Refractive Dual Band Infrared Imager Optical Design

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Received: Jul. 27, 2016, Revised: Oct. 25, 2016, Accepted: Dec. 6, 2016, Available Online: Aug. 8, 2017
DOI: 10.18869/acadpub.ijop.11.2.133

ABSTRACT— Infrared imagers are important for reorganization and monitoring. This paper discusses the design of an infrared imager. Optical design in medium wavelength infrared (MWIR) and long wavelength infrared (LWIR) bands is different and needs distinct detectors and materials. Reflective systems are not suitable due to their small field of view (FOV) and vignetting. Refractive dual band optical system has been designed with considering both regions assessment and each band detector specifications.

KEYWORDS: Infrared imagers, dual band, medium wavelength infrared (MWIR), long wavelength infrared (LWIR), Thermal infrared.

I. INTRODUCTION

Infrared cameras are very important to identify and care. These cameras used to night vision, remote temperature measurement, in-line quality control, search and rescue.

The camera design in the mid-infrared camera medium wavelength infrared (MWIR) (3-5 µm) is different with the thermal TIR (8-12 µm) due to distinct in detectors and materials [1-4]. Reflective systems are not suitable due to their small field of view (FOV) and vignetting [1].

With production of new dual band detectors the produce and use of a dual band infrared optical system for long wavelength infrared (LWIR) and MWIR regions, is seems logical [5-11].

This paper presents the design of an infrared camera. Considering both regions requirements and detectors specifications, a common optical system is designed. Infrared materials' properties and their choosing method are described. The design of the dual band optical imaging system and its quality are analyzed and results are presented.

II. OPTICAL SYSTEM DESIGN

A. Infrared Lens Materials

The optical system has no reflective surface and formed from IR transparent elements. Germanium is a versatile infrared material commonly used in imaging systems, but in the mid infrared region, large dispersion of the germanium causes high chromatic aberration.

Abbe number V# is the quantification for the dispersion, defined for the one region as follows:

$$V\# = \frac{n_C - 1}{n_L - n_H} \tag{1}$$

where n_C, n_L, and n_H are respectively refractive indices in central, minimum and maximum wavelengths of the spectral region.

Whatever the Abbe number is smaller, dispersion becomes high, while low dispersion materials have higher Abbe number. For example, the germanium has large Abbe number about 4 [1, 2].

The silicon and germanium couple are used for correction of the chromatic aberration. Due to the low transitions of the silicon in thermal infrared area (Fig. 1), we could not use this couple for dual imaging system design.

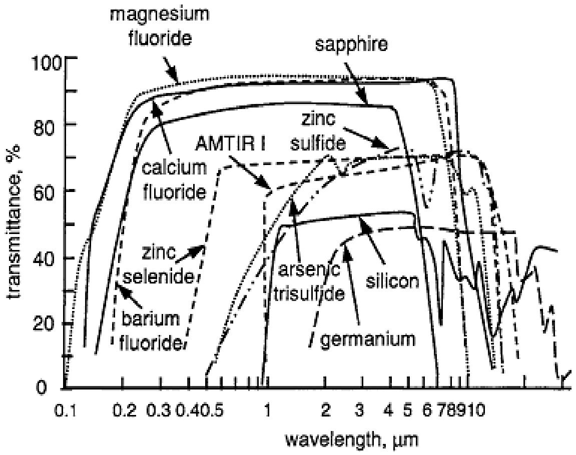


Fig. 1: Transmittance spectrum of infrared materials [1]

Table 1 shows the refraction index and Abbe number of the infrared materials in LWIR and MWIR regions.

Table 1. IR specifications of materials in (a) LWIR and (b) MWIR

	Region	n_L	n_H	n_C	V#
	Length	10µm	8µm	12µm	
a	CAF2	1.300	1.350	1.231	2.5
	ZnS	2.202	2.223	2.176	25.5
	ZnSe	2.407	2.418	2.393	57.2
	AMTR1	2.498	2.504	2.490	114.5
	GERMA	4.003	4.005	4.002	869.1
	SILCN	3.422	3.422	3.421	1818.9
	Region	n_L	n_H	n_C	V#
	Length	4µm	3.4µm	5µm	
b	CAF2	1.410	1.415	1.399	25.8
	ZnS	2.252	2.255	2.246	136.5
	ZnSe	2.434	2.437	2.431	223.7
	AMTR1	2.514	2.517	2.511	277.9
	GERMA	4.025	4.035	4.015	157.2
	SILCN	3.429	3.433	3.426	364.1
SILICN and AMTR1 are silicon and GERMA and CAF2 are germanium infrared materials, respectively.					

