

DESIGN OF OPTICAL BAND-PASS FILTER USING OXIDE MATERIALS FOR MULTIDIMENSIONAL ARRAYS

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

By

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
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SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY (DEEMED TO BE UNIVERSITY)

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APRIL 2021



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**DEPARTMENT OF ELECTRONICS AND COMMUNICATION
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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **DEEPTHIKA SHIWANI M (37130106)** and **DEEKSHAA J (37130105)** who carried out the project entitled "**DESIGN OF OPTICAL BAND-PASS FILTER USING OXIDE MATERIALS FOR MULTIDIMENSIONAL ARRAYS**" under our supervision from September 2020 to April 2021.

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DECLARATION

We, **DEEPTHIKA SHIWANI M (37130106)** and **DEEKSHAA J (37130105)** hereby declare that the Project Report entitled “**DESIGN OF OPTICAL BAND-PASS FILTER USING OXIDE MATERIALS FOR MULTIDIMENSIONAL ARRAYS**” done by us under the guidance of **Mr. L JEGAN ANTONY MARCILIN M.Tech.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Electronics and Communication Engineering.

1)

2)

DATE:

PLACE:

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. N. M. NANDHITHA, M.E., Ph.D. Dean, School of Electrical and Electronics Engineering** and **Dr. T. RAVI, M.E., Ph.D. Head of the Department, Department of Electronics and Communication Engineering** for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Mr. L Jegan Antony Marcilin M.Tech., Assistant Professor, Department of Electronics and Communication Engineering** for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of the project work.

We wish to express our thanks to all teaching and Non-teaching staff members of the **Department of Electronics and Communication Engineering** who were helpful in many ways for the completion of the project.

We express our gratitude to our parents for their constant encouragement and support for the completion of the project.

ABSTRACT

Optical bandpass filters are used in optical communications, fluorescence microscopy, and astronomy. They are constructed using multilayer structures composed of alternating dielectric layers with high and low refractive indices. This paper describes the design of an optical band-pass multilayer filter that will be used for future filter applications. To achieve the same, we have used the frequency range within the visible spectrum which is 380(~400)-700nm. The wavelength in which the band-pass filter works is 4647nm. Since this filter is a multilayer structure, a 4 layer stack is designed with two oxide elements namely Silicon Dioxide (SiO_2) and Titanium Dioxide (TiO_2). The refractive indices of the elements mentioned above will be 1.4595 and 2.7771 respectively. The substrate used for the multilayer stack is BK7 Glass whose refractive index is 1.4595. The thickness of the higher and lower refractive materials are 82nm and 8nm respectively. A total of 4 layer filter is constructed as the multilayer structure.

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CHAPTER 1

INTRODUCTION

1.1 OPTICAL FILTERS

An optical filter selectively transmits one part of the optical spectrum, whilst rejecting different portions. In easy words, Optical filters are passive gadgets that permit the transmission of a particular wavelength or set of wavelengths of light and blocks the others.

Optical filters are very essential in laser test applications. Laser protection glasses are optical filters you may put on to defend your eyes from laser radiation. They usually clear out a small variety of wavelengths to let you see your environment even as operating on an optical test even as a laser is became on. It could be very essential to put on protection glasses which can be rated for the laser wavelength being used

Optical filters also are crucial as optical additives in laser experiments. For instance, whereas measure the photoluminescence (PL) of a material, all of the light being emitted from the spot this can be being excited through a laser is coupled into an optical fiber and measured in a very spectrometer. The light of the laser might be terribly intense, and counting on what value the wavelength of photoluminescence is, the laser light ought to conquer that signal. Applying a filter for the laser wavelength someplace among the film and the lens that collects the light coming from the film reduces or removes the laser peak, allowing us to see the photoluminescence peak clearly.

1.1.1 Types of Optical Filters

There are lessons of optical filters which have one of a kind mechanisms of operation: absorptive filters and dichroic filters.

Absorptive filters have a coating of various organic and inorganic substances that soak up positive wavelengths of mild, hence allowing the favored wavelengths to pass through. Since they soak up light energy, the temperature of those filters will

increase all through operation. They are simple filters and may be brought to plastics to make much less steeply-priced filters than their glass-primarily based totally counterparts. The operation of those filters does now no longer depend upon the perspective of the incident light however at the homes of the cloth that makes up the filters. As a result, they're correct filters to apply while pondered light of the undesirable wavelength can motive noise in optical signal.

Dichroic filters are greater complex of their operation. They include a sequence of optical coatings with particular thicknesses that are designed to mirror undesirable wavelengths and transmit the favoured wavelength variety. This is completed with the aid of using inflicting the favoured wavelengths to intervene constructively at the transmission facet of the clear out whilst different wavelengths intervene constructively at the mirrored image facet of the filter.

On the premise of wavelength ranges, There are 3 types of optical filters: short-pass filters, long-pass filters, and band-pass filters. A short-pass filter permits shorter wavelengths than the cut-off wavelength to go through, while it attenuates longer wavelengths. Conversely, a long-pass clear out transmits longer wavelengths than the cut-on wavelength whilst it blocks shorter wavelengths. A band-pass clear out that shall we a unique variety, or band, of wavelengths to head through, however attenuates all wavelengths across the band. A band-pass clear out that shall we a unique variety, or "band", of wavelengths to head through, however attenuates all wavelengths across the band. A monochromatic filter is an intense case of a band-pass clear out which transmits handiest a completely slim variety of wavelengths.

1.1.2 *Advantages and Disadvantages*

Advantages:

The following are the advantages of optical filters

- Absorptive filters - Cost-effective; wide availability; scratch-resistant; excellent environmental and chemical resistance.
- Dichoric filters - Precise transmission; capability for thin filter; wide variety of simple or complex types possible.

Disadvantages

The following are the disadvantages of optical filters:

- Absorptive filters - Poor transmission slope; not suitable for precision applications; heat-sensitive; breakdown after prolonged use; necessary thickness.
- Dichoric filters - Expensive; increased angle sensitivity; ineffective at blocking wide wavelength ranges.

1.1.3 Applications

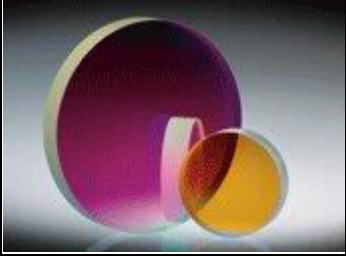
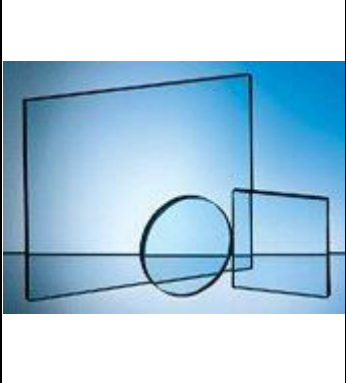
The following are the applications of Optical filters

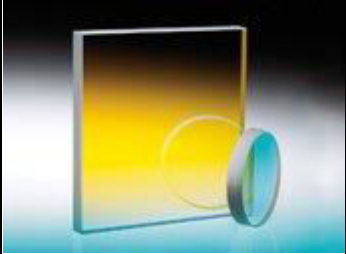
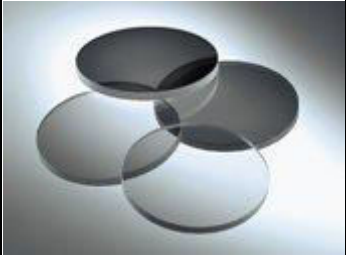
- In structures for laser beam diagnostics with CCD-cameras
- Measurement of laser power, pulse energy and pulse duration
- Spectroscopy
- A set of bandpass filters for mercury lamps, laser lines, and different desires are available.

1.2 KINDS OF OPTICAL FILTERS

Table 1.1 : Different kinds of optical filters

Sample product image	Type of the filter
	BandpassFilters Bandpass filters have extremely narrow band (<2nm to 10nm) or broadband (50nm and 80nm) transmittance across the substrate. They are notably angle sensitive, thus care ought to be taken once mounting and putting them within an optical setup. hard sputtered filters ought to be chosen to maximise the transmission of designated wavelengths

	LongpassFilters Longpass filters transmit all wavelengths longer than the specified cut on wavelength. Longpass filters include cold mirrors, colored glass filters, and Thermoset ADC (optical cast plastic) filters.
	ShortpassFilters Shortpass filters transmit all wavelengths shorter than the specified cut off wavelength. Shortpass filters include IR cutoff filters, hot mirrors, and heat absorbing glass.
	HeatAbsorbingGlasses Heat absorbing glasses will transmit visible light and absorb infrared radiation. The absorbed energy is then dissipated as heat into the air around the glass. Forced air cooling is typically recommended to remove the excess heat. Heat absorbing glass can also be used as shortpass filters.
	ColdMirrors Cold mirrors are specific types of dichroic filters designed to have high reflectivity in the visible spectrum while maintaining high transmission in the infrared. Cold mirrors are designed to be used in any application wherever heat build-up can cause harm or adverse effects.
	Hotmirrors Hot mirrors are specific types of dichroic filters designed to have high reflectivity in the infrared spectrum and high transmission in the visible. Hot mirrors are used primarily in projection and illumination systems.
	Notch Filters Notch filters are designed to stop a pre-selected bandwidth whilst sending all other wavelengths within the design range of the filter. Notch filters are accustomed to remove a single laser wavelength, or narrow band, from

	an optical system
	Color substrate filters Color substrate filters are factory-made from substrates with inherently totally different absorption and transmission properties across a specific spectral region. Color substrate filters are usually used as long pass and band pass filters. The boundary between transmission and interference is less sharp compared to some coating based mostly filters.
	DichroicFilters Dichroic filters are coated with thin-films to achieve a desired transmission and reflection percentage across a given spectrum. They are often used as color filters (both additive and subtractive). Dichroic filters are slightly angle sensitive but are far more forgiving than interference filters
	NeutralDensity(ND)Filters Neutral density (ND) filters are designed to reduce transmission evenly across a portion of a certain spectrum, UV, visible or IR. There are two main types of Neutral Density filters namely absorptive and reflective filters. The absorptive kind absorbs light that's not transmitted through the filter, whereas the reflective kind reflects it back toward the direction from which it had been incident. Special care ought to be taken once using the previous kind so as to make sure that any mirrored light doesn't interfere with the application setup. ND filters are usually accustomed forestall blooming or overexposure of cameras and alternative detectors.

