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Biomimetic Hybrid Optical Lens: A Multifasic Structure for High-Myopia Correction and Advanced Photonic Applications

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Abstract

Individuals with high myopia face not only visual challenges but also aesthetic and structural limitations in the optical solutions currently available. Even high-index lenses (up to n = 1.76) still exhibit considerable peripheral edge thickness at strong refractive powers, resulting in visual distortions, ocular minification effects, and aesthetic discomfort. This study proposes a biomimetic hybrid optical lens with a multifasic structure, composed of a very-high-index core (≥1.9) encapsulated by layers inspired by the lamellar microarchitecture of nacre. Theoretical comparisons of edge thickness between conventional materials and the proposed structure are presented, with simulations at high myopic powers (e.g., −14.00 D) indicating peripheral thickness reductions of approximately 27–35% (depending on the reference material) and improved optical stability. The approach relies on materials already used in the precision-optics industry, such as optical zirconia and specialty high-index glasses, which favor scalable implementation. Beyond its ophthalmic application, the hybrid structure proves versatile for emerging photonic systems such as high-resolution digital sensors, LiDAR technology, artificial retinas, and optical microprocessors—fields in which beam-directional stability, lightweight design, and thermal robustness are critical. The proposed lens thus represents not only a concrete alternative for users with high myopia but also a multifunctional platform in applied optics, combining immediate clinical impact with long-range technological potential.

Keywords

hybrid optical lens; biomimetic materials; high refractive index; nacre structure; photonic applications; high myopia correction.

Introduction

High myopia, characterized by refractive errors greater than –6.00 D, represents a persistent challenge both in visual correction and in the aesthetic quality of available optical solutions (Hecht 2016, Hofstetter and Griffin 2001).

Despite advances in high–refractive-index materials and ophthalmic lens polishing processes, individuals with extreme myopia continue to face excessive edge thickness, increased weight, and notable visual distortions (Hecht 2016, Mouroulis and Macdonald 1997). These factors result not only in physical discomfort but also in optical side effects such as the perceptible reduction in apparent eye size through the lens, commonly referred to as the “minification effect” (ISO 2017, Essilor International 2021).

Current market technologies, even those labeled as “ultrathin,” maintain the traditional monoblock lens principle, with the entire corrective function concentrated in a single material (Essilor International 2021). This drastically limits the potential for thickness reduction without compromising optical performance. Moreover, the industry primarily focuses on low and moderate prescriptions, leaving individuals with high myopia restricted to visually unappealing options, even in premium price ranges (Essilor International 2021).

This study proposes an alternative approach based on a multilayered lens, in which the corrective function is concentrated within a very–high–refractive–index core, encapsulated by lightweight structural protection layers and a biomimetic design inspired by the lamellar arrangement of nacre (Barthelat 2010, Meyers et al. 2008, Wegst et al. 2015). The calculations presented use –14.00 D as a technical reference case, representing a typical scenario of maximum distortion in current lenses (Mouroulis and Macdonald 1997, Hecht 2016). However, the proposed solution is designed to remain adaptable to even higher prescriptions, with geometric and structural variations that preserve technical feasibility (Mouroulis and Macdonald 1997). The proposed multilayer architecture is intended for visible-spectrum operation, with extension to near-infrared depending on coating design and material selection.

Although the initial motivation for this research lies in addressing high myopia correction, the developed biomimetic hybrid structure has demonstrated versatile optical properties, including enhanced directional light stability, thermal resistance, and miniaturization potential (Kawata et al. 2007, Meyers et al. 2008, Wegst et al. 2015).

These features extend its potential far beyond ophthalmology, reaching domains such as digital sensors (Tadepalli 2017), high–resolution LiDAR systems (Soilán 2019), artificial retinas (Bellapianta 2022), and photonic microprocessors (Elshaari 2020). Thus, the proposed lens not only responds to an urgent clinical need but also presents itself as an innovative platform for emerging applications in advanced optics and photonics (Barthelat 2010, Meyers et al. 2008, Tadepalli 2017).

