

**IMPACT OF INTERFACING MOLECULES ON THE COATING OF THE HIGH
AND LOW REFRACTIVE INDEX DIELECTRIC MATERIALS ON GLASS
SUBSTRATE**

A Project Report Phase - II

Submitted in partial fulfillment of the requirements for the award of Bachelor
of Engineering Degree in Electronics and Communication Engineering

By

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(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **MALE SAI VAMSHI** (Reg. no. **39130270**) who carried out the project entitled “IMPACT OF INTERFACING MOLECULES ON THE COATING OF THE HIGH AND LOW REFRACTIVE INDEX DIELECTRIC MATERIALS ON GLASS SUBSTRATE” under my supervision from November 2022 to April 2023.

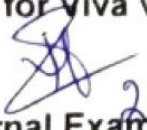
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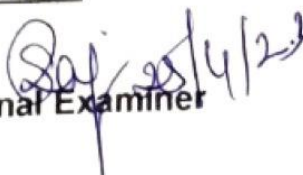
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DECLARATION

I MALE SAI VAMSHI (Reg. No. 39130270) hereby declare that the Project Report entitled "IMPACT OF INTERFACING MOLECULES ON THE COATING OF THE HIGH AND LOW REFRACTIVE INDEX DIELECTRIC MATERIALS ON GLASS SUBSTRATE" done by me under the guidance of Mr. L. JEGAN ANTONY MARCILIN, M.Tech., Department of Electronics and Communication Engineering, at SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY, CHENNAI is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Electronics and Communication Engineering.

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ABSTRACT

Various optical applications need the design of optical band pass filters of a particular wavelength. Interference filters are the most widely filters where interference results in strengthening the amplitude of central wavelength and attenuating the other wavelengths. Performance of the filter is measured in terms of transmission coefficient and the ability to attenuate the remaining wavelengths. It is dependent on the choice of the dielectric material, thickness of each dielectric material and the stacking of the dielectric materials. In this work, the impact of thickness and stacking on the transmission coefficient for the design of thin film optical band pass (464.7 nm) is studied. Two different sets of dielectric materials namely $\text{TiO}_2/\text{SiO}_2$ and MgF_2/ZnS are used. Various wavelengths such as 656.3, 486.1, 464.7 nm are quite significant which are used for health monitoring of thermonuclear machines.

The optical thin film filters which work on constructive and destructive interference are the ideal choices. These filters are multilayered with a pair of high and low refractive index dielectric materials. Significantly high transmission index at the desired wavelength and relatively low transmission at the other wavelengths are desired. With this as the objective, it is necessary to design the filter. Various optimization techniques are used for identifying the suitable design of the filters. To choose the parameter combination that provides the most excellent performance, optimization of the design parameters is entailed. The goal of this work is to improve the optical band filter using the GOA method. The ideal design is determined by assessing several characteristics such as thickness, refractive index, Full-Width at Half-Maximum (FWHM), and the impact of choosing optical properties, which increases transmission potential. Initially, an alternate multi-layer stack with 28, 30, and 32 layers is created by altering the thickness while keeping the dielectric substances high and low refractive indices constant. By adjusting the thickness of each layer, the GOA algorithm achieves the best practical solution. The proposed method is implemented using MATLAB and the outcomes show the efficacy of the proposed technique. The transmittance, reflectance, and FWHM using the proposed GOA are found to be 99.9% respectively.

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
GOA	Grasshopper Optimization Algorithm
GA	Genetic Algorithm
FWHM	Full-Width at Half-Maximum
PVD	Physical Vapour Deposition
CVD	Chemical Vapour Deposition
CCP	Capacitive Coupled Plasma
AMF	Axial Magnetic Field

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

An optical thin film is composed of multiple layers of dielectric material with defined thickness stacked on a substrate. However, designing such films to achieve desired optical properties is a complex task. The primary challenge in modeling optical filters is to determine the construction parameters that can help attain the desired optical instruments. The extinction coefficient of the medium's surface, refractive index, number of layers in the system, layer order, and thickness are major construction parameters that need to be considered. These parameters are combined into a parameter vector for analysis. The productivity of the multilayer at any stage is determined by estimating the measure of merit function, which is a single-value function calculated by evaluating various quantities in the multilayer.

Traditional methods for designing optical thin films use different quantities, such as the angle of incidence, reflectance at a specific wavelength, and the plane of polarization. Among these quantities, the angle of incidence, reflectance, and plane of polarization receive significant consideration. To develop the transmittance or optical spectral reflectance in the multilayer thin film coating, a well-utilized method is to vary the refractive index, which is known as an optical interference filter. This technique helps achieve the desired optical properties in the film. In summary, designing optical thin films requires considering multiple construction parameters and evaluating different quantities in the multilayer to determine the measure of merit function, which ultimately leads to the desired optical instruments.

Numerous Traditional methods for designing multi-layer optical filters include graphical, analytical, and numerical techniques. Analytical techniques are the fastest, but not very flexible. Numerical methods, on the other hand, are effective in solving complex issues and provide better solutions to problems that are inaccurate or time-consuming with other methods. Synthesis and refinement methods are the most common numerical methods used. In numerical methods, the crucial factor is the initial modeling, which should be closest to the required performance.

Although analytical and numerical methods are effective in solving complex issues related to multi-layer optical filter design, they are often time-consuming and may not always provide optimal solutions. To overcome this, pre-fabrication design is required to achieve better performance and cost-effectiveness. However, obtaining a global optimal solution can be a challenging task, as most optimization techniques tend to get stuck in local optima, especially when the dimension of the problem is increased. To address this, various global and local optimization algorithms such as annealing method, Monte Carlo method, needle method, and GA techniques are used to model multi-layer optical interference filters. In particular, the Needle method is used to design interference filters and attain the optimal modeling parameters of the filter. Nonetheless, finding the global optimal solution remains a challenge.

The proposed system introduces an optimization strategy, called GOA, for designing optical filters that efficiently transmit light. Among the numerous stochastic optimization techniques, population-based algorithms inspired by nature are of great interest as they emulate the traits of living creatures to solve real-world problems. The GOA algorithm takes in the parameters of the optical thin film filters to be optimized and obtains optimal values for the parameters that are suitable for the design purpose. Specifically, the GOA algorithm considers a combination of design parameters and the transmittance profile as input to determine the optimal thickness of the layers. The main contribution of the proposed grasshopper optimization algorithm is to achieve the optimal model for optical thin film filters. The proposed GOA approach is utilized to obtain optimal model parameters of the optical filters, in terms of transmittance and reflectance, by tuning both the number and thickness of layers with constant refractive index measures. The purpose of this project is to develop a filter that specifically targets carbon gas among the various gases emitted by the plasma in Aditya Tokamak. The primary goal is to measure the disruptions caused by the plasma due to unpredictable conditions. The C3 filter is responsible for identifying carbon gases present in the gases emitted from the plasma. To achieve this, a filter with 5-6 layers of selected material needs to be designed. Although there are various types of filters available, the team has opted to use an optical filter due to its numerous advantages over other types of filters.