1.3 KEYWORDS

While filters share many of the same specifications with other optical components, there are a number of specifications unique to filters that should be understood in order to effectively understand and determine which filter is best for your application.

- *Central Wavelength*

Central Wavelength Center Wavelength (CWL), used in shaping band pass filters, describes the centre of spectral bandwidth over that the filter transmits. Traditional Coated Optical Filters have a tendency to acquire a most transmission close to the middle wavelength, while Hard Coated Optical Filters have a tendency to have a reasonably flat transmission profile over the spectral bandwidth.

- *Bandwidth*

Bandwidth is a wavelength range accustomed indicate a specific part of the spectrum that passes incident energy via a filter. It is likewise referred to as FWHM (Fig 1.1) Illustration of Centre Wavelength and Full width at half maximum.

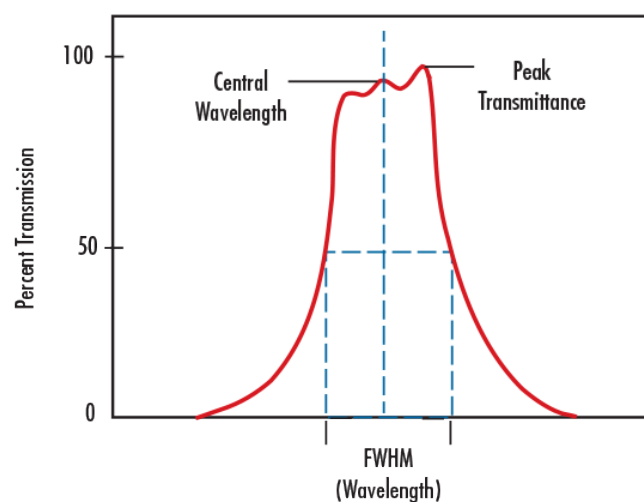


Fig: 1.1: Centre Wavelength and Full Width at Half Maximum

- *Full Width-Half Maximum*

Full Width-Half Maximum (FWHM) describes the spectral bandwidth over which a bandpass clear out out will transmit. The higher and decrease restriction of that bandwidth is described on the wavelengths wherein the filter achieves 50% of the most transmission. For example, if the most transmission of the filter is 90%, the wavelengths at which the filter achieves 45% transmission will outline the higher and decrease limits of the FWHM. FWHM's of 10nm or much less are taken into consideration narrowband and frequently used for laser clean-up and chemical detection. FWHM's of 25 – 50nm are frequently utilized in gadget imaginative and prescient applications; FHWM's of greater than 50nm are taken into consideration broadband and commonly utilized in fluorescence microscopy applications.

- *Blocking Range*

Blocking Range is a wavelength interval used to indicate a spectral place of energy that is attenuated via way of means of the filter (Figure 2). The diploma of its blocking off is generally laid out in phrases of optical density.

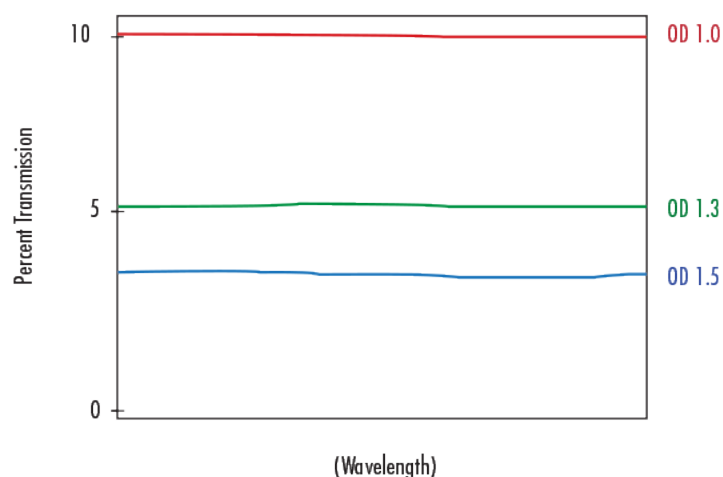


Fig: 1.2: Blocking Range

- *Slope*

Slope is a specification regularly described on aspect filters, inclusive of shortpass or longpass filters, to explain the bandwidth over which the clear out out transitions from excessive blockading to excessive transmission. Given because the

percentage of the cut-wavelength, slope may be unique from lots of beginning and stop points. We can also say that the slope is defined as the gap from the 10% transmission factor to the 80% transmission factor. For example, a 500nm longpass clear out out with a 1% slope could be anticipated to transition from 10% transmission to 80% transmission over a 5nm (1% of 500nm) bandwidth.

- *Optical Density*

Optical Density (OD) describes the quantity of energy blocked or rejected through a filter. A excessive optical density value suggests low transmission, and occasional optical density suggests excessive transmission. Optical densities of 6 or extra are used for severe blocking off wishes together with Raman spectroscopy or fluorescence microscopy. Optical densities of 3.0– 4.0 are ideal for laser separation and clean-up, device vision, and chemical detection, while optical densities of 2.0 or much less are best for colour sorting and keeping apart spectral orders.

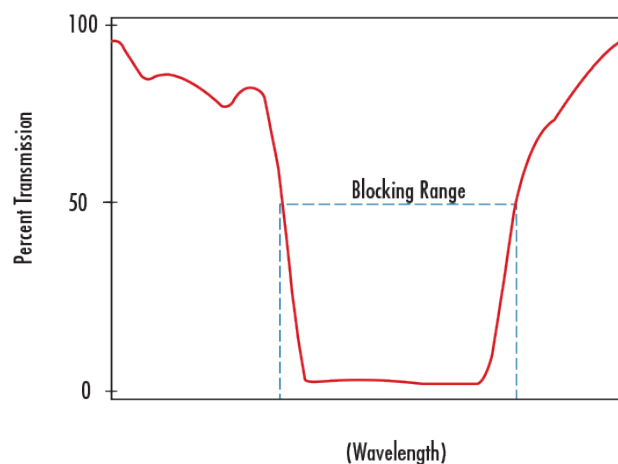


Fig: 1.3: Optical Density

- *Transmittance*

The ratio of the normal components of transmitted and incident irradiance or, alternatively, the ratio of the total transmitted beam power to the total incident beam power is called transmittance and this is represented in percentages.

CHAPTER 2

LITERATURE SURVEY

B.A. Belyaev, V.V. Tyurnev and V.F. Shabanov (2014) have proposed to design an optical bandpass filter with equalized passband ripples of a given magnitude. Their filter is product of dielectric materials, accommodates coupled half-wavelength resonators and multilayer mirrors. They have proposed a filter layout which starts with the synthesis of the multimaterial filter prototype whose mirrors encompass quarter-wavelength layers. In the prototype, the optimal refractive indices of the layers are obtained by a special optimization based on universal rules. The thicknesses of the mirrors' layers withinside the very last filter are computed the usage of derived formulas. They have used silicon-air bandpass filter with a functional bandwidth of 1%.

Haoyan Wang, Lin Yang and Lei Zhang (2019) put forward a low-loss optical bandpass filter with narrow bandwidth demonstrated their distinguished performance in comparison with a third-order microring resonator using the Scattering Matrix method. The Scattering matrix method is a general computation for the analysis of electromagnetic propagation with respect to orthogonal modes ranging from low frequencies to RF/Microwave frequencies and frequencies within the optical region.

Yi-Jun Jen and Meng-Jie Lin (2018) have proposed a multilayer narrow bandpass filter that consists of silver and silicon thin films is designed using the admittance tracing method. Owing to the low loss of silicon in the infrared range, the peak transmittance at a wavelength of 950 nm exceeds 85%. In order to eliminate the sidebands that are adjoining to the passband, a compact four-layered shape is proposed to generate an angle-insensitive spectrum. In fabrication, a silver-silicon multilayer is deposited alternatively as a multilayer structure

Gaurav Dwivedi, Nancy Sharma, Vemuri Sri Ranga Sai Praveen Kumar, Sunita Parinam, Mukesh Kumar, Neelam Kumari, Vinod Karar and Ami Sharma (2016) propose an alternate stack of 26 layers using Alumina and Silica which is designed and fabricated to realize optical bandpass filter at 660

nm wavelength for 45° angle of incidence with Alumina selected as high refractive index material and Silica as low refractive index material . Designed filter was fabricated in e-beam vacuum coating plant on BK-7 glass substrate under reactive oxygenated environment. The fabricated optical filter is characterised with the help of UV-Vis-NIR spectrophotometer to obtain the transmittance spectrum in the visible range which is around 400-800 nm.

