Design Requirement of LWIR Optical Filter for LAPAN-A4 Satellite

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Abstract— A filter is a device or instrument which is able to pass a specific signal and also remove other signals. There are several types of optical filters: bandpass filter, long-pass filter, and short-pass filter. The next microsatellite developed by Satellite Technology Center is LAPAN-A4 Satellite. This satellite brings Medium Resolution Multispectral Imager (MRI) using SLIM4 and also Experiment LAPAN Line Imager Space Application (ELLISA). Moreover, this satellite also brings thermal imager which is called microbolometer, and experiment Short Wave Infrared (SWIR) camera. Especially for spectral band Long Wave Infrared (LWIR) cameras in LAPAN-A4 satellite will be narrowed down to 10.4µm – 12.5µm, therefore a band filter is needed for blocking and passing these wavelengths. The method used to design the optical bandpass filter LWIR microbolometer camera is by determining the required spectral response. The response spectral required refers to the LANDSAT 8 Thermal Infrared Sensors (TIRS) bands 10 and 11 with spectral response 10.60-12.51µm, Centre Wavelength (CWL) of band 10 and 11 are 10.9µm and 12.0 µm, and Full-Width Half-Maximum (FWHM) of both band are 0.6 µm and 1µm), and also determine the substrate filter material to be used. The design results show that, the LWIR bandpass filter has a spectral response of 10.4-12.5µm, CWL 11.45µm, and FWHM 2.1µm, max peak transmission is 80.21%, and capable of blocking at wavelengths of 7-10.4 µm and 13-16.5 µm, the material used in this design uses Germanium (Ge) because it has a wavelength of 2-16 µm which can work on spectral IR transmission.

Keywords—Bandpass Parameters, LAPAN-A4 satellite, Germanium(Ge), Wavelength.

I. INTRODUCTION

A filter is a device or instrument which is able to pass a specific signal and can also remove other signals [1]. In the field of electronics and communication, there are various kinds of a filter, the same thing also exists in the optical field known as an optical filter. An optical filter is a device or instrument that can pass or block certain wavelengths. Optical filters are used in fluorescence microscopy, photography, optical instrument, spectroscopy, military, aviation, and others.

There are several types of optical filters: bandpass filter, long-pass filter, and short-pass filter. A bandpass filter is a filter that transmits a certain range of wavelengths or frequencies and blocks out wavelengths or frequencies outside it [2]. A shortwave pass (SWP) filter is an optical filter that blocks longer wavelengths and transmits shorter wavelengths. And the Longwave pass (LWP) filter is the opposite, it's blocking shorter wavelengths and transmitting longer wavelengths [3]. Spectral response is described as sensor sensitivity versus the optical radiation at different wavelengths. Spectral response is described as the sensitivity of the sensor versus the input source [4]. From the spectral response, we can find out the value of the sensitivity of the sensor at a certain wavelength. Figure 1 is the difference between bandpass filters.

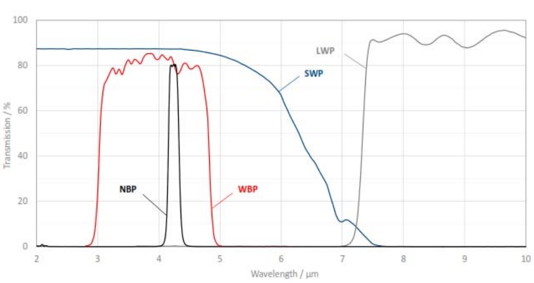

Fig. 1. Different Optical filters

The next microsatellite developed by Satellite Technology Center is LAPAN-A4 Satellite. LAPAN-A4 satellite is predicted to be launched in the middle of 2020. This satellite brings Medium Resolution Multispectral Imager (MRI) using SLIM4 [5] and also Experiment LAPAN Line Imager Space Application (ELLISA). Moreover, this satellite also brings thermal imager which is called microbolometer, and experiment short wave infrared (SWIR) camera.