Optical filters are widely used to selectively transmit light of certain wavelengths and remove harmful UV rays. Absorptive filters and interference filters are the most commonly used types of optical filters, with their properties describing the changes in refractive index with respect to changes in wavelength. To ensure optimal performance of the optical system, mechanical properties such as elasticity, density, and hardness must be considered to prevent mounting difficulties. Optical filters find applications in fluorescence microscopy, spectroscopy, clinical chemistry, and imaging.

The Aditya Tokamak is a device designed to confine plasma in a torus shape, with "tokamak" being the Russian word for this type of magnetic confinement device used for producing controlled thermonuclear fusion power. The Aditya Tokamak is a medium-sized tokamak installed at the research Centre for Plasma Research. The tokamak is designed in the shape of a revolving circle in a 3D axis, containing both poloidal and toroidal elements. The device is used to contain hot plasma and produce controlled thermonuclear fusion power to generate electricity.

Deuterium and tritium are used as fuel and are heated up to 1000 degrees to produce the hot plasma. A vacuum is placed inside the torus to contain the plasma, and it must be maintained within a certain temperature range to avoid disruptions. The horizontal magnetic windings are known as "poloidal field magnet," and the vertical windings are known as "toroidal field magnet." The magnetic confinement device provides thermonuclear fusion power by containing the hot plasma, and its radius ranges from 0.25m-0.75m.

In summary, optical filters are commonly used to selectively transmit light and remove harmful UV rays. The Aditya Tokamak is a device designed to produce controlled thermonuclear fusion power by confining hot plasma in a torus shape using a magnetic confinement device. It contains both poloidal and toroidal elements and must maintain a certain temperature range to avoid disruptions. The device is used to generate electricity, and its radius ranges from 0.25m-0.75m.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY

In this section, the current methods of designing optical filters and the difficulties associated with the existing model are discussed, which inspired the development of the proposed model.

FILM OPTICAL BAND PASS FILTERS

Zaheer Abas Khan et al (2001) utilized the layer-by-layer assembly method to fabricate a thin film optical filter, which was prepared by colloidizing gold and silver nanoparticles. The filter was functional in the visible and UV range of the electromagnetic spectrum. On the other hand, S.W. Xue et al (2008) studied the impact of annealing on thin film optical filter design. The researchers used the sol-gel technique for the deposition of the thin film, and they observed an increase in the refractive index with an increase in temperature during the annealing process.

In 2008, Yun-Pei Chan and colleagues studied the nonlinear absorption of thin films using high order resonance. They observed enhanced nonlinearity near the resonance excitation, and found that Zinc Oxide, with its wide band gap and high binding energy at room temperature, is suitable for this purpose. In 2012, Dr. Gaillan, H. Abdullah and their team designed a narrow band pass filter using thin film for dense wavelength division multiplexing.

Several techniques such as sputtering, Chemical Vapour Decomposition, and Physical Vapour Decomposition (PVD) are employed for deposition. Prism cheer grating is used for multiplexing. Saeed N. Turki (2015) has developed an optimized InfraRed band pass filter with high and low refractive index materials such as ZnS and cryolite, respectively, deposited on a glass substrate. The increase in the number of orders leads to higher transmission and lower FWHM. Moreover, a decrease in wavelength shifting is observed as the angle of incidence rises.

Bin Alexander and colleagues (2017) conducted a study on the acceleration of rotating plasma flows in crossed magnetic fields. Their experimental setup included a solenoid and permanent magnets, which induced an azimuthal electric field that rotated electron and ion flows in opposite directions. The change in axial magnetic flux resulted in induction acceleration of the plasma flow. By applying the linearity of the Maxwell equations, the researchers were able to describe the electric and magnetic fields of the system. The interaction of the azimuthal electron and ion flows with the radial component via the Lorentz force led to the axial acceleration of both particles in the same direction. This resulted in the acceleration of the twirling plasma flow in a cylindrical vortex in the axial direction, leading to energy and momentum transfer. The findings of this study could potentially be useful in the development of plasma thrusters.

In 2017, Scott Robertson and colleagues developed a model to analyze the acceleration of plasma from a high magnetic field source region to a lower field region. This model integrates the equations of motion for both electrons and ions, and incorporates a source term for replenishing plasma in the source region, acceleration from the ambipolar electric field, and acceleration from the magnetic mirror force. By applying the gyro fluid equation for axial motion, they were able to determine the acceleration of plasma from the source region, which is useful in plasma experiments that involve helicon sources and plasma processing setups.

In 2017, Geraldo Roberson et al developed an integrable and area-preserving map to represent magnetic surfaces with triangularity in single null divertor tokamaks. The map allows for the representation of various asymmetric geometries of magnetic surfaces, and the shape of the cross section of these surfaces plays a crucial role in plasma stability and confinement in fusion reactors. The methodology used for constructing the map involves the use of trajectory integration method and equilibrium model. The map can be used to investigate the dependence of stability and deposition patterns on different equilibrium parameters. Additionally, it allows for the determination of the escape patterns of magnetic field lines on the divertor plates.

In 2017, Qin Hang and colleagues conducted an analysis of the Experimental Advanced Superconducting Tokamak (EAST). They found that having a good understanding of the total plasma inductance helped in mapping the discharge of the vertical magnetic field using Maxwell's equations. They also derived a relationship between the vertical magnetic field and line-averaged density during the flat-top phase for a given plasma current. Increasing the strength of the vertical magnetic field can result in achieving high temperature, high density, high beta, and high bootstrap current fraction. The achievement of high confinement mode and long-pulse steady-state operation is considered an important goal in current magnetic fusion energy research.

M.Afsharmanesh et al (2017) used simulations to investigate collisional power dissipation in helicon plasma. They adjusted plasma density and magnetic field strength to maximize power absorption. The study focused on two types of RF antennas - half helix and Nagoya type-3 - and used the CST Microwave Studio code for simulations. Results showed that power deposition was significantly asymmetric above a certain ratio. This asymmetric absorption was favorable for efficient ion beam extraction from helicon plasma sources. Overall, the study offered insights into factors that influence power dissipation and ion beam extraction in helicon plasma.

