Reduced SWAP Polymeric, Nanolayered, Spherical, Gradient Refractive Index (GRIN) Lenses in Imaging Systems

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Abstract: Night vision goggle eye piece and objective systems are described leveraging spherical gradient refractive index lenses fabricated from polymeric nanolayered materials. A reduction in objective length, 15%, weight, 28%, and eyepiece weight, 24%, was achieved.

OCIS codes: (160.5470) Polymers; (160.4670) Optical materials; (160.4610) Optical Fabrication (110.0110) Imaging Systems; (110.2760) Gradient-index lenses

1. Introduction

Gradient refractive index (GRIN) optical lenses, fabricated from a laminated series of nanolayered polymer thin films with customizable refractive indices, were utilized in an optical redesign of a night vision goggle objective assembly to reduce unit length and weight. A recent nanolayered polymer films approach to fabricating GRIN optics, **Figure 1**, [1,2] enabled the design of expanded diameter, 10 to 100 mm, lenses with spherical or aspheric surface shapes comprised with an internal spherical, non-linear refractive index gradient to contribute added optical power and chromatic aberration corrective capabilities [3,4]. Utilizing open sourced nanolayered polymer optical GRIN lens .dll files [5], the NVG objective system optical design was completed in Zemax OpticStudio16. The design effort goals were to: (1) match or exceed on-axis MTF performance as compared to a baseline, all glass element, NVG Objective design, (2) reduce NVG objective optical lens weight by a minimum of 50%, and (3) shorten the NVG objective assembly unit length while maintaining f/# can compatible to the existing unit intensifier tube. The following sections of the abstract present a description and comparison of the NVG eye piece and objective nanolayered GRIN optical designs, as compared to the all glass baseline system and give an overview of the nanolayered GRIN optic prescription enabling the system optical performance, and provide an overview of the materials fabrication process to create the novel GRIN optic.

