



MATERIAL MATTERS: A COMPREHENSIVE REVIEW OF OPHTHALMIC LENS MATERIALS

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Abstract: The domain of ophthalmic lenses has seen remarkable advancements in lens materials over the past century, transitioning from conventional glass to advanced polymer-based option. This review comprehensively covers the evolution of lens materials, optical properties of various ophthalmic lens materials, and matching the lens requirements to the patient's lifestyle and needs including crown glass, CR-39, polycarbonate, Trivex, high-index plastics (1.60, 1.67, 1.74), MR series lenses (MR-8, MR-7, MR-10, MR-174), photochromic lenses, and polarized lenses. The benefits of every material is evaluated and the review concludes by making the practitioners understand the importance of the dispensing of spectacle lenses according to the patient requirements.

Keywords: Ophthalmic lens materials, Refractive index, Photochromics, High-index plastic lenses, Polycarbonate, Trivex, Polarized lenses.

I. Introduction:

Ophthalmic lenses play a crucial role in refractive error correction, visual acuity improvement, as spectacles are the easiest and non-invasive way of correcting refractive errors like myopia, hyperopia, astigmatism and presbyopia. According to WHO, a global prevalence of 2.2 billion people tend to have some kind of visual impairment – for near or distance(1) The visual impairment could have been prevented in about half of the estimated cases i.e. 1 billion people, where one of the leading causes for impairment in distance vision is uncorrected refractive errors i.e. 88.4 million and for near vision loss is presbyopia (826 million)(1)(2) Thus, stating that almost 80% of the cases are manageable and avoidable by optical interventions (like spectacle lenses and contact lenses) and surgeries(3). The optical industry transitioned from using conventional glass lenses to now maximally using various plastic ophthalmic polymers like CR-39, Polycarbonate, Trivex lenses, high-refractive-index plastic lenses and MR series lenses. In the late 13th century, Italian monks used convex crown glass lenses (refractive index 1.523, Abbe value 58.5) for reading, prized for optical clarity but heavy (density 2.55 g/cm³) and prone to shattering (4). The 1930s introduced poly(methyl methacrylate) (PMMA), a lighter plastic, followed by CR-39 (refractive index 1.498, density 1.31 g/cm³, Abbe value 59.3) in the 1940s, which offered superior clarity and dominated 90% of the market (5). However, CR-39's limited impact resistance spurred the adoption of polycarbonate in the 1970s, initially for military use, with a refractive index of 1.586, density of 1.20 g/cm³, and tenfold impact resistance, though its low Abbe value (30) caused chromatic aberrations (6). In the 2000s, Trivex™ emerged, blending polycarbonate's impact resistance with CR-39's clarity (refractive index 1.53, Abbe value 45, density 1.11

g/cm³), alongside inherent UV protection (4). Recent innovations include high-refractive-index (1.60–1.90) and bio-based lenses, addressing sustainability and high-power prescriptions (5). Now, spectacles are not limited to vision correction but also cater to eye/vision protection. There are some special lens materials which along with correcting the vision protect the eyes with speciality lenses like photochromics and polarized lenses.

II. Aim:

To provide analysis of ophthalmic lens materials, evaluating their optical properties, advancements, and applications to guide future developments in vision correction and eye care by fostering awareness among optometrist, opticians and even the wearer of spectacle lenses.

III. Objectives:

The objectives of this review paper are to deliver informative analysis of lens materials, specifically to support the educational and practical needs of optometrists, opticians and spectacle lens wearers. The paper aims to outline the historical evolution and classification of lens materials, from traditional glass and early plastics to modern high-index polymers. Furthermore, the paper intentions to evaluate the optical characteristics of all the materials, directing on their optical clarity, durability, and even exploring the speciality lens materials for vision correction and protection requirements. Finally, the paper seeks to identify and propose future directions for the development of pioneering ophthalmic lens materials that improve functionality, patient comfort, and overall ocular health.

