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**HYBRID LENS DESIGNS IN HD μLED HEADLAMPS**

# Hybrid Lens Designs in HD $\mu$ LED Headlamps

## Lighting at a Turning Point

The evolution of automotive lighting has entered a critical phase. With adaptive driving beam (ADB) systems and intelligent exterior lighting moving into mainstream production, high-resolution micro-LED ( $\mu$ LED) technology is emerging as a central enabler.  $\mu$ LEDs provide pixel-level control of light output, allowing real-time adaptive responses to road conditions and opening opportunities for new OEM brand signatures.

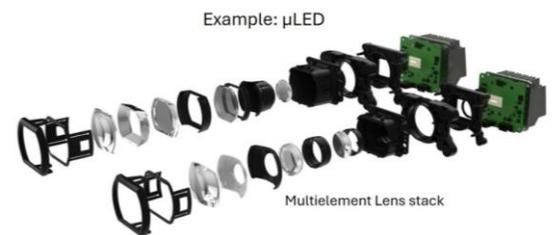
Yet the promise of  $\mu$ LEDs comes with engineering complexity. Optical designs must deliver unprecedented resolution and efficiency, while also surviving demanding automotive environments. Thermal management, manufacturing scalability, and cost competitiveness all play equally important roles. Within this environment, lens hybridization—the strategic use of glass and plastic elements within a single optical system—offers a balanced pathway forward.

## $\mu$ LEDs and the Rise of Optical Complexity

Conventional matrix LED systems typically consist of one to three optical elements, with tolerances around 50  $\mu$ m. These systems are relatively simple to assemble, relying on well-understood glass or plastic optics.



By contrast,  $\mu$ LED-based systems often demand four or more elements, assembled with sub-10  $\mu$ m alignment precision. This leap in complexity is driven by the compact, small individual pixel, and high-intensity nature of  $\mu$ LED chips. Achieving their full potential requires far tighter control of aberrations, resolution, and uniformity across the field, all within compact, thermally stable optical stacks.



*Picture source: Porsche Newsroom*

## The Value of Hybrid Lens Design

Hybridization blends the complementary strengths of glass and plastic. Together, these materials enable optical stacks that are often smaller, more efficient, and cost-balanced while meeting the performance demands. The final lens design is often the result of an iterative process and always strives to be well-balanced, taking into account all individual considerations and client requirements. No matter the final products, the initial base assumptions are always the same:

- Glass elements offer low coefficients of thermal expansion (CTE), stability over lifetime, and a wide variety of refractive indices. Their behavior under stress and temperature cycling is predictable, making them a backbone for critical focusing elements.
- Plastic elements excel in cost-effective shaping. Aspherical surface geometries, non-radial forms, and even rectangular optics can be produced directly in molding. Prototyping is faster, and high-volume production can significantly reduce costs.

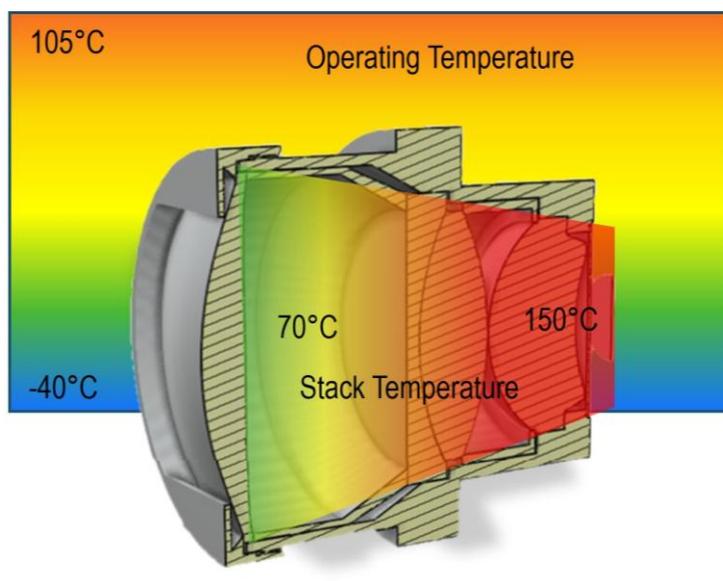
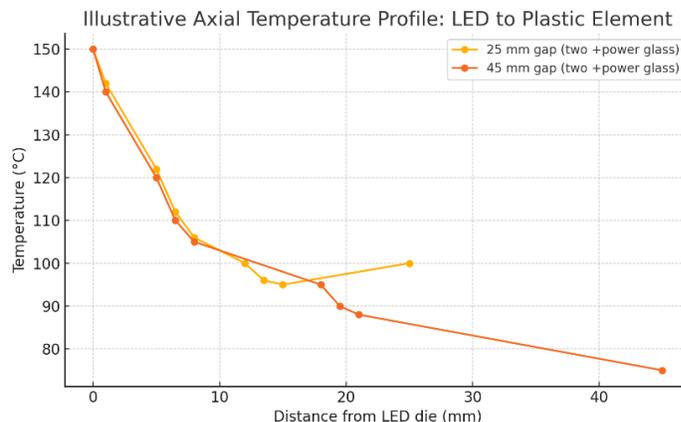
## Reliability Considerations for Plastics