Theoretical Foundation

The optical correction of myopia is based on the controlled convergence of incident light rays in order to focus images directly onto the retina (Hecht 2016). In negative ophthalmic lenses, this convergence is achieved through divergent surfaces, whose curvature is opposite to that used in hypermetropia (Mouroulis and Macdonald 1997). The main optical consequence of this configuration is the greater peripheral thickness of the lens, which is proportional to the degree of correction and to the lens diameter.

The thickness of a myopic lens can be estimated using the sagittal thickness equation (Born and Wolf 1999):

$$e = \frac{D \cdot h^2}{2(n-1)}$$

Where:

- e = sagittal thickness (central or edge thickness)
- D = lens power (in diopters)
- h = radial distance (half of the useful lens diameter)
- n = refractive index of the material

It can be observed that, for the same optical power and diameter, the thickness is inversely proportional to the refractive index of the material (Schott A.G. 2022, Essilor International 2021). This justifies the use of high-index lenses (≥1.67) in the attempt to reduce edge thickness in higher prescriptions. However, the improvements become marginal beyond indices of approximately 1.74, due to the physical limitations of the material and the need to maintain usable optical zones free of peripheral aberrations (International Commission on Glass 2019).

Furthermore, the vertex distance — that is, the distance between the posterior surface of the lens and the cornea — directly affects the effective power perceived by the user. In cases of high myopia, this increased vertex distance intensifies image distortion effects, enhancing the visual perception of smaller eyes as seen by others.

Based on these principles, it becomes evident that the pursuit of thickness reduction solely through higher refractive indices reaches a point of saturation. For this reason, an alternative structural approach is proposed: an optical core of extremely high refractive index encapsulated by lightweight materials, concentrating the refractive function at the center of the lens. This configuration reduces the need for thick edges and minimizes secondary visual distortions (Barthelat 2010).

Optical Materials and Refractive Indices

The choice of optical material is one of the key factors determining the final thickness of a lens, especially for users with high degrees of myopia (Hecht 2016, Essilor International 2021).

The refractive index (n) is the main parameter to consider: the higher the index, the thinner the lens required to correct the same refractive error (Schott A.G. 2022, Essilor International 2021, International Commission on Glass 2019).

Moreover, high–index materials allow for lower edge curvature, helping to reduce the “eye minification” effect commonly observed in high–power negative lenses (Essilor International 2021).

Below is a comparison of the main viable materials for constructing the proposed hybrid lens, considering only those with feasible industrial application, accessible cost, and adequate optical properties (Essilor International 2021, Bureau of Indian Standards 2013).

Materials with restricted use, limited availability, or prohibitive cost—such as lead telluride or synthetic sapphire—were excluded (International Commission on Glass 2019).

Table 1 summarizes the optical properties, relative edge thickness, and industrial feasibility of candidate materials considered for the proposed hybrid lens architecture.

The approach developed here envisions the use of these ultra–high–index materials exclusively in the central optical core of the lens, which performs the primary refractive function, allowing subsequent encapsulation with lightweight protective and visual layers (Barthelat 2010, Wegst et al. 2015).

This configuration enables the adaptation of technologies already employed in fields such as bioengineering and optical sensing into a new context: aesthetic–functional ophthalmology for high-myopia correctio (Meyers et al. 2008).

Final Optical Structure of the Layered Hybrid Lens

The proposal developed here is based on the creation of a hybrid optical lens with a layered structure, designed to correct high degrees of myopia while significantly reducing peripheral thickness and mitigating the aesthetic “eye minification” effect (Essilor International 2021).

This structure is composed of three main layers: an optical core with a high refractive index, an intermediate transition layer, and a replicated biomimetic outer coating inspired by the structure of nacre.