The microbolometer camera on the LAPAN-A4 satellite has the following specifications, provided by Xenics with Gobi 640 CL, spectral band 8-14µm, array type a-Si microbolometer, pixel 640(W) x 480(H), pixel pitch 17 µm, frame rate 50Hz, no cooling, A/D conversion resolution 16 bit, and interface using base camera link (CL)[6]. Especially for spectral band LWIR cameras will be narrowed down to 10.4µm –12.5µm, therefore a band filter is needed to block and pass these wavelengths. The use of optical filters has been applied in LAPAN-A3 satellites. The LAPAN-A3 LISA camera has used an optical filter to produce the required spectral response. The use of these filters is felt quite optimal to pass and block unnecessary wavelengths. Therefore, the use of optical filters will also be implemented on the LAPAN-A4 satellite microbolometer camera. Filter design or simulation is needed to determine the spectral response and FWHM range that can be generated by a microbolometer camera. By doing the design or simulation process the spectral response produced by the microbolometer camera is as expected.

This paper is organized as follows, first, a general theory about the bandpass filter, then the methodology used in this research, design requirement of bandpass filters which consist of bandpass parameter also materials, result and discuss, the final section is some conclusion of this research and future works.

II. Methodology

The method used to design the optical bandpass filter LWIR microbolometer camera is by determining the required spectral response. The response spectral required refers to the LANDSAT 8 Thermal Infrared Sensors (TIRS) bands 10 and 11 spectral response. The Figure 2 and Table 1 shows the response spectral of band 10 and band 11 TIRS LANDSAT8 which is used as a reference.

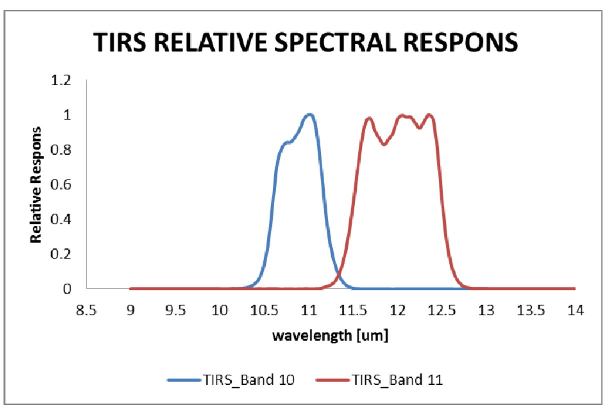

Fig. 2. Spectral Response TIRS bands 10 and 11 LANDSAT 8[7][8]

TABLE I. TIRS Characteristics

TIRS Band	Center Wavelength (µm)	Wavelength (µm)	Bandwidth (µm)	Spatial Resolution (m)
10	10.9	10.60-11.19	0.6	100
11	12.0	11.50-12.51	1.0	100

As we know, TIRS Landsat 8 has 2 bands, namely TIRS1 bands 10 which have 10.60µm-11.19µm spectral and TIRS2 bands 11 which have 11.50µm - 12.51µm spectral. However, the reference in the bandpass filter design is the TIRS bands 10 and 11 of LANDSAT8. After the spectral selection is determined, the next step is bandpass filter characterization that will be made like as determining of central wavelength, cut on and cut off wavelength, peak transmission, blocking range, blocking Optical Density (OD), and selection of substrate filter material to be used. The filter material will affects the value of the peak-transmission. Figure 3 shows the methodology process in this research.

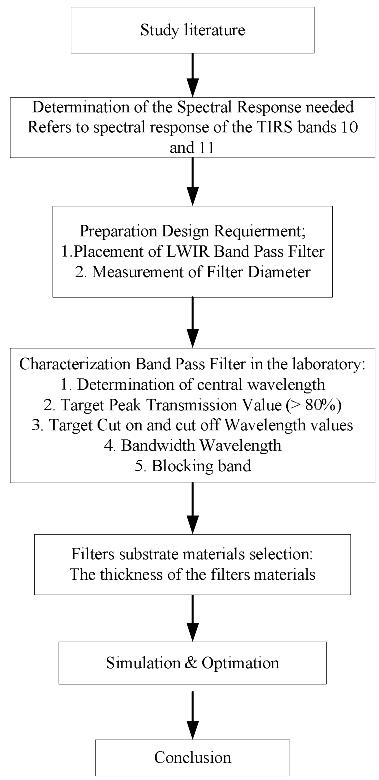

Fig. 3. Methodology Flow chart

III. Design Requirement of LWIR FILTER

Based on the methodology in chapter 2, the design of bandpass filter for LAPAN-A4 satellite LWIR microbolometer camera was made as the following design specifications;

A. Spectral Respons of LWIR LAPAN-A4

As explained at the beginning of the chapter, the spectral response of microbolometer camera has a range of 7µm -16µm (Figure 4), this spectral range is too wide, it will be narrowed to 10.4µm –12.5 (both of TIRS bands 10 and 11).