Manoj Niraula, Jae Woong Yoon, and Robert Magnusson (2015) have proposed an experimental bandpass filter fashioned in a single patterned silicon layer on a quartz substrate. Its performance corresponds to bandpass filters requiring 15 traditional Si/SiO₂ thin-film layers. An experimental filter presented exhibits a transmittance of ~72%, bandwidth of ~0.5 nm, and low sidebands spanning ~100 nm. The proposed technology is integration-friendly and opens doors for further development in various disciplines and spectral regions where thin-film solutions are traditionally applied.

Qinghua Wang, Bingtao Gao, Michaela E Raglione, Huixin Wang, Baojia Li, Fatima Toor, Mark A. Arnold, Hongtao Ding (2019) have mentioned that the aim is to provide a comprehensive review of THz band pass meta-materials related to several areas. First, the design fundamentals and geometrical patterns of THz band pass meta-materials are summarized. Second, fabrication methods are reviewed, including typical micro- and nano fabrication techniques and laser micromachining techniques. More importantly, for these meta-materials different engineering methods are reviewed for tuning and modulation of the THz transmission resonance. Both passive and active modulation methods are included in this discussion. The passive method involves changes in the geometrical pattern of the filter material and the active method performs in situ modulation of properties by applying an external physical field. Finally, the potential applications and prospects for future research of THz band pass meta-materials are discussed.

Hanh Hong Mai (2020) proposes a new construction design of a distributed Bragg reflector (DBR) filter and a Fabry–Pérot (FP) filter. It uses needle technique

as a synthesis method. This optimized DBR and FP filter has a proper number of layers with controlling thickness $\text{TiO}_2/\text{SiO}_2$. They are utilized to transmit only a certain narrow band of wavelengths while blocking the others. As a proof of this concept, the filters are designed to selectively transmit only a very narrow band of wavelength at 780 nm which is the near infrared (NIR) fluorescent emission from Alexa Fluor 750 dye. The obtained results show that the optimized filters represent advanced spectral performance. It can be used to improve the sensitivity and the imaging contrast in fluorescence microscopy.

A.Beheshti Asl, A.Rostami, I.S. Amir (2020) propose a band pass THz filter based on multilayer meta-materials is proposed, designed and simulated numerically. The functional behavior (filtering property) of the bilayer meta-surface is investigated considering a single bilayer cylinder in the periodic system. The cylinders are the basic elements in the unit cell. Then we show that the increase in the number of cylinders will increase the bandwidth. Also, the center frequency is tunable through changes in the dimension of the basic element. The main advantages of the proposed structure help us to realize terahertz filters are wideband, tunable, and easy to build. It is shown that the bandwidth of the proposed band pass filter is about 1 THz and the amount of transmittance is close to 93%

Jing Wan, Jiangyun Miao, Jinwen You, Linlin Xu, and Xinyue Xie (2020) propose a silicon optical filter utilizing multiple semi-rings to realize optical filtering. The structure of such filters is simple, adjustable, and integrated. By changing the number and spacing distance of semi-rings, the properties of the optical filter can be flexibly adjusted to meet different application requirements. Research results show that the optical filter has a 3 dB bandwidth of 2.52 nm, a free spectral range of 11.33 nm, and a finesse of 4.50. The silicon optical filter with multiple semi-rings is compared with a Mach–Zehnder-interferometer-based optical filter with the traditional structure, and it shows better performance. To the best of our knowledge, our work provides a new method for finding adjustable optical filters with compact structure and good performance.

Jeoung, Chan-Gwoun , Kang, Young Kim, Sun-Youb –Jin (2007) say that The recent, a large capacity of telecommunication networks is required in order to it is in proportion to capacity of information communication increase and to satisfy a demand because of the demand about Internet, a multimedia service of internet, Video of internet protocol(VoIP), Audio/Video streaming. As a result, Dense Wavelength Division Multiplexing (DWDM) technologies are emerging to be a prevailing the method of solving it without additional optical fiber network building and high-speed equipment. Therefore this thesis proposed the optical filter of fiber/multilayer slab coupled structure combining it to multilayer slab waveguide by polishing the cladding of one side of fiber to design the optical filter having these functions. When a separation distance of fiber and slab was $3\mu\text{m}$, The optical filter proposed as the simulation result was satisfied with a DWDM filter characteristic with FWHM of 0.1nm on TM mode and TE mode as 32nm polarization independence in a communication window of $1.3\mu\text{m}$ when center wavelength was each $\lambda_0=1.274755\mu\text{m}$ and $\lambda_0=1.30591\mu\text{m}$.

Mingzhi Lu, Wenzao Li, and Elliott R. Brown (2011) present We propose a multilayer complementary metamaterial structure fabricated on a crystal quartz substrate measuring between 100 and 700 GHz. The concept of a second-order terahertz bandpass filter is realized by this structure, and it offers a superior quality factor, steepness of skirts, and out-of-band rejection. Physical limitations on the quality factor and insertion loss have also been studied, including the skin depth of the metal and the optical phonon resonance in quartz. Based on these factors, a series of higher frequency filters has been designed, and simulation results are provided.

Xinrong Wang and Hiroshi Masumoto (1998) have proposed a Thirty one layer $\text{TiO}_2/\text{SiO}_2$ optical filters with graded refractive index profiles were fabricated by helicon plasma sputtering at room temperature. Multilayer films were deposited on glass (BK7) and Si (100) substrates simultaneously and sequentially. The measured transmittance spectrum exhibited a reflectance of 99.8% at a central wavelength of 730 nm and high transmittance over the wavelength region outside of the reflected band as a result of the suppression of the sidelobes. The experimental transmittance spectrum corresponded almost completely with that

calculated based on the optical multilayer film theory and using the measured refractive indices of TiO₂, SiO₂ and TiO₂–SiO₂ composite films. Transmission electron microscopic observations confirmed the expected microstructure of the filter.

Minoru YAMADA, Yasuhiro YAMANE (1996) presented a generalized design method for an optical filter consisting of a dielectric multilayer structure is proposed to get an arbitrary profile of the wavelength dispersion of reflectivity or transmittance. The basic concept of the method lies in the fact that the wavelength dispersion of the reflectivity is approximately determined by taking the inverse Fourier transformation of the refractive index profile of the multilayer structure. Construction of a filter with only three different values of refractive index is described.

M.A. Butt S.A. Fomchenkov, A. Ullah, M. Habib R.Z. Ali (2016) report a design for creating multilayer dielectric optical filters based on TiO₂ and SiO₂/MgF₂ alternating layers. We have selected Titanium dioxide (TiO₂) for high refractive index (2.5), Silicon dioxide (SiO₂) and Magnesium fluoride (MgF₂) as a low refractive index layer (1.45 and 1.37) respectively. Miniaturized visible spectrometers are useful for quick and mobile characterization of biological samples. Such devices can be fabricated by using Fabry-Perot (FP) filters consisting of two highly reflecting mirrors with a central cavity in between. Distributed Bragg Re-flectors (DBRs) consisting of alternating high and low refractive index material pairs are the most commonly used mirrors in FP filters, due to their high reflectivity. However, DBRs have high re-flectivity for a selected range of wavelengths known as the stopband of the DBR. This range is usually much smaller than the sensitivity range of the spectrometer. Therefore, bandpass filters are required to restrict the wavelength outside the stopband of the FP DBRs. The proposed filter shows high quality with an average transmission of 97 % within the passbands and the transmission outside the passband is around 3 %. Special attention has been given to keep the thickness of the filters within the economic limits. It can be suggested that these filters are exceptionally promising for florescence imaging and narrow-band imaging endoscopy.

Ph. Refregierm (1990) demonstrated a method of constructing optimal multicriteria filters for optical pattern recognition is presented. In the particular case of synthetic discriminant function filters, this method is illustrated for double-optimization criteria, and filters that are not overspecialized are obtained, in contrast with traditional techniques. Furthermore, a rigorous comparison between different filters, with respect to the considered criteria, is provided with this approach.

Thomas Begou, Fabien Lemarchand, Frédéric Lemarquis, Antonin Moreau, Julien Lumeau (2019) present a thorough description of high-performance thin-film optical filters with high flatness. These components can combine several tens or hundreds of layers and are manufactured using plasma-assisted reactive magnetron sputtering. Stress compensation is achieved using dual-side coatings with appropriate spectral function. Examples are described of highly reflecting mirrors at 515 nm with 15 nm flatness peak-to-valley up to and over 75 mm diameter aperture, narrow bandpass filters, and filters with broadband controlled transmission.

