EVALUATION OF CHALCOGENIDE LENSES USED IN THERMAL VISION SYSTEMS

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The aim of this paper is the evaluation of an objective that will operate in the infrared spectrum, made exclusively with chalcogenide glasses and that will work in correlation with a thermal sensor of microbolometer type VOx without cooling, in 7,5 ÷ 13,5 μm domain. The investigation uses four sorts of chalcogenides: $Ge_{30}As_{13}Se_{32}Te_{25}$ (IRG23), $Ge_{10}As_{40}Se_{50}$ (IRG24), $Ge_{28}Sb_{12}Se_{60}$ (IRG 25) and $As_{40}Se_{60}$ (IRG 26). These sorts of glasses represent a solution in the fulfilment of the infrared objective because the processing of the chalcogenide glasses can be done by conventional technologies, that are accessible to the most of optic glasses producers and another reason is that 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.

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1. Introduction

The advances in thermal vision systems are based on achievement in sensors, optics, electronics and, in the last years of recent study regarding amorphous chalcogenide materials. The recent experiments have demonstrated that the chalcogenides could be an alternative solution for classical optical materials in such application where is used infrared radiation [1, 5].

Generally, lenses used in the thermal imaging are typically fabricated using expensive single-crystal materials like Ge and ZnS by the costly single point diamond turning process. Due to the fact that chalcogenide glasses are characterized by high values of the refractive index, in thermal domain are suitable for applications in relation to the light including infrared transparency [1-4] and represent a potential solution to reduce costs, by using the compression melding method to fabricate infrared optic [6,7].

Infrared chalcogenides offer good transmission from SWIR to LWIR range and provide properties such as low dn/dT and low dispersion. Due to these facts, enable optical designers to engineer colour-correcting optical systems without thermal defocusing [10].

2. Experimental details

For the considered application (observation of the objects placed at distances up to 300m), it has outcome to be opportune an object that ensures a focal length about 25 mm and a thermal sensor having the pixel size p_H = 0,017mm and the horizontal pixel number, N_H = 640 pixels.

The IR objective with chalcogenides was projected using ZEMAX Optic Studio 15 software, considering the following aspects:

A good correction (adjustment) of optical aberration, in order to obtain a proper image on the entire field of view (FOV) and for the entire spectral range of sensitivity of IR lenses;

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The achievement of a resolution (R_S) of at least 30 lp/mm on the entire FOV, in correlation with the size *p* of a sensor's pixel as it results in the formula (1):

$$R_S = \frac{1}{2 * p}[lp / mm] \quad (1)$$

where: p=0,017 mm;

The use of a reduced number of lenses having a thickness as small as possible and a relative illumination as big as possible to minimize the most of energy losses, caused by reduced transmission of the chalcogenide glasses.

The used objective, having 25 mm focal length, 30 degrees angular field of view (AFOV) and composed exclusively of chalcogenide glasses, has in its structure four lenses, as in the picture below (Fig.1).

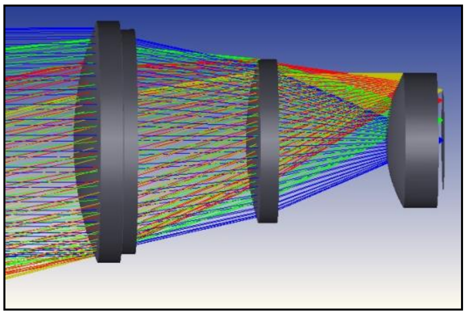

Fig. 1. The configuration of chalcogenide glasses objective with 25 mm focal length

The elaborated optical scheme has the following characteristics:

- Focal length: f'_{ob}=25mm
- Big relative illumination (F/#=1)
- Maximum angular field of view: $AFOV_{max}$ = 30°
- Maximum image distortion: -1,25%
- Good aberrational correction on the entire spectral domain: 8 -12μm
- Resolution assured in the entire field of view: minimum 30 lp/mm
- Vignetting: 0% to 12,5° and 1,16% to 15° (half of AFOV)
- Used optic glasses: IRG23, IRG25, IRG26 (chalcogenide-SCHOTT)