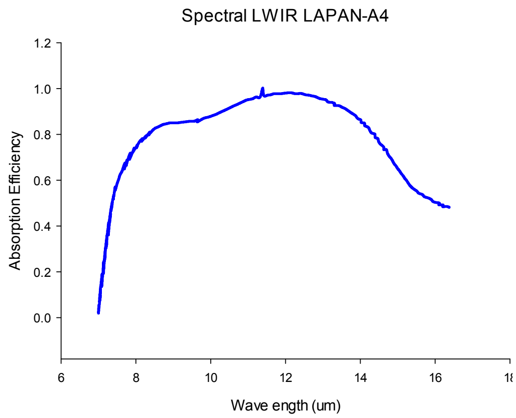

Fig. 4. Spectral Respons LWIR camera in LAPAN A4

Microbolometer on LAPAN-A4 satellite will use the 150mm lens and 1.6 F-number. This lens is compatible with uncooled detector type, so it's very easy to install with materials like germanium (Ge) or Silicon (Si). The LWIR filter is planned to be installed in front of CCD microbolometer camera (Gobi 640CL) LAPAN-A4 satellite.

B. Bandpass Parameters

The transmission range of the bandpass is characterized by the centre wavelength (CWL), half-power bandwidth (HPBW), and peak transmission (TPK). The peak transmission should not fall below a value of 70% so that the detector signal does not become too low. With the cut-on and cut-off wavelength, the transmission is exactly half of the peak transmission. Figure 5 shows the transmission range of a bandpass filter.

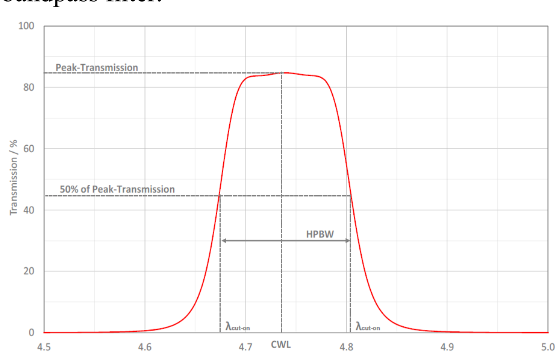

Fig. 5. Transmission range of a bandpass filter.

The centre wavelength indicates the "middle" of the bandpass filter and is calculated from the cut-on and cut-off wavelengths [9].

$$CWL = \frac{\lambda_{cut-on} + \lambda_{cut-off}}{2} \quad \textbf{(1)}$$

Outside the passband, in the blocking range, the transmission of the filter should be as little as possible (< 0.1 … 1%), since additional, otherwise disturbing signal parts result. Since these parts are not affected by the value to be measured, with which the bandpass is aligned, a transmission in the blocking range reduces the measuring sensitivity of the application.

While for cut-on and cut-off wavelength, describes an optical filter edge transition where transmission increases sharply over an increasing wavelength range. They are defined as the point on each respective edge where transmission reaches 50% of the peak (Figure 6), and are also known as 50% edge points and half-power wavelengths.

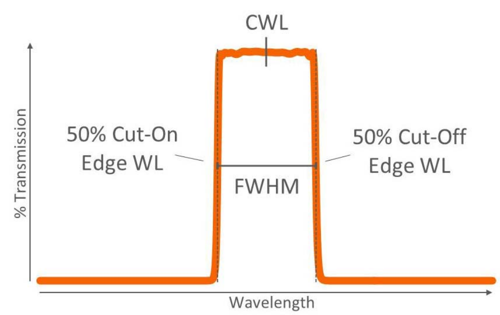

Fig. 6. Cut-on and cut-off wavelengths, center wavelength (CWL), and full-width at half-maximum (FWHM) for a bandpass filter.

Like centre wavelength and full-width half-maximum below, cut-on and cut-off wavelengths can either be specified as nominal or with a ± wavelength tolerance. In the case of dichroic filters specified using average polarization, it is common to evaluate cut-on and cut-off wavelengths using the average of the wavelengths corresponding to 80% and 20% of peak transmittance. This is because the hitch that arises due to polarization splitting is generally seen around the 50% edge point.

For blocking bands is a general term that refers to wavelength-specific beam attenuation by means of reflectance, absorbance, or both. Almost filters, the attenuated beam is not directed to another path in the system so specifying reflectance is not necessary. However, the majority of optical filters and coatings used at larger angles of incidence, such as dichroic filters and high-reflectivity (HR) mirrors, are designed to split or reflect the beam within the system, so these are necessarily specified with reflection bands instead of blocking.