Due to the difference in lenses Abbe number, the chromatic aberration of the optical system can be corrected and optimized (Fig. 2) [1, 2].

B. *Infrared Detectors*

For maximum system sensitivity, most thermal imaging systems use cryogenically cooled detectors which operate at the liquid nitrogen temperature of 77 K or even lower.

This reduced temperature in cooled detectors is very important to reduce thermally induced noise to a level lower than that of the signal, from the scene being imaged.

These detectors are the high sensitive, especially when small "temperature targets" are observed over very long distances. Cooled detectors operate within the MWIR.

Uncooled infrared detectors do not require cryogenic cooling. One of the common designs is based on the microbolometer. Uncooled detectors operate within the LWIR region. This type of detector is generally much less expensive than the cooled type camera. One of the cost effective factors to consider is that cooled systems will be best to use beyond detection ranges of more than 5 km. Another major contributing factor is the price of the lens of the complete system [2, 6, 7, and 12].

The 320×256 (40 µm pixel size) focal plane array (FPA), mid-format 2-Color MWIR/LWIR Quantum Well Infrared Photodetectors (QWIP) are one of the dual band detectors, the specifications of which are given in Table 2.

Table 2. Specifications of 320×256 (40 µm pixel size) FPA, mid-format 2-Color MWIR/LWIR QWIP detector [12]

Detector type	QWIP, MWIR/LWIR
Array size	320×256
Pixel size	38 µm
Pixel pitch	40 µm
Quantum efficiency	15 % for MWIR and 6% for LWIR

C. *Optical System Design*

Optical system is a 100mm f/2 imager with 320×256 (40 µm pixel size) FPA detector (Table 3).

Table 3. Imager specifications

Parameter	Quantity
Focal length	100mm
Array size	320×256
Pixel size	40 µm
FOV	9 degree
Spectral region	MWIR and LWIR

The design of optical system performed with OSLO optical design software. We choose a merit function for optimizing the optical system.

Due to the sensitivity curve of the infrared detectors, optical system design in 3.3-5 µm and 8 to 12 µm ranges are selected, respectively for MWIR and LWIR regions. The zinc sulfide (ZnS) and zinc selenide (ZnSe) couple are used for designing the optical system. ZnS and ZnSe have the same behavior in MWIR and LWIR regions. Both of them are transparent in the mid-infrared and thermal infrared spectrum. Their distinct Abbe numbers are useful to chromatic aberration correction (Table 1).

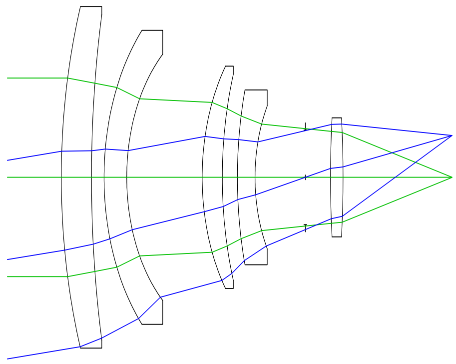


Fig. 3. Layout of designed optical system.

Designed optical system can be used separately for each of the MWIR and TIR spectral regions with the dependent detector (Table 4).

Table 4 Specification of the surfaces of the designed system of Fig. 3.

Surface	Radius (mm)	Thickness (mm)	Aperture Radius (mm)	Glass type
1	125.51	12	40	ZnSe
2	208.51	5	37	
3	53.00	9	35	ZnS
4	40.74	30	28	
5	46.95	8	25	ZnSe
6	78.96	6	23	
7	82.26	7	21	ZnS
8	-	20	17	
9	183.07	10	14	ZnSe
10	-177.15	5	14	

The vignetting of designed system for cooled detector with cold stop is acceptable. Although with increasing the lenses aperture or adding a relay lenses, we can completely omit the vignetting.

One lens can be used simultaneously for two MWIR and TIR detectors by the help of a beam splitter (Fig. 4). To minimize the beam splitter aberration effect, its thickness must be reduced or replace it by a cube beam splitter. However, the effect of beam splitter is negligible.