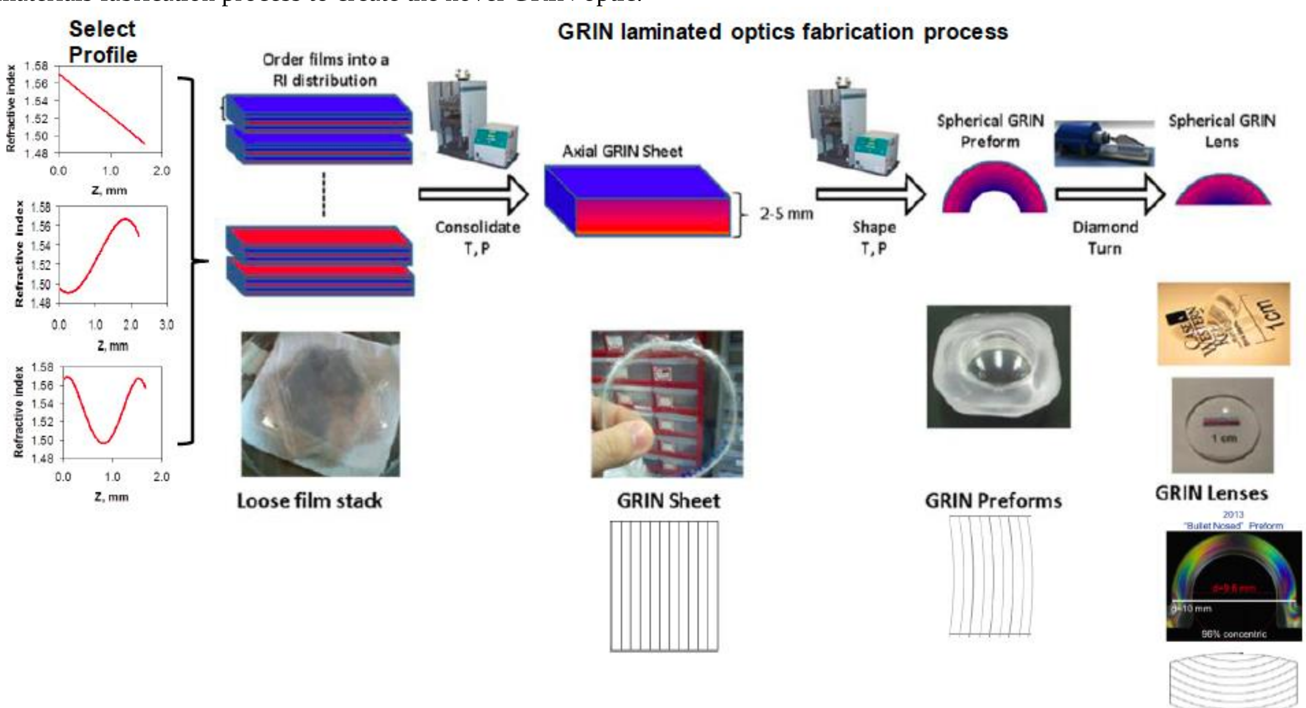


Fig. 1. GRIN optics fabrication process overview

2. Objective Optical Design

A representative all glass night vision goggle eye piece design was compared to a new nanolayered GRIN optic containing version to reduce the number of system optical elements, system weight, while maintaining eye piece mechanical footprint/integration and performance criteria of existing parts. The optical system redesign to incorporate the GRIN technology into the eye piece optical lens assembly was accomplished utilizing commercial optical design software, Zemax OpticStudio16 and open sourced custom .dll extension files [5] created by the Naval Research Laboratory. Incorporation of the GRIN .dll extension files and an acrylic and styrene based nanolayered materials catalogue file populated view optical material optical dispersion curves enabled substitution of one or more of the homogenous glass optics with a nanolayered GRIN lens. The optical design process with nanolayered GRIN elements enables the designer a greater number of design degrees of freedom within the optical system to improve performance without relying on just lens external geometry and material of construction. Additional variables introduced and utilized during the design optimization process include: the number of GRIN elements in a design, GRIN element position in the lens train, GRIN element iso-index curvature, and the shape/magnitude of the internal lens gradient refractive index profile. Based on optical system performance based optimizer functions included as standard options in Zemax, the NVG eye piece optical system was redesigned from a six lens, all glass system with an optical assembly weight of 81 grams to a GRIN system comprised of four lenses (one of those a GRIN lens) with an assembly weight of 11 grams, **Figure 2**. As-fabricated and experimentally measured on axis MTF system performance, **Figure 3**, showed similar optical performance to the glass retro fit system with the elimination of two optical elements and a reduction in overall assembly eight by nearly 25%.

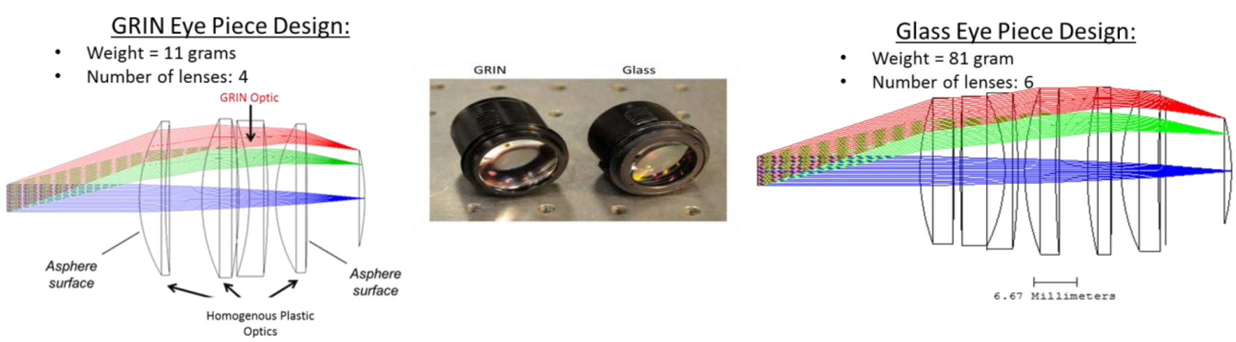


Fig. 2. Comparison of all glass and GRIN plastic eye piece optical design

The internal refractive index distribution of the nanolayered GRIN optic was non-linear. The lens fell entirely within the manufacturing limits of the nanolayered plastic lens fabrication process described in **Figure 1**. The lens was fabricated, assembled with the prescribed homogenous optics and characterized for on axis MTF performance, **Figure 3**. The assembled NVG eye piece was characterized to meet the design on-axis MTF performance of the glass system while maintaining the weight savings as simulated by the Zemax optical design.

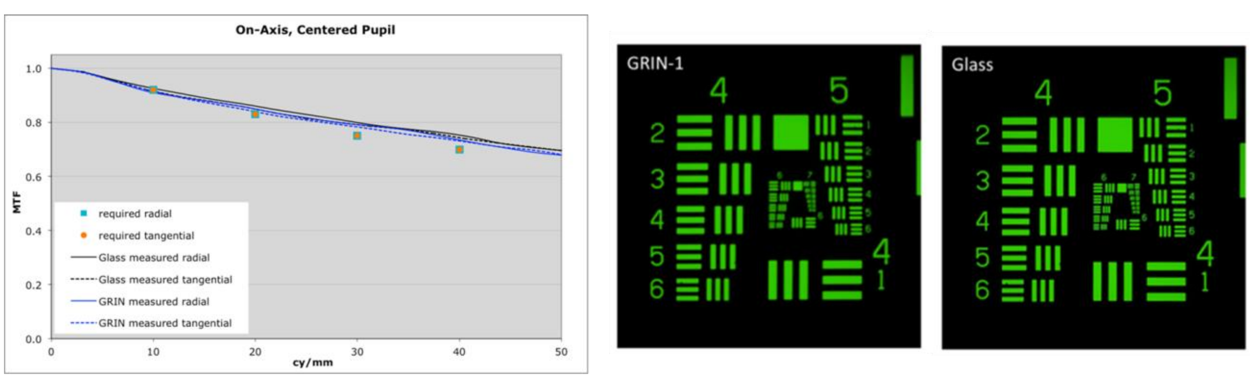
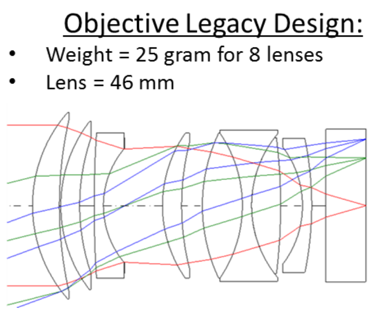