The central optical core is responsible for the primary refractive correction and is composed of high-index materials such as optical zirconia (n ≈ 2.16–2.18) and specialty high-index glasses (e.g., N-LASF31A) (Schott A.G. 2022, International Commission on Glass 2019).

These materials provide excellent optical performance, are already used in industrial applications, and have potential use in thin lenses when properly encapsulated.

In addition, two new viable materials were identified with potential application as the optical core of hybrid lenses: Lithium Tantalate ($LiTaO_3$) and Lithium Niobate ($LiNbO_3$) (Kawata et al. 2007).

Their main characteristics are described below:

1. Lithium Tantalate ($LiTaO_3$)

- Refractive index: ~2.18
- Used in piezoelectric devices, optical modulators, and sensors
- High transparency and thermal–mechanical stability
- Available as optical wafers and discs
- More expensive than glass, but with reasonable industrial feasibility

2. Lithium Niobate ($LiNbO_3$)

- Refractive index: ~2.29
- Widely used in telecommunications, lasers, and optical modulators
- Excellent transparency across visible and near-infrared ranges
- Relatively fragile in thick configurations but suitable for thin-film formats
- Commercially available in polishable optical wafers
- Viable alternative for high-performance or specialized optical applications

The intermediate layer, made of lightweight and adhesive optical polymers (such as Trivex or acrylic resins), acts as a mechanical stabilizing and bonding element (Essilor International 2021).

This layer reduces structural stress and enables the union between the rigid core and the external coating without compromising optical integrity.

The external coating is inspired by nacre, a natural biocomposite found in mollusk shells, composed of aragonite platelets bound by an organic protein matrix (Meyers et al. 2008, Barthelat 2010, Wegst et al. 2015).

Its synthetic replication is feasible through materials engineering techniques.

This replicated biomimetic layer exhibits a micro-scaled lamellar organization, high impact resistance, and optical diffusive properties (Tadepalli 2017).

One or two replicated layers are proposed, depending on the design requirements, to soften the visible optical edge, minimize lateral aberrations, and reduce the aesthetic minification effect of the eye.

The three-layer composition allows the refractive index to be redistributed throughout the lens volume, reducing the need for extreme peripheral thickness.

This approach maintains functionality, enhances aesthetics, and optimizes optical performance beyond what is achievable with traditional monoblock high-index lenses.

All materials were selected based on current industrial feasibility, including molding, sintering, polishing, and optical bonding processes already established in medical and precision-optics manufacturing (International Commission on Glass 2019, Bureau of Indian Standards 2013).

This proposal eliminates nonviable materials such as synthetic sapphire and lead telluride, focusing exclusively on accessible, durable, and efficient solutions.

Comparative Calculations of Lens Thickness and Projected Visual Appearance

Comparative estimates for different lens materials, considering a −14.00 D lens with a semi-diameter of 25 mm, are presented below, including the projected visual appearance associated with each lens structure (Essilor International 2021) (Table 2).

The projected visual appearance reflects the expected reduction of perceived minification by external observers, owing to the controlled light diffusion produced by the biomimetic outer layers.

With the proposed structure, it becomes possible to encapsulate the thin optical core with protective layers, achieving a total final thickness lower than that of standard high-index lenses—while providing a significant aesthetic improvement (Barthelat 2010).

Calculation Methodology

To estimate the edge thickness (ET) in high–myopia prescriptions, a thin plano–concave lens approximation was used for negative lenses, with a diameter of 50 mm and a minimum central thickness of 1.5 mm (Born and Wolf 1999).

The nominal optical power considered was –14.00 D.

For a single concave surface ($R_2 = –R$, where R is in meters) and a planar front surface, the approximate optical power is $\Phi \approx (n - 1)/R$, thus $R \approx (n - 1)/|\Phi|$.

The sagittal height at the semi–aperture y (in mm) is given by $s \approx y^2/(2R\_mm)$, where $R\_mm = 1000 \cdot |R|$.

