Polymer Multilayer Coatings for

Heads-Up Display Combiners

A Collaboration Whitepaper on Narrowband Reflective Coatings

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Collaboration Whitepaper | Not a Funding Request

This document is formatted as a collaboration whitepaper—an informal genre intended to invite research partnerships. It is not structured as a journal paper and is not submitted for peer review.

1. Overview

1.1 Purpose

This whitepaper proposes an investigation into polymer multilayer films as narrowband reflective coatings for heads-up display (HUD) and helmet-mounted display combiners. The combiner's function—reflecting display light at specific wavelengths whilst transmitting ambient light—falls within the general class of optical behaviour that structural-colour polymer films produce. Whether such films can achieve the spectral precision required by HUD systems (centre wavelength tolerance, full width at half maximum, angular acceptance) has not been demonstrated and remains the central open question.

Three candidate polymer film architectures are considered: block copolymer (BCP) self-assembled photonic films, co-extruded polymer multilayer films, and laminated multi-film stacks. These represent fundamentally different manufacturing processes with different performance trade-offs, and they are treated separately throughout this document.

1.2 Market Context

The total HUD market, including automotive applications, is valued at approximately GBP 6 billion and projected to reach GBP 20–40 billion by 2033. The military HUD market forms a subset at GBP 1.2–5 billion, growing towards GBP 7–10 billion by 2030. These are total addressable market (TAM) figures. The serviceable addressable market (SAM) for an alternative polymer-based coating technology has not been estimated and would depend on cost competitiveness, qualification outcomes, and the fraction of HUD architectures that would benefit from conformable or roll-to-roll-manufactured combiners.

1.3 Potential Advantages

The key potential advantage over existing vacuum-deposited inorganic rugate filters—the current state of the art, produced by companies such as Gooch and Housego (Ilminster, UK)—is conformability to curved substrates and the possibility of roll-to-roll manufacturing cost reduction for high-volume applications. This potential cost advantage is inferred from the general economics of roll-to-roll polymer processing compared to batch vacuum deposition, but no cost model specific to HUD combiner coatings has been developed.

The weight of a vacuum-deposited coating, being microns thick, is negligible relative to the combiner substrate. The advantage of a polymer approach is not coating mass but substrate conformability, enabling curved combiners without complex vacuum tooling, and roll-to-roll manufacturing cost reduction for high-volume automotive applications. For military helmet-mounted displays where total headgear weight must stay below strict limits, any weight advantage would come from enabling lighter polymer substrates rather than from the coating itself.

2. Technical Background

HUD combiners require narrowband reflective coatings. The state of the art is vacuum-deposited inorganic rugate filters—coatings with smooth sinusoidal refractive index profiles that produce clean narrowband reflection with suppressed sidelobes (Southwell, US Patent 5,576,886, 1996). Gooch and Housego manufactures these coatings commercially for military applications.

Multi-notch capability is increasingly important as HUD systems move from monochrome green phosphor sources to full-colour RGB LED or micro-LED display sources. A polymer multilayer film could, in principle, be engineered with multiple reflection bands corresponding to red, green, and blue display wavelengths, each with narrow FWHM to maximise ambient transmission between bands. No such polymer film has been demonstrated for this application. [HYPOTHESIS]

2.1 Conformability as Advantage

Not all HUD architectures use curved combiners; some use flat combiners where conformability offers no benefit. The conformability advantage applies specifically to curved-combiner HUD designs. The fraction of current or planned automotive and military HUD systems that require curved combiners has not been surveyed, and this is noted as an open question in Section 5.

2.2 Applicable Standards and Jurisdictions

The applicable qualification pathway depends on the target market. For US military applications, MIL-PRF-13830 governs optical component performance and MIL-STD-810 governs environmental testing. For UK military applications, DEF STAN 00-35 covers environmental testing and DEF STAN 59-411 covers optical specifications, with specific requirements dependent on platform and procurement authority.

For automotive applications internationally, UNECE Regulation No. 43 governs automotive glazing in EU and UK markets. SAE J1960 (accelerated weathering) is a US standard commonly used internationally but may not satisfy all EU/UK type approval requirements. Any development programme would need to identify the specific target jurisdiction and qualification standards early. This whitepaper does not assume a single jurisdictional pathway.

3. Technical Requirements and Candidate Architectures

A prior-art search was conducted during January–February 2026 using open literature and patent databases. Rugate filter HUD combiners are established prior art (Southwell, US Patent 5,576,886). Gooch and Housego and other optical coating manufacturers may hold proprietary unpublished work that could not be identified in an open literature search.

No published work was found that uses self-assembled BCP or co-extruded polymer films for HUD combiner coatings. This novelty claim is qualified: proprietary or classified work in this area may exist. The absence of published prior art does not guarantee absence of prior art.