IV. Ophthalmic Lens Materials

1. GLASS LENSES

Glass lenses, often termed mineral lenses, had been the cornerstone of ophthalmic use for centuries as its optical properties made it as the ideal material to be used as spectacle lenses. The glass material used for ophthalmic lenses made by mixing sand, soda, and lime, in which various oxides can be added to either change refractive index or give tint to the material(7).

1.1. Crown glass

Ophthalmic crown glass material, which is now almost obsolete from spectacle lens usage, established a benchmark of optical quality as it is a highly transparent material, has an abbe value of 58.6 ensuring minimal chromatic aberration, while its inherent hardness provides superior scratch resistance without requiring protective coatings(7). It also resists most chemicals and does not discolor on aging(7). This is the most commonly used glass lens material having a refractive index of 1.523, density of 2.54g/cm³ and UV cut-off of 320nm(4,8). This material is not preferred due to its heavy weight and its tendency to break and chip easily(4).

1.2. High-Index Glass

The addition of titanium dioxide to the glass lens mixture gave high-index glass materials like 1.60, 1.70, 1.80 and 1.90 indexes(7). The advantage of high-index glass was that it will reduce the lens thickness in high powers giving a better cosmetic appeal(8). 1.60 index glass lenses (abbe value 42) are available in spherical and aspheric designs and in bifocals and progressive addition lens, fused flat-top bifocals are available upto 1.70 index (abbe value 31, specific gravity 2.99g/cm³), and single vision lens options in still higher indexes like 1.80 index (abbe value 25.4) and 1.90 index(8). By adding alkali metal oxides like titanium oxide and zinc oxide, increased the weight of the lenses as the added materials had higher specific gravity and lowering abbe value, thus, increasing chromatic aberration(8–10).

2. PLASTIC LENSES

The popular lens material being used for spectacle lenses is plastic polymers, also called organic lens material. Plastic spectacle lenses consist of polymers, which are long-chain molecules featuring numerous interconnecting branches or crosslinks, offering greater flexibility and enhanced impact resistance compared to glass(10). Their preference is due to numerous advantages over conventional glass lenses, such as better impact resistance, reduced weight, and a thinner profile(5). While CR-39 is commonly utilized as eyeglass lenses, contemporary materials such as polycarbonate and Trivex exhibit reduced crosslinking and provide exceptional impact resistance(8,10). Lenses with a high refractive index are generally composed of polyurethane resins, which contribute to a lighter lens material and consequently a lower density(9,10). A notable advancement in this field is MR-174™, a bio-based plastic high refractive index lens material that is manufactured through environmentally sustainable manufacturing techniques(11).

2.1. CR-39 lens material

CR-39 has been the predominant polymer utilized for plastic lenses. This material was created by PPG Industries, where 'CR' signifies Columbia Resin, and the numeral 39 indicates the specific variant of Columbia Resin(8).

The primary advantage of CR-39 and other plastic materials in comparison to glass is their reduced density, resulting in a lens that weighs approximately fifty percent less than a crown glass lens of same size and power(7), making it comfortable for the wearer(4). With a refractive index of 1.498 and an Abbe value of 59.3, CR-39 rivals crown glass in optical clarity and minimized chromatic aberration and became the most common plastic lens material by the 1980s(4). At a density of 1.31 g/cm³, CR-39 is half the weight of crown glass, enhancing comfort. CR-39 outperforms glass against high-velocity, pointed impacts, though it may shatter under extreme force(8). CR-39 readily accepts dyes, making it ideal for tinted lenses(6).

Without coatings, CR-39 is prone to scratching, necessitating scratch-resistant layers (4,8). Additional UV coatings are required, as CR-39 only absorbs UV up to 355 nm. CR-39 is 25–30% thicker than polycarbonate or high-index plastics, less suitable for high prescriptions (4).

CR-39 is ideal for patients with low to moderate prescriptions seeking cost-effective, lightweight lenses with excellent optics. It suits those requiring tinted lenses for fashion or light sensitivity but is not recommended for rimless frame fittings. It is less ideal for active sports due to moderate impact resistance(4).