Despite their advantages, plastics present challenges when subjected to high thermal loads and operating temperature ranges that span a wide range. Elevated temperatures and repeated cycling can lead to:

- **Aging effects**, such as moisture absorption and index drift.
- **Degradation in transmission**, resulting in yellowing over time.
- **Coating vulnerabilities**, including abrasion and crazing.

High-end automotive plastics have been used in automotive camera optics for decades, and they are recognized for mitigating these risks. However, it comes at a significant cost—often 10 to 20 times more than common PMMA or PC.

Therefore, the role of plastics must be carefully defined in any hybrid design, ensuring they complement rather than compromise long-term reliability.



## Engineering Trade-Offs in Hybridization

Designing hybrid stacks requires decisions across several dimensions:

- **Element placement relative to the  $\mu$ LED source** – glass remains preferred for high-flux, high-heat positions (close to the  $\mu$ LED source).
- **Surface geometry** – leveraging plastics for aspherical optical surfaces, outer flanges, and shapes that would be prohibitively expensive in glass.
- **Lifetime stability** – balancing need for optical coatings (efficiency, straylight), abrasion resistance, and long-term exposure to high temperature gradients.
- **Performance outcomes** – optimizing resolution, uniformity, efficiency, and color performance while containing costs.

In many cases, hybrid stacks enable OEMs to reduce overall mechanical dimensions of the optical system while maintaining performance and manufacturability.

## Compact Architectures in Practice

Recent Sunex products demonstrate how hybridization and ultra-compact designs enable next-generation HD  $\mu$ LED-based headlamp systems:

- A 48° HFOV all-glass lens achieves compact packaging with an outer diameter (OD) and total track length (TTL) just a little above 30mm
- A 24° HFOV hybrid lens reduces system size by 35% compared to conventional designs, supporting the trend for smaller headlamp systems.

These examples demonstrate that hybrid stacks and innovative design solutions enable both performance and packaging improvements, supporting future  $\mu$ LED-chip sizes.



*Sunex DSL092 Hybrid Projector Lens*

## Key Takeaways

- **Hybridization balances trade-offs** between mechanical size, performance, and cost.
- **Material selection matters**, with glass ensuring the required thermal stability, while plastics enable innovative geometries.
- **Reliability must remain a central goal**, particularly when considering thermal cycling and extended lifetime.
- **Compact projection lens designs are achievable**, enabling the proliferation of  $\mu$ LED-based HD headlamp systems that balance performance and OEM aesthetics.

## Conclusion – Engineering for Reliability

The transition to  $\mu$ LED headlamps represents not just a new technology, but a new design paradigm. Success depends on integrating optical design, materials science, thermal analysis, and manufacturing expertise into a cohesive system strategy.

**Hybrid lens design offers a proven pathway:** by combining glass and plastic elements thoughtfully, engineers can achieve the right balance of reliability, optical performance, and cost efficiency.



*Sunex DSL030 Compact Projector Lens*

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Scan the QR code to access product datasheets, case studies, incl. a Design Guideline, and more.