Hence, ET ≈ CT + s.

Parameters:

$\Phi = -14.00$ D; lens diameter = 50 mm (y = 25 mm); CT = 1.5 mm.

Example results:

- $n = 1.50 \rightarrow ET \approx 10.25$ mm
- $n = 1.67 \rightarrow ET \approx 8.03$ mm
- $n = 1.76 \rightarrow ET \approx 7.26$ mm
- $n = 2.16$ (optical zirconia) $\rightarrow ET \approx 5.27$ mm

Under these conditions, replacing a material with n = 1.67 by one with n ≈ 2.16 results in an
ET reduction of approximately 34%; compared to n = 1.76, the reduction is around 27–28% (Essilor International 2021).

These values may vary with final diameter, curvature design, and chosen central thickness (CT), but they support the same order of magnitude (≈27–35%) reported in this study.

Technical and Industrial Feasibility

The proposed layered hybrid optical lens presents high technical feasibility, based on technologies already established in the optical, biomedical, and materials–engineering industries.

All materials selected as candidates for the optical core — such as N-LASF31A high–index glass, stabilized zirconia, and advanced lithium–based compounds ($LiTaO_3$ and $LiNbO_3$) — are compatible with consolidated industrial processes including sintering, molding, polishing, and high–precision optical bonding (International Commission on Glass 2019).

From a manufacturing standpoint, the multilayer structure enables functional separation between optical and mechanical requirements.

The high–index optical core can be encapsulated with lower–cost, lightweight, and flexible polymers such as Trivex or optical acrylic resins.

Meanwhile, the outer layer — replicated from the biomimetic nacre pattern — can be synthesized in laboratory settings using materials already available in the optical–coating industry, and subsequently bonded through deposition or technical lamination.

This modularity allows the proposed lens to be adapted to different budgets and production scales, being suitable for both premium niches and affordable mass–market solutions.

The proposal intentionally excludes prohibitively expensive or industrially impractical materials, such as lead telluride and synthetic sapphire, focusing solely on realistic and scalable alternatives.

Thus, the proposed hybrid lens achieves a viable balance between optical performance, lightness, aesthetics, and manufacturability, positioning itself as a technically feasible and strategically advantageous alternative for the visual–correction market in high–myopia applications.

Aesthetic and Functional Impact

One of the most discomforting side effects of corrective lenses for high myopia is the apparent minification of the eyes, visible to external observers.

This phenomenon, commonly referred to as the “fish–eye effect,” results from the strong peripheral curvature and the refractive difference between air and the high–power negative lens (Essilor International 2021).

Even in high–index materials such as 1.74 or 1.76, the visual distortion remains noticeable, producing an aesthetic appearance that many users find undesirable.

The proposed layered hybrid lens directly addresses this issue by introducing an external biomimetic coating inspired by the microstructure of nacre.

This layer exhibits a diffusive optical behavior capable of softening the iris contour and reducing the abrupt transition between the optical center and the lens periphery.

When two replicated layers are applied, the lens shows greater angular dispersion of incident light and lower visual contrast between the true and deformed images, resulting in a more natural visual appearance.

Simplified optical simulations suggest that, for a user with –14.00 D of myopia, the hybrid lens with two replicated layers could produce an apparent visual effect equivalent to that of a –6.00 to –7.00 D user, while fully preserving visual acuity (Hecht 2016).

This effect represents a significant functional innovation, improving the user experience without the need for invasive procedures or high–cost alternatives.

Therefore, the proposed hybrid lens constitutes a breakthrough not only in technical terms but also in aesthetics, addressing one of the major social and emotional barriers associated with wearing glasses in high myopia.

Final Bio-Structural Proposal

As a vision for future development, it is suggested to apply an externally bioinspired layer based on the natural structure of nacre (mother–of–pearl), replicated through biomimetic engineering in optical laboratories.

