of materials[7].In place of more traditional polymers and other materials, polymer nanocomposites offer great potential. Among the inexpensive and simple ways to alter the polymer structure by adding nanofillers to polymers to improve their resistance to heat, mechanical stress, moisture, and flame compared to regular polymers in recent decades[8].As a result of having these embedded particles within the polymer matrix, the host material's physical properties are altered. Particular polymer ceramic hybrid composites show promise as multidisciplinary functional materials due to their advantageous optical, electrical, thermal, mechanical, and antibacterial properties[9].Because of their adaptability and simplicity, polymer composites are currently receiving a lot of attention in the energy sector. [10].

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2. Polymer Blends

Blending two polymers together or more is a simple way to create a new polymeric material it has superior properties that improve upon those of the individual polymers used. Using existing polymers as a starting point for a new type of material saves time and money compared to discovering and testing out entirely new monomers and polymerization techniques[11].Polymer blends have numerous medical and pharmaceutical uses, such as in the delivery of drugs, the repair of bones and other tissues, the immobilization of enzymes, and the dressing of wounds[12].The most equation that applies to mixtures with various components is:

$$\Delta Gm = \Delta Hm - T\Delta sm \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

Where (ΔGm) is the free energy of mixing, and (ΔHm)is the enthalpy of mixing (heat of mixing) and(ΔSm) is the entropy of mixing. In order for two substances to mix, ΔGm must be less than (0)[13].One of the reasons this method has not progressed as quickly as it could have been because of the difficulties it has encountered is that most physical blends of different high molecular weight polymers prove to be immiscible. This means that the constituents of a blend tend to form distinct phases when mixed, each of which is dominated by a constituent of the same kind[14].Polymer blend formation is a common practice for creating novel materials with improved properties. Due to the generally unfavorable enthalpy of phase separation, most polymer blends tend to phase separate, leading to subpar mechanical properties. Since polymer blends' performance is largely dependent on the interface of polymer components, controlling phase behavior and morphology becomes an important factor[15].

3. Nanocomposites and their Applications

Nanocomposites are composites made up of two or more phases with distinct chemical or structural properties, where one phase exists at the nanoscale level. There is a noticeable difference in behavior between these materials and typical composites with microscale structures [16],which are one of the most crucial components of today's technological world, Depending on the thickness of the reinforcement used, composites can be placed into one of three broad categories. Composites can be broken down into three categories micro composites, macro composites and nanocomposites[17]. Nanocomposites with a size of 100 nm or less are a cutting-edge innovation in the material sciences. There are novel physical, functional, and service properties in the second group of materials[18,19]. Numerous studies on characteristics of composites and nanocomposies comprised electrical and dielectric characteristics[20-25], optical characteristics[26-40], to utilize in different fields included optoelectronics and electronic [41-62], piezoelectric and sensors [63-80], environmental and radiation shielding [81-93], energy storage[94,97] and biomedical[98-104]. Nanoparticles' size-induced properties allow for the creation of novel applications and the incorporation of adaptability into existing systems across a wide range of disciplines, including catalysis, optics, microelectronics, and many more[105].Nanotechnology is the investigation and control of matter at the nanometer scale (1–100), where novel phenomena give rise to novel practical uses[106].Nanotechnology is the science and engineering of creating and utilizing structures on the atomic, molecular, and microscopic scales, as well as incorporating these nanoscale components into larger systems. Chemistry, physics, materials science, engineering, and industrial production are just some of the scientific disciplines it touches on.[107]. Some of the potential applications of nanotechnology are as follows[108].

- Antibacterial dressings and coatings
- Diagnostic microsensors for more precise medicine
- Barriers for thermal and optical applications
- Thin-film photovoltaic solar cells on a miniaturized scale, with applications ranging from portable electronics to transportation.

