INVESTIGATIONS ON INFRARED CHALCOGENIDE GLASSES USED IN NIGHT VISION DEVICES

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The modern night vision technology uses the advantages of both the image intensifiers technology and infrared sensors technology, namely a clear image, very good resolution, very good target identification probability - for image intensification and ability to see, practically, under any environmental conditions - for infrared sensors. Chalcogenides may represent an alternative for night vision systems objectives because high transmission quality is guaranteed across a wide range of the infrared spectrum images and offer images with nearly similar quality with that given by classical optical glass materials which are operating in the infrared spectrum. The paper presents how the $Ge_{30}As_{13}Se_{32}Te_{25}$ influences the image quality when it is used as a combination of lenses.

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1. Introduction

The traditional night vision technology with image intensification amplifies light to such level of brightness that the human eyes can detect. Another night vision technology uses infrared thermal sensors, which sense radiant energy differences.

The combination of these two technologies into a single electro-optical device requires advanced optical glasses able to transmit electromagnetically radiation from visible to infrared.

On the other hand, the new microbolometers technology improves the image quality. Detector array with smaller pixels will be increasingly smaller and, accordingly, the infrared camera will be more compact, faster lenses, with better image quality. Also, the lower cost of uncooled detector arrays is driving down the cost of the infrared imaging optics [1].

Decreasing the optical aberrations, in order to have a good image quality offered by the infrared camera objective, requires the use of additional lenses with major impact on size, weight and, not the least, price. In this way, classical infrared materials tend to be much more expensive when compared to visible or near infrared optical glasses [1, 2].

This compromise between quality and price over a large spectral domain (VIS, NIR, SWIR and LWIR) could be solved by chalcogenides because high transmission quality is guaranteed across a wide range of the infrared spectrum, from the near-infrared (NIR) to long wavelength infrared (LWIR) regions and low glass transition temperatures.

Chalcogenide glasses could represent a cost – effective [3], high performance alternative to germanium in many infrared optical designs that demand consistent performance, with minor defocusing, across broad temperature ranges.

Today, commercially available chalcogenide glasses are mainly composed of cheap and abundant selenium with germanium content ranging from 20% to 33% (atomic percentages). It is generally much easier and faster to produce glass blanks than to grow single crystals [2].

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2. Experimental details

A large number of optical materials transmit in the infrared region of the spectrum. However, the list of materials is quite limited when physical characteristics, workability, and cost are considered. Germanium is less expensive than zinc selenide or zinc sulfide, the most used materials for infrared night vision systems. Since chalcogenide and silicon have become an order of magnitude less expensive than germanium, its use in infrared lens systems has greatly increased in recent years [7].

Taking into account the quantity of information that is supplied by the multispectral night vision devices, our investigation is based on studying how the $Ge_{30}As_{13}Se_{32}Te_{25}$ influences the image quality when is used like a combination of lenses.

An important task in most night vision infrared applications is to maximize the amount of light falling onto the detector [1, 2]. The absorption of radiation through multiple thick elements may significantly reduce transmission.

The analyzed solution represents a Petzval $Ge_{30}As_{13}Se_{32}Te_{25}$ lens, based on the assumption that the traditional Petzval lens, which operates in the visible waveband, provides good image quality in the region where the horizontal field of view is on the order of 10^o to 20^o and the lens is working in the vicinity of f/1.5 [4]. Also, we assume that the image quality provided by Petzval $Ge_{30}As_{13}Se_{32}Te_{25}$ isn't affected by the processing video signal of SWIR camera used.

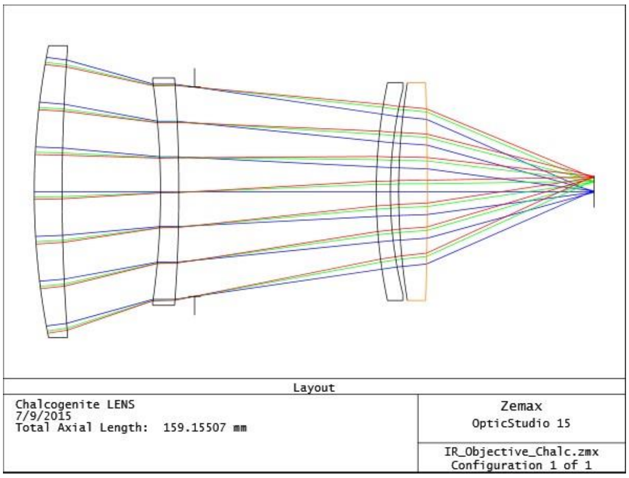

Fig. 1. Petzval $Ge_{30}As_{13}Se_{32}Te_{25}$ optical layout

Petzval $Ge_{30}As_{13}Se_{32}Te_{25}$ optical layout, with 127 mm focal range and f_{nr} = 1.6 lens, was specifically designed by using Zemax OpticStudio 15 software for a 640 × 512 uncooled SWIR microbolometer array, with 25 µm pixels. The lens covers a 5° horizontal field-of-view (FOV), and operates over 0.9-1.7 µm but with possibility to extend range up to 4.2 µm.

