Semarak Proceedings of Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.my/index.php/spaset/index
ISSN: 3083-9807

Modeling of Spectrometer using Zemax OpticStudio Simulation

Siti Nadhirah Zainurin[1], Wan Zakiah Wan Ismail[1,*], Irneza Ismail[1], Juliza Jamaludin[1]

[1] Faculty of Engineering and Built Environment, Universiti Sains Islam Malaysia, Malaysia

ABSTRACT

A comprehensive model of a spectrometer is developed using Zemax OpticStudio, a cutting-edge optical design and simulation software. The study aims to design, simulate, and evaluate the spectrometer's performance, focusing on parameters such as beam wavelength range, optical component parameters, optical ray, and light irradiance. By employing Zemax's advanced ray tracing and system optimization, this research demonstrates the software's capabilities in enhancing spectrometer designs, making it an invaluable tool for diverse applications, including scientific research, environmental monitoring, and others. The system has integrated the concept of the Czerny-Turner spectrometer design configuration with the light propagation theory. The Physical Optics Propagation (POP) analysis is used for visualizing and analyzing light beam propagation. For the designed system evaluation, the modeling result is mainly based on light intensity (peak irradiance) as a function of wavelengths.

Keywords: *Spectrometer design; Zemax OpticStudio; optical simulation; ray tracing; physical optics propagation; Czerny-Turner*

1. Introduction

Modeling is important to assist the development process of a spectrometer by enabling designers to create, test, and refine optical systems in a virtual environment before physical prototypes are built. Before designing a spectrometer, it is necessary to determine the features, elements, and parameters required. The spectrometer's optical components, such as light sources, lenses, gratings, and detectors, are modeled to study how different configurations impact overall performance. In other words, modeling allows for the precise design of spectrometers by simulating how optical components interact.

Furthermore, this study modeled a spectrometer using Ansys Zemax OpticStudio. The Zemax OpticStudio is a comprehensive and readily available commercial optical design software tool that integrates all the features to simulate, optimize, and validate the optical design system before physical prototypes are built [1]. OpticStudio is a user-friendly interface that combines analysis, optimization, and tolerancing tools to design. Hence, the modeling is done to develop an optimized hardware design for the spectrometer. The optical design processes involve developing a conceptual optical design, ray tracing an optical layout, and varying parameters of the specification to improve performance.

In this research, the system has integrated the concept of the Czerny-Turner spectrometer design configuration with the light propagation theory. The Physical Optics Propagation (POP) analysis in

* *Corresponding author.*
E-mail address: drwanzakiah@usim.edu.my

https://doi.org/10.37934/spaset.1.1.153157a

Zemax software is employed to visualize and assess the behavior of light beam propagation [2]. To evaluate the performance of the designed system, the modeling results focus primarily on analyzing peak irradiance as a function of wavelength. In essence, modeling serves as a bridge between theoretical design and practical implementation, ensuring that the spectrometer's optical system is optimized for its intended function while reducing the risks and uncertainties associated with physical trials. Here, we introduce the design simulation of the optical spectrometer-based Czerny-Turner configuration.

2. Methodology

2.1 Theoretical Study

2.1.1 Czerny-Turner

The Czerny-Turner configuration is a specific arrangement of optics in spectrographs. The Czerny–Turner configuration is one of the compact and flexible spectrometer designs, consisting of a single detector instead of a detector array and requiring fixed components [3]. This optical system arranged in a triangular layout consists of a light source, a slit, two mirrors which are collimating and focusing mirrors, a reflecting-type diffraction grating, and a detector [4,5]. Light enters the system and is reflected by the first mirror onto the diffraction grating, which disperses the light into its component wavelengths. The second mirror then refocuses the dispersed light, directing it towards the detector through the slit. Figure 1 shows the layout of the modeled spectrometer in Zemax that integrated the concept of the Czerny-Turner. LF is the focal length of the collimating mirror, LF is the focal length of the focusing mirror, G is grating constant and Wslit is slit width. Different types of spectrometers may have additional parameter settings in the design. This spectrometer modeling is used to evaluate how the light passes through the spectrometer.