(H. M. Shanshool*et al*) in 2016[109],prepared the (PMMA-PS-PVDF-PVA) blend with a different concentrations of (ZnO) NPs .It was found that the concentration of ZnONPs was inversely related to the observed low UV transmittance, which was observed in the visible region of the UV-visible transmittance spectra. As the proportion of ZnO NPs in the nanocomposites increased, the energy gap shrank. (S. Devikala*et al*.) in 2018[110], prepared the (PMMA/TiO2) nanocomposites. characteristics of the samples included (XRD, FTIR, DSC, and SEM). The structural, morphological, and conductivity properties of the composite were all enhanced by the incorporation of TiO2 NPs. With an increase in TiO2 concentration and temperature, the dielectric constant and alternating current conductivity both rose. The synthesized polymer composites could be used in numerous technical contexts.(K. Kannan*et al*.) in 2018 [111], fabricated (PEG-PVP/Ag2S) polymer nanocomposites by solvent casting. The vibrational nature of the bond presented in the prepared material was investigated using FTIR. The results showed that the SEM image confirms the sample's surface smoothness. (M. H. Suhail) in 2019[112], prepared (PEG-PVA) blend with different concentrations of MnCl2 using the casting method. There is an increase in the concentration-dependent absorption coefficient, refractive index, extinction coefficient, and dielectric constants. (M. Bafna*et al.*) in 2019 [113],examined the optical parameters of (PMMA-K_2CrO_4). They added nanoparticles (K_2CrO_4) to the PMMA polymer in different weight ratios. The optical results showed the absorption coefficient, extinction index, refractive index, and real and imaginary of the dielectric constant improvement when potassium chromate was added.(P. Raniet al) in 2020 [114],prepared (PVA-PEG) blend nanocomposite films reinforced with various loadings of (CBNPs) nanoparticles. FTIR spectroscopy was used to investigate the structural properties of (PVA-PEG-CBNPs) nanocomposites, revealing the interaction of CBNPs with the polymer blend. The addition of CBNPs lade to improve dielectric properties.(J. Q. M. Almarashi and M. H. Abdel-Kader) in 2020[115], synthesized (PVA-PEG) blend with (CuS) NPs by using a casting technique. The optical transmittance revealed an apparent decrease. the results showed effect of nanoparticle concentrations on dispersion parameters and optical constants. The optical energy gap decreased from (5.3 to 3.3)eV with the CuS NPs incorporation. (P. Dhatarwal *et al.*)in 2021 [116],studied the polymer nanocomposite (PNC) films comprising (Al_2O_3) and (SiO_2) nanoparticles dispersed in PMMA matrix. The results showed that the transmittance, UV-Vis absorbance, and reflectance spectra of these films changed gradually as the (Al_2O_3) and (SiO_2) content of the films increased. With increasing filler concentration, the energy bandgap decreases while refractive indices and optical conductivity improve. (Z. K. Heiba*et al.*) in 2022 [117], studied the optical parameters of (PVA/PEG) blend and added Nano gadolinium oxide (Gd2O33). The results showed that the optical bandgap of the blend was decreases. As the percentage of Gd2O3 in the mixture increased, the refractive index and extinction coefficient values improved. (F. S. Jaber *et al.*) In 2022 [118], designed the (Si_3N_4) and (SiBr4) doped (PVA) as promising semiconductors materials . New structures made of PVA/Si_3N_4/$SiBr_4$ were found to have superior optical and electronic characteristics. Wide absorption spectra and an energy gap of about (0.35 eV) in PVA/Si_3N_4/$SiBr_4$ structures make them applicable in many areas of electronics and photonics.

4. Nanomedicines

Nanotechnology is ushering in a new era in medicine, one in which tiny devices are used to better diagnose and treat diseases [119].Targeted drug delivery is one of the greatest challenges in medicine[120]. Drugs are conventionally administered in the patient orally in capsule or liquid forms. However, this approach is not always effective in targeting specific cells for treatment, diagnosis, or imaging[121]. The use of nanoparticles in medicine has the potential to usher in a new era of technological innovation that will allow for not only the creation of novel drugs but also the reformulation of existing drugs to boost their efficacy, enhance their delivery, and minimize their side effects[122].Several types of nanomedicines have been created and put to use in both clinical and non-clinical settings through commercial channels. Nanomedicines have demonstrated useful properties, such as increased binding capacity to biomolecules, increased circulation duration and blood concentration, and efficient transport through fine capillary blood vessels and lymphatic endothelium. Nano-formulations differ from traditional medicines due to their unique physicochemical properties[123].Due to their nanoscale dimensions, they are typically composed of thousands of atoms and have a sizable surface area, allowing for a greater therapeutic payload to be transported to or encapsulated within the nanostructure. High therapeutic loads can cause more extensive damage to cancer cells at the targeted site after therapeutics have been delivered and recognized by a receptor[124].For pharmacologically active agents to be effective, NPs must be designed to overcome biological barriers, enter damaged cells, and release their payload at the optimal rate and in the correct dose[125].

5. Polymethylmethacrylate (PMMA)

Polymethylmethacrylate, or PMMA, is a linear thermoplastic polymer with the formula (C5H8O2)n. Its glass transition temperature is 85 degrees Celsius and its melting point is 160 degrees Celsius[126].PMMA has great mechanical strength, hardness, high rigidity, transparency, and insulation properties, among other desirable qualities[127].The range of its refractive index, between 1.3 and 1.7, also makes it an excellent optical material. PMMA is one of the best organic optical materials due to its low weight ,powerfulness under pressure, and shatter resistance and is widely used a replacement for inorganic glass[128].Poly methyl methacrylate is a polymer frequently used in the dental industry, including dental labs (use in denture and retainer fabrication as well as maintenance) and dental clinics (for use in making temporary crowns on dentures) as well as in manufacturing (include denture-making)[129].Due to its rigidity and weight, polymethyl methacrylate is increasingly being replaced by acrylic resins in the fabrication of prosthetic eyes for ocular or orbital prostheses[130].Figure (1) shows molecular formula of PMMA[131].Table (1) shows important properties of PMMA polymer[132].