3. Results and discussion

3.1 Results

The image quality obtained using the proposed optical scheme of this objective is presented in Modulation Transfer Function (MTF) diagram, computed for four different values of AFOV. In accordance with Fig. 2, easily should be identified: blue diagram of the center of the FOV, green – half AFOV of 5°, red – half AFOV of 10°, yellow – half AFOV of 12,5°. The black limit from diagram represents the quality limit that cannot be over-passed, due to the diffraction limits of this objective configuration. All zones except the FOV center's are represented by two diagrams, T diagram – in tangential plane and respectively S diagram in the sagittal plane.

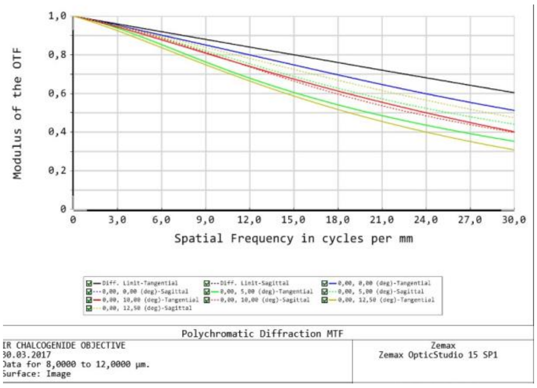

Fig. 2 Modulation Transfer Function diagrams – MTF

The MTF diagram analysis, ensure the capacity of the developed objective to separate the 30lp/mrad resolution – specific to the resolution of the sensor used - in entire FOV.

Furthermore, the image quality was evaluated by the spot analysis for various zones of FOV, according to Fig. 3.

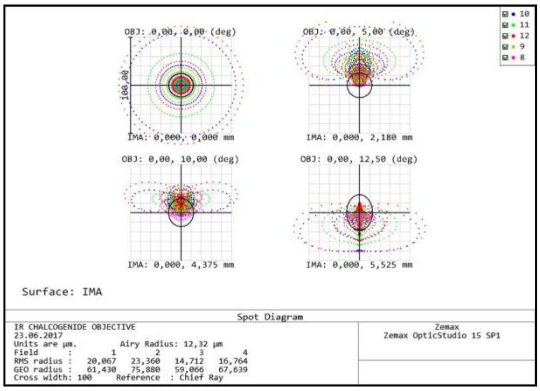

Fig. 3 The spot diagrams in four zones of the image field

Good correction of astigmatism aberration/field curvature and distortion aberration of image on entire FOV are presented on their specific diagrams (Fig. 4). It is obvious that the correction of the chromatic position (axial) is good, because it doesn't count more than 0,07mm on the entire spectral domain of interest: 8÷12μm.

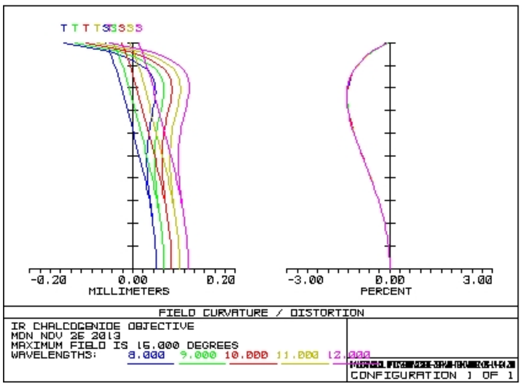

Fig. 4 Field curvature and distortion diagrams

Maybe the most suggestive graphical representation of an optical system correction's is *RAY FAN PLOT* diagram – Fig. 5 – which represents the transversal aberration in image plane, at diamterical gettthe image plane entrdiametricalof the system, fothe entrance pupild wave length. The reference is thwavelengthl ray and the evaluation was done for those two mutually perpendicular planes: sagittal - XZ plane and tangential – YZ plane.

The diagrams confirm the chromatic correction and geometrical aberration for each predefined fieldzones,emphasizes the critical elements oftangentiall plane between 10° and 15°.