2.2. Polycarbonate lenses

Polycarbonate, introduced to the ophthalmic market in 1977, is renowned for its exceptional impact resistance (6). Initially used in military and industrial applications, its adoption surged in the 1980s following the Optical Laboratories Association's "duty to warn" initiative, emphasizing safety (6), thus, material which was used as industrial protective eyewear made its way into the optical industry as practitioners became more careful regarding ocular injuries resulting from shattered spectacle lenses(8).

Polycarbonate is made up of very long chains of atoms and the sliding chain of atoms allows the material to bend on impact and deform without shattering(6), thus, making polycarbonate is 10 times more impact-resistant than CR-39, making it ideal for safety eyewear(4). With a refractive index of 1.586 and a density of 1.22 g/cm³(8), polycarbonate offers thin, lightweight lenses, i.e 20–25% thinner and lighter than CR-39(4).

These lenses have a relatively low Abbe value (approximately 30), which can lead to noticeable chromatic aberrations, causing color fringing particularly in strong prescription or eccentric gazes(6,8). Absorption of 100% UV-B (290nm-320nm) and 98% UV-A (320nm-380nm) takes place with scratch resistant coated polycarbonate.

Polycarbonate is categorized as a thermoplastic due to its tendency to soften upon exposure to heat. This material is termed as unbreakable lens due to its flexibility but however very soft by nature and thus, is prone to scratching; therefore, it is imperative that polycarbonate lenses are treated with a scratch-resistant coating on both surfaces. Its softness requires mandatory scratch-resistant coatings (6–8). Polycarbonate(PC) resists dyes, thus cannot be tinted(6). It has more surface reflections than crown glass or CR-39 so

polycarbonate is better with anti-reflective coatings(7). PC lenses are cumbersome in manufacturing and fitting due to their soft nature.

Polycarbonate is the material of choice for children, monocular patients, and those engaging in sports activities due to its safety profile(8). It is the most preferred choice for fitting in rimless/three-piece frames. It is less suitable for patients sensitive to chromatic aberration or requiring custom tints.

2.3. Trivex lenses

Developed by Pittsburgh Plate Glass (PPG) Industries in the early 2000s, Trivex combines the impact resistance of polycarbonate with the optical clarity of CR-39 (6), thus is a “quasi-thermoset” structure(6,7). Originally designed for military applications as “visual armor” (6). PPG Industries marketing literature indicates the “tri” in Trivex as a tri-performance lens material; which provides a triple combination of superior optics, impact resistance, and ultra light weight(8).

Trivex has a refractive index of 1.53, specific gravity of 1.11 g/cm³(8), making it the lightest optical lens material among all and an Abbe value of 43-45(8), which in turn reduces the chromatic aberration and giving better clarity as compared to polycarbonate.

Trivex has high impact Resistance, matches polycarbonate, passing ANSI Z87.1 standards at 1.0-mm center thickness (6). It tints quickly and uniformly, unlike polycarbonate and is more scratch resistance than polycarbonate, resists cracking and splitting at the drilled holes making it ideal for rimless frames (6,8). It has good resistance to damage from chemicals(8).

Trivex lenses are more expensive and are slightly thicker than polycarbonate for high prescriptions due to lower refractive index (4).

Trivex is ideal for patients with mild to moderate prescriptions seeking a balance of safety, clarity, and aesthetics. It is acceptable in rimless frame wearers and those requiring tinted lenses for light sensitivity or fashion.

2.4. High- Index Plastics

High-index plastics, typically polyurethane plastics are acrylic high-index plastics with refractive indices from 1.60 to 1.74, emerged to address the thickness and weight issues of high-prescription lenses. Materials like MR-7, MR-8, MR-10, and MR-174 (developed by Mitsui Chemicals) utilize thiourethane and polyurethane resins, with MR-174 incorporating bio-based components for sustainability (5,11,12). These lenses are 15–30% thinner than CR-39, enhancing cosmetic appeal.(4) High-index lenses significantly reduce lens thickness, ideal for high prescriptions and are lightweight than glass, improving comfort(4).