Fig. 3. Glass and plastic GRIN NVG eye piece on-axis MTF and measured images of Air Force bar chart by glass and GRIN assemblies.

3. Objective Optical Design

Optical design simulations to convert a supplied all glass night vision goggle objective design to a design containing one or more nanolayered GRIN optics was accomplished utilizing commercial optical design software, Zemax OpticStudio16 and open sourced custom .dll extension files previously described for the eye piece case study. Similar to the NVG eye piece GRIN system, the objective optical was redesigned from an eight lens, all glass system with an optical assembly weight of 53 grams and 46 mm length to a GRIN system comprised of six lenses (one of those a GRIN lens) with an assembly weight of 38 grams and length of 39.2 mm. Design simulated optical performance, **Figure 4**, showed reduced system spot size even with the elimination of two optical elements and a reduction by more than 1/7 the system length.



Field	RMS Spot Diameter (620 - 870 nm)	
	All Glass Legacy	Plastic GRIN
On-Axis	8.4 µm	1.3 µm
12.6°	27 µm	3.5 µm
19°	53 µm	3.7 µm

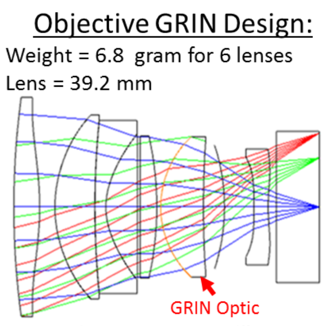


Fig. 4. Comparison of all glass and GRIN plastic objective optical design

The nanolayered GRIN element utilized in the NVG objective design, **Figure 5**, is an 18.5 mm diameter, 5.5 mm thick slightly aspheric, conic, singlet. The internal GRIN distribution is spherical and non-linear as shown. The lens falls entirely within the manufacturing limits of the nanolayered plastic lens fabrication process described in **Figure 1**. The completed optical lens will be comprised of over 700,000 individual nanolayers of acrylic and styrene based polymer materials based on the supplied optical recipe.

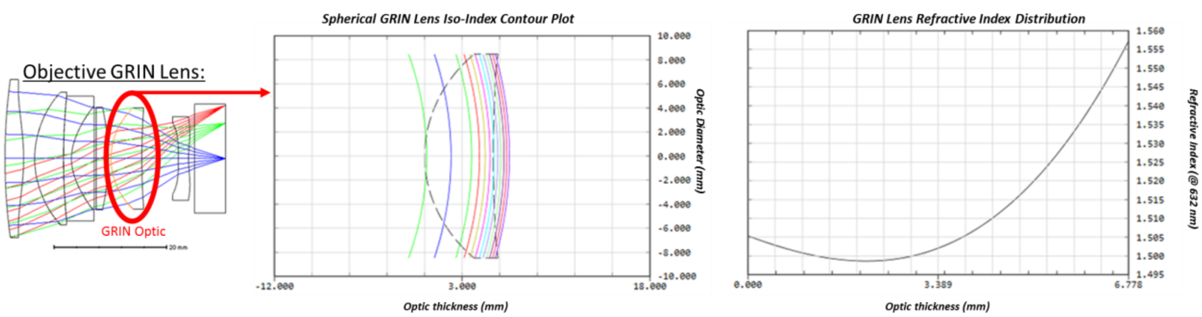


Fig. 5. Nanolayered Polymer GRIN optic internal spherical shaped iso-refractive index contour plot and refractive index distribution

4. References

[1] S. Ji et al., "A bio-inspired polymeric gradient refractive index (GRIN) human eye lens," Opt. Express **20** (24), 26746-26754 (2012).
[2] S. Ji et al., "Polymeric nanolayered gradient refractive index lenses: technology review and introduction of spherical gradient refractive index ball lenses," Opt. Engineering **52** (11), 112105-112105, (2013).
[3] R.A. Flynn et al., "Achromatic GRIN singlet lens design," Opt. Express **21** (4), 4970-4978 (2013).
[4] G. Beadie et al., "Achromatic Gradient Index Singlet Lens," U.S. Patent Application 20130003186 A1 (2013).
[5] "Grin Lens/Zemax-Spherical-GRIN," Available Online: https://github.com/GrinLens/Zemax-Spherical-GRIN/releases, accessed 12/8/2016.