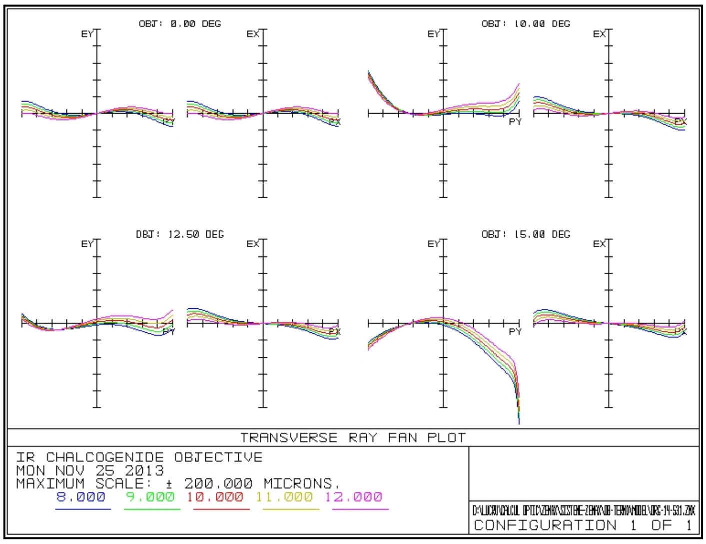

Fig. 5 RAY FAN PLOT diagrams

In Fig. 6 is presented a simulated picture using ZEMAX15 software with the entire FOV, which should be a good thermo-vision image. At the same time the quality of the image should be a reason of the fairness calculus of the objective.

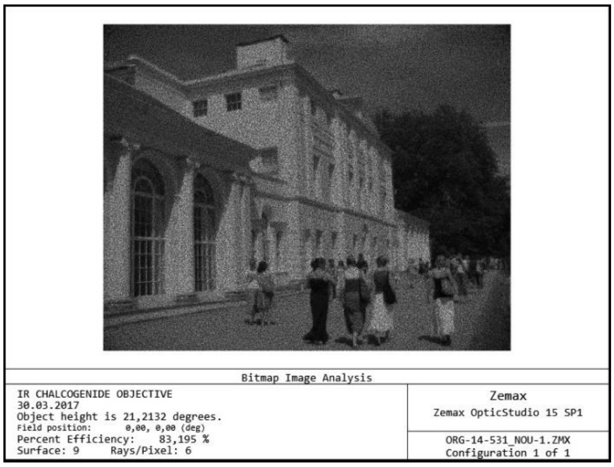

Fig. 6 Simulated image in ZEMAX15

3.2 Discussion

To assure a betterenergeticc efficiency in conditions of obtaining a relative aperture equal to unity, the objective was projected to be without vignetting. This performance is demonstrated by the vignetting diagram presented in Fig. 7, where the limit of the FOV is not bigger than 1,2%. Although the performance of aberrational correction can get much better by the introduction of a vignetting towards the limit of FOV, we have considered the criterion of the objective's energetic efficiency to be a priority, in conditions of poor internal transmission of the chalcogenide glasses.

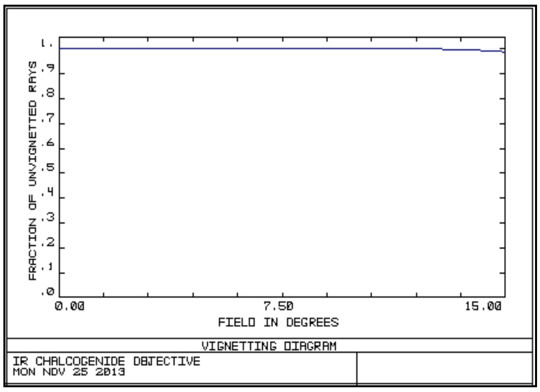

Fig. 7 Vignetting diagram of the ray bundle through the objective

The internal transmission of the resulted objective was determined as the product ofthe individual factorss of spectral internal transmission of the all lenses used. In this manner was obtained the global internal transmission of the objective (Fig. 8).