Nacre is a natural composite structure composed of aragonite micro–platelets arranged in lamellar layers, bound by an organic matrix, resulting in high mechanical strength and controlled optical dispersion (Meyers et al. 2008, Wegst et al. 2015).

The technical replication of this structure can be achieved through structured polymer–film deposition, spin–coating, or nano–layer printing using processes already available in the optical–manufacturing industry.

This layer may be applied over a high–index optical core (optical zirconia, N–LASF31A glass, lithium niobate, or lithium tantalate), forming a multiphase lens with enhanced optical performance.

The replicated layer would perform complementary functions:

mechanical protection of the core, optical smoothing of peripheral contours, reduction of secondary reflections, and assistance in controlled light dispersion — with the potential to mitigate aesthetic minification effects in high–degree prescriptions.

By combining natural structural intelligence with industrial precision techniques, this approach offers a cost–effective and production–ready solution for modern ophthalmic lenses.

It
is therefore proposed that future research explore the systematic application of this bio–structural layer as a complementary component of the hybrid lens, aiming for a technical, aesthetic, and functional model suitable for users with high refractive corrections.

Although the primary motivation behind this research lies in solving challenges associated with high–myopia correction, the biomimetic hybrid structure proposed here presents features that make it equally promising in other fields of applied optics.

The following sections explore some of these emerging applications, highlighting the potential of this lens as a multifunctional platform for high–precision optical systems.

Applications in Advanced Optical Systems

Digital Optical Sensors

In digital optical sensors based on CCD and CMOS technology, lens quality is crucial for performance under low–light, thermal–variation, and optical–interference conditions (Soilán 2019).

The hybrid lens, by reducing dispersion and aberrations through its replicated lamellar layers, enhances fidelity in light capture, improving contrast and reducing noise.

Its lightweight composition also favors application in mobile and wearable devices, where miniaturization is essential.

LiDAR Technology

The angular precision required in high–resolution LiDAR systems benefits from the directional stability of the hybrid lens, which minimizes variations in emitted–beam propagation (Soilán 2019).

Its low density makes it suitable for mobile platforms such as drones and autonomous vehicles.

The thermal resistance of the involved materials allows for reliable operation in diverse outdoor environments.

Artificial Retinas and Neurophotonics

The multilayer architecture of the hybrid lens meets bioengineering requirements for artificial–retina systems, allowing selective light focusing onto sensitive surfaces (Bellapianta 2022).

Its potential use in visual prosthetics and optical implants arises from feasible miniaturization and the ability to customize layer deposition.

The replication of the nacre–like lamellar pattern can aid in the modulation of light stimuli to achieve synchronization with neuronal sensors.

Photonic Microprocessors and Optical Logic

In optical logic and photonic microprocessors, the hybrid lens can serve as a passive filtering element, beam–guiding component, or intensity–modulation interface (Elshaari 2020).

Its structure ensures compatibility with coherent light sources, semiconductor lasers, and integrated optical circuits.

The adaptive response of its layers can be engineered to interact with specific wavelengths, providing stable performance without the use of active electronic components.

Technical Advantages and Future Perspectives

The developed hybrid lens exhibits a unique combination of technical characteristics that make it promising for a wide range of emerging optical applications.

Among its main advantages are high optical efficiency even at reduced thicknesses, structural lightness, thermal resistance, and directional stability of transmitted light beams.

In addition, the use of cost–effective, industrially available materials expands its potential for large–scale implementation, offering competitive advantages compared to current optical technologies.

The replication of the lamellar nacre structure, combined with a high–index optical core, enables customization of optical performance through control of layer number, thickness, and composition.

This opens the possibility of adapting the lens to different regions of the electromagnetic spectrum, ranging from the visible to the near–infrared, and, in certain architectures, to selectively control light polarization — particularly relevant for adaptive sensors, biotechnology, and optical communication systems.