Optical filters such as longpass or shortpass edge filters, bandpass filters, and notch filters are specified with the transmission in terms of percent and blocking in units of optical density (OD), a high optical density value indicates low transmission, and low optical density indicates high transmission. Optical densities of

6 or greater are used for extreme blocking, optical densities of 3.0 – 4.0 are ideal for laser separation and clean-up to calculate OD using equation 2, while optical densities of 2.0 or less are ideal for color sorting and separating spectral orders. Where OD is optical density and T is transmission in percent.

$$OD = -\log_{10}\left(\frac{T}{100}\right) \qquad \textbf{(2)}$$

C. Bandpass filter Materials

There is no essential difference in design rules of optical objectives for visible and IR ranges. The design of IR optics is only more limited because there are significantly fewer materials suitable for IR optical elements, in comparison with those for the visible range, particularly for wavelengths over 2.5 μm[10].

Metallic coatings are typically used as reflective coatings of IR mirrors. There are four types of most often used metallic coating, namely bare aluminium, protected aluminium, silver, and gold. They offer high reflectivity, over about 95%, in the 3–15 μm spectral range. Bare aluminium has a very high reflectance value but oxidizes over time. Protected aluminium is a bare aluminium coating with a dielectric overcoat that arrests the oxidation process. Silver offers better reflectance in the near IR than aluminium and high reflectance across a broad spectrum. Gold is a widely used material and offers consistently very high reflectance (about 99%) in the 0.8–50 μm range. However, gold is soft (it cannot be touched to remove dust) and is most often used in the laboratory.

Most glasses used to manufacture optical elements for visible and near-infrared range transmit well light up to about 2.2 μm and can be used for SWIR optics. Thermal imagers use almost exclusively two spectral bands: 3 to 5 µm or 8-14 µm. Therefore, materials typically considered for infrared optics are those suitable to transmit infrared radiation in the spectral range from 2 µm to 14 µm.

The list of potential materials that could be used to manufacture infrared refractive optics is quite long: AMTIR-1 (Amorphous Material Transmitting Infrared Radiation), barium fluoride (BaF2), cadmium telluride (CdTe), calcium fluoride (CaF2), cesium bromide (CsBr), cesium iodide (CsI), fused silica-IR grade, gallium arsenide (GaAs), germanium (Ge), lithium fluoride (LiF), magnesium fluoride (MgF2), potassium bromide (KBr), potassium chloride (KCl), silicon (Si), sodium chloride (NaCl), thallium bromoiodide (KRS-5), zinc selenide (ZnSe), zinc sulfide (ZnS). However, only several most popular materials used to manufacture refractive optical objectives for thermal imagers will be discussed in the paper.

Basic parameters of these materials are presented in Table 2 and their IR transmission is shown in Figure 7. Germanium (Ge) is a silvery metallic-appearing solid of very high refractive index (> 4) that enables the design of high-resolution optical systems using a minimal number of germanium lenses. It uses transmission range constitutes from 2 to about 15 μm. It is quite brittle and difficult to cut but accepts a very good polish. Germanium is non-hygroscopic and non-toxic, has good thermal conductivity, excellent surface hardness, and good strength. Additionally, due to its very high refractive index, antireflection coatings are essential for any germanium transmitting optical system.

TABLE II. CHARACTERISTICS OF SOME FILTERS IR MATERIALS[10]

Material	Wave band (µm)	Index of Refraction (nd)	dn/dT ($10^{-6}K^{-1}$)	Density (g/cm^3)	Characteristic
Germanium (Ge)	2-12	4.0031	404	5,32	Semiconductor, used in Thermal Imaging,
Silicon (Si)	1.2-7.0	3.422	160	2.33	Low cost, Used in spectroscopy, MWIR system
Galium Arsenide (GaAs)	3-12	3.274	150	5.32	Semiconductor, visibility
Zink Sulfide (Zns)	3-13	2.631	38.7	5.27	Excellent in visible and IR, Harder, More Chemically
Zink Seleneida (ZnSe)	0.5-20	2.403	61	5.27	Low Absorption, High Resistance
Calium Fluoride (CaF_2)	3-5	1.434	-10.6	3.18	Low Absorption, Used in Spectroscopy, Cooled thermal
Sapphire	3-5	1.768	13.1	3.97	Good Transmission in IR, Used in IR laser systems
BF7 (Glass)	0.35-2.3	-	3.4	2.51	Optical glass
Magnesium Flouride (MgF_2)	3.5-5	1.413	1.7	3.18	Used in Windows, lenses, good transmission from visible to MWIR