Yanhan Zhu, Subash Vegesna, Vladimir Kuryatkov, Mark Holtz, Mohammad Saed, and Ayrton A. Bernussi (2012) report a Bandpass filter based on double-stacked metamaterial layers separated by an air gap for operation at terahertz frequencies. Several stacking configurations were investigated designed for a ~ 0.5 THz center frequency. The filters exhibited improved spectral transmission properties when compared with conventional ones based on single metamaterial layers. 3 dB bandwidth of ~ 78 GHz and sidelobe suppression ratio > 16 dB were determined when symmetric or asymmetric double layers were stacked. We demonstrate that superior frequency selectivity can be achieved when metamaterial layers with different unit cells are used. Good agreement was found between measured and simulated transmission response.

J. M. Slaughter, Brian S. Medower, R. N. Watts, C. Tarrio, T. B. Lucatorto, and Charles M. Falco (1994) report the results of extreme-ultraviolet reflectance measurements and structural characterization of multilayer mirrors made by sequential sputter deposition of Si and B₄C. Compared with Si/Mo multilayers, Si/B₄C have a much narrower bandpass ($\delta\lambda$) and better off-peak rejection but lower peak reflectance (R_0). Mirrors with three different designs gave the following results: $R_0 = 0.275$ and $\delta\lambda = 0.31$ nm at 13.1 nm and normal incidence; $R_0 = 0.34$ and $\delta\lambda = 1.1$ nm at 18.2 nm and 45°; and $R_0 = 0.30$ and $\delta\lambda = 2.0$ nm at 23.6 nm and 45°. These multilayers exhibited excellent stability on annealing at temperatures up to 600°C.

Adriana Szeghalmi, Michael Helgert, Robert Brunner, Frank Heyroth, Ulrich Gösele, and Mato Knez (2009) propose an Al₂O₃ and TiO₂ thin films have been deposited on Si wafers, quartz, BK7 glass, and polycarbonate substrates by atomic layer deposition (ALD). The refractive indices and growth rates of the materials have been determined by spectroscopic ellipsometry and transmission electron microscopy. The influence of substrate temperature and precursor on the refractive indices has been investigated. The refractive index of TiO₂ significantly increases with temperature, whereas the Al₂O₃ films are temperature insensitive. The films deposited using H₂O₂ as oxygen source show a slightly higher refractive index than the films prepared with H₂O. Multilayer narrow-bandpass filters and broadband antireflective coatings have been designed and produced by ALD.

Alain Jody Corso, Paola Zuppella, Piergiorgio Nicolosi, David L. Windt, E. Gullikson, and Maria Guglielmina Pelizzo (2011) say that Novel capping layer structures have been deposited on periodic Mo/Si multilayers to optimize reflectance at 30.4 nm. Design, deposition and characterization of such coatings are presented. Most of the structures proposed show improved performance with respect to standard Mo/Si multilayers and are stable over time. Reflectance at 121.6 nm and in the visible spectral range have been also tested to explore the applicability of such coatings to the Multi Element Telescope for Imaging and Spectroscopy (METIS) instrument, a coronagraph being developed for the ESA Solar Orbiter platform

I.Wakabyashi; O. Yokoyama T. Koizumi K. Miyauchi (2000) presents a design method and examples of dielectric multi-layer bandpass filters with Butterworth characteristics for three-media system in the optical wavelength range. The external medium of the filter is air, BK-7, or Si while the filter itself consists of SiO₂ and TiO₂ layers. The percentage bandwidth is below 10 percent. The angle of incidence is below 30 degrees with s and p polarized ray. Attenuation characteristics of designed filters agree well with design objectives.

Haojie Chang Weixing Sheng Jie Cui Jie Lu (2020) propose a multilayer dual-band bandpass filter with two independent paths combined between common input and output ports is proposed in this letter. Slot-coupled resonators and hairpin-line resonators form the two passbands centered at 2.4 and 5 GHz with 3-dB fraction bandwidth of 8% and 8.8%. Discriminating coupling is used in this letter to introduce a transmission zero (TZ) at third harmonic, validated by synthesis equations. And more TZs located at sideband of both passbands are obtained by source-load coupling. All these TZs contribute to high selectivity and extended stopband. The proposed filter is fabricated through a multilayer substrate to validate the design. Both simulated and measured results are in good agreement.

Gaillan H.Abdullah , Bushra. R.Mahdi, Farah .G (2013) present three designs band-pass filter with different number of layers are presented. These designs are concerned with a theoretical study on optoelectronics. physics to design and These designs consist of two material TiO₂ / SiO₂ as high / low index. analyze band-pass filter The wavelength range from 600 to 850nm and the design wavelength 700nm. The results show that the effects of angle of incident on the characteristics curve Transmission vs. wavelength for each design. The resulting design approach to push pulse durations further into the single-cycle regime.

B. A. Belyaev Vladimir Tyurnev V. F. Shabanov (2014) mentions that Optical bandpass filters usually represent multi-layer dielectric structures in which the layers with high and low refractive indices alternate. In the case when the mirror layers have a thickness multiple to the quarter wavelength, their reflectance is the

largest. In this case, they do not disturb the resonant frequencies of resonators, while the stopbands have an identical depth on both sides of the passband. The optical filters, the multilayer mirrors in which contain only the quarter wavelength layers and are fabricated from two materials, have a substantial disadvantage consisting of the high optical passband ripple. It is related to the impossibility of a smooth fine tuning of the reflectance of such mirrors both between resonators and on the input and output of the filter. The prototype filter contains resonators in the form of half wave-length dielectric layers with a low refractive index, each of which is separated from the next resonator or from free space on the input and output of the device by a multilayer dielectric mirror consisting of quarter wavelength layers.

H. Arabshahi and M. Asmari (2010) propose that their filters are designed to work for wavelength in the range of 1550 - 1600 nm. Our calculation results show good convergence rate and higher performance in comparison with results based on genetic algorithm. The calculated result for band pass filter layers of SiO_2 and SnTe have also shown that the transmittance parameter is about 0.994. The results for narrow filters show that the values of S and P reflectance parameter are in fair agreement with other methods and average transmittance parameter is about 0.985 which is 25% better than flip-flop results.

Vemuri SRS Praveen Kumar, Mukesh Kumar, Neelam Kumari, Vinod Karar and Amit L Sharma (2019) report the fabrication of a high reflective filter with excellent uniformity for demanding optical interference filters. To achieve this, films were deposited in different batches at three different angular positions using electron beam deposition technique. The coatings were carried out using indigenously designed flat jig holder without shapers. Fourteen alternating layers of high and low refractive index films were deposited on BK7 substrates of dimensions 186×150 mm by using aluminum dioxide (Al_2O_3) and silicon dioxide (SiO_2) evaporation grade granuals. Individual layers in the stack were deposited at quarter wave optical thickness at a wavelength of 550 nm. To examine the optical properties of multilayer optical films, Gonio-spectrophotometer was used. Roughness and thickness of all the samples were evaluated using Stylus Profilometer and Coherence Correlation interferometer. Surface properties such

as wettability, adhesion and hardness were studied. Additionally, to investigate the change in chemical bonding and structural properties of the coating materials used for evaporation before (bulk powdered material) and after deposition of thin films (material left in the crucible after deposition process), FTIR and XRD studies were carried out.

Muhammad H. Asghar, Muhammad Shoaib, Frank Placido, Shahzad Naseem (2008) propose a Complex multilayer skinny film filters for optical packages organized and characterised on this work. E-beam reactive evaporation approach has been used as a deposition process. In the primary stage, optimized character movie layers of TiO_2 , Ta_2O_5 , and SiO_2 are deposited and characterised optically and structurally earlier than the deposition of multilayered structures. The filter designs are primarily based totally upon 33 layered $\text{SiO}_2/\text{TiO}_2$ and $\text{SiO}_2/\text{Ta}_2\text{O}_5$ configurations on glass substrate. These designs are optimized to attain wideband transmission withinside the seen spectrum. After deposition, the 2 filter configurations are characterised optically and structurally the use of spectrophotometry, atomic pressure microscopy (AFM), X-ray diffraction (XRD) and scanning electron microscopy (SEM). $\text{SiO}_2/\text{Ta}_2\text{O}_5/\text{glass}$ filter has been determined touchy to deposition situations considering that excessive absorption is determined in multilayered configuration for the as-deposited samples. Post-deposition annealing of the filter withinside the temperature variety one hundred fifty to 250°C turned into additionally executed with the intention to examine the impact of temperature on absorption and spectral traits of the filter. Comparison of the 2 filter configurations turned into additionally executed to investigate their suitability for optical packages. Adhesion of the 2 filters turned into determined to be superb via way of means of way of tape-peel test.

ZHANG Jin-sheng, ZHANG Jin-long, NING Yong-qiang, WANG Li-Jun (2013)

say that cccording to the special requirements of space communication, a 1 555 nm high transmittance and broad band-pass filter was designed and prepared to operate under high temperature and high humidity environments. TiO_2 and SiO_2 were selected as coating materials to produce a large refractive index difference and the Quarter-wave Optical Thickness (QWOT) film was designed based on the design theory. Then, the nonQWOT film was optimized by using the needle

optimization and double sided coating by Optilayer software. The monitoring technique in the experiment was combined with direct monitoring and indirect monitoring, and the method were also discussed. A filter film with a transmittance of 97% in the center wavelength and a halfwidth of 50 nm was manufactured under electron beam evaporation by ion assisted. Experiments show that the wavelength shift of the filter film is only 0.2 nm in a high temperature of 100 °C and a low temperature of 30 °C for 3 hours each. Moreover, the film maintains high stability and reliability, which meets the requirements of space communication.