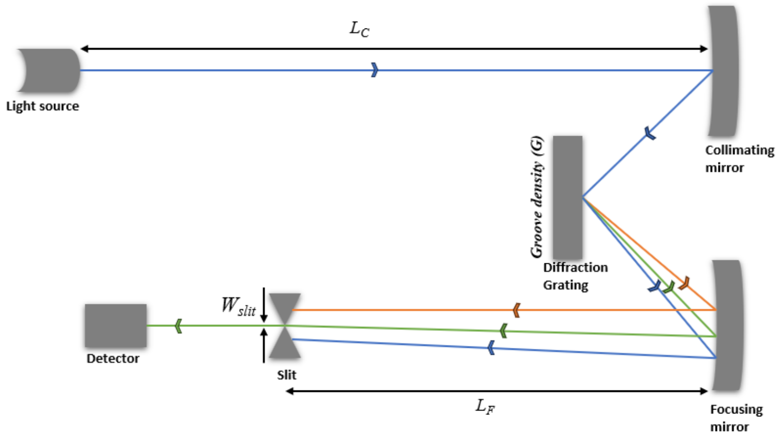

Fig. 1. Czerny-Turner modeled spectrometer

2.2 Design and Simulation of Optical Spectrometer

2.2.1 Design parameters

The parameters of each optical component such as the surface type, the radius of curvature, thickness, lens material, and others defined in the Lens Data Editor (LDE) window are listed in Table 1. Values of parameters present in the LDE are according to the designed spectrometer. The optical design is described by a set of surfaces through which light passes sequentially. Sequential ray tracing assumes that light travels from surface to surface in a defined order. In this modelling, the wavelength range is covered from ultraviolet (UV), and visible (Vis) to infrared (IR) region. The spectrometer simulation also is carried out using a diffraction grating of 600 lines/mm.

Table 1
Lens data editor window in Zemax

Surface Type	Material or Lines/um	Radius [cm]	Thickness [cm]	Semi-diameter [cm]
Source (OBJ)	-	Infinity	6.5	0.00
Collimating mirror (1)	Mirror	-10.00	-1.0	0.40
Grating (2)	0.6	Infinity	1.0	0.40
Focusing mirror (3)	Mirror	-10.00	-5.0	0.40
Slit (4)	-	Infinity	-1.0	0.50
Detector (IMG)	-	Infinity	N/A	0.15

2.2.2 3D layouts ray viewer

After defining the required surface and other relevant parameters involved in the design, the software provided a pictorial layout of the spectrometer, as shown in Figure 2. This included the source, slit, collimating mirror, diffraction grating, focusing mirror, and image at the last surface which is the detector. The design and simulation of the spectrometer are carried out using the physical optics propagation algorithm for three different wavelength ranges which are UV, Vis, and IR. The 3D viewer is used for visualizing and analyzing light beam propagation and the arrangement of optical surfaces. In other words, it is useful for qualitatively observing the effects of each surface, location of object, direction of light, ray splitting, and others.

