Hilla University College Journal For Medical Science

Manuscript 1056

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HILLA UNIV COLL J MED SCI 2025;3:8–14

ORIGINAL STUDY

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The Creation and Theoretical Assessment of Polymethyl Methacrylate (PMMA) Incorporated with SiO_2 Nanoparticles to Improve Optical Characteristics and Correct Contact Lens Performance

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Abstract

This research evaluated and synthesized a contact lens material based on polymers. The foundation substance is polymethyl methacrylate, or PMMA. In order to increase the total refractive index of the lens, silicon dioxide (SiO_2) nanoparticles with an average diameter of 30 nm were added. The PMMA has been supplemented with concentrations of 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% of SiO_2 nanoparticles. Investigations were conducted on how various SiO_2 concentrations affected the optical properties of PMMA lenses. An analysis using spectroscopy was performed to determine the impact of varying SiO_2 concentrations on the lens's characteristics. By utilizing Zemax programs, this research investigated how the synthesized lens material behaved in various conditions. Through simulation, this research found the correlation between material composition as well as optical performance through revealing the amount of SiO_2 nanoparticles. Based on the research experimental and theoretical evaluation, an ideal concentration of SiO_2 of 3% was determined for the highest modulation, henceforward, the optimum lens material. This result showed the impacts of adding SiO_2 nanoparticles to PMMA in boosting the refraction index of the lenses without ignoring their optical belongings.

Keywords: Spectrum, Polymer, Optical, Lens, Nanoparticles

1. Introduction

Polymers are essential to the creation of optical materials because of their extraordinary properties and adaptability. due to the fact that it offers better optical qualities than other polymers. Polymethyl methacrylate (PMMA) is one of these polymers that is particularly helpful for making lenses and other applications. PMMAs' toughness and endurance are crucial qualities that make them a dependable material in demanding circumstances [1–3].

PMMA is a strong and reliable material for optical applications because of its lessened tinting effects when exposed to UV radiation. Unlike ordinary glass, which over time may experience color distortion due to the same factors, PMMA maintains both its clarity and its initial appearance [4–6].

One of the main areas of scientific inquiry is the production of mixed polymers containing high-reflecting index nanoparticles. These nanoparticles may be able to increase their optical properties through decreased scattering losses and increased light transmission. In optical applications, one method to get around these problems is to use highly index refractive nanoparticles [7–9]. Optical technology can be revolutionized

Received 28 February 2025; revised 12 April 2025; accepted 15 April 2025.
Available online 30 June 2025

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https://doi.org/10.62445/2958-4515.1056

by these mixes. The creation of mixing combinations of polymers with improved optical characteristics may create new opportunities for a range of useful applications by addressing the difficulties related to polymeric research [9–11].

The atypical capacity of silicon dioxide nanoparticles to preserve the thermal and physical characteristics of PMMA while enhancing its optical properties. How well SiO_2 nanoparticles are dispersed throughout the polymer matrix determines how much of an improvement it can make to the properties [6, 12, 13].

The alterations in the concentration of nanoparticle SiO_2 in PMMA lens material could have an important impact on their optical performance. Nevertheless, this concentration needs to be cautiously regulated to prevent any negative belongings on clarity caused by dispersion. In order to achieve the optimum results, an appropriate ratio within both of these substances must be determined to enhance the lens's visual clarity and limit any harmful effects on its qualities [14–16]. The modulation transfer function (MTF) is the most fundamental factor to be taken into account when evaluating the performance of the lens. It makes available an evaluation of lens contrasts at dissimilar frequencies, in addition, it has special effects on the final image's quality as well as resolution [17–19].

The present research intends to generate polymer composites incorporating nanoparticles made of SiO_2 and PMMA in order to increase the possible uses of PMMA-based optical lenses.

2. Materials and methods

2.1. Theoretical segment

2.1.1. MTF

MTF curve analysis is a useful tool for assessing not just the sharpness but also the clarity of a lens across a variety of spatial frequencies. At a given frequency, higher MTF values signify better performance. MTF offers information on signal fidelity over a range of bandwidths and can be interpreted in this sense as the output-to-input ratio of a system of linearity. So as

$$MTF\,(f) = \frac{Output\,(f)}{Input\,(f)} \tag{1}$$

Comparably, a lens's MTF is

$$MTF\,(v) = \frac{Output\,(v)}{Input\,(v)} \tag{2}$$

Where, in contrast to the frequency employed in electronics, ν is the frequency that is spatial and may be multi-dimensional. MTF is essentially a measurement of an object's accuracy as perceived through a lens.