Mukesh Kumar, Neelam Kumari, Amit L. Sharma, Vinod Karar, and R K Sinha (2019) designed a multilayer band pass filter using 11 layers of alternate TiO_2 and SiO_2 were fabricated on a BK7 substrate using ion assisted electron-beam deposition technique. The filter was designed to have maximum transmission at 545 nm (Green) with adequate bandwidth to allow maximum energy transmission in the green wavelength band. The fabricated filter was found to have a bandwidth of 45 nm with a peak transmission of 91.5% at 545 nm.

D. Caputo, E. Parisi M. Carpentiero, A. Nascett, G. de Cesare, M. Tucci, F. Pavanello (2015) presents the design, fabrication and characterization of a system based on thin film technology for the selective detection of the natural fluorescence of Ochratoxin A. To this aim, the system optically couples an amorphous silicon photosensor with a long pass multi-dielectric filter, deposited on glass substrates. In particular, the filter rejects the wavelengths coming from the excitation source (centered at 340 nm) and transmits the emission spectrum (centered at 465 nm) of the mycotoxin, reducing therefore the background noise. The basic structure of the a-Si:H photosensors is a p-type/intrinsic/n-type stacked junction, deposited by Plasma Enhanced Chemical Vapor Deposition at temperatures ranging from 210 to 300 °C. Its responsivity at 465 nm is equal to 185 mA/W. The long pass filter is an interferential filter, constituted by alternating layers of TiO_2 and SiO_2 . It has been designed by using a freeware software, and deposited by electron beam Physical Vapor Deposition at 250 °C. A very good agreement between modeled and experimental data of transmittance and reflectance has been achieved. In particular, transmittance of the filter varies by

almost four orders of magnitude between 360 nm and 400 nm, showing its suitability in rejecting the excitation light.

Tatiana Amotchkina, Michael Trubetskov, Marcus Schulz, Vladimir Pervak (2019) say that the mid-infrared (MIR) spectral region has become more and more interesting for bio-medical laser applications since large organic molecules exhibit their fundamental vibrational and rotational modes in this range. In this rapidly developing research area, high-quality optical interference coatings are highly demanded. In many laser systems, it is required to separate initial high-power near-infrared beams originated from a driving laser from lower power MIR components emerged in a nonlinear crystal through a nonlinear process (for example, frequency difference generation). The corresponding multilayer dichroic filters reflecting the radiation in the near-infrared range and transmitting the MIR radiation are required. The coatings exhibit desired reflectance and phase in a near-infrared range and high transmittance in a required MIR region. The acceptable levels of reflectance and transmittance, width of the high-reflectance and high-transmittance ranges, polarization states as well as the angle of incidence are dependent on the laser setup. Along with the specified spectral performance, non-optical properties such as good adhesion, low mechanical stress, thermal stability, are of outmost importance. Low stress is crucial in order not to deform the laser beam wave front of the entire laser system and to avoid thermal lensing. Therefore, the choice of the appropriate evaporation materials and optimization of the high-vacuum deposition processes on the one hand and selection of optimal design solutions on the other hand are key elements in development of advanced multilayer optics for laser systems.

CHAPTER 3

AIM AND SCOPE OF PRESENT INVESTIGATION

3.1 EXISTING METHODOLOGY

An experiment was held to design a two-layered filter with a specified design. The wavelengths of the $[\text{Er}_2\text{O}_3/\text{TiO}_2]^6$ film was 514, 524, 540 and 980 nm. Those values are controlled by controlling the film thickness. The filters consist of two (6 pairs) Bragg reflecting mirrors which is enclosed by a cavity $[\text{Er}_2\text{O}_3]^2$. These materials are designed and fabricated to obtain a wavelength of 514 nm. These two films were prepared using the corresponding targets. 1. Optical transmittance and 2. Photographs of those prepared films. All layers in this mirrors have a thickness of a quarter of wavelength, $(\lambda/4n)$, which was 51.0 nm for TiO_2 and 65.6 nm for Er_2O_3 . Where n corresponds to the refractive index of the both the materials or either one at their designed wavelength. The optical resonance cavity had a thickness of 131.2 nm, resulting in a total thickness of 5129 nm. Er_2O_3 and TiO_2 films were first grown for aligning the rate of the deposition, by measuring the transmission spectra, and by calculating the wavelength dispersion of the refractive indexes from the Fabry oscillations. Then, it was grown to achieve a resonance wavelength of 514 nm. The deposition time was fixed at 90 min. Uniform films were obtained with high transmittance value with maximum of 80% of values. The thickness of TiO_2 and Er_2O_3 films were 40 and 73.5 nm, which is measured by a alpha step. And corresponding to those thickness, their deposition rates are 0.44 and 0.82 nm/min resp. Those films when examined by the XRD spectrum and those of the TiO_2 films when prepared without heating the substrate provides us the almost amorphous. The spectrum when heated at 400 °C with the substrate, reveals the crystalline nature of the films as peaks which corresponds to their anatase structure. At first, the thin film of the Er_2O_3 is prepared without heating the substrate. And at the wavelength of 222 nm the film exhibits the peaks. The spectrum of the prepared thin films at the substrate is of 400 °C. It is found that the crystallinity of the prepared films is firmly depended on the substrate's temperature, which exhibits peaks at four various wavelengths as 222, 413, 512 and 514. These two films which can act as a magnet-Optics bandpass filter, were

prepared using the magnetron sputtering deposition method. By controlling and varying the film thickness and the deposition time respectively, the deposition was performed 26 times to prepare the multilayer films. The FESEM image of the thin film reveals the presence of the 26 layers on a uniform film. That uniform film has a thickness of 1480 nm which is 129 nm lower than that of the designed thickness of the film, which achieves a thickness difference of 3.3%. The film, it has a light reddish-brown colour also is transparent in nature. The film gives out the transmittance at the wavelength of 460 and 520 nm which is lower than 20%, and a high transmittance of 490 nm which is about 70%. The highest transmittance is about 80%, which is centred around 490 nm. These are again shifted towards the shorter wavelengths compared with the designed value as 514 nm. In addition to that, the film's thickness is also altered as per the designed value. Thus the wavelength shift can be attributed to the low crystallinity and variations in the thickness of the two films Er_2O_3 and TiO_2 .

3.2 PROPOSED METHODOLOGY

In this project, we propose to build a successfully working Optical Band pass filter using the elements Silicon Dioxide (SiO_2) and Titanium Dioxide (TiO_2) stacked in alternate layers using a BK7 Glass as substrate. The following is the specifications used in this project.

3.2.1 SPECIFICATIONS

- Software Used : MATLAB (R2019b)
- Wavelength range : 400-700nm
- Wavelength used : 4647nm
- Elements used : Silicon Dioxide (SiO_2) and Titanium Dioxide (TiO_2)
- Substrate used : BK7 Glass
- Refractive index of SiO_2 at 4647nm : 1.4665
- Refractive Index of TiO_2 at 4647nm : 2.7771
- Refractive Index of BK7 Glass : 1.4595
- High refractive index material (m_2) : TiO_2
- Low refractive index material (m_1) : SiO_2
- Thickness of High refractive index material (t_h) : 82nm

- Thickness of Low refractive index material (t_l) : 8nm
- Number of layers (N) : 4
- Combination used : $m_2*m_1*m_1*m_2*m_1*m_1*m_2*m_2$

Since this is a software project, a software called MATLAB (MATrix LABoratory) is used to design the optical band pass filter. MATLAB is a programming, numerical computation platform developed by MathWorks. It is a flexible platform which allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages.