In their 2017 experiment, Dingee Yang et al aimed to improve the control of arc plasma and investigate the characteristics of plasma jets in the presence of a magnetic field. They utilized a Helmholtz coil to generate different axial magnetic fields (AMFs) and observe their effect on the transfer of arc column and appearance of cathode plasma jets. Three methods were employed to analyze the appearance and inclination of cathode plasma jets, as well as the mechanism behind their formation. The results showed that the individual cathode plasma jets can be controlled by varying the AMF, which in turn affects the interaction between arc plasma and electrodes. Changing the direction of the composite magnetic field vector was achieved by introducing the external imposed AMF.

Denis Eremin and colleagues (2017) presented a model to explain the excitation of resonant surface waves in large Capacitive Coupled Plasma (CCP) reactors commonly used in the plasma processing industry. The model illustrated how these modes are initiated and their impact on the radial plasma density. The paper provided insights into the physics of high-frequency CCP reactors and their potential effects on plasma uniformity. The study demonstrated that the non-uniformities caused by the modes disappear in highly collisional plasmas due to significant mode damping.

OPTIMIZATION TECHNIQUES

In 1997, Thomas A. Cusick and his colleagues used the space state matrix technique to address complexity issues in finite and infinite impulse response problems related to filters. They also used genetic algorithm methods to handle filters of different sizes and weightage. S. Tibuleac (2001) utilized genetic algorithm optimization and search techniques to design a narrow line width bandpass filter using diffractive thin layer film. They achieved resonance of the guide mode by interference action in single and multilayer grating of the waveguide, resulting in a narrow width line, maximum peak value, and less transmission of sideband. Felix C.M. Bettonvil and his team (2006) designed a tunable Ha filter using the Serco system and studied various layers of the atmosphere with particle nature of Ha by changing the wavelength using a lyot filter. For designing thin film optical bandpass filters, particle swarm optimization and genetic algorithm are two popular optimization techniques. H. Arabshshi (2010) used swarm optimization algorithm and various particle models to design optimal thin film filter layers and achieve global optimization.

OPTICAL FILTERS USING BRAGG MIRRORS

In 2000, Dmitry N. Chigrin developed a single dimension photonic crystal filter using periodic interference of thin film. This filter utilized dielectric for dispersion between the band gap of crystals and Bragg mirror technique for laser emission in the dense WDM through a narrow filter band. The photons were focused in the single dimensional crystal, and their propagation in solid took place by the ballistic method. The optical geometry was approximated by assuming that the wavelength of the photon should be smaller than the size of the source and detector and the distance between them. The flux and surface frequency had an inverse relationship with each other. Mulul Agrawal (2008) studied coherent trapping in broad bands using thin-film cells. They used the Bragg mirror technique to enhance photo detector in the resonance cavity. The organic cell, which operated in solar light, increased the current and polarization angle of incidence. SiO_2 and TiO_2 were used as low and maximum index materials. A dielectric mirror was designed specifically to enhance the cell's absorption.

MICROSTRUCTURE DESIGN

In 2004, D.M. Beggs and his team optimized an optical filter by using a square-shaped passband. They achieved a wide transmission profile and smoothness in the filter by using an absorption material as the base. Bragg reflectors and anti-reflective coatings were used in various optoelectronic devices. The coefficient of transmission did not reach unity when the frequency was within the Bragg reflector stop band frequency.

In 2008, W.P. Ng and his team analyzed the relationship between chromatic dispersion and interference errors. Chromatic dispersion could result in intersymbol interference, which may lead to errors. However, this issue can be avoided by using a parallel optical filter that allows all frequencies, unlike a single-mode filter. The all-pass filter can be used in error-free communication, and the bit error rate can be reduced by implementing this filter design in optical communication blocks. In 2011, R. Kitsomboonloha and his team tuned the nanoparticle multilayer composite insulator structure for optical filtering purposes.

In many optical filters, the filtering process relies on interference and resonance mechanisms achieved by controlling and tuning the band of materials. Plasmon resonance nanoparticle absorption is used to reduce costs, and the amplitude of the nanoparticle is adjusted to achieve spectral tuning. The peak value is determined by the bi-layer of metal, and the layers can be grown through automatic dip coating. The performance of the filter can be improved by reducing the size of the particle and the refractive index.

OPTICAL FILTERS USING POLARISATION

Kazunori Suzuki and his team (2001) examined the optical properties of polarization fiber, which is important for high transmission rate, and found that the birefringence is higher than that of induced stress fiber. The diameter of each hole in the fiber was observed through scanning electron microscope (SEM). Ignacy et al (2004) investigated the optical properties of Plasmon, such as sample thickness and coupled emission, and observed that the lifetime of poly vinyl alcohol (PVA) was not as expected. Prisms were used for polarization. William L. Barends (2006) explored a route for optical sub-wavelength and examined the surface level Plasmon. The dispersion in the surface Plasmon-Polariton was studied to understand the relationship between the wave vector in-plane and the frequency of angle. The depth of penetration in the plasma surface was calculated, and effective coupling technique was proposed to avoid energy loss. Atul Kulkarni et al (2013) used DNA as a thin film and sensor to detect alpha radiation in nanometers. Artificially designed DNA was observed through reflectance spectroscopy using Am source to calculate distance and time.

2.2 Related Works

Rabady and colleagues (reference [1]) utilized the PSO method to achieve global optimization in the design of optical filters, which outperformed the GA approach. However, the PSO method may sometimes result in local optima.

In reference [7], the authors proposed a GA and Taguchi-based approach for optimizing optical parameters to achieve high transmittance in live-streaming systems. However, this approach may suffer from convergence issues and is not highly recommended.

The author of reference [8] suggested a parallel pre-determined paradigm for designing optical filters that considers real production constraints, which is a more desirable and rigorous option. Nevertheless, this technique has its own recurring difficulties.

In reference [9], a pattern of optical thin film based on the Fourier transform was created to establish a starting population, which was then optimized using GA. The results showed that GA improves the manufacturing of optical thin films. However, using GA for design and optimization purposes requires a significant amount of computing time to achieve the desired outcomes.

2.3 PROBLEM STATEMENT

The current methods of optical filter design face several challenges including:

- Using GA as the optimization technique poses a difficult challenge in achieving reliable outcomes as the quality of the results is a complex problem [5].
- The spectrum often does not achieve high performance in high wavelength regions as compared to regions with shorter wavelengths [5].
- Maintaining regularity in the spectrum of transmission is a challenging task, especially in the high wavelength domain.

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 DESIGN METHODOLOGY

A multilayer optical bandpass filter has been developed for the visible range at normal incidence with central wavelengths of 656.3 nm, 486.1 nm, and 464.7 nm. The filter was constructed using alternating layers of high and low refractive index materials, with three different material arrangements chosen for each. The high refractive index materials used were Zinc sulfide (ZnS) and Titanium dioxide (TiO₂), while the low refractive index materials were magnesium fluoride (MgF₂) and silicon dioxide (SiO₂).