The optical design uses four $Ge_{30}As_{13}Se_{32}Te_{25}$ lens (Figure 1). The design takes into account the Silicon cover window in front of the detector. The overall length from the first optical surface to the image plane is 197 mm and the maximum diameter of the optics is 86 mm.

$Ge_{30}As_{13}Se_{32}Te_{25}$ glasses was chosen because of excellent transmission in the SWIR (figure 2), low dn/dT and low dispersion (figure 3), permitting color correcting optical systems without thermal defocusing. Furthermore, the $Ge_{30}As_{13}Se_{32}Te_{25}$ glass can be processed using conventional grinding and polishing techniques, single point diamond turning or molding to support low- to high-volume component-level manufacturing [5].

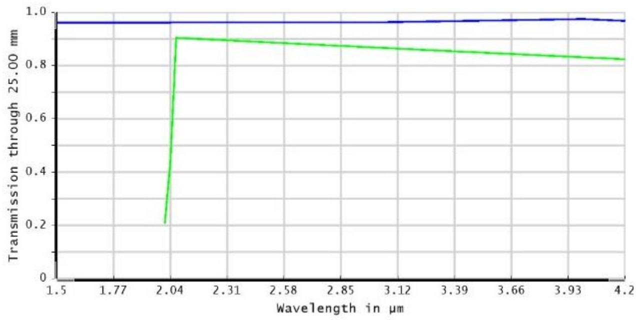

Fig.2. Internal transmission vs wavelength (green color for Germanium, blue color for $Ge_{30}As_{13}Se_{32}Te_{25}$)

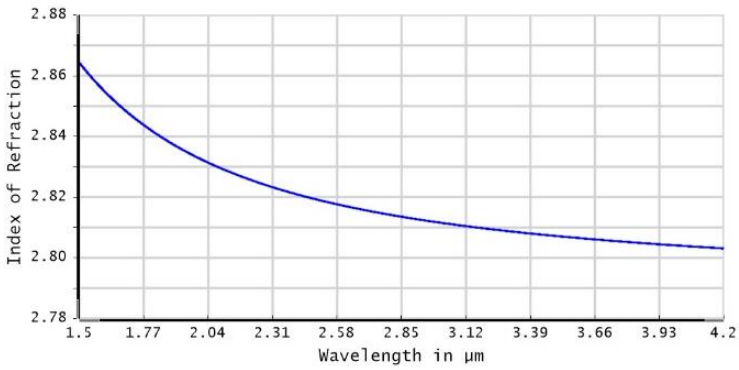

Fig. 3. Index of refraction vs wavelength

For the wavelength range of 1.5 to 4.2 µm, the change in index for $Ge_{30}As_{13}Se_{32}Te_{25}$ is about 0.06. Chromatic aberration was corrected by using the right combination of lens.

3. Results and discussion

3.1 Optical performance

The criterion for the merit function optimization was selected to maximize the performance below Nyquist frequency of 15cy/mm.

A 25 µm pixel pitch implies a Nyquist spatial frequency of 13 lp/mm. Figure 4 shows the polychromatic nominal modulation transfer function (MTF) plots on-axis, at the horizontal field (24°), and at the diagonal corner (31°). At 13 lp/mm, the nominal MTF is 76% on-axis, 50% at the horizontal field, and 20% at the diagonal corner. Focus can be manually adjusted and locked at the desired working distance. The MTF performance is maintained constant over the entire focus range (0.5 m to infinity).