3.2.2 **WORKFLOW OF THE PROJECT**

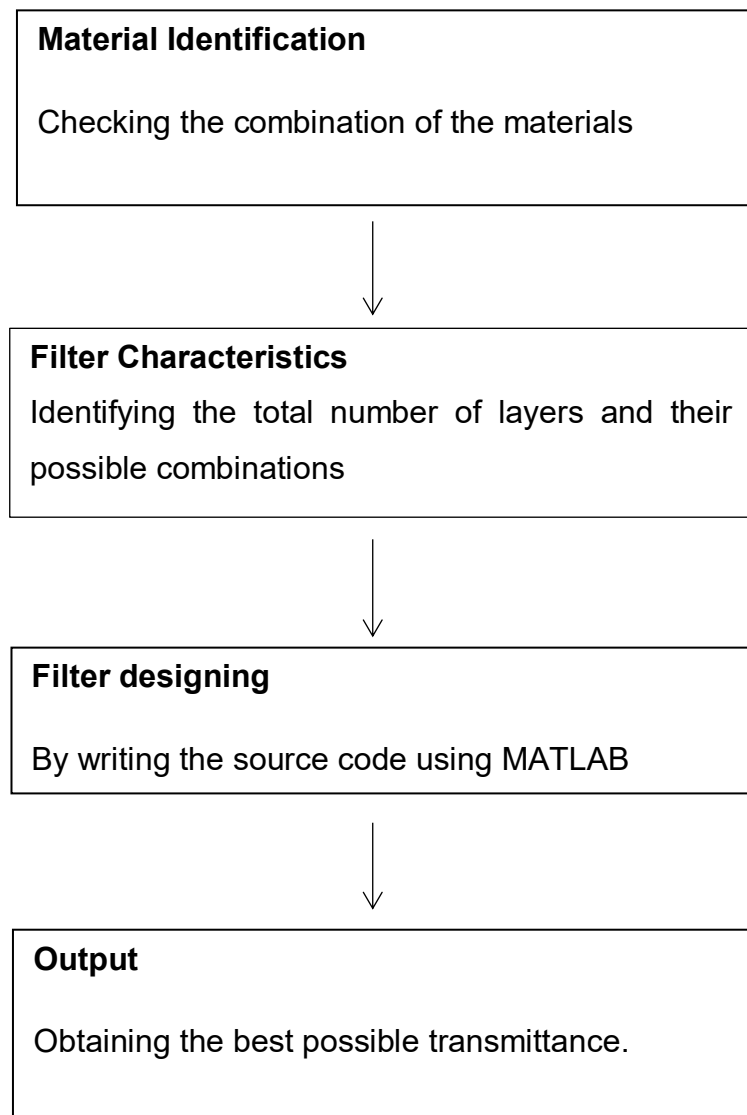


Fig:3.1: Workflow of the project

There are a total of three steps to complete the project namely Material Identification, Filter Designing and Output. The first step is called Material Identification where we tried various combinations of oxide elements which goes well on sync. By doing so, we got to the conclusion to use SiO₂ and TiO₂. This is done by comparing the refractive indices and measure the upward or downward trend of transmittance. If the transmittance is somewhere around the range where we can work on altering other factors, they're the elements which are used.

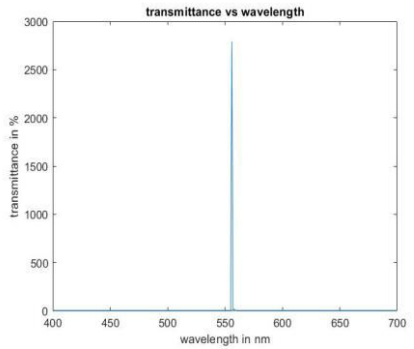
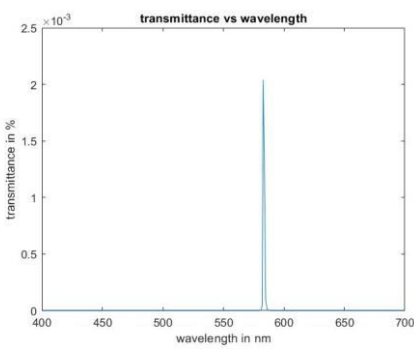
Once we find the two elements, the next step is to design the filter using the MATLAB software where the source code is written with all the required parameters as input and an output graph with wavelength (nm) in x axis and transmittance(%) in y axis. Then the wavelength is set as 4647nm and set the refractive indices of the elements with respect to 4647nm. Then, the layers are set along with their combinations. Finally, the thickness of high and low refractive indices are altered in a fashion to get the best possible transmittance below 100. Transmittance can never be 100% and if that happens, it's technically wrong.

CHAPTER 4

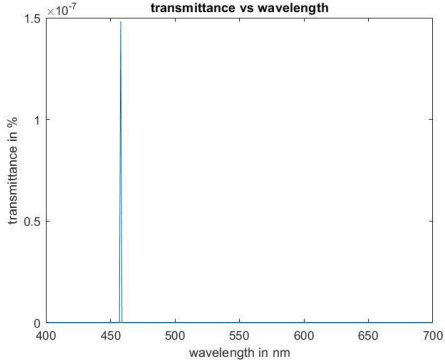
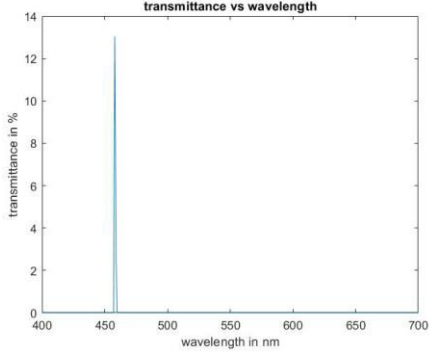
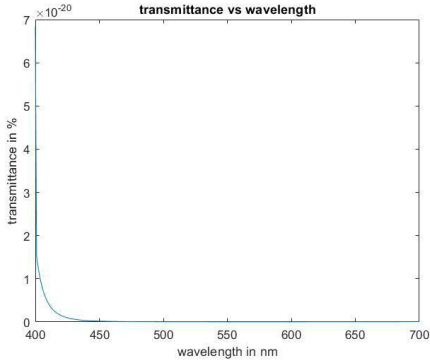
RESULTS AND DISCUSSION

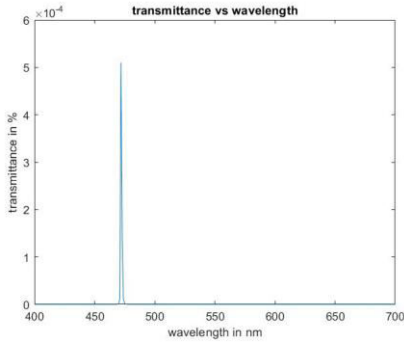
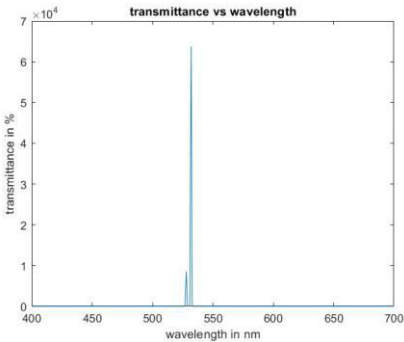
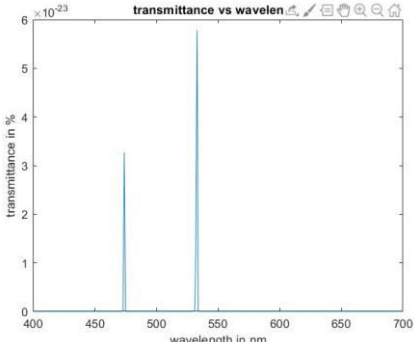
Many combinations were experimented by varying the thickness of higher and lower refractive index, but very few of them produced an appropriate peak in our desired transmittance. All the results are attached below in a tabular column which were obtained during the process.

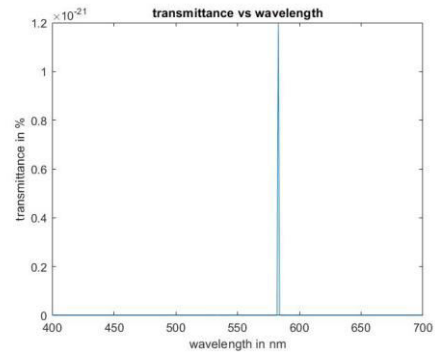
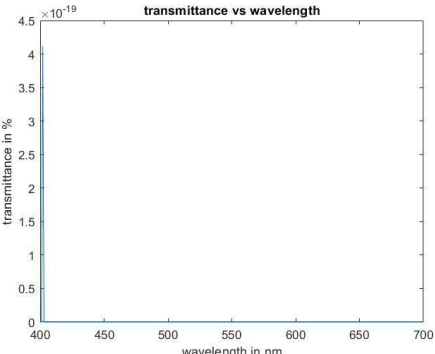
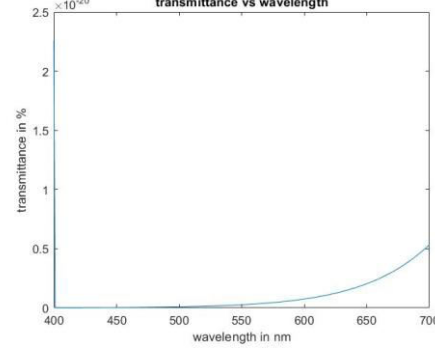
Table 1.1: Incorrect Waveforms

wavelength	Refractive index of SiO ₂ and TiO ₂	Th – Ti ratio	No. of layers	Output Waveforms
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	100:8	4	x=556nm y=2789% 
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	105:15	4	X=583nm Y=0.002039% 

4647nm	1.4665 (SiO2) 2.7771 (TiO2)	145:15	4	X=403nm Y=2.806 e ⁻⁰⁶ %
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	120:15	4	X=667nm Y=0.01082%
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	135:15	4	X=700nm Y=5.253 e ⁻⁰⁷ %

4647nm	1.4665 (SiO2) 2.7771 (TiO2)	165:25	4	X=458nm Y=1.483 e⁻⁰⁷% 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	165:5	4	X=458nm Y=13.04% 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	65:35	4	X=400nm Y=6.832 e⁻²⁰% 

4647nm	1.4665 (SiO2) 2.7771 (TiO2)	85:15	4	X=472nm Y=0.0005098% 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	95:5	4	X=532nm Y=63790% 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	256:545	4	X=533nm Y=5.777 e^-23% 

4647nm	1.4665 (SiO2) 2.7771 (TiO2)	420:545	4	X=583nm Y=1.196 e⁻²¹% 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	4200:55	4	X=402nm Y=4.118 e⁻¹⁹% 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	26:55	4	X=700nm Y=5.342 e⁻²¹% 