2.1.2. Tangential and sagittal image

In optics, the dispersion of light rays from a source point along the optical axis is referred to as the tangential and sagittal picture. A point light source emits a beam of light rays toward the tangential plane, which the optical axis as well as the light source can define. The main ray passes through the center of the source, while the rest of the rays are dispersed uniformly along the y-axis in the pupillary plane. Two rays are at the pupil's edge, one on either side of the primary beam. As seen in Fig. 1, this configuration of rays in the area of interest is referred to as the tangential distribution. Analyzing tangential and sagittal images in optical systems, including lenses is essential for determining image formation in addition to aberrations. The sagittal picture is created by rays perpendicular to the tangential plane, whereas the tangential image is made by lights that lie in a plane that contains an object's point and the axis of vision [20–22].

The most basic optical property that measures how light travel through a material is its refractive index (n). The expression for the complex refractive index is (n + ik), where k represents the imaginary component (the extinction coefficient) and n represents the actual part (the refractive index). The amount of light reflected at the contact point between the two mediums is described by the reflectivity phenomenon, represented by the letter R. Eq. (3) provides the relationship.

$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \tag{3}$$

One would measure the reflectivity at various wavelengths and use equation Eq. (4) to extract particular refractive indices at particular wavelengths, such as n_{486}, n_{587}, and n_{656}, among others.

Another crucial optical metric is the Abbe number (V), which expresses how widely light is dispersed within a substance. It is computed with the following formula:

$$V = \frac{n_d - 1}{n_F - n_C} \tag{4}$$

Where the refractive indices at certain wavelengths related to the Fraunhofer lines are represented by (n_d, n_F, and n_C). The Abbe number gives information on the amount of chromatic aberration that a lens built of a specific material is likely to have.

Fundamental characteristics are required to simulate the way light interacts with different optical

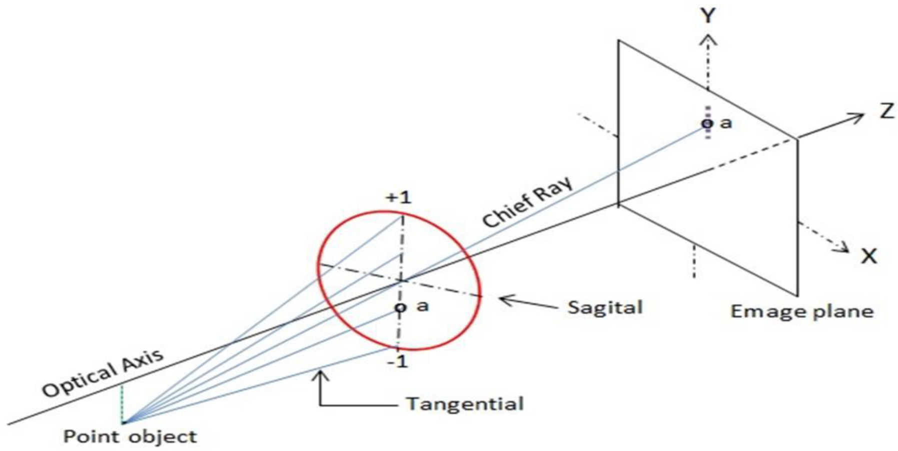

Fig. 1. The sagittal and tangential planes concerning the pupil.

components in practical circumstances, such as Zemax software, an effective optical design tool. The Liou and Brennan model precisely describes how light enters and departs the eye, offering insights for bettering eyesight and lens design.

2.2. *Practical segment*

2.2.1. *Base sample preparation*

The PMMA polymer powder needs to be dissolved in chloroform solvent to create the base sample as instructed. This method is commonly used in various scientific studies and experiments, particularly in the fields of polymer chemistry and materials science [23–25].

(10 ml) of chloroform solvent was measured and added to a glass container and then placed on a sample mixing device (stirrer) and then (1 gm) of PMMA polymer powder was measured, the polymer was added gradually with the solvent, the sample mixing device was kept by continuous stirring of the mixture For (30 min), until the powder is completely dissolved in the solvent. Then the sample is poured into a glass container and left to dry at a temperature of (24°C).