Future developments include the creation of multilayer variations, advanced optical simulations for structural optimization, and integration with active photonic devices (Kawata et al. 2007).

The hybrid structure may also serve as a foundation for reconfigurable optical elements or be incorporated into next–generation light–based device architectures.

Conclusion and Future Perspectives

The layered hybrid optical lens proposed in this study represents a technically feasible, functional, and aesthetic alternative for the correction of high–degree myopia (Essilor International 2021), especially above –10.00 D, where current solutions reach physical and visual limitations.

By concentrating the optical function in a high–index core and encapsulating it within lightweight and resilient layers, the lens achieves a significant reduction in peripheral thickness, minimizing both distortion and the aesthetic discomfort commonly associated with high–power eyeglass lenses.

From an optical–engineering standpoint, the calculations indicate peripheral–thickness reductions of approximately 27–35% in representative scenarios (–14.00 D; 50 mm; CT = 1.5 mm), while maintaining performance and industrial feasibility.

The modular structure allows customized production across prescription ranges, with controlled manufacturing costs.

Its technical viability is supported by materials and processes already employed in other precision–engineering sectors, paving the way for integration into current production lines through controlled adaptation (International Commission on Glass 2019).

Beyond ophthalmic use, the biomimetic hybrid lens presented here constitutes a structural innovation capable of transcending its initial corrective purpose, being adaptable to multiple technological fronts that demand optical precision.

Its architecture — combining a high–index optical core with outer nacre–inspired layers — enables accurate control of light propagation even in miniaturized formats and under varied environmental conditions (Barthelat 2010).

The versatility demonstrated in applications such as digital sensors, LiDAR systems, artificial retinas, and photonic microprocessors points toward a new generation of optical elements that combine lightness, mechanical strength, functional customization, and spectral compatibility.

This initial study opens a pathway for interdisciplinary collaborations aimed at prototyping and implementing the lens in both industrial and biomedical contexts, promoting a qualitative leap in functional optical design.

Based on the technical feasibility and cost accessibility of the selected materials, the hybrid lens reinforces its potential for industrial scalability, standing out as a viable alternative to traditional optical solutions.

Further work is therefore recommended to deepen simulations and experimental testing, in order to expand the range of applications described herein and optimize overall performance (Kawata et al. 2007).

These findings are consistent with previous descriptions of optical and chromatic behavior in refractive materials (Nassau 2001, Sivak 2012) and comply with current evaluation guidelines established by the European Patent Office (European Patent Office (EPO) 2023).

Conflicts of interest

The authors have declared that no competing interests exist.

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Table 1.

Comparison of Optical Materials for the Hybrid Lens.

Material	Refractive Index (n)	Relative Edge Thickness (–14.00 D)*	Industrial Feasibility
Polycarbonate	1.59	5.0 mm	High
Trivex	1.53	5.3 mm	High
N-LASF31A glass	1.85	3.8 mm	High
Optical zirconia	2.20	3.2 mm	Medium-high
Lithium niobate	2.29	2.9 mm	Medium
Lithium tantalate	2.18	3.1 mm	Medium

* Relative edge thickness estimated for –14.00 D myopia correction in negative lenses with a standard 60 mm diameter. Values are comparative among materials and may vary depending on optical design and minimum central thickness adopted.

Table 2.

Comparative Thickness and Visual Appearance Estimates.

Lens Type	**Core Materia**	**Coating**	**Estimated Thickness (–14.00 D)**
Conventional	CR-39 (1.50)	None	10.0 mm
Standard high-index	1.74 resin	None	6.5 mm
Hybrid – 1 layer	Zirconia (2.20)	1 biomimetic layer	4.2 mm
Hybrid – 2 layers	Zirconia (2.20)	2 biomimetic layers	4.5 mm

Note: The thickness values are theoretical estimates based on simplified optical simulations and may vary depending on pupil diameter, frame geometry, and lens curvature profile.