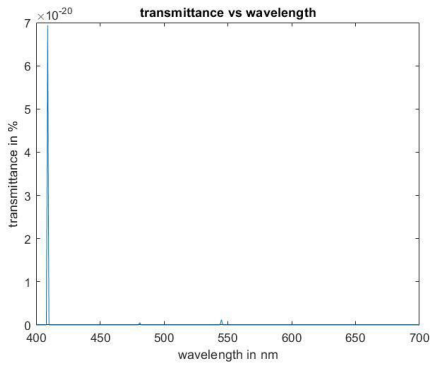
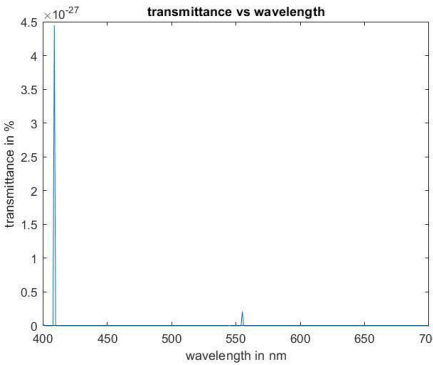
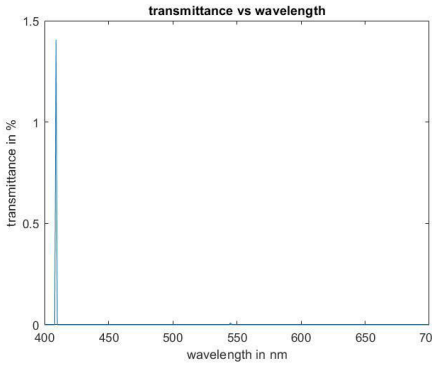
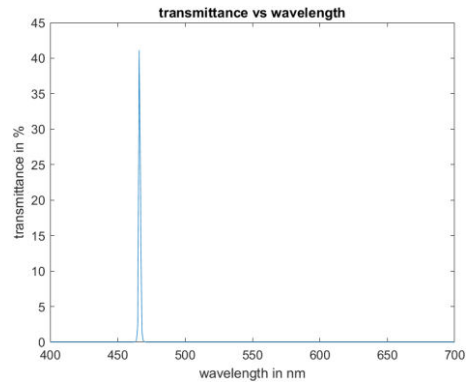
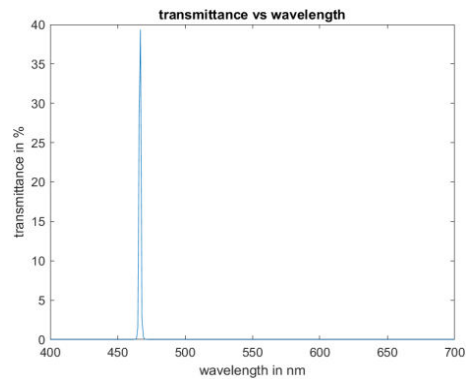
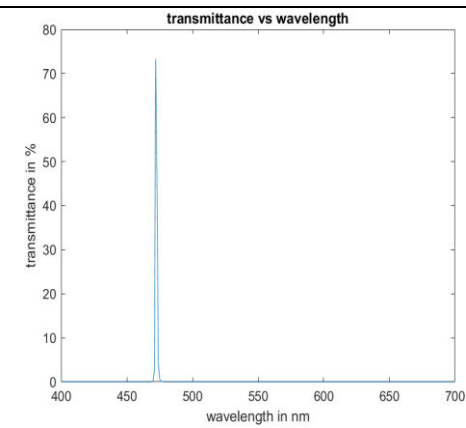
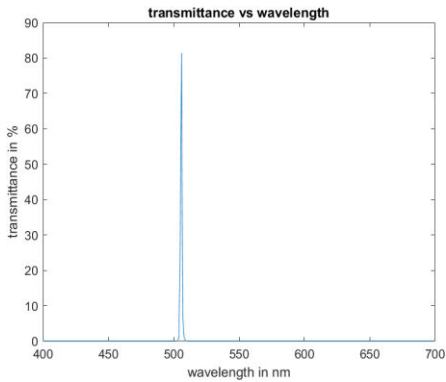
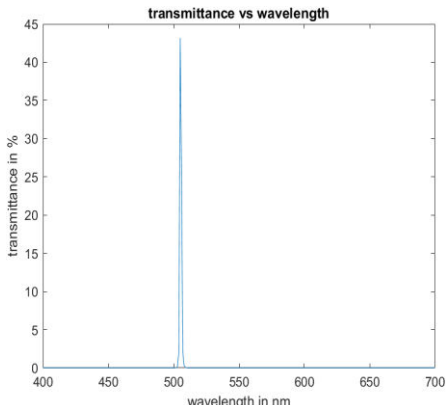
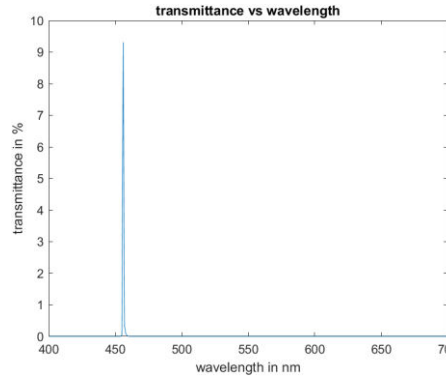
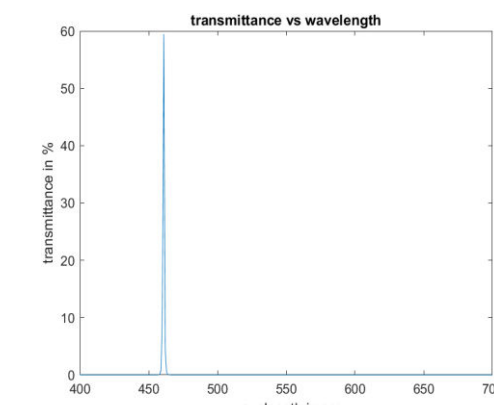
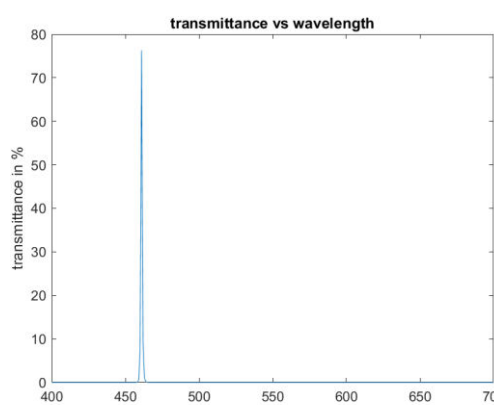
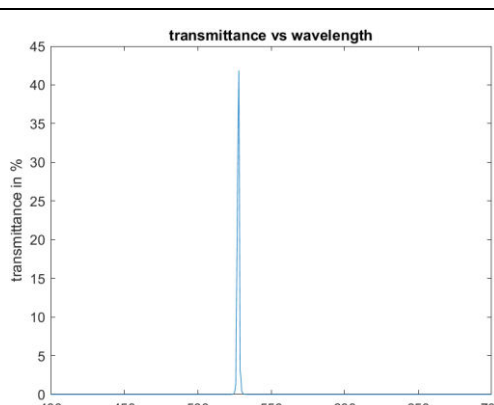
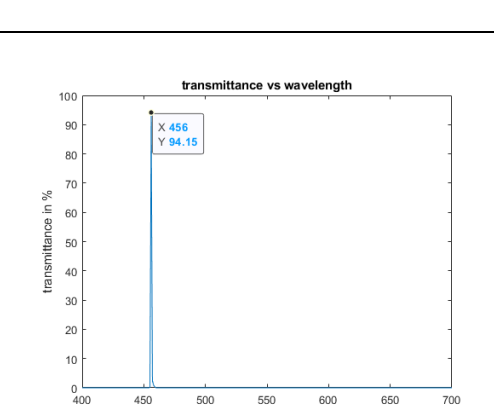
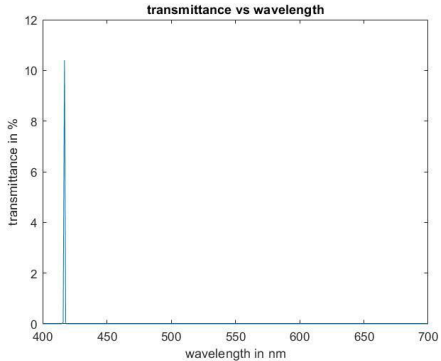
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	260:558	4	X=409nm Y=6.936 e ⁻²⁰ 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	2600: 558	4	X=409nm Y=4.445 e ⁻²⁷ 
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	0:558	4	X=409nm Y=1.406% 

Table 4.2: Correct Waveforms

wavelength	Refractive index of SiO ₂ and TiO ₂	Th – Ti ratio	No. of layers	Output Waveforms
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	84:1	4	x=466nm y=41.12% 
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	84:2	4	x=467nm y=39.36% 
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	85:3	4	x=472nm y=73.28% 