A high transmission optical filter is created to operate within the wavelength range of 400nm to 700nm. The design considers three distinct thickness limits and three different substrate refractive indexes. The optical filter can be designed using 28, 30, or 32 layers with substrate refractive index of 1.5143, 1.5224, and 1.524, respectively. A MATLAB computer program is utilized to optimize the optical parameters for better transmittance and reflectance profiles using the GOA optimization algorithm.

A multilayer optical bandpass filter was designed for normal incidence in the visible range and centered at wavelengths of 656.3 nm, 486.1 nm, and 464.7 nm. The filter was constructed using layers of high and low refractive index materials, with Zinc sulfide and Titanium dioxide as the high refractive index materials and magnesium fluoride and silicon dioxide as the low refractive index materials. The design aimed to achieve good transmission in the wavelength range of 400 nm to 700 nm. To achieve this, three different thickness limits and three substrate refractive indices were considered for the design, resulting in filters with 28, 30, or 32 layers and substrate refractive indices of 1.5143, 1.5224, and 1.524, respectively.

A MATLAB program was developed to optimize the transmittance and reflectance profiles of an optical thin film filter using the GOA optimization algorithm. However, there are challenges associated with conventional optical filter design methods:

- The Grasshopper optimization algorithm (GOA) method may have unstable convergence speed and an imbalanced trade-off between exploration and exploitation [10].
- The Monte Carlo method requires more time and computation to approximate the solution, making it less preferable.
- The GA method is computationally expensive and time-consuming for optimization, as noted in [11]. These limitations provide motivation for developing an improved method of optical filter design.

The challenges with conventional optical filter design methods highlight the need for further research and development in this area. The GOA method, despite its potential benefits, may not always be reliable due to its unstable convergence speed and imbalanced trade-off between exploration and exploitation. Similarly, the Monte Carlo method is less preferred due to the large amount of time and computation required to approximate the solution. Finally, the GA method, although widely used in optical filter design, is often limited by its high computational cost and time-consuming optimization process.

These limitations emphasize the need for a more efficient and effective approach to optical filter design. Further research can focus on developing new algorithms that provide better performance, faster convergence speed, and improved trade-offs between exploration and exploitation. This could lead to new breakthroughs in optical filter design that improve overall performance and reduce costs.

3.2 EXISTING SYSTEM

The selection of two dielectric materials, ZnS with high refractive index and MgF₂ with low refractive index, was based on their properties and usage. MgF₂ is highly pure and suitable for optical coating, and has been used for many years in anti-reflection and multi-layer coatings. It is insoluble and hard when deposited on a hot substrate, evaporates cleanly and completely without outgassing or spitting, and is resistant to thermal and mechanical shocks. ZnS is also insoluble in water and well-suited for optical coating on a BK7 glass substrate.

The team optimized the magnesium fluoride layer using the thermal evaporation method, and determined that six layers of dielectric material were the most efficient for optical coating. The thickness of each layer, measured in nm, was predicted using mathematical equations with a MATLAB tool. The results were then analyzed by comparing the wavelength in nm to the transmittance coefficient.

Optical filters are devices that allow selective transmission of light at specific wavelengths and are commonly used in photography, optical instruments, and color stage lighting. They are usually made of glass or plastic and can be either dyed in the bulk or have interference coatings. Dichroic filters, a type of thin film filter, are created by coating a glass substrate with a series of optical coatings using the interference principle. The layers are arranged in a sequential series to achieve the desired wavelength, while other wavelengths cancel out or reflect destructively as the peaks and troughs of the wave overlap. These filters are costly and are available in long pass, band pass, and short pass types.

Thermonuclear fusion power is a source of heat that can be used to generate electricity. Fusion occurs when two small nuclei combine to form a heavier nucleus, releasing energy in the process. Two types of reactors are currently used for conducting nuclear fusion: magnetic confinement reactors and inertial confinement reactors. In magnetic confinement reactors, the aim is to keep ions close together for a longer time period in order to facilitate fusion. Inertial confinement reactors, on the other hand, use

laser fusion and ion beam fusion to induce fusion. However, magnetic confinement reactors offer the advantage of avoiding the need for materials that can withstand the high temperatures generated by nuclear fusion reactions. To achieve fusion, the magnetic confinement reactors use induction coils to produce a heating current of more than a million amperes. The hot plasma is kept from contacting the walls of the reactor by using magnetic and centripetal forces to keep it moving along circular or helical paths.

The major issue caused by magnetic islands in fusion reactions is referred to as a major disruption, which is a sudden and complete loss of plasma confinement resulting in large electromagnetic and pressure forces in the surrounding structure. Plasma, which is hot ionized gas and often considered the fourth state of matter, is present within the vacuum. Disruptions occur at sufficiently high plasma density or plasma current, and can emit gases like H alpha, H beta, Carbon, etc. These disruptions can be caused by unpredictable conditions, and one mechanism is the nonlinear coupling of two islands that generate a large stochastic magnetic region within the plasma volume, leading to the destruction of plasma confinement. Magnetic islands typically grow slowly on a timescale of milliseconds when they are uncoupled or only loosely coupled. However, if two magnetic islands with different helicity grow and overlap, the resulting region can explosively grow into a stochastic magnetic region of poor confinement. If the initial islands were large enough, this can lead to the termination of the discharge and the destruction of a large percentage of the plasma confinement. In order to detect these disruptions, we can observe the emission of CIII gases transmitted at a wavelength of 464.7nm.

Thin-film optical interference filters are essential components used in various applications such as optical networks and scientific research. To achieve the desired filtering pattern, it is necessary to carefully select the appropriate combination of thicknesses for the thin film layers during the development process.

CHAPTER 4

EXPERIMENTAL METHODS AND ALGORITHMS USED

4.1 PROPOSED SYSTEM

GRASSHOPPER OPTIMIZATION ALGORITHM IN OPTICAL FILTER DESIGN

Most optimization strategies are inspired by the foraging behaviors of animals searching for food. Similarly, the GOA optimization strategy is based on the characteristics of grasshoppers in finding their food. The proposed GOA optimization strategy has a dynamic nature that improves the convergence of optimization problems. It also strikes a balance between exploration and exploitation phases, resulting in both local and global optimal solutions, ultimately leading to the best global solution [8]. The GOA algorithm is utilized to optimize the parameters of the optical filter, including thickness, number of layers, and refractive indices, to obtain the best model that meets the desired transmission characteristics of the filter.

In Aditya Tokomak, the detection of H-alpha emissions is crucial for various scientific studies. However, the wavelength of H-alpha emission falls in the visible light region, which means that it is necessary to design an optical filter that can selectively transmit light of the required wavelength while rejecting all other wavelengths. This is where optical filters come in, which are created by coating one or more thin layers of optical materials on a substrate.