2.2.2. *PMMA plus SiO_2 sample preparation*

To guarantee adequate dispersion as well as integration, the samples have to go through several preparation processes. First, 10 mL of chloroform solvent was added to a container of glass containing nanoparticles of SiO_2, in the amount indicated in Table 1. Subsequently, the SiO_2 powder is broken up into aggregates, and uniform dispersion is guaranteed by using an ultrasonic oscilloscope set to maximum power for three minutes. Lastly, the process is finished by progressively adding PMMA powder to the liquid in mixing sample. This stage guarantees that PMMA is dispersed equally throughout the mixture. The mixture is stirred constantly for 30 minutes. To attain homogeneity in the polymer sample containing SiO_2, stirring is essential. After the sample has been stirred, it was put into a glass container and allowed to dry. Drying supports the solvent to evaporate as well as the distributed SiO_2 nanoparticles in the polymer matrix to solidify.

Table 1. The mixing ratios of samples consisting of PMMA polymer to which SiO_2 nanoparticles are added.

No.	Mixture	PMMA wt%	SiO_2 Nanoparticles wt %
1	Pure PMMA	100%	0%
2	PMMA + 0.1% SiO_2	99.90%	0.10%
3	PMMA + 0.2% SiO_2	99.80%	0.20%
4	PMMA + 0.3% SiO_2	99.70%	0.30%
5	PMMA + 0.4% SiO_2	99.60%	0.40%
6	PMMA + 0.5% SiO_2	99.50%	0.50%

3. Results and discussion

Comprehension of the optical properties of SiO_2-doped PMMA composites requires a comprehension of the absorption spectra shown in Fig. 2. The PMMA matrix's SiO_2 nanoparticles have a substantial impact on how the material interacts with light at different wavelengths. The ultraviolet (UV) region of the absorption spectrum usually exhibits a prominent peak, which is ascribed to electronic transitions occurring inside the SiO_2 nanoparticles and the PMMA matrix of polymers. UV shielding or filtering applications may benefit from its high absorption in the UV area [26–29]. Absorbance steadily decreases as one approaches the visible spectrum and near-infrared regions. This behavior shows that although the composite absorbs UV light well, it gets more transparent at longer wavelengths. This feature is crucial for

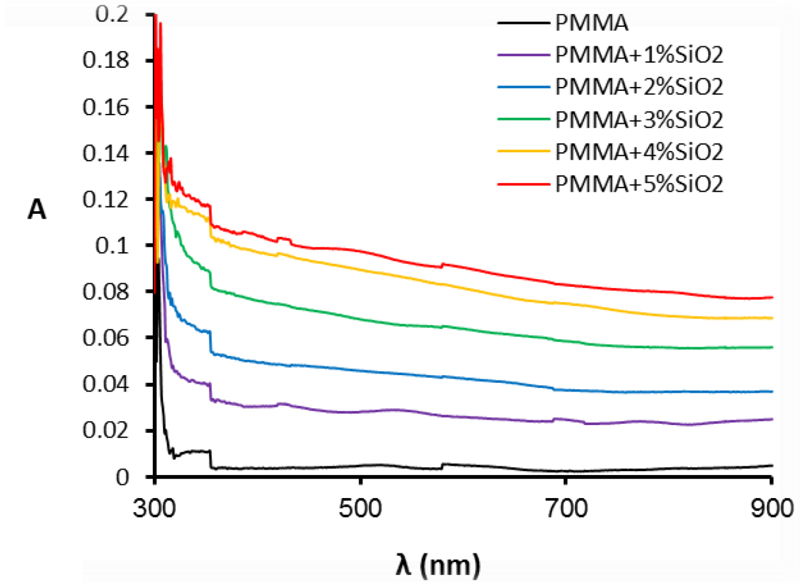

Fig. 2. Demonstrates how the wavelength absorbance of polymer PMMA changes with SiO_2 nanoparticle concentration.

situations where UV protection must coexist with visibility or transparency [21, 30, 31].

Higher concentrations of SiO_2 nanoparticles appear to increase absorbance, which implies that these nanoparticles improve light-matter interactions in the composite material. This behavior is partly explained by the larger surface area and possible scattering effects resulting from higher nanoparticle loading. The PMMA matrix absorbance increases over the whole spectral range under study as more SiO_2 nanoparticles are added because they offer more locations for absorbed light and scattering [32–34].

The wavelengths' refractive indices (n_{486}, n_{587}, and n_{656}) were extracted using Eq. (4). The Abbe number (or V-number or V-value) is crucial to understanding chromatic dispersion in optical materials—how much a light spreads into its constituent colors as it passes through them. In ophthalmic applications like those modeled by Zemax with Liou & Brennan's model, understanding dispersion helps predict the performance of lenses at different wavelengths—critical to compensating for vision without introducing color fringing or aberrations.