High production costs make these lenses expensive(5). Higher refractive indices increase surface reflections and reduce abbe value necessitating anti-reflective coatings (4,7).

MRTM Series - The high-index lens from Mitsui Chemicals are optical materials with high refractive index, high Abbe number, low specific gravity and high impact resistance are obtained by polymerizing monomers of thiourethane based high index lens material(13).

MR-8TM has abbe value of 41 with minimum chromatic aberration, refractive index 1.60, impact resistance, and thermal resistance(12,13). MR-7TM has good stability, has an index of 1.67 is extremely light, with abbe value of 31, good impact resistance and better color tintability(13,14). MR-10TM has excellent thermal resistance, abbe value of 31 and 1.67 refractive index(12,13). MR-174TM is an eco-friendly, ultra-thin lens material having highest refractive index and the abbe value of 32 (13,14). MR-160DGTM is the green initiative of Mitsui Chemicals as the materials are plant-derived (13).

High-index plastics are best for patients with high prescriptions seeking thin, lightweight, and cosmetically appealing lenses. MR-174 is particularly suitable for environmentally conscious patients, though cost may limit accessibility.

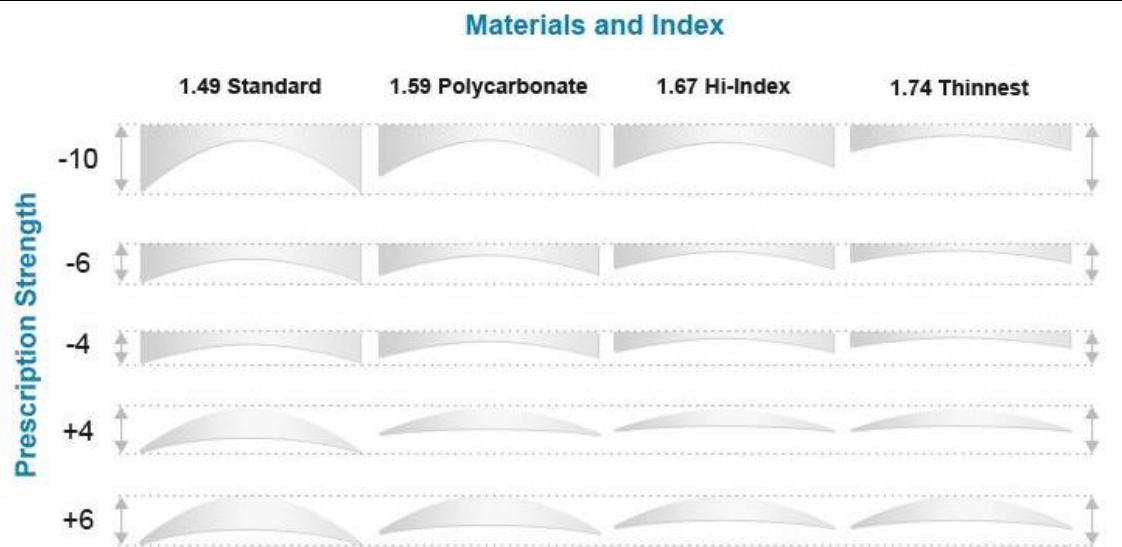


Figure SEQ Figure * ARABIC 1: Thickness comparison among different ophthalmic materials (15).

3. SPECIALITY LENS MATERIALS

3.1 Photochromic lenses

Photochromic lenses, introduced by Corning in 1964 with PhotoGray, darken in response to UV light (300–400 nm) and lighten indoors (7). Glass photochromics use silver halide crystals, while plastic photochromics employ organic dyes via either of the follows - imbibition surface technology, in-mass technology, multimatrix, dip Coating, front surface coating and transbonding(8). Modern photochromics offer faster reaction times and broader transmission ranges.