Several materials are commonly used for optical coating, including Zinc sulphide, Magnesium fluoride, Titanium dioxide, and Silicon dioxide. However, the choice of material for the H-alpha filter design depends on its refractive index. Both high and low refractive index materials must be used to prevent complete reflection or refraction of the incident light.

After considering the various materials available, Titanium dioxide (TiO_2) and Silicon dioxide (SiO_2) were chosen for the H-alpha filter design. TiO_2 is a tasteless and odourless white powder of high refractive index and wide band-gap. It exhibits high transmittance in the visible region and is suitable for optical coating and as opacifiers. Additionally, TiO_2 can be manufactured using different techniques like sputtering, sol-gel, pulse laser deposition, electrode position, etc., which makes it a cost-effective option for large area deposition.

On the other hand, Silicon dioxide (SiO_2) is the most abundant oxide on earth's crust and is an amorphous and smooth material of lower refractive index. Its durable and insoluble nature makes it suitable for optical coatings, especially in nuclear reactors. By carefully selecting and combining these materials, the H-alpha filter can be designed to selectively transmit the required wavelength while blocking all other wavelengths, thus allowing for the accurate detection of H-alpha emissions in Aditya Tokomak.

SUBSTRATE

BK7 glass, which is a high-quality optical glass with excellent properties, will be used as the substrate for the thin layers of materials. This glass is highly homogeneous with low rates of bubbles and inclusions, and it exhibits exceptional transmittance in the visible and near IR regions. Its optical properties make it suitable for use in a variety of applications, including lenses, prisms, mirrors, and filter coatings.

NUMBER OF LAYERS AND THEIR THICKNESS

The process began by testing a two-layer combination of the materials, followed by exploring many layer combinations with varying thicknesses for each material. MATLAB was a crucial tool in this process, as mathematical formulas for transmittance and reflectance were developed and tested using this software. The transmittance was then traced and analyzed for each combination. As a result, numerous outputs were generated from this process.

The GOA algorithm follows a set of algorithmic steps which are as follows:

Step 1: Initialization of parameters: This involves initializing the various parameters such as high and low refractive index, thickness, and the number of layers of the optical film. Additionally, the maximum number of iterations is also initialized at this stage.

Step 2: Population initialization: The next step is population initialization, where the number of grasshoppers is initialized based on the materials used, such as MgF2, ZnS, TiO2, and SiO2. Each grasshopper in the GOA algorithm possesses a position vector that indicates its current position represented as,

$$G_u = (G_1, G_2, \dots, G_n) \quad (u = 1, 2, \dots, n) \quad (4.1)$$

where G_u represents the total number of grasshoppers in the search space, ranging from 1 to n , and G_n refers to the n th search agent. The fitness of each search agent is also stored.

$$F_u = (F_1, F_2, \dots, F_n); \quad (4.2)$$

The fitness values of each grasshopper are stored in the form of the expression mentioned above. This allows for the determination of the fittest grasshopper among the entire population.

Step 3: Sorting of solutions: After the fitness values of each grasshopper are computed, they are sorted in ascending order based on their fitness measure. The solutions with lower fitness values are discarded, while the one with the best fitness measure is selected as the new solution. If the best solution does not improve, the old solution is retained.

$$G_j^{t+1} = \sum_{\substack{l=1 \\ l \neq j}}^{I=1} str |G_l - G_k| \left(\frac{G_l - G_k}{z_{kl}} \right) - a w_c^\Lambda + b w_f^\Lambda \quad (4.3)$$

In the GOA algorithm, the movement of each grasshopper is determined by a mathematical equation that includes several parameters. These parameters include the constant of gravitation (a), a drift constant (b), a unit vector (wc) along the axis of the Earth, and a wind vector (w). The equation can be expressed as:

The original expression cannot be directly used to solve the optimization problem, so some modifications are necessary to make the algorithm converge at a specific point. Therefore, the equation is modified as follows:

$$G_j^{t+1} = Const \sum_{\substack{l=1 \\ l \neq j}}^n Const \frac{u_l - l_l}{2} str |G_l - G_k| \left(\frac{G_l - G_k}{z_{kl}} \right) + M_z^A \quad (4.4)$$

The original expression for the GOA algorithm cannot be used directly for solving optimization problems, and so it has been modified to converge to a specific point. The updated equation includes the upper and lower bounds of the Wth dimension, the measure of the W dimension in the objective, and a constant to contract the repulsion, attraction, and comfort zones. The resulting equation is the final update equation for the GOA algorithm, which is used to optimize the parameters of the optical filter to enhance its performance.

Step 4: Sorting of solutions: The sorting process of the GOA algorithm involves arranging the grasshoppers according to their fitness values, and removing the solutions with lower fitness measures. The solution with the best fitness value is chosen as the new solution, while the previous solution is retained if it has a better fitness value. This helps in improving the performance of the algorithm by selecting the best solutions at each iteration.

Step 5: Termination: The termination criteria for the GOA algorithm is reaching the maximum number of iterations, after which the best solution is considered as the final output [8]. Table 4.1 presents the pseudocode of the GOA algorithm.

S.No	Pseudocode of Grasshopper optimization algorithm
1	Begin
2	Input: $G_u = (G_1, G_2, \dots, G_n)$;
3	Output: G_j^{t+1}
4	Create a starting group of grasshoppers based on the chosen materials.
5	Set the initial values for parameters such as high and low refractive index, thickness, and the number of layers in the optical film.
6	Maximum iteration initialization
7	Every search agent's
8	{
9	Update the new answer in line with equation (4)
10	Evaluate the fitness of each answer, F_u
11	Examine the appropriateness of each response, F_u
12	Sort the answers according to the fitness metric.
13	Reconsider the fitness metric
14	If
15	{
16	$f_{u,old} < f_{u,new}$
17	}
18	Replace the old solution with the new solution
19	Else
20	Maintain the old solution as the best solution
21	}
22	Update position of grasshoppers based on fitness
23	End
	Result G_j^{t+1}

Table: 4.1: Pseudocode of GOA in optical filter design

CHAPTER 5

RESULTS AND DISCUSSIONS

The outcomes of the proposed GOA model's use in the ideal optical thin film filter design are discussed in this section.

5.1 EXPERIMENTAL SETUP

The proposed model was experimentally implemented using MATLAB, on a Windows 10 operating system with 64-bit architecture and 16GB RAM. The use of MATLAB facilitated a simple and effective implementation of the model.

5.2 EVALUTION INDICES

In the proposed model, the evaluation of performance is based on two indices: reflectance and transmittance. Transmittance is the measurement of the flux that passes through a surface, normalized to the flux that is incident on the surface. Reflectance, on the other hand, is the measurement of the flux that is reflected by a surface, normalized to the flux that is incident on the surface.