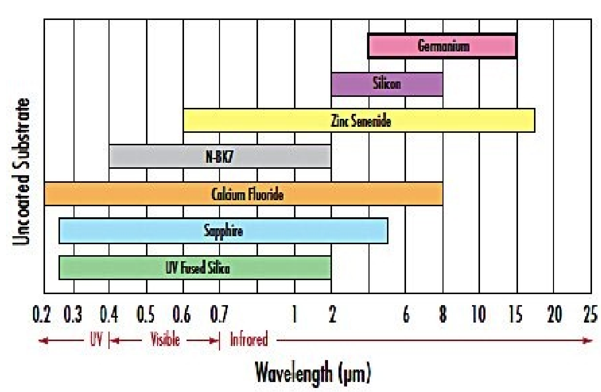

Fig. 7. Transmission range of LWIR materials [10]

Germanium has low dispersion and is unlikely to need colour-correcting except in the highest-resolution systems. A significant disadvantage of germanium is the serious dependence of its refractive index on temperature, so germanium lenses may need to be thermalized. In spite of high material price and cost of antireflection coatings, germanium is a favourite choice of optical designers of high-performance infrared objectives for thermal imagers. So that, in this design the main of material, we choose Germanium (Ge) as substrate the LWIR bandpass filter.

D. Basic Design parameters of LWIR Optical Filters

This design of LWIR optical bandpass filter is based on spectral response, bandpass parameters, and materials. In summary, the expected output is illustrated in Table 3 below. Table 3 is the technical parameters used as a reference in the process of making LWIR bandpass filters on the LAPAN-A4 satellite.

TABLE III. BASIC PARAMETERS OF LWIR FILTERS

Specification	Value	Tolerance
Type filter	Wide bandpass filter	
Shape	Circle / Disk	
Diameter (mm)	32.50	± 0.5
Clear Aperture	>80-90 % of Diameter filter	
Place	Between Sensor Si uncooled microbolometer and Lens	
Central Wavelength (µm)	11.450	± 0.5%
Transmission	>75%	
Cut on wavelength (µm)	10.400	± 100
Cut off wavelength (µm)	12.500	± 100
BW (FWHM) (µm)	2.100	
Blocking range (µm)	7.000-10.400 13.000-16.500	
Blocking OD	Around to 2-3	
Material substrate	Germanium (Ge)	
Thickness (mm)	1-2	± 0.5

From this table, an LWIR bandpass filter is designed, to produce the output as shown in Table 3.

IV. RESULT AND DISCUSS OF DESIGN LWIR OPTICAL BANDPASS FILTERS

A. Layout of Design LWIR Optical

Based on the results of measurements that have been made, it is obtained, the shape of the bandpass filter is a circle, the diameter of the LWIR bandpass filter is 32.5 mm, and the thickness of the filter is 1-2 mm, with a tolerance of ± 0.5 as ilustrated in Figure 8. This filter will be installed later between the Gobi 640CL microbolometer camera sensor with a 150mm lens size, with a Clear aperture value of 80% - 90%. The clear aperture is defined as the diameter or size of an optical component that must meet specifications [11]. Outside of it, manufacturers do not guarantee the optic will adhere to the stated specifications. Due to manufacturing constraints, it is virtually impossible to produce a clear aperture exactly equal to the diameter, or the length by width, of an optic. Of the total diameter value so that the clear aperture value is 29.25 mm. Because the distance between the clear aperture and the lens diameter is very close, the LWIR lens will not use housing or unmounted.