The Liou and Brennan eye model is a sophisticated model used to simulate the optical properties of the human eye. It is highly easy to utilize in optical design software like Zemax, which is used in designing and analyzing complex optical systems. The model includes various anatomical components of the eye, such as the cornea, lens, pupil, and retina, each with specific parameters like radius of curvature, thickness, refractive index, and conic constants. Table 2 provides critical data inputs required to model the human eye within Zemax software based on the Liou and Brennan model. Each row of the table is an individual surface or component of the eye. All these parameters are significant in modeling exactly how light travels through different segments of the eye in order to come to rest on the retina.

Zemax uses these accurate input parameters from Table 2 to simulate how light passes through each part of this theoretical eye model under varying conditions—e.g., changes in wavelength or angle of incidence—to create lenses that closely mimic natural vision. By incorporating both geometric optics principles (e.g., Snell's Law) and wavefront analysis techniques into its computation algorithms, Zemax can be employed for the prediction of visual acuity performances from given design choices during lens development processes optimized for individual patient needs or population studies.

Up until an ideal concentration—3% in this case, as illustrated in Fig. 3—is reached, it was discovered that raising the concentration of SiO_2 nanoparticles increases both sagittal and tangential MTF values [25, 26]. When compared to other formulations, the lens material shows better contrast and clarity at this concentration. Nevertheless, going over this ideal concentration causes the MTF performance to decrease, suggesting that improving material qualities and preserving efficient optical performance are not mutually exclusive [18, 35, 36].

Materials research used in making optical lenses is a significant area in materials science and engineering.