The proposed method employs reflectance and transmittance as the evaluation indices. Transmittance refers to the rate of flux transmitted by the surface relative to the rate of flux incidence on the surface. Reflectance, on the other hand, refers to the rate of flux reflected by a surface relative to the rate of flux incidence on the surface. Additionally, the full width at half maximum (FWHM) is used to represent the spectral bandwidth within which the bandpass filters transmit.

5.3 COMPARATIVE METHODS

To demonstrate the effectiveness of the proposed model in designing optical filters, it is compared with the GA technique.

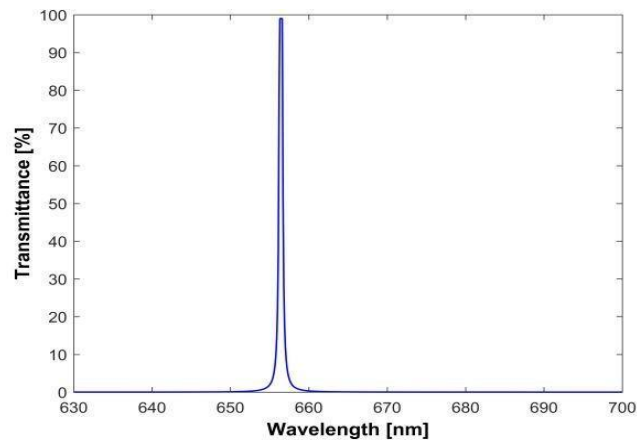
5.4 ANALYSIS BASED ON TRANSMITTANCE AND REFLECTANCE

This section presents the evaluation of the proposed method in terms of transmittance and reflectance through six cases. In the analysis using GOA, the thickness value is varied while the refractive index value is kept constant. Table-2 illustrates the number of layers considered for each of the six cases.

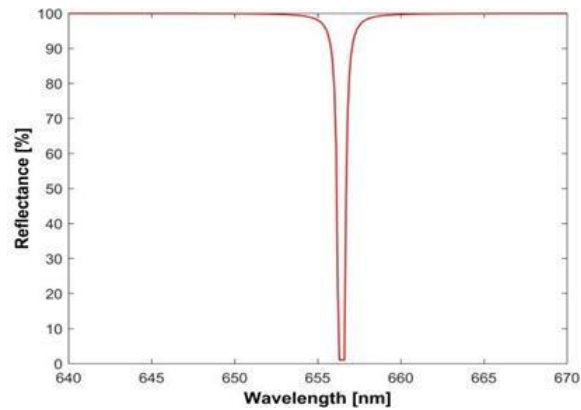
S.No	Cases	Number of layers
1	Case1	30
2	Case2	32
3	Case3	28
4	Case4	30
5	Case5	28
6	Case6	32

Table:5.1 *Description of layers*

Case 1: In case 1, the central Wavelength = 656.3 nm, ZnS (High refractive index) = 2.3432, MgF2 (Low refractive index) = 1.3766, and the Substrate (BK7 glass) = 1.5143. Figure-1 shows the transmittance and reflectance measures corresponding to case 1. When the wavelength is 656.3 nm, the transmittance is 99% and the reflectance is 1%.



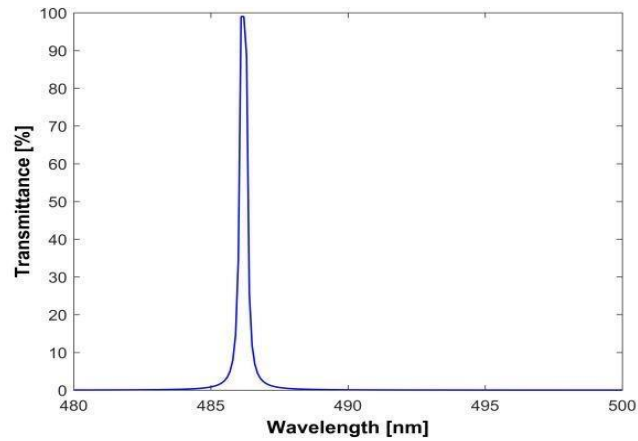
(a)



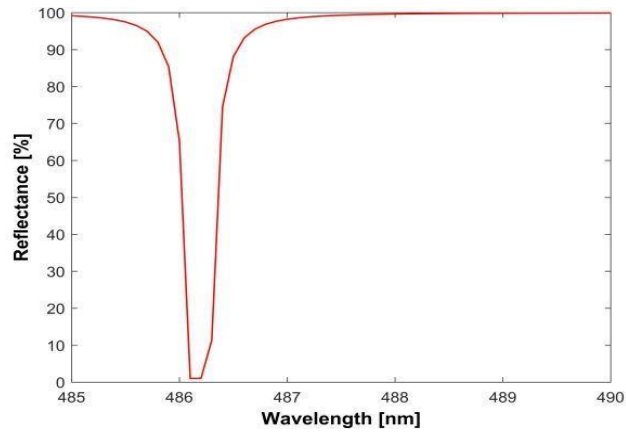
(b)

Fig:5.1: Case1, (a) Transmittance, and (b) Reflectance

Case 2: In case 2, the central Wavelength =486.1 nm, ZnS =2.4319, MgF2=1.3802, Substrate (BK7 glass) = 1.5224. Figure 2 shows the transmittance and reflectance measures corresponding to case 2. When the wavelength is 486.1 nm, the transmittance is 99% and the reflectance is 1%.



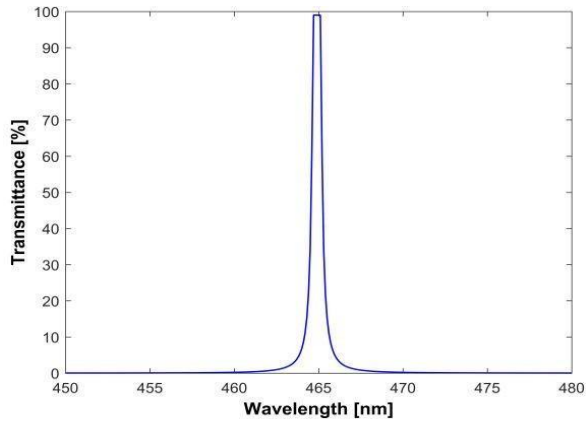
(a)



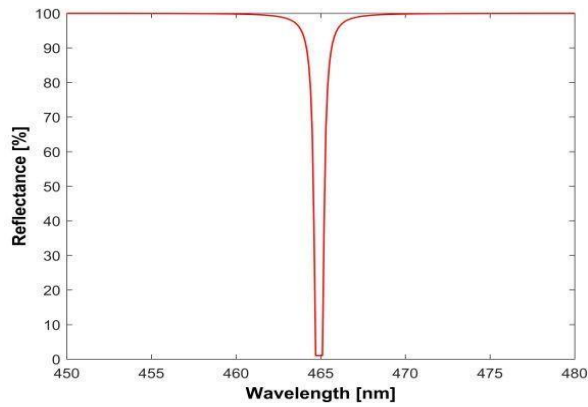
(b)

Fig:5.2: Case 2, (a) Transmittance, and (b) Reflectance

Case 3: In case 3, the central Wavelength =464.7 nm, ZnS =2.4533, MgF2=1.3809, Substrate (BK7 glass) = 1.5224. Figure-3 shows the transmittance and reflectance measures corresponding to case 3. When the wavelength is 464.7 nm, the transmittance is 99% and the reflectance is 1%.