It is a versatile lens that combines prescription correction with protection from the harmful UV rays of the sun, eliminating the need for separate sunglasses and enhancing comfort (8).

There is limited darkening in vehicles as UV-blocking windshields prevent full darkening (8). Plastic photochromics degrade with UV exposure, reducing efficacy (8).

Photochromic lenses suit patients frequently transitioning between indoor and outdoor environments, such as drivers or outdoor workers. They also are advised to people who are photo-sensitive. It is recommended in patients of cataract, pterygium, etc as prolonged exposure to ultraviolet (UV) radiation is associated with a range of serious health conditions, including pterygium, cataracts, climatic droplet keratopathy, solar retinopathy, and uveal melanoma (15). They are less ideal for those needing consistent dark tints or driving in low-UV conditions.

3.2. Polarized lenses

Polarized lenses are designed to reduce glare from reflective surfaces (e.g., water, snow, pavement) by filtering horizontally polarized light. They are typically made from materials like polycarbonate or high-index plastics, with a polarizing filter (e.g., polyvinyl acetate, PVA) embedded or coated onto the lens (8). Powered polarizing lenses are made by bonding the polarizing sheet between two glass or plastic lenses, one of plano power and the other made to the desired optical prescription (7).

Polarized ophthalmic lenses are specifically designed to help in glare reduction to eliminate the horizontally vibrating component of light, thereby diminishing the intensity of light reflected from horizontal surfaces (8), thus, enhancing visual comfort in bright environments. This lens reduces veiling glare, making colors appear more vivid and improving contrast. Most polarized lenses block 100% UV radiation, protecting against cataracts and macular degeneration. Availability is in various lens styles (single vision, bifocals, progressives) and materials (glass, plastic, high index plastics). Polarized lenses minimize glare from roads and windshields, reducing eye fatigue and improving reaction times.

Orientation sensitivity can cause decrease in the effectiveness of polarization if the lens is tilted (e.g., head tilting), as per Malus' law, allowing some polarized light to pass(8). It may interfere with polarized

screens, such as LCD displays (e.g., car dashboards, gas pumps) if oriented perpendicularly to the display's polarization(4,8). Strong tints may alter color perception, making it unsuitable for prolonged use (4).

Polarized lenses are ideal for those with photophobia or post-cataract surgery patients for less discomfort in bright condition, general people stepping out in the sun, drivers, outdoor enthusiasts facing intense glare and also ideal for fishing, boating, and beach activities. They are less suitable for skiers, golfers, pilots, or individuals frequently using LCD displays, as polarization may interfere with visibility or performance.

V. Conclusion:

As the time progressed, the advancements in ophthalmic lens material demonstrated novelty, by addressing the limitations and enhancing beneficial optical properties of materials. From glass to gradient, optical lens material inventions came a long way. The interplay of chemistry, physics, and patient needs lead to ophthalmic lens material development. Each spectacle lens material offers unique advantages and disadvantages, making them suitable for different patients according to their needs and lifestyle. Thus, these materials reveal a spectrum of options catering to varied visual, aesthetic, and lifestyle needs, empowering practitioners and wearers to make informed choices based on optical performance, comfort, and health considerations. This review paper would thus, help the optometrists and opticians in dispensing the appropriate lens to the patients in turn giving better wearer satisfaction.

VI. Future scope:

The future of ophthalmic lens materials holds significant promise, driven by ongoing innovations and evolving visual demands. Next step of innovation in ophthalmic lens materials lies in developing biodegradable polymers and improving recycling systems to minimise environmental impact. Collective efforts between material scientists, optometric researchers, and industry stakeholders will be essential to translate these innovations into accessible, cost-effective solutions, safeguarding that future lens materials meet the diverse needs of wearers while evolving clinical practice and education in optometry. Advancements in lens manufacturing techniques to further enhance the lens performance could be explored.

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