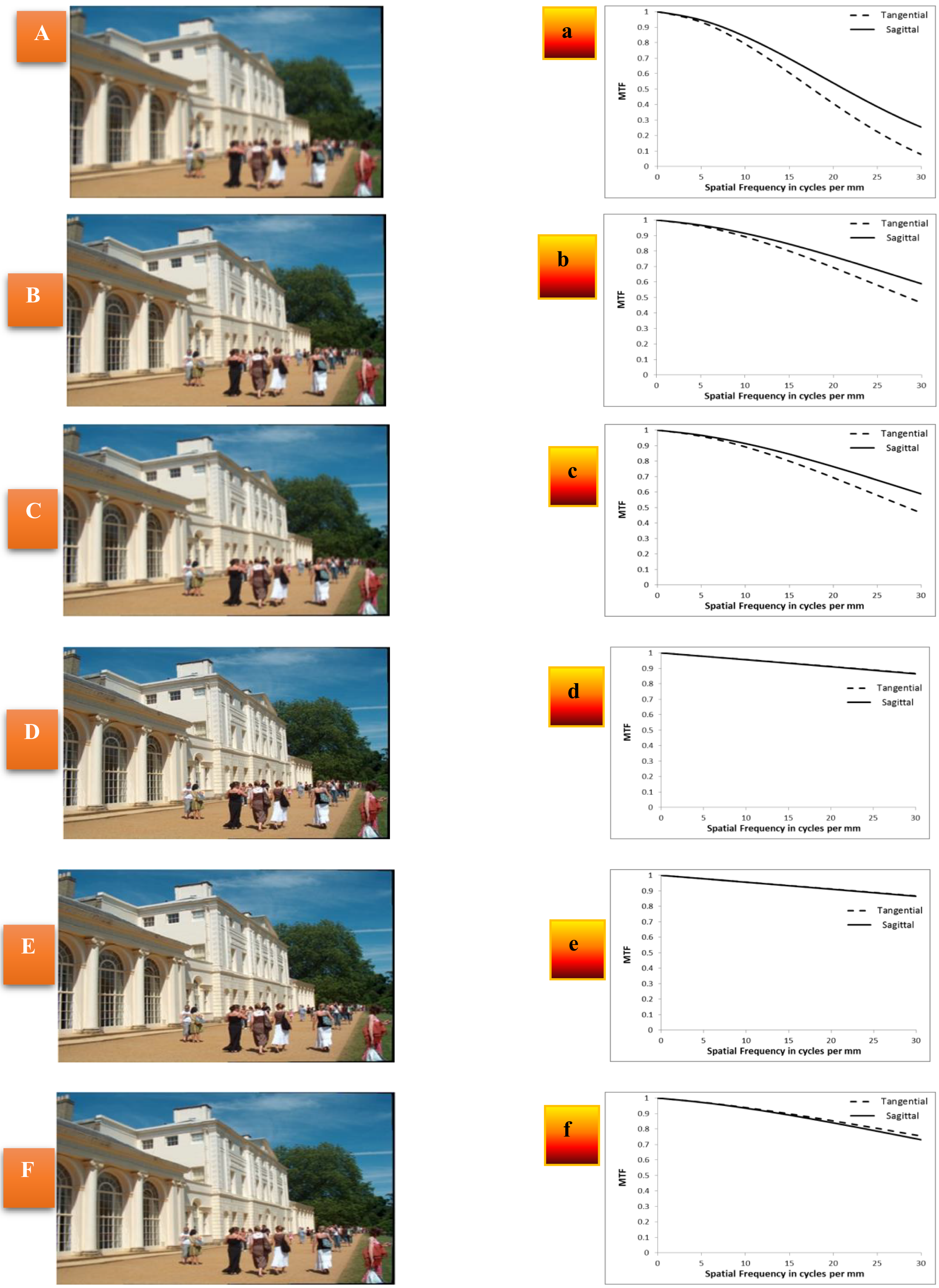

Fig. 3. Model picture in a white light.
***A**: (Pure PMMA), **B**: (PMMA + 0.01 % SiO_2 nanoparticles), **C**: (PMMA + 0.02 SiO_2 nanoparticles), D: (PMMA + 0.03 SiO_2 nanoparticles), E: (PMMA + 0.04 SiO_2 nanoparticles), F:(PMMA + 0.05 SiO_2 nanoparticles) **(a-f)**: MTF in the spatial frequency cycle per mm.*

Silicon dioxide (SiO_2) and its forms, such as silicon trioxide (SiO_3), are widely considered for their potential benefits in lens property enhancement. However, the explicit influence of SiO_3 addition on the expiry time or durability of lenses has not been extensively investigated or documented in existing literature [37].

The "expiry time" of a lens refers to the duration over which it maintains optimum performance before

Table 2. Input and output data for the Liou and Brennan eye model of the ZEMAX program: The Liou and Brennan eye model is a detailed computer simulation of the human eye intended to mimic the intricate mechanisms through which light behaves in ocular tissue. The model is extensively used in vision science and optical engineering to understand visual optics and refractive errors and to design corrective lenses.

Surfaces	Radius(mm)	Thickness(mm)	R	νd	Conic
Anterior Cornea	7.78	0.57	1.379	50.23	–0.18
Cornea posterior	6.4	3.16	1.335	50.23	–0.6
Lens's front	12.4	1.59	-	-	0
Lens-Back	∞	2.43	-	-	0
Pupil	∞	0	1.34	50.23	0
Retina	–12	-	-	-	0
Vitreous Humor	–8.1	16.24	1.336	50.23	0.96

degrading with regard to its operation. Expiry time is established through material composition, environmental exposure, and mechanical wear [38, 39].

- Chemical Stability: SiO_3 can impart improved chemical stability through the formation of an environmentally resistant protective layer that shields from UV light and other types of environmental degradation.
- Mechanical Durability: By potentially enhancing structural integrity of the lens material, SiO_3 could reduce micro-abrasions and surface wear over time.
- Moisture Resistance: Silicon-based materials have a tendency to promote hydrophobicity, which could help maintain clear lenses by reducing issues with moisture.

Whereas these are the theoretical benefits, direct empirical evidence focused on SiO_3's effect on lens expiry time is scarce. Other studies focus on broader categories of silicon compounds but do not specifically isolate the effect of SiO_3 [40].

While SiO_3 can potentially lengthen the expiry date of lenses through enhanced stability and strength, detailed research is needed to confirm these effects empirically. Future research should prioritize highly controlled experimentation separating the influences of SiO_3 from those of other silicon-based additives [38].

4. Conclusion

According to the results, optical characteristics are improved throughout a wide spectrum range when SiO_2 nanoparticle concentration is raised. Improved light transmission, fewer scattering losses, and better refraction index matching between the lens substance and its surroundings are some of the reasons for this improvement. Because of its exceptional optical transparency over a broad range of wavelengths, SiO_2 is a great option for lens applications.

The lens material's overall density, as well as its dimensional stability, is increased by the addition of silicon dioxide concentration, which leads to better light transmission performance.

The experiment has indicated that 3% is the ideal concentration for nanoparticles of silicon dioxide because larger concentrations could result in appreciable reflecting or absorbance inefficiencies. At this optimal concentration, the nanoparticles strengthen the matrix mechanically and preserve its purity, improving performance metrics like transmittance as well as the refractive index at different wavelengths.

Conflict of interest

Nothing to announce.

Funding

No grants from public, commercial, or nonprofit funding organizations were given for this research.

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