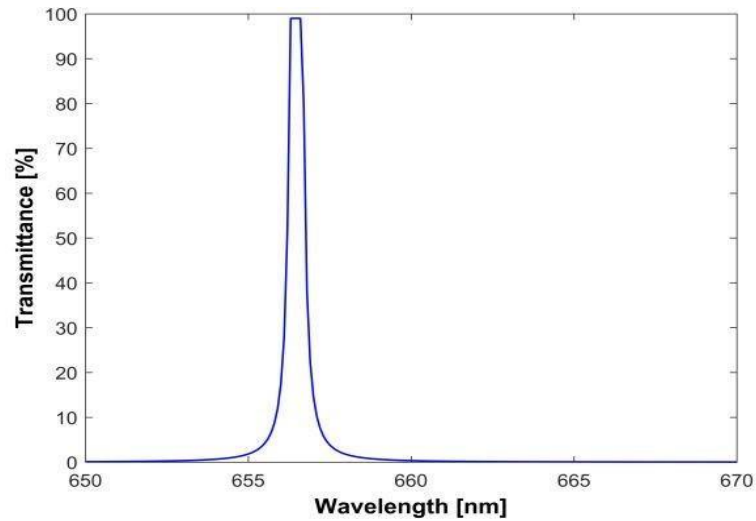
(a)



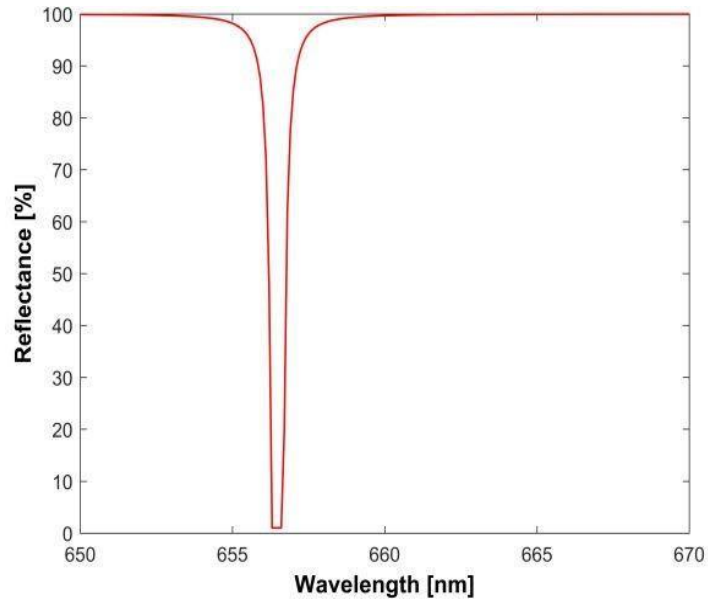
(b)

Fig:5.3: Case 3. (a) Transmittance, and (b) Reflectance

Case 4: In case 4, the central Wavelength =656.3nm, High refractive index (TiO₂) = 2.5709, Low refractive index (SiO₂) =1.4564, substrate (BK7glass) =1.5143. Figure-4 shows the transmittance and reflectance measures corresponding to case 4. When the wavelength is 656.3nm, the transmittance is 99% and the reflectance is 1%.



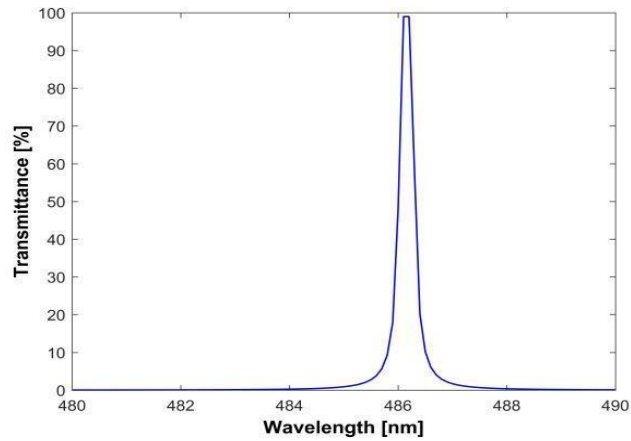
(a)



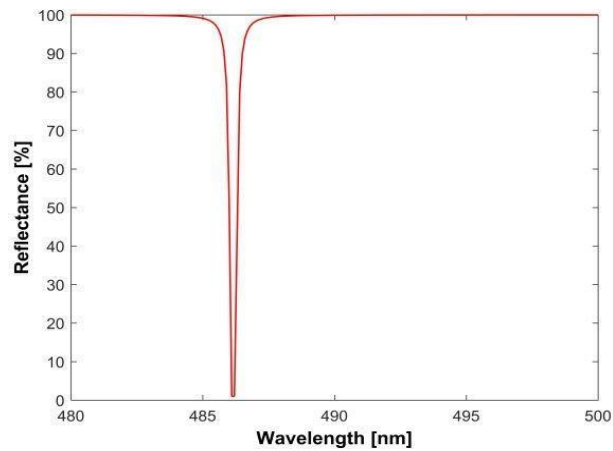
(b)

Fig:5.4: Case 4. (a) Transmittance, and (b) Reflectance

Case 5: In case 5, the central wavelength=486.1 nm, high refractive index (TiO₂) =2.7346, Low refractive index (SiO₂) =1.4631, Substrate (BK7 glass) = 1.5224. Figure-5 shows the transmittance and reflectance measures corresponding to case 5. When the wavelength is 486.1 nm, the transmittance is 99% and the reflectance is 1%.