Fig. 8. Illustration of LWIR optical Filter (Circle, D=32.5mm, H =1mm)

B. Spectral Performance

The LWIR sensor that is used in the LAPAN-A4 satellite is the Gobi-640-CL type. The datasheet shows that the sensor has a spectral response at wavelength of 7 µm - 16.4 µm. Based on the spectral response of the sensor, the wavelength of the reference spectral (thermal IR LANDSAT 8 bands 10 and11) and bandpass parameters in Table III. Then a bandpass filter was designed for the LAPAN-A4 satellite microbolometer LWIR camera. Simulation results show that LWIR spectral input (7µm -16.4 µm), wavelength generated after passing through the filter is 10.4 µm-12.5 µm. The wavelength range can be said to be as expected because it is the same as the reference spectral wavelength TIRS LANDSAT 8 bands 10 and 11. The LANDSAT 8 spectral table that is used as a reference can be seen in table 1 in the methodology chapter. Figure 9 is the spectral response of the design of the bandpass filter, the filter response is then multiplied by the spectral response of the LWIR Gobi-640-CL sensor (spectral input) and transmittance filter to produce spectral response output as shown in Figure 10. Overall, the Spectral performance produced by the LWIR filter design that has been made has represented the range of LWIR bands as needed, and optimization has also been done. So the results of the filter design that has been made have met the required target that is approaching Spectral Bands 10 and 11 of LANDSAT8.

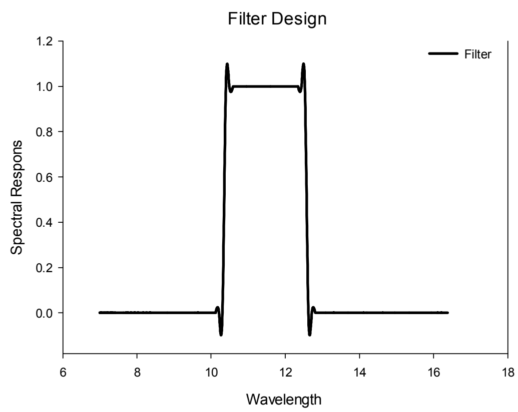

Fig. 9. LWIR Optical bandpass filter

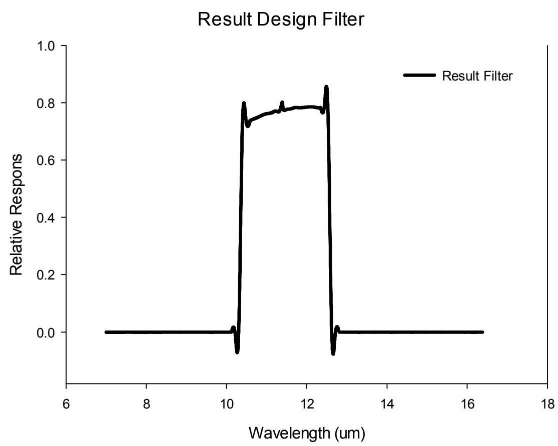

Fig. 10. LWIR Result Optical Bandpass Filter

C. Bandpass filter Performance

Bandpass filter that is designed shows that the filter can generate the expected output response spectral that is response spectral which has a wavelength of 10.4 µm - 12.5 µm. The resulting bandpass filter has central wavelength (CWL) characteristics at 11.45µm, bandwidth (FWHM) is 2.1 µm, with the bandwidth value, the filter that has been designed is called the wide bandpass filter, cut on the wavelength at 10.4µm, cut off the wavelength at 12.5 µm. With these characteristics the optical filter can generate a spectral response at a wavelength of 10.4 µm - 12.5 µm and blocking spectral response of sensors at wavelengths of 7 µm - 10.4 µm and 12.5 µm - 16.5 µm. For details please see figure 11, shows the spectral comparison of inputs and outputs of wavelength.

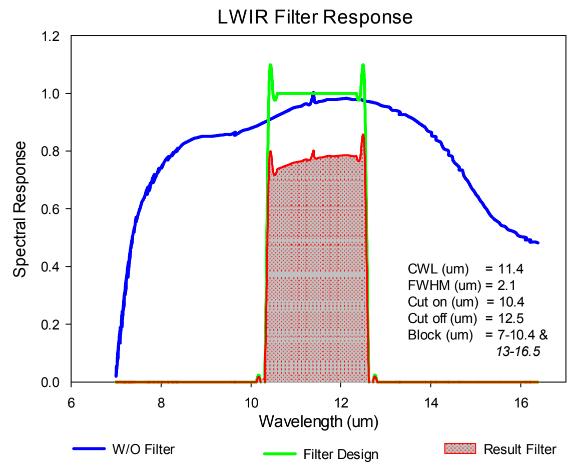

Fig. 11. LWIR Optical Respon

Bandpass filter that has been designed is capable of producing an average transmission of 76.94%, and the maximum transmission at a value of 80.21%, the transmission value must be > 75% in order to be able to properly transmit power [9], the transmission value is expressed in percent which means the amount of power received by the detector compared to the total power is available. It can be stated that the transmission value of the design has met the required target of > 75%. The transmission value and optical density value of the design results can be seen in Figure 12 below.