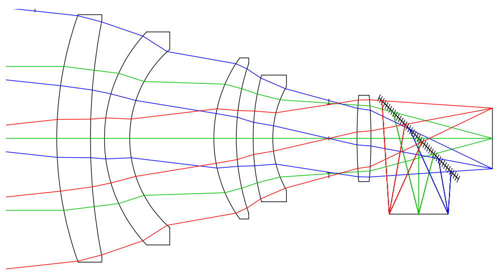


Fig. 4. Designed optical system with beam splitter

With using new dual band detectors, we could use this optical system simultaneously at LWIR and MWIR regions [3- 5].

D. Optical System with Cold Stop

If cooled detectors, or focal plane arrays (FPAs), are allowed to “see” any thermal energy other than the energy contained within the scene being viewed, then the sensitivity is reduced. In addition, if the magnitude of this nonscene energy changes or modulates over the field of view, then system has undesirable image anomalies. In order to achieve maximum sensitivity and avoid image anomalies, the IR FPA is cryogenically cooled and mounted into a thermally insulated “bottle,” or dewar, assembly [1] (Fig. 5).

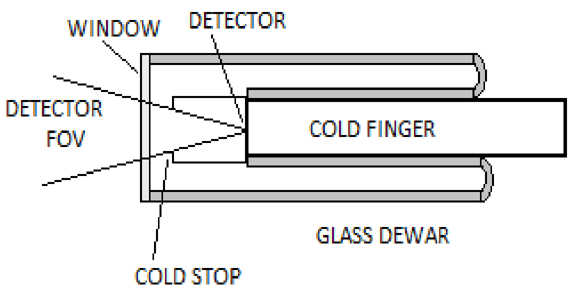


Fig. 5. Typical Detector Dewar Assembly

A baffle, called a cold shield or cold stop, is located inside the dewar, as shown in Fig. 5. An IR system is said to be 100% cold stop efficient if the detector can see or record energy only from the field of view [1].

We could decrease vignetting with adding relay section to optical system and reach to 100% cold stop efficiency.

The front objective lens is reimaged into the cold stop plane. Rays from various fields of view are shown all superimposed at image plane (Fig. 6).

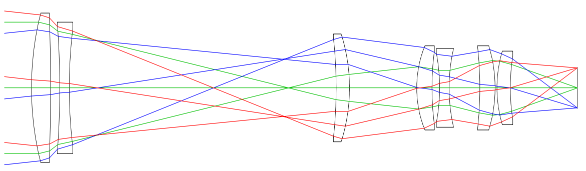


Fig. 6. Designed optical system with relay lens.

The end surface (surface 15) selected as aperture stop to have 100% cold stop efficient. This system diameter is smaller than the previous one, but its length is higher (Tables 4 and 5).

Table 5. Specifications of the surfaces of the optical system designed with cold stop of Fig. 6

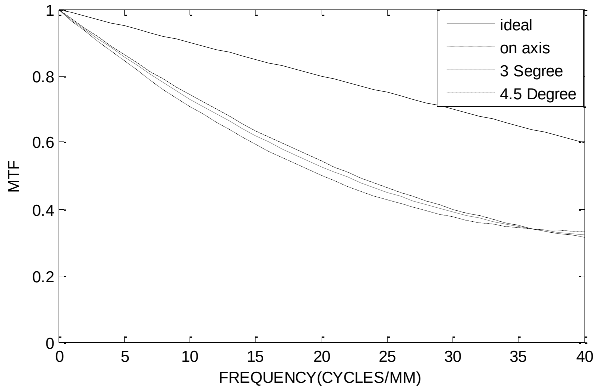
Surface	Radius (mm)	Thickness (mm)	Aperture Radius (mm)	Glass type
1	85.94	10.0	28.5	ZnSe
2	-603.0	4.83	28.5	
3	-232.93	5.0	25	ZnS
4	139.21	140	22.5	
5	-130.56	7	19	ZnSe
6	-50.55	35.3	20.5	
7	31.97	8	16	ZnSe
8	78.21	4	14	
9	-51.28	5	13	ZnS
10	50.12	16.1	15	
11	-103.37	8.0	16	ZnSe
12	-40.00	1.0	16	
13	36.51	7	14	ZnS
14 (aperture stop)	57.48	35.17	12	
15	--	--	8	

The relay section decreases the entrance ray and optical system diameter. The aperture stop of optical system is at the detector cold shield.

