Optical window design for MWIR camera

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Abstract. One important element in camera optical systems is the optical window because it serves as an element in the optical system to provide a clear aperture to transmit the desired radiation as well as to keep both environments separate and bear the atmospheric differences such as temperature and pressure. In designing the window there are several things to note besides the design of the optomechanical system such as window installation and structural considerations, as well as the impact of optical performance degradation due to the installation of this window. This paper discusses some important considerations for the design of optical windows with special specifications for medium wave infrared (MWIR) optical systems such as the material used, the minimum thickness associated with the pressure rating, the distance from the window to the aperture stop or the pupil as this is important when designing for degradation the wavefront is minimal and optimized to get a design whose effect on the optical degradation is very small.

1. Introduction
Microsatellite development program in LAPAN has become a national program in the framework of mastery in space technology, especially satellite. Beginning with the LAPAN-TUBSAT satellite built in 2003-2005 and was launched on January 7, 2007 [9]. The next LAPAN satellite program that has been launched and still orbiting and functioning well up until now is the LAPAN-A2 and LAPAN-A3 satellites [8]. According to LAPAN satellite planning roadmap, the upcoming satellite launches are LAPAN-A4 and LAPAN A-5 satellites. Along with this, to support the development of future microsatellites with remote thermal sensing missions requires a reliable optical system in order to function properly in accordance with the characteristics of the camera. The main design considerations are optical materials, size components, shape, and manufacturing tolerances [1][2][3][4]. All of these attributes vary on stage design and can have a significant impact on the cost of producing the optical systems.

There are several reasons for optical engineer require transparent windows on their optical systems design. Besides can protect a system from dust and debris, windows also provide environmental and vacuum seals.

This paper describes optical window design for MWIR Camera operating in the 3,0 - 4,0 µm wavelength band. The objective of the analysis is to get an ideal thickness of window material thickness associated with the pressure rating, the distance from the window to the aperture stop or the pupil.

2. Theory
Optical windows are flat, optically transparent plates that are typically designed to maximize transmission in a specified wavelength range while minimizing reflection and absorption. They are often used to protect optical systems and electronic sensors from an outside environment. Because windows introduce no optical power into a system, windows should be selected based on the material
transmission properties, optical surface specifications, and the mechanical properties that match with the application [7].

Optical windows usually consist of two flat surfaces. Using equation (1), the value of \( T \) as the thickness of the window can be calculated by following formula [12]:

\[
T = 1.06D \frac{P}{F_a}
\]

where \( P \) is load per unit area, \( D \) is unsupported diameter for the circular window, and \( F_a \) is apparent elastic limit.

![Figure 1. Focal shift due to a plane parallel plate.](image)

In that case, the window will cause the focus of the system to shift as shown in figure 1. Equation (2) gives the approximate focal shift (\( \Delta z \)) in terms of the index (\( n \)) and the thickness (\( t \)) of the window [10].

\[
\Delta z = \frac{n-1}{n} t
\]

a uniform pressure differential the optical path difference (OPD) through the window is given by equation (3) [5][6].

\[
\text{OPD} = (8.89 \times 10^{-3}) (n-1)\Delta P^2 d^5\frac{E}{h^2}
\]

where \( n \) is the refractive index of the window material, \( \Delta P \) is the pressure differential, \( d \) is the window diameter, \( E \) is the material Young’s modulus and \( h \) is the window thickness.

3. Methodology

The process was initiated by determining window materials. Choosing a material for a window is critical. The material must be able to transmit over the desired MWIR wavelength. Based on this criteria, ZnSe was chosen as window material and investigated on its thickness size. We were calculating the thickness by considering several parameters, i.e. diameter, Load per unit area and Apparent Elastic Limit. Utilizing ZEMAX software was the next stage, where entering the starting point into the ZEMAX package in accordance with the setting of the basic design parameters. After optimizing the starting design, we were analyzing the optimized design to achieve the final design specification.

In order to strengthen and to make sure our optimization design, the iteration process has been applied throughout the analysis. The iteration evaluation was to adjust between the process of optimize starting design and analyzing the optimized design. After the desired performance is met, the optical window final design was constructed. The whole design analysis is shown in figure 2.
4. Discussion and result
It is very important that optical windows be taken into consideration early in the optical design so that any powered elements in the system can negate the aberrations induced by the window. In this case, we present the results of case studies of optical window usage on optical infrared design with wavelength 3.0 μm up to 4.0 μm. From calculation, we get 1,208 mm for the window thickness. Figure 3 shows optical design before and after ZnSe Window addition. ZnSe – Zinc selenide is an infrared transparent material that is commonly used for IR windows [11]. There are many analysis tools inside the ZEMAX software which enabling to used to analyze the performance of an optical system. For our analysis process, we only utilized Chromatic Focal shift and Optical Path Difference as analysis tools.