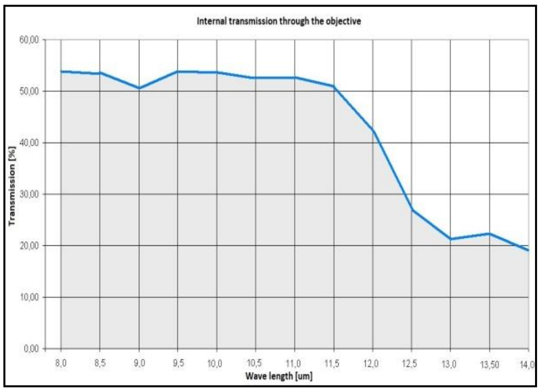

Fig. 8 The total internal transmission through the IR projected objective

The internal factor of the spectral transmission does not take into account the losses by reflection on the input and output surfaces of the optical piece. In a real case, when a ray tracer is going through the diopter – a separation plane between two homogenous environments having different optical index – is refracted and also reflected, generating an additional decreasing (in addition to absorption) of energetic flow transmitted through a material.

It's known that the reflection influence of the chalcogenide glasses (*n* =2,5÷2,8) is much bigger than the glasses used in the visible domain (*n* =1,5÷1,8). Therefore, the reflection factor of a chalcogenide glass has a medium value, R=0,2, whereas an optical glass, used in VIS domain, has the medium reflection factor equal with R=0,06.

A higher value of the reflection factor determines a lower transmission factor. In our case, using an IR objective composed by 4 chalcogenide lenses, the transmission factor will be under 1%. This makes the current configuration to be impossible to use in future analysis. However the thin anti-reflection coating in vacuum technology should be used to increase the transmission factor. This idea should be a starting point for the future applied research in chalcogenide glasses used in LWIR domain.

Although the reflection on both surfaces of the diopter is neglected, a low efficiency in term of energetic efficiency is obtained. This thing results from the spectral effectiveness of the computed camera-objective system, which is presented in Fig. 9. The diagram below represents a matching between the relative spectral sensibility of FLIR-640 sensor and the internal transmission through the IR projected objective (Fig. 8).

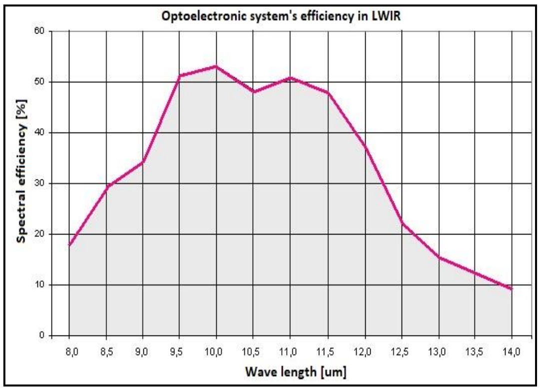

Fig. 9 Spectral efficiency diagram of the projected objective

4. Conclusions

Regarding the exclusive use of the chalcogenide glasses at the realization of an optical system in thermo-vision domain, there are some aspects which can be emphasized:

Even if the diversity of chalcogenide glasses is at the moment quite limited, calculation of an optical scheme, which is viable for an IR objective consisting only of that kind of glasses, is difficult but achievable;

Because of the reduced internal transmission of these glasses, it is necessary to use as few lenses as possible, with low thickness;

In order to obtain a better energetic efficiency of IR objective, it is necessary to assure a relative aperture as big as possible and an image without vignetting in the entire FOV;

In view of increasing the global spectral transmission of an optical system, a thin anti-reflection coating in vacuum technology should be used.

To sum up, the weaker spectral transmission of chalcogenide glasses is considerable attenuated when it comes to objective calculation, both by the lack of vignetting and by the increasing of relative aperture (d/f´=1). It is known that the luminosity (E) of an objective (its capacity to transpose in the image's plan an energetic flow as big as possible from the target) depends on the square of the relative aperture: E=k(d/f´)2. Therefore, the computed objective with the relative aperture 1/1 ensures an energy gain of 21%, compared with the relative aperture 1/1,1 of an objective having focal distance 25mm (similar to the FLIR objective).

Acknowledgement

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