3.1 Polymer Film Architecture Definitions

Block copolymer (BCP) self-assembled photonic films are those in which nanoscale periodic structures form spontaneously via thermodynamic self-assembly of block copolymer molecules. Within the parent project (Project Labradorite), these are sometimes described using the shorthand "Boggild architecture," referring to a specific lamellar stacking geometry inspired by the microstructure of labradorite feldspar. This term is not established in the photonics literature and is used here only as a shorthand for "BCP lamellar photonic film with structural-colour properties." The underlying physics—thin-film interference from periodic refractive index variation—is well established; what is proposed as novel is the application to HUD combiners. [HYPOTHESIS]

Co-extruded polymer multilayer films are produced by forcing two or more polymer melts through a die that creates hundreds of alternating layers with controlled thicknesses, following the approach used in 3M multilayer optical film technology. Layer thicknesses are set by die design and process parameters, not by self-assembly. This is the most established polymer multilayer manufacturing route. [DEMONSTRATED]

Laminated multi-film stacks consist of multiple single-band reflective films bonded together to achieve multi-notch spectral profiles. This route is technically simpler but adds thickness and introduces interface reflections.

3.2 Multi-Notch RGB Design Pathway

A single-period BCP film produces one reflection band. To achieve three reflection peaks for full-colour HUD, several design pathways are possible.

The first option is a chirped or graded BCP architecture, varying BCP molecular weight through the film thickness to produce multiple periodicities. This requires controlled gradient synthesis that has not been demonstrated for BCP photonic films. The second is lamination of three separate single-band films. This is technically simpler but adds thickness and introduces additional interface reflections. The third is a co-extruded polymer multilayer with a designed layer sequence, using programmed layer thicknesses in a co-extrusion process to produce multiple reflection bands. This is the most established manufacturing route but does not use BCP self-assembly. [TARGET]

None of these approaches has been demonstrated for HUD combiner applications. The framing is not limited to multi-notch RGB or nothing—intermediate configurations such as dual-band green-plus-red for specific HUD systems, or single-band films for augmented reality headsets where monochrome operation is acceptable, may represent viable application pathways that avoid the multi-notch engineering challenge.

4. Target Applications

4.1 Automotive Windscreen-Projected HUD Systems

High-volume, cost-sensitive applications may be well suited to roll-to-roll manufacturing. Environmental requirements include thermal cycling from 40 to +105°C, 2000 hours of UV and condensation cycling per SAE J1960 or equivalent under UNECE R43 for EU/UK markets, and cleaning agent resistance per ISO 2812-1. [TARGET]

4.2 Augmented Reality Headset Optics

Conformable, lightweight narrowband reflectors for consumer wearable devices present a distinct opportunity. Environmental requirements are less severe than automotive or military, though optical quality requirements for uniformity and scatter may be demanding at small form factors. [TARGET]

4.3 Military Helmet-Mounted Display Combiners

These are weight-critical applications with severe environmental requirements: 55 to +120°C thermal range, 10g vibration per MIL-STD-810 or DEF STAN 00-35, and altitude pressure changes. Optical requirements per MIL-PRF-13830 (or UK equivalent) include wavefront distortion below /4 and scatter below 0.1%. If polymer films cannot meet automotive environmental specifications, military specifications are categorically out of reach—automotive qualification therefore serves as a prerequisite gate. [TARGET]

4.4 Multi-Notch RGB Combiners

Full-colour HUD systems require one of the design pathways described in Section 3.2. Dual-band or application-specific single-band configurations are also applicable and may represent more achievable near-term targets. [TARGET]

4.5 Liability Considerations

If a polymer HUD combiner coating degrades in service—through thermal cycling spectral shift or delamination, for instance—causing incorrect display information, the question of liability allocation arises. In automotive applications, liability would typically follow the product liability chain from coating manufacturer through combiner integrator, HUD system OEM, and vehicle manufacturer, governed by product liability law in the relevant jurisdiction. In military applications, liability and acceptance are governed by the procurement contract and qualification testing.

Any development programme would need to address liability allocation early, particularly at the point where a polymer coating is proposed as a replacement for a qualified inorganic coating. This whitepaper does not assign liability—it flags the question as a requirement for any future development plan.

5. Open Questions Requiring Collaboration

The following questions define the scope of work that a collaborative research programme would need to address. Each represents a gap in the current knowledge base that cannot be resolved without specialist input.

5.1 Optical Scattering and Wavefront Distortion. What are the optical scattering and wavefront distortion characteristics of polymer multilayer films compared to vacuum-deposited inorganic coatings? MIL-PRF-13830 requires wavefront distortion below /4 and scatter below 0.1%. No polymer multilayer film has been characterised to these specifications. BCP self-assembled films exhibit grain boundary structures whose typical grain sizes range from sub-micron to tens of microns depending on annealing conditions. The scattering loss contribution of these grain boundaries has not been estimated for the film thicknesses and wavelengths relevant to HUD combiners. A rough estimate based on published BCP grain size data and Rayleigh-Gans scattering models would help determine whether the MIL-PRF-13830 scatter limit is plausibly achievable before committing to fabrication.