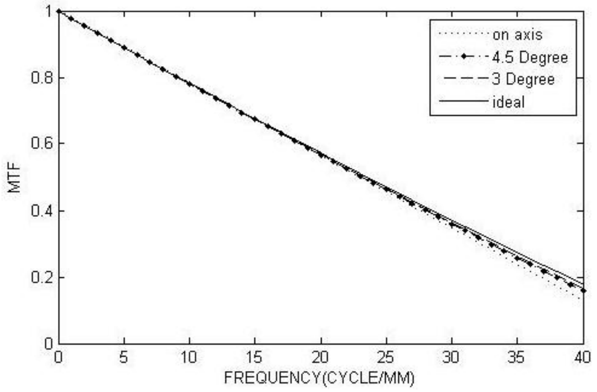
E. Analysis of Optical Systems

To optimize the uncooled optical system, the image spot size in two spectral regions has been considered as error function (merit function) and optimization is performed [13-15].

Figures 7(a) and 7(b) show the modulation transfer function (MTF) of the optical systems in the two channels. The MTF is acceptable at 40 cycle/mm frequency.



(a)



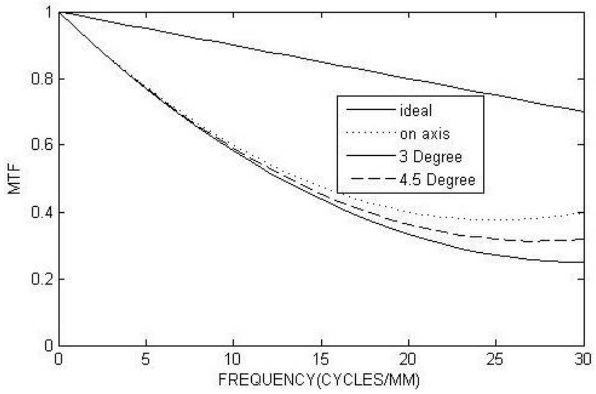
(b)

Fig. 7. Modulation transfer function of the optical system with relay lens for ideal case (diffraction limited), on axis (at 0° field of view), 3 and 4.5 degrees fields of view for: a) 3.3 to 5 µm and b) 8 to 12 µm.

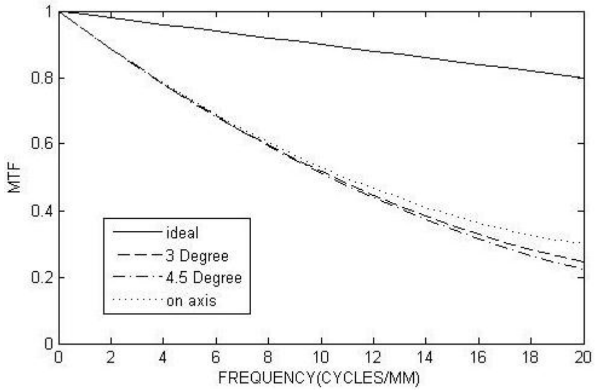
Due to aperture stop location constraint of the cooled optical system (with relay lens), its optimizing is more difficult. The aperture stop must be located at the detector cooled stop. The optimized system diameter becomes smaller (Table 5) but its image quality decreases (Fig. 8).

Figures 8(a) and 8(b) show the MTFs of the optical systems for the two channels. The MTFs of the optical systems for MWIR and LWIR are higher than 0.2 at 30 cycle/mm and 20 cycle/mm frequencies, respectively.

The number of lenses at uncooled and cooled optical systems are 5 and 7 respectively (Figs. 3 and 6).



(a)



(b)

Fig. 8. Modulation transfer function of the optical system with relay lens for ideal case (diffraction limited), on axis (at 0° field of view), 3 and 4.5 degrees fields of view of: a) 3.3 to 5 µm and b) 8 to 12 µm: a) 3.3 to 5 µm and b) 8 to 12 µm.

The MTF of uncooled system (without cooled stop) is better (Figs. 7 and 8), but its vignetting and diameter are larger than cooled system.

III. CONCLUSION

With using appropriate materials with different dispersion witch has been transparent in both spectral regions of medium wavelength infrared (MWIR) and long wavelength infrared (LWIR), dual band infrared imaging system with uncooled and cooled detectors were designed and optimized. By comparison of uncooled and cooled infrared imaging systems, it has been shown that the image quality of uncooled imaging system is better.

ACKNOWLEDGEMENTS

The author is grateful to the Amir kabir University of Technology (AUT) research office for their support.

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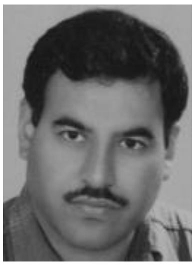

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