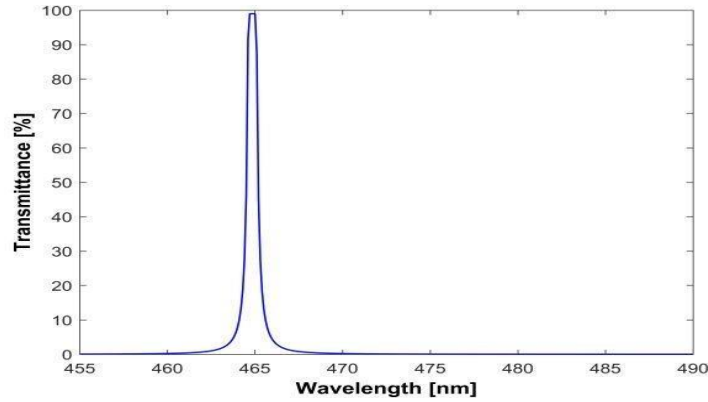
(a)



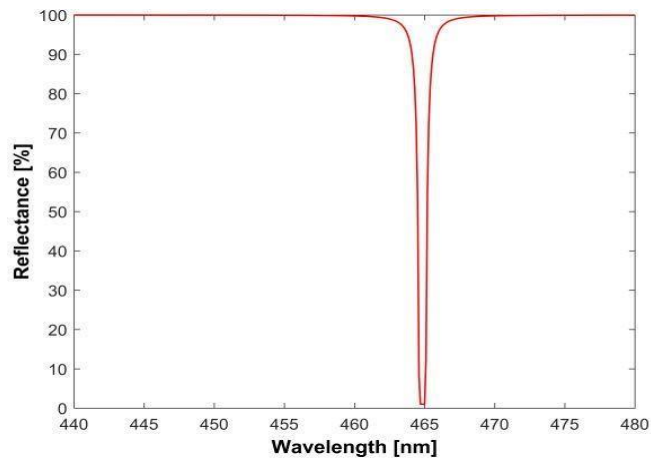
(b)

Fig:5.5: Case 5. (a) Transmittance, and (b) Reflectance

Case 6: In case 6, the central wavelength =464.7 nm, high refractive index (TiO₂) =2.7771, Low refractive index (SiO₂) =1.4645, substrate (BK7 glass) = 1.524. Figure-6 depicts the reflectance and transmittance measures corresponding to case 6. When the wavelength is 464.7 nm, the transmittance is 99% and the reflectance is 1%.



(a)



(b)

Fig:5.6: Case 6. (a) Transmittance, and (b) Reflectance

The experimental results indicate that the previously existing GA-based model for designing optical filters outperforms the proposed GOA model in terms of transmittance, reflectance, and FWHM.

Table:5.2: This table represents a comparison of the GA and GOA methods in terms of transmittance, reflectance, and FWHM. The results indicate that the proposed GOA algorithm outperforms the GA method with higher transmittance, lower reflectance, and smaller FWHM values. This demonstrates the effectiveness of the GOA approach in designing optical filters for transmission applications.

Table:5.2: Comparative Discussion

Cases	Methods	Transmittance (%)	Reflectance (%)	FWHM (nm)
CASE 1	GOA	99.2933	0.7067	1.1
	GA	84.6188	15.3812	7.1
Case 2	GOA	99.7356	0.2644	1.4
	GA	87.4494	12.5506	3.2
Case 3	GOA	97.7409	2.2591	1.2
	GA	87.1673	12.8327	3
Case 4	GOA	99.3366	0.6634	1.2
	GA	88.0136	11.9864	2.6
Case 5	GOA	98.7732	1.2268	1.5
	GA	88.8172	11.1828	3
Case 6	GOA	98.9943	1.0057	1.7
	GA	89.1042	10.8958	3.2

CHAPTER 6

CONCLUSION

This study aimed to design an optical thin film filter using the grasshopper optimization algorithm (GOA), with a constant refractive index, and analyze the effect of optical constraints such as thickness and reflectance on the convergence of the design solution. The GOA was utilized to optimize the refractive index and thickness parameters to achieve an improved transmittance profile. The results showed that using thickness as the optimization variable provided better outcomes than refractive indices, in line with current modeling expectations. A population of 100 and thickness measure as the optimization variable led to convergence with respect to fitness function and the imposed constraints of GOA. Future work could explore the use of hybrid optimization algorithms to design optical thin film filters with enhanced performance, rather than relying on single meta-heuristic algorithms.

In this system, a new multi-objective algorithm inspired by the navigation behavior of grasshopper swarms in nature is proposed. The algorithm models the interaction of individuals in the swarm using a mathematical model that includes attraction force, repulsion force, and comfort zone. The model is used to approximate the global optimum in a single-objective search space, and an archive and target selection technique are integrated to estimate the Pareto optimal front for multi-objective problems. The performance of the algorithm is benchmarked using a set of standard multi-objective test problems and compared with other algorithms in the literature using three performance indicators. The results show that the proposed algorithm provides competitive results in terms of the accuracy of obtained Pareto optimal solutions and their distribution. This research was published in 2017 by Springer Science and Business Media, LLC.

This system represents an optimization-based approach for designing an optical thin film filter, taking into account optical constraints such as thickness, reflectance, and FWHM. The effectiveness of using different optimization variables, including refractive index and thickness, was evaluated using the GOA algorithm to achieve an improved transmittance profile. The results obtained with the proposed GA method were compared to other existing optimization methods, such as GA, and GOA, and were found to outperform them in terms of transmittance, reflectance, and FWHM. In the future, hybrid optimization techniques will be used to design optical thin films that can deliver even better results. The study was conducted using two different sets of dielectric materials, and the feasibility of using the modified GA algorithm for optimizing the design of optical bandpass filters was demonstrated.

- Average deviation and the relationship between the frequency and the change in frequency is inverse in nature and can be influenced by the optimization of the transmission band, which can result in either strong or weak threshold coupling. This optimization can be achieved using a square-shaped transmission band.
- An all-pass optical fiber functions as an equalizer without introducing any amplitude distortion parameters and with minimal loss. In other words, it is capable of equalizing a signal's frequency response without affecting its amplitude, which can be a desirable feature in certain applications. Additionally, the use of all-pass optical fibers can result in lower signal loss compared to other equalization methods.
- Genetic algorithms are employed to deal with filters of varying sizes and compositions, incorporating weightings as well.

- Undesirable interference tends to escalate as the number of layers grows, necessitating the use of fewer layers.
- The optoelectronic device that is most suitable among the different types of crystals is the photonic crystal.
- In order to prevent the σ and π components of the H α line, polarizers are occasionally employed. Spectroscopy ports are utilized to observe the discharge of hydrogen in large helical devices.
- In certain cases, the Lorentz electric field arises as a result of a magnetic field that is parallel to the electric field.
- The filter algorithm is employed to correct artifacts, and time-frequency wavelet decomposition analysis is conducted. Alpha power is estimated by calculating the average frequency band of alpha, and the response of the hemodynamic function is evaluated.

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