5.2 Environmental Durability. What is the environmental durability of polymer multilayer films in automotive (40 to +105°C) and cockpit (55 to +120°C) environments? Candidate polymer pairs such as PS-b-PMMA, PS-b-P2VP, and PS-b-PI have coefficients of thermal expansion (CTE) that differ, typically by 20–80 ppm/K between blocks. Over a temperature excursion of 145 K (automotive) or 175 K (military), this differential expansion would change layer thicknesses and shift the reflection centre wavelength. A first-order estimate of this shift has not been calculated but is needed to assess whether it falls within typical HUD FWHM tolerances of ±2–5 nm. If the estimated shift exceeds this tolerance, the polymer approach may be fundamentally unsuitable for these thermal environments without active compensation.

5.3 Multi-Notch Capability. Can multi-notch RGB reflection profiles be achieved? Which design pathway—chirped BCP, laminated films, or co-extruded multilayer—is most viable? Are intermediate configurations such as dual-band or single-band for augmented reality worth pursuing first?

5.4 Performance Target Definition. What are the optical requirements (centre wavelength, FWHM, reflectivity, angular acceptance) for current-generation military and automotive HUD combiners? These specifications are needed to define performance targets for any polymer coating development. The absence of defined performance targets is acknowledged as a gap in this proposal.

5.5 Conformability Demand. What fraction of current and planned automotive and military HUD systems use curved combiners where conformability would be advantageous?

5.6 Cost Modelling. What would a realistic cost model for roll-to-roll polymer photonic coating production look like, compared to vacuum deposition cost per unit area for HUD combiner coatings? No cost comparison has been performed.

5.7 Spatial Uniformity. What is the spatial uniformity of BCP self-assembled or co-extruded polymer films over combiner-sized areas (approximately 100 to 300 cm²)? BCP self-assembly is known to produce domain structures with spatial variation in periodicity and orientation. Uniformity over these areas is not demonstrated and is a potential disqualifying limitation.

6. Known Risks and Limitations

6.1 Environmental Durability [High Risk]

Polymer multilayer films undergo thermal cycling expansion and contraction at differential rates between the two polymer layers. This causes layer thickness changes that shift the reflection centre wavelength, producing colour fringing visible to the HUD user. Delamination between layers is also a risk at temperature extremes. Automotive (40 to +105°C) and military (55 to +120°C) environments are severe.

This risk is acknowledged but not yet quantified: the magnitude of the expected wavelength shift depends on the CTE mismatch of the specific polymer pair, and no calculation has been performed (see Section 5.2). Until this calculation is done, the severity of this risk cannot be assessed by a reviewer.

6.2 Optical Quality Gap [High Risk]

Vacuum-deposited inorganic coatings achieve MIL-PRF-13830 quality (wavefront distortion below /4, scatter below 0.1%). Polymer multilayer films have not been characterised to these specifications. Surface roughness, internal scattering from BCP grain boundaries, and birefringence may all degrade optical quality below acceptable thresholds.

BCP grain boundary scattering is a particular concern: if scattering exceeds the 0.1% limit at the characterisation stage, the military application pathway is eliminated before environmental testing begins. No estimate of grain boundary scattering loss has been calculated (see Section 5.1).

6.3 Multi-Notch RGB Pathway [Medium Risk]

Full-colour HUD requires simultaneous red, green, and blue combiner bands. All three design pathways—chirped BCP, laminated films, and co-extrusion—have unresolved challenges. Without a multi-notch solution, the polymer approach can only address monochrome HUD systems or single-band augmented reality applications.

The monochrome green phosphor HUD market is believed to be declining as systems transition to full-colour displays, although military legacy systems may have extended procurement tails that sustain demand for single-band combiners longer than commercial markets. This is a qualitative assessment based on industry trend reporting; no market data is cited.

6.4 Proprietary Prior Art [Medium Risk]

Gooch and Housego and other optical coating manufacturers may have proprietary work on polymer-based HUD coatings. Commercial sensitivity means relevant prior art may exist but remain unpublished. The novelty claim in Section 3 is therefore inherently limited to the open literature. A freedom-to-operate analysis would be required before any commercial development.

6.5 Technology Readiness and Development Timeline

This proposal is at an early conceptual stage, estimated at TRL 1–2 (basic principles observed, technology concept formulated). Reaching a qualified coating suitable for either automotive or military application would require multiple years of materials characterisation, process development, environmental qualification, and system integration testing. A realistic development timeline might span 5–10 years and would involve significant capital investment in fabrication and testing infrastructure. No development timeline or budget estimate has been prepared.