While the OD value obtained value 2. OD value, inversely proportional to the optical transmission value, the higher the optical transmission value, the OD value will be lower, and if the optical transmission value is lower then the OD value is higher [12].

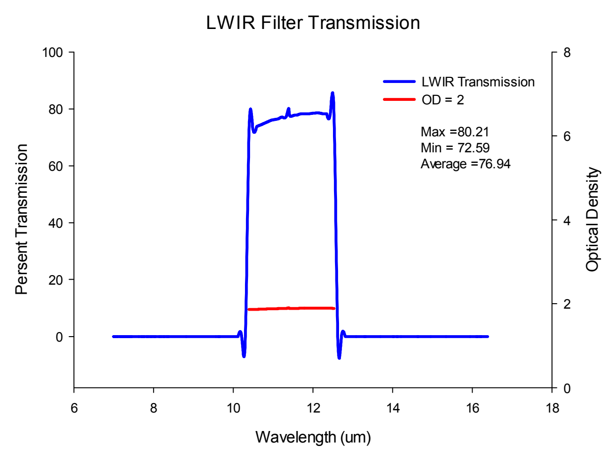

Fig. 12. LWIR Filter Transmission

D. Bandpass materials

When choosing the correct IR material, there are three simple points to consider, the first is thermal properties, optical materials are placed in environments where they are subjected to varying temperatures. CTE (coefficient of thermal expansion) is the rate at which a material expands or contracts given a change in temperature, the specification of Ge shows that value of melting points is 963^{0}C[13]. The second is transmission, the transmission show that different applications operate within different regions of the IR spectrum. The last is index of refraction, IR materials vary in terms of index of refraction farther than visible materials do, allowing for more variation in system design.

Of the three reasons and based on table II (Characteristics of some Filters IR Materials) then the material that can be used to manufacture these filters is Ge material. The material can be used in a range of wavelengths 2-16µm[14] and functionally by the expected sensor application, namely as thermal imaging. Figure 13 shows the transmission of germanium material to the filter design that has been made. Based on Figure 13, the average uncoated Ge transmission in the wavelength range of 10.4 µm - 12.5 µm obtained an average transmission of 41.21% for the state of uncoated germanium material. The LWIR bandpass filter design results show that the thickness of the desired Ge material is around 1-2 mm with a tolerance of ± 0.5, so it is expected that the thickness and the professionally coated process of the Ge material can transmit large power that matches the desired target.

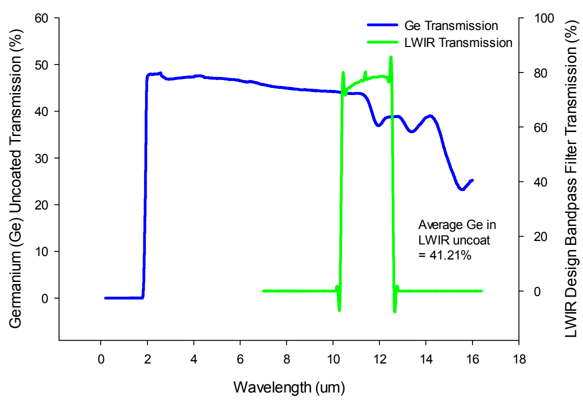

Fig. 13. LWIR Filter Vs Ge Uncoated Transmission

V. Conclusion

Based on the design requirements and the results of the discussion in chapters 3 and 4, then LWIR bandpass filter is needed to approach the spectral response results on bands 10 and 11 of Landsat8. Based on the TIRS bands 10 and 11 of Landsat8 spectral target (10.60-12.51 µm), while the design results show that the central wavelength is 11.45 µm, the spectral response is in the range 10.4-12.5 µm, and the bandwidth is 2.1 µm. Based on these data, it can be concluded that the design results of the bandpass filter for the Gobi 640CL LWIR camera that have been made is able to approach the target of the desired spectral response bands 10 and 11 of Landsat8, also using materials substrate using Ge, The material can be used in a range of wavelengths 2-16µm and functionally by the expected sensor IR application, also uncoated the Germanium capable transmit power around 41%, It is expected that the bandpass filter on the LAPAN-A4 satellite LWIR camera can improve imaging on thermal imaging mapping.

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