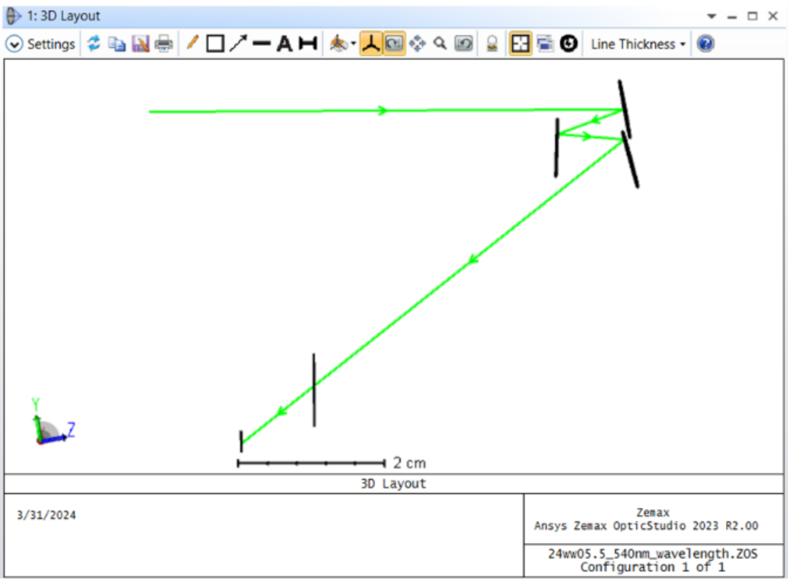

Fig. 2. Zemax 3D layouts ray viewer.

3. Simulation Results

Spectrometer modeled design performance is analyzed using Zemax analysis tools such as physical optics propagation window, spot diagram, and footprint diagram.

3.1 Image of The Spectral Irradiance

Spectral irradiance is the irradiance of the surface per unit frequency or wavelength. POP feature propagates an arbitrary coherent optical beam through the optical system. The spot diagram in the POP analysis window is shown in Figure 3. It displayed the list of data of the propagated beam at 540nm wavelength and the peak irradiance value is 0.44 Watt/cm2. The POP analysis computes the beam irradiance on a plane tangent to the chief ray at the point where the chief ray intercepts the surface. Peak irradiance value refers to the maximum irradiance in power per area. Irradiance at the center was maximum because most of the rays were focused at the center, moving away from the center decreased the irradiance, and energy per unit area delivered to the surface also decreased [6].

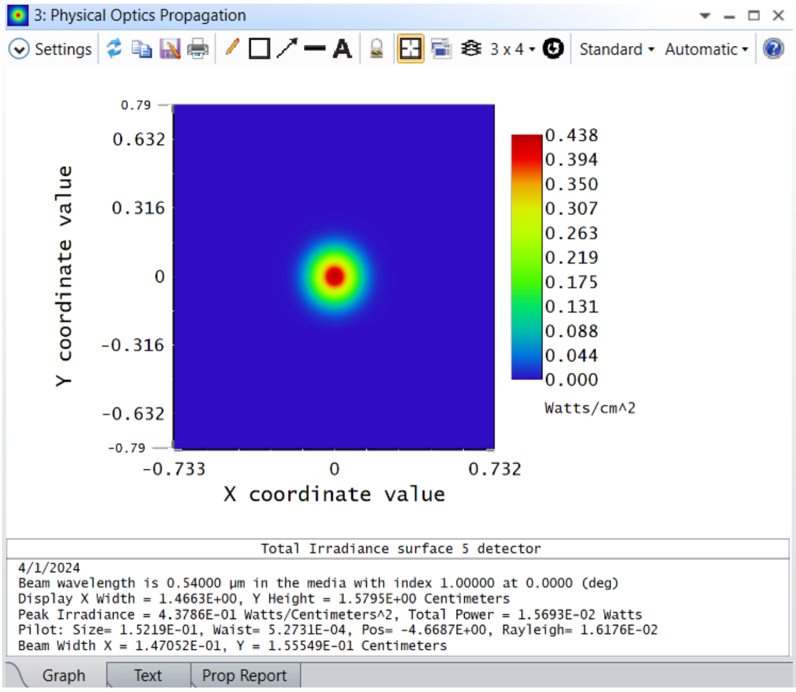

Fig. 3. Spot diagram in POP window at 540nm

3.2 Footprint Diagram

Another analysis tool used is a footprint diagram at the detector surface for 540nm wavelength as shown in Figure 4. It displays the footprint of the beam superimposed on any surface and checks the surface apertures. The surface value can change to any type of surface, and it is used to show the beam footprint for specific surfaces.