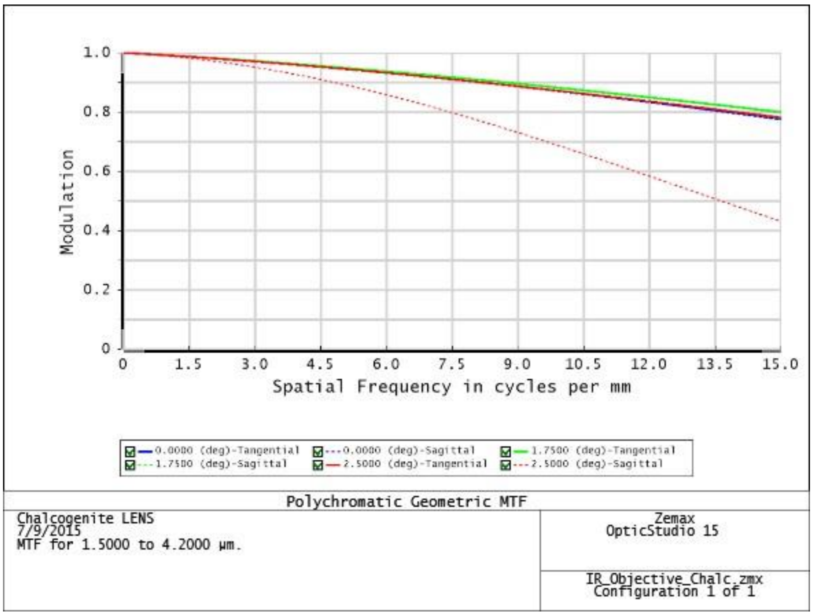

Fig.4. Polychromatic geometric MTF

Field curvature and distortion plots are shown in Figure 5.

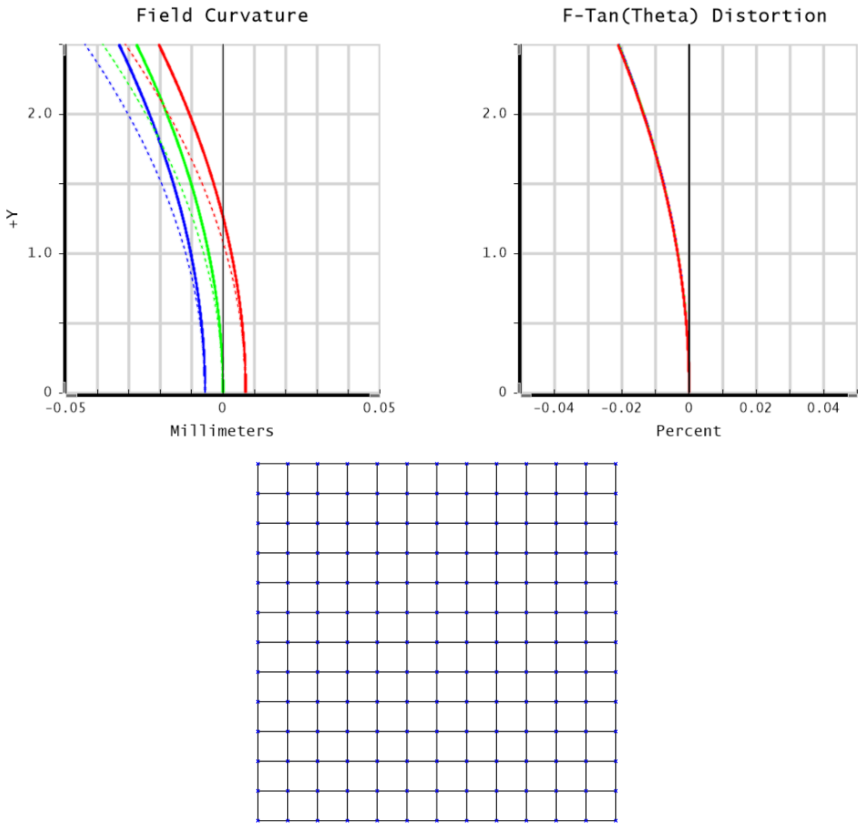

Fig.5. Left: field curvature and distortion plots (vertical axis is the field angle 0 to 2.5°).
Right: grid distortion.

Distortion is negative (barrel), and is 0.0211% at the maximum diagonal field. Usually, the night vision cameras are electronically calibrated, due to the variation in the relative illumination across the image plane. In order to be well corrected, the relative illumination on the night vision sensor should not vary more than 15% between maximum and minimum value [1]. Typically, the relative illumination tends to decrease towards the peripheral fields because of cosine 4 falloff rule and because of decrease in size of the effective entrance pupils with the field angle. In our case, the effect of cosine 4 falloff is negligible because the exit pupil is located at infinity in the object space, and all the chief rays fall perpendicular onto the image plane. Figure 6 shows the variation of the fraction of enclosed energy with radius from centroid.