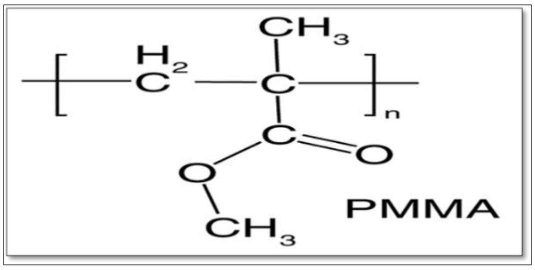

Figure 1 Molecular formula of PMMA[131]

Table 1 Important properties of PMMA polymer[132]

Property	PMMA
Density (g/cm3)	1.18
Glass Transition Temp. (Tg) (C^{o})	110 to 120
Melting Point (C)	220–240
Water Absorption (%)	0.3
Surface Hardness (Rockwell)	M92, M90-M100

6. Polyethylene glycol (PEG)

It has the formula H (OCH2CH2)n OH, where n is the typical number of oxyethylene repeating groups, and can be found in a wide variety of common consumer goods. It is approved for use in a variety of laxatives due to its low toxicity and low hazard risks[133].PEG's high structural flexibility, biocompatibility, amphiphilicity, absence of steric hindrances, and hi Polyethylene glycol (PEG) is a class of water-soluble polymers with a wide range of molecular weights that exhibits desirable characteristics including resistance to proteins, low toxicity, and immunogenicity, high hydration capacity are what have contributed to its widespread renown[134,135], that is widely used across a wide range of industries (cloth, rubber, textiles, wood, metal, pharma, coatings, cosmetics, etc.). PEG is also obtainable in different geometric shapes.

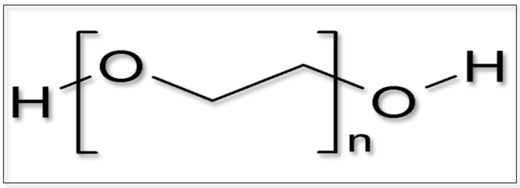

Figure 2 The chemical structure of PEG[136]

Table 2 Important physical properties of PEG polymer[137]

Properties	Description
Appearance	Clear liquid or white solid
Density	1.1–1.2
Melting point	54–58 ∘C
Degradation temperature	234 ∘C
Toxicity	Non-toxic and non-immunogenic
Stability	Stable under ordinary conditions of useand storage
Odour	Mild

Figure(2) gives the chemical structure of PEG[136].Table (2) shows important physical properties of PEG polymer[137].

7. Silicon nitride (Si_3N_4)

Silicon nitride (Si_3N_4) is a nitrogen compound of highly covalent bond[138]. the bonding in Si3N4 can be estimated to be 70% covalent in character[139].Due to its versatile mechanical and electronic properties, silicon nitride has attracted significant technological interest. Silicon nitride is characterized by a high density, a high melting temperature, low mechanical stress, and high resistance to thermal shock. It has been considered the standard material for engine parts and cutting tools because of its exceptional mechanical properties at high temperatures. There is a high dielectric constant in it[140],In addition to its use in the ball and roller bearings, this material is being considered for use in energy conversion systems, industrial heat exchangers, wear-resistant material in metals processing, and various other engineering applications[141]. Silicon nitride is a material that has been considered for use in both high-temperature gas-cooled reactors and very high-temperature reactors, both of which are used in nuclear fusion[142].Si_3N_4's durability and chemical inertness make it a good candidate for coating magnetic thin films in disk drives[143].Table (3) shows physical and mechanical properties of Si_3N_4[144]

Table 3 Physical and mechanical properties of Si_3N_4[144]

Properties	**Si_3N_4**
Melting point (°C)	1900
Density (g cm−3)	3.17–3.20
Hardness (GPa)	18
Thermal Conductivity (Wm^{-1} K^{-1})	10–162
Fracture Toughness (MPa m1/2)	Crystal Structure
Crystal Structure	Hexagonal

8. Conclusion

This article includes a recent review on PMMA and PEG doped with different materials. The previous studies showed that the PMMA and PEG nanocomposites have numerous applications in optical, optoelectronics, biomedical, electronics fields. The nanostructures of Si_3N_4 NPs doped PMMA/PEG blend may be considered as a key for different recent applications.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

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