The framing of this whitepaper as a collaboration invitation should not obscure the fact that bringing a polymer HUD coating to production readiness is a substantial research and engineering programme.

7. Invitation to Collaborate

This whitepaper is issued as an open invitation to research collaboration. The project is not seeking funding at this stage. The aim is to bring together specialist expertise that can address the open questions identified in Section 5.

Expertise is sought in HUD optical design and combiner engineering, to define the performance targets against which any polymer coating must be measured. Collaborators with experience in military avionics and helmet-mounted displays would help clarify qualification pathways and current specification requirements. Those working in automotive HUD systems could assess conformability demand and applicable standards across jurisdictions.

On the materials side, expertise in polymer multilayer film fabrication—both BCP self-assembly and co-extrusion—is needed to assess manufacturing feasibility and spatial uniformity. Optical coating characterisation and environmental testing capability would generate the performance data identified in Section 5. Cost modelling for roll-to-roll polymer film production versus vacuum deposition would close one of the most significant analytical gaps.

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The author is an independent researcher with a background in Systems Engineering. This proposal is presented as a conceptual framework for collaboration, not as a claim of specialist expertise in photonics or optical coatings. Its value depends on whether specialist collaborators find the concept worth investigating.

8. References

8.1 Internal Project Documents

Project Labradorite: Commercial Applications of Synthetic Labradorescence (Deep Research Report, February 2026). This internal document defines the “Boggild architecture” terminology used in Section 3.1. The term refers to lamellar BCP photonic film structures and is not a standard term in the photonics literature.

8.2 External References

Southwell, W.H. (1996) US Patent 5,576,886—Rugate filter structure for HUD optical combiners.

Gooch and Housego plc (Ilminster, UK)—Commercial manufacturer of rugate filter coatings for military HUD.

MIL-PRF-13830—US military performance specification for optical components.

MIL-STD-810—US military standard for environmental engineering considerations and laboratory tests.

DEF STAN 00-35—UK Ministry of Defence standard for environmental testing.

DEF STAN 59-411—UK Ministry of Defence standard for optical specifications.

UNECE Regulation No. 43—Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles.

SAE J1960—Accelerated exposure of automotive exterior materials using a controlled irradiance xenon-arc apparatus.

ISO 2812-1—Paints and varnishes—Determination of resistance to liquids—Part 1: Immersion in liquids other than water.

Appendix A: Document Metadata

Appendix B: Glossary

Appendix C: Methodology and Transparency Statement

Author Context and Expertise

This work is grounded in 30 years of multi-sector experience in Systems Engineering. The analytical framework reflects professional history, focusing on practical application. The author's expertise is in Systems Engineering, not photonics or optical coatings; this proposal identifies a potential application area and seeks specialist collaborators rather than claiming domain authority.

Digital Methodology and Accessibility

In the spirit of transparency, I utilised a suite of Generative AI tools—specifically Claude, Google Gemini, and ChatGPT—to assist in the production of this paper. These tools were employed as force multipliers for data synthesis and editorial accessibility. As a writer with dyslexia, I leverage these models as assistive technology to refine grammar and streamline sentence structure.

Verification and Integrity

Whilst AI assisted in processing data, the intellectual oversight is entirely human. I performed manual validation of all citations and accept full responsibility for the accuracy and originality of the final output.

Appendix D: Raw Author Notes

The concept for polymer multilayer HUD combiner coatings arose from the broader Project Labradorite research programme, which investigates commercial applications of synthetic labradorescence—the structural colour phenomenon observed in labradorite feldspar.

The original insight was that if block copolymer self-assembly can produce the nanoscale periodic structures responsible for labradorescence, and if those structures create narrowband reflection, then the same mechanism might serve as a narrowband reflective coating for HUD combiners. The proposal amounts to asking: can we replace vacuum-deposited inorganic rugate filters with a polymer film that self-assembles its own periodic refractive index structure?

The three-architecture framework (BCP self-assembly, co-extrusion, and lamination) emerged during the review process as it became clear that conflating these very different manufacturing approaches weakened the proposal. Each has distinct advantages: BCP self-assembly is the most scientifically interesting but least proven; co-extrusion is the most established but least novel; lamination is the simplest but adds thickness and interface problems.

The open questions in Section 5 are genuine—these are things I cannot answer from a Systems Engineering background and that require specialist collaborators. The scattering question (5.1) and the thermal stability question (5.2) are potential programme-killers: if either one shows the polymer approach is fundamentally unsuitable, the project stops. Identifying these early is the whole point of seeking collaboration before investing further.

Appendix E: Change Log

This document was prepared using the templates22 protocol for formatting consistency. Editorial corrections, structural reorganisation, and standards compliance were applied during the formatting process. The intellectual content, analytical framework, and all technical claims originate with the author.