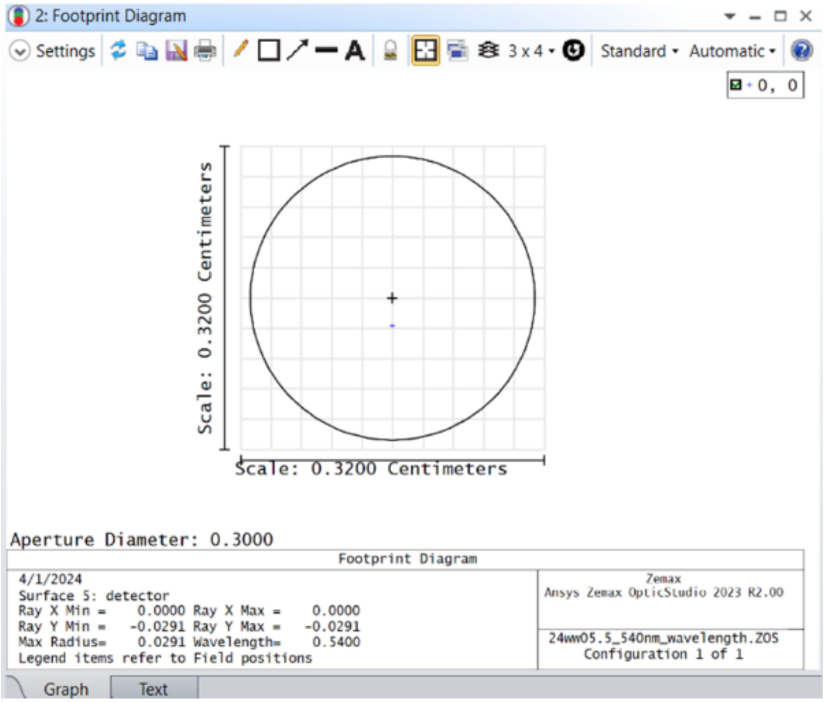

Fig. 4. Footprint diagram at 540nm

4. Conclusions

An optical Czerny-Turner based spectrometer was designed and simulated using Zemax OpticStudio simulation software. The results with the spectrometer were analyzed based on the ray tracing, and peak irradiance in the spot and footprint diagram. Different types of spectrometers may have additional parameter settings in the design. The spectrometer modeling is used to evaluate how the light passes through and the spectrometer system performance. This study highlights the potential for modeling an efficient spectrometer before developing the compact hardware spectrometer for optical measurements.

Acknowledgement
We would like to acknowledge Ministry of Higher Education, Malaysia for Fundamental of Research Grant Scheme (FRGS/1/2021/WAB02/USIM/02/1) and Universiti Sains Islam Malaysia for USIM-MMU Matching grant (USIM/MG/MMU-PPKMT-ZDA/FKAB/SEPADAN-S/70822).

References
[1] Zemax, Ansys. *Ansys Zemax OpticStudio—Comprehensive Optical Design Software*.
[2] “Exploring “Exploring Physical Optics Propagation (POP) in OpticStudio,” *Knowledgebase*, n.d.
[3] Naeem, Muddasir, Tayyab Imran, Mukhtar Hussain, and Arshad Saleem Bhatti. "Design simulation and data analysis of an optical spectrometer." *Optics* 3, no. 3 (2022): 304-312. https://doi.org/10.3390/opt3030028
[4] “Spectrometer design guide - Ibsen Photonics.”
[5] Naeem, Muddasir, Noor-ul-ain Fatima, Mukhtar Hussain, Tayyab Imran, and Arshad Saleem Bhatti. "Design simulation of Czerny–Turner configuration-based Raman spectrometer using physical optics propagation algorithm." *Optics* 3, no. 1 (2022): 1-7. https://doi.org/10.3390/opt3010001
[6] Naeem, Muddasir, and Tayyab Imran. "Design and simulation of Mach-Zehnder interferometer by using Zemax optic studio." *Acta Scientific Applied Physics* 2, no. 3 (2022).