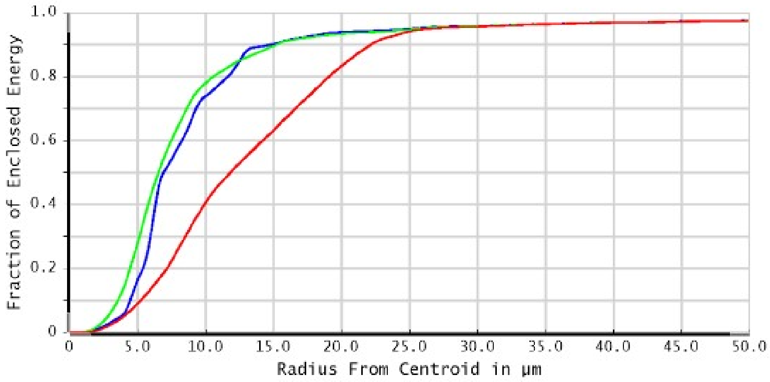

Fig. 6. Fraction of Enclosed Energy vs Radius from Centroid (blue for 0^0, green for 1.75^0 and red for 2.5^0)

3.2 Thermal compensation

One of the most significant problem in the infrared domain is focus shift with temperature. The change in focal length (*df*) with temperature can be calculated as

$$df = \frac{f}{n-1}\frac{dn}{dt}dt[7]$$

where f is focal length.

Even in our case, the shift of the focal plane position with temperature is a significant issue because we would like that the night vision systems to operate over a broad temperature range [8]. This effect is caused by the change in refractive index with temperature dt/dn, and the change in curvatures and thicknesses lens with temperature dl/dt.

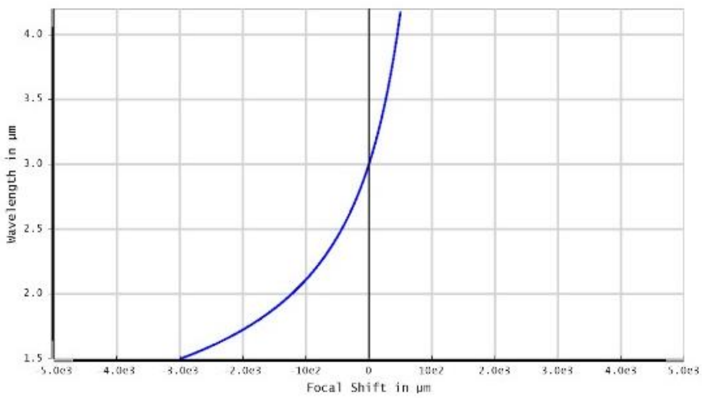

Fig. 7. Chromatic focal shift vs Wavelength

In our case, for a typical temperature change, from -40°C to +60°C, the maximum focus shift is 0,350mm (figure 7).

4. Conclusions

Starting from the above results and discussion chapter, one can conclude that the chalcogenide lens could be a solution for night vision objective offering approximately the same image quality like germanium. The good image quality of the virtual prototypes has proven that chalcogenide lens molding is a viable technology for night vision applications.

In conclusive remarks, chalcogenide materials are future prospective materials which would provide less expensive technical devices in the field of night vision electro - optics, offering high transmission quality across a wide range of the infrared spectrum, from the near-infrared (NIR) to long wavelength infrared (LWIR) regions and low glass transition temperatures.

Acknowledgement

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References

[1] George Curatu, Brent Binkley, David Tinch, and Costin Curatu, Using molded chalcogenide glass technology to reduce cost in a compact wide-angle thermal imaging lens, Proc. SPIE 6206, Infrared Technology and Applications XXXII, 62062M (18 May 2006);
[2] Abhay Kumar Singh, Journal of Non-Oxide Glasses **3**(1), 1 (2012).
[3] Daniel W.Hewak, Dominic Brady, Richard J. Curry, Greg Elliott, Chung-Che Huang, Mark Hughes, Kenton Knight, Arshad Mairaj, Marco Petrovich, Rob Simpson and Chris Sproat, Chalcogenide glasses for photonics device applications, Optoelectronics Research Centre, University of Southampton, UK;
[4] Smith, W.J., Modern lens design, Second Edition, SPIE Press, ISBN 0-07-143830-0;
[5] A.B. Seddon, Journal of Non-Crystalline Solids **184,** 44 (1995).
[6] Zakery, A, Elliott, S.R, Optical Nonlinearities in Chalcogenide glasses and their Applications, 2007, ISBN 978-3-540-71066-0;
[7] Allen Mann, Infrared Optics and Zoom Lenses, SPIE PRESS, ISBN 0-8194-3510-4, p.25;
[8] V. Povey, SPIE, Optical System Design, Analysis and Production for Advanced Technology Systems, **655,** 142 (1986);
[9] Jun Bin Ko and Tea-Sik Myung, Journal of Ceramic Processing Research. **12**(2), 132 (2011).
[10] S. Gu, N. Zhang, Q. Zhang, R. Pan, Chalcogenide Letters, **12**(5), 257 (2015).