Figure 2. Process flowchart.

Figure 3. Optical design: (a) before ZnSe window addition, and (b) after ZnSe window addition.
Figure 4. Chromatic focal shift: (a) before ZnSe window addition, and (b) after ZnSe window addition.

Figure 5. Optical path difference (object 0°): (a) before ZnSe window addition, and (b) after ZnSe window addition

Figure 4 shows chromatic focal shift before and after ZnSe window addition. After optimization, ZnSe as a window contributes to minimize the chromatic aberration on the central wavelength but maximized chromatic aberration on the minimum and maximum wavelength. The chromatic aberration describes the variation of focal length for different wavelength. Chromatic aberration is a refraction that occurs because the light has different wavelengths that have different focal points. Chromatic aberration is a refraction defect that occurs because light has different wavelengths that have different focal points. We could see the result from figure 4b that the minimum focal shift is 0 µm appears in minimum wavelength 3.4-3.5 µm, meanwhile maximum focal shift 3.6 µm happened at 3 µm. So, this is very acceptable value in the design.

The optical path difference (OPD) is defined as the difference between the ideal unaberrated and the aberrated wavefronts. For a perfect optical system, the optical path, or distance, from an object point to a corresponding image point will be equal for all wavefronts. Figure 5 shows Optical Path Difference before and after ZnSe window addition. The OPD is negative because the ideal unaberrated wavefront curves in more than the aberrated wavefronts.

Based on the simulation, the optical design result that has been added ZnSe window gives a small chromatic on the minimum and maximum wavelength. This aberration value is generally sufficient, but if we want to improve optical performance it is necessary to optimize and iterate to reduce the value of chromatic aberration at 3 µm and 4 µm wavelength.

5. Conclusion
Generally, optical window design for MWIR camera has met our expectation. Nevertheless, there are several things that have to review and evaluate, such as optical design and mechanical/thermal analysis.
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References
[1] A. Bustanul, A.M. Tahir, and P. Irwan, “The Preliminary Analysis of Spectral Radiance Design of IR Bolometer Sensor for Wild Fire Detection in Indonesia,” Proceedings of ICS 2014: Space for development, 2014.
[2] Arifin, B. Tahir, M. A. and Priyanto. I, “Analysis of Lapan’s IR Microbolometer Design for Volcano Activity”, Proceedings of ICARES 2015, IEEE, 2015.
[3] Arifin, B. Priyanto. I, and Tahir, M. A, “The Development and Design of Lapan’s IR Camera Equipment with Mirobolometer Sensor”, Proceedings of IGARSS 2017: International Cooperation for Global Awareness, IEEE, 2015.
[4] A. Bustanul, P. Irwan, A. M. Tahir, and B. Firman., “The Initial Design of Lapan’S IR Micro Bolometer Using Mission Analysis Process,”, Proc. of SPIE vol.10030, 2016.
[5] Balazs Ihracska, Roy James Crookes, Diogo Montalvão, Mohammad Reza Herfatmanesh, Zhijun Peng, Shahid Imran, Theodosios Korakianitis, “Opto-mechanical design for sight windows under high loads”, Materials & Design Volume 117, 5 March 2017, Pages 430-444, https://doi.org/10.1016/j.matdes.2016.12.080
[6] Daniel Vukobratovich, Paul Yoder, “Fundamental of Optomechanics”, CRC Press, Taylor & Francis Group, LLC, 2018.
[7] Edmund Optics, “Understanding Optical Windows”, https://www.edmundoptics.com/resources/application-notes/optics/understanding-optical-windows/ (10 June 2017).
[8] J T Nugroho, Zylshal, G A Chulafak, D Kushardono, “Performance of LAPON-A2 satellite data to classify land cover/land use in Semarang, Central Java”, IOP Conference Series: Earth and Environmental Science, 54 (2017) 012098, doi:10.1088/1755-1315/54/1/012098
[9] Robertus Heru Triharjanto, Harry Bangkit, M. Arif Saifudin, “Development of Space-based Magnetic Activities Measurement Mission in Lapan’s Micro-Satellites”, The 21st CERES International Symposium, SOMIRES 2014 - The 2nd Symposium on Microsatellites for Remote Sensing
[10] Scott Lilley, “An introduction to optical windows”, OPT1 521 December 3, 2013, University of Arizona.
[11] https://www.newport.com/f/zinc-selenide-parallel-windows (23 July 2017).
[12] The Design of Pressure Windows, https://www.crystran.co.uk/documents