4647nm	1.4665 (SiO2) 2.7771 (TiO2)	91:3	4	x=506nm y=81.42%	
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	91:2	4	x=505nm y=43.17%	
4647nm	1.4665 (SiO2) 2.7771 (TiO2)	82:9	4	x=456 y=9.312%	

4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	83:1	4	x=461nm y=59.46%	
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	83:2	4	x=461nm y=76.31%	
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	95:2	4	x=528nm y=41.87%	
4647nm	1.4665 (SiO ₂) 2.7771 (TiO ₂)	82:8	4	x=456 y=94.15%	

4647nm	1.4565 (SiO2) 2.7771 (TiO2)	150:5	4	X=417nm Y=10.4%	
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WAVELENGTH = 456 nm
 TRANSMITTANCE = 94.15%

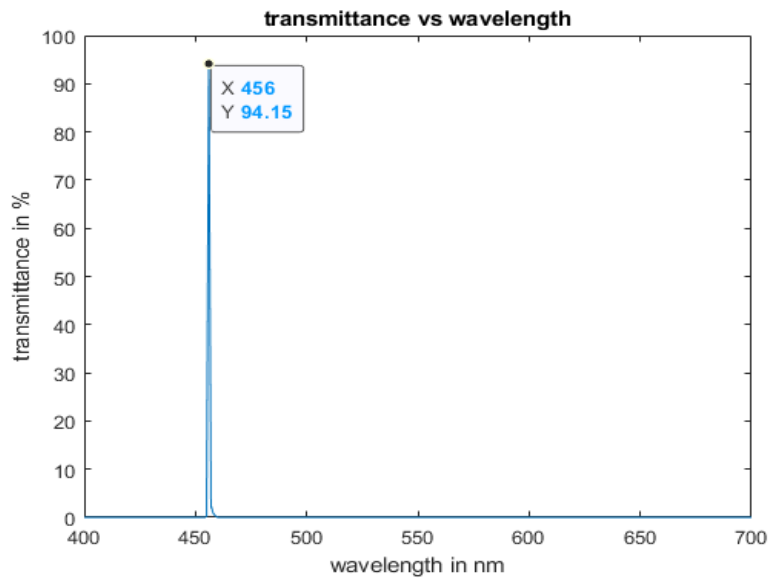


Fig: 4.1 Output Waveform

As per the proposed methodology, MATLAB was used as the platform to design an optical bandpass filter using SiO2 and TiO2 oxide materials. By changing various combinations of th and tl, the perfect output was presented which was selected from a set of correct waveforms on the basis of highest transmittance. The graph depicts a linear progressing peak in the bandpass filter with transmittance of 94.15% with a thickness values as 82nm and 8nm with wavelength of 4647nm.

CHAPTER 5

CONCLUSION

Thus, our conclusion describes that our project is to design an optical band pass filter to fabricate a multilayer structure using oxide materials. After analysing so many varieties of oxide materials with their refractive index, we have chosen TiO_2 and SiO_2 into account to work with. A glass substrate is used for fabricating the materials together. Once we have chosen the two materials. The next step is to design the filter using MATLAB software, in which we have got the required parameters in the source code as input and the output graph with wavelength(nm) and transmittance (%) in their X and Y axis respectively. The wavelength is set as 4647nm and their refractive index is set according to the wavelength. The thickness of the higher and lower refractive index is altered in such a way to get the best transmittance below 100. We tried out so many combinations by varying the thickness values with setting up the wavelength as constant. But none of them provided an appropriate peak in our desired wavelength. And at last, we have got our desired transmittance at 94.15% at a wavelength of 456 nm with thicknesses as 82nm and 8nm. And thus we got out output wavelength as desired.

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169-371301056-37130105 FINAL

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Submission date: 16-Apr-2021 12:53PM (UTC-0400)

Submission ID: 1561114391

File name: 169-371301056-37130105_FINAL.docx (615.84K)

Word count: 8990

Character count: 51001

DESIGN OF OPTICAL BAND-PASS FILTER USING OXIDE MATERIALS FOR MULTIDIMENSIONAL ARRAYS

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

By

Deepthika Shiwani M (37130106)

Deekshaa J (37130105)



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **DEEPTHIKA SHIWANI M (37130106)** and **DEEKSHAA J (37130105)** who carried out the project entitled **"DESIGN OF OPTICAL BAND-PASS FILTER USING OXIDE MATERIALS FOR MULTIDIMENSIONAL ARRAYS"** under our supervision from September 2020 to April 2021.

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Submitted for Viva voce examination held on _____

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DECLARATION

We, DEEPTHIKA SHIWANI M (37130106) and DEEKSHAA J (37130105) hereby declare that the Project Report entitled “DESIGN OF OPTICAL BAND-PASS FILTER USING OXIDE MATERIALS FOR MULTIDIMENSIONAL ARRAYS” done by us under the guidance of Mr. L JEGAN ANTONY MARCILIN M.Tech., is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Electronics and Communication Engineering.

1)

2)

DATE:

PLACE:

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. N. M. NANDHITHA, M.E., Ph.D. Dean, School of Electrical and Electronics Engineering** and **Dr. T. RAVI, M.E., Ph.D. Head of the Department, Department of Electronics and Communication Engineering** for providing us necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Mr. L Jegan Antony Marcilin M.Tech., Assistant Professor, Department of Electronics and Communication Engineering** for his valuable guidance, suggestions and constant encouragement paved way for the successful completion of the project work.

We wish to express our thanks to all teaching and Non-teaching staff members of the **Department of Electronics and Communication Engineering** who were helpful in many ways for the completion of the project.

We express our gratitude to our parents for their constant encouragement and support for the completion of the project.

ABSTRACT

Optical bandpass filters are used in optical communications, fluorescence microscopy, and astronomy. They are constructed using multilayer structures composed of alternating dielectric layers with high and low refractive indices. This paper describes the design of an optical band-pass multilayer filter that will be used for future filter applications. To achieve the same, we have used the frequency range within the visible spectrum which is 380(~400)-700nm. The wavelength in which the band-pass filter works is 4647nm. Since this filter is a multilayer structure, a 4 layer stack is designed with two oxide elements namely Silicon Dioxide (SiO₂) and Titanium Dioxide (TiO₂). The refractive indices of the elements mentioned above will be 1.4595 and 2.7771 respectively. The substrate used for the multilayer stack is BK7 Glass whose refractive index is 1.4595. The thickness of the higher and lower refractive materials are 82nm and 8nm respectively. A total of 4 layer filter is constructed as the multilayer structure.

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CHAPTER 1

INTRODUCTION

1.1 OPTICAL FILTERS

An optical filter selectively transmits one part of the optical spectrum, whilst rejecting different portions. In easy words, Optical filters are passive gadgets that permit the transmission of a particular wavelength or set of wavelengths of light and blocks the others.

Optical filters are very essential in laser test applications. Laser protection glasses are optical filters you may put on to defend your eyes from laser radiation. They usually clear out a small variety of wavelengths to let you see your environment even as operating on an optical test even as a laser is became on. It could be very essential to put on protection glasses which can be rated for the laser wavelength being used

Optical filters also are crucial as optical additives in laser experiments. For instance, whereas measure the photoluminescence (PL) of a material, all of the light being emitted from the spot this can be being excited through a laser is coupled into an optical fiber and measured in a very spectrometer. The light of the laser might be terribly intense, and counting on what value the wavelength of photoluminescence is, the laser light ought to conquer that signal. Applying a filter for the laser wavelength someplace among the film and the lens that collects the light coming from the film reduces or removes the laser peak, allowing us to see the photoluminescence peak clearly.

1.1.1 TYPES OF OPTICAL FILTERS

There are lessons of optical filters which have one of a kind mechanisms of operation: absorptive filters and dichroic filters.

Absorptive filters have a coating of various organic and inorganic substances that soak up positive wavelengths of mild, hence allowing the favored wavelengths to

pass through. Since they soak up light energy, the temperature of those filters will increase all through operation. They are simple filters and may be brought to plastics to make much less steeply-priced filters than their glass-primarily based totally counterparts. The operation of those filters does now no longer depend upon the perspective of the incident light however at the homes of the cloth that makes up the filters. As a result, they're correct filters to apply while pondered light of the undesirable wavelength can motive noise in optical signal.

Dichroic filters are greater complex of their operation. They include a sequence of optical coatings with particular thicknesses that are designed to mirror undesirable wavelengths and transmit the favoured wavelength variety. This is completed with the aid of using inflicting the favoured wavelengths to intervene constructively at the transmission facet of the clear out whilst different wavelengths intervene constructively at the mirrored image facet of the filter.

On the premise of wavelength ranges, There are 3 types of optical filters: short-pass filters, long-pass filters, and band-pass filters. A short-pass filter permits shorter wavelengths than the cut-off wavelength to go through, while it attenuates longer wavelengths. Conversely, a long-pass clear out transmits longer wavelengths than the cut-on wavelength whilst it blocks shorter wavelengths. A band-pass clear out that shall we a unique variety, or band, of wavelengths to head through, however attenuates all wavelengths across the band. A band-pass clear out that shall we a unique variety, or "band", of wavelengths to head through, however attenuates all wavelengths across the band. A monochromatic filter is an intense case of a band-pass clear out which transmits handiest a completely slim variety of wavelengths.

1.1.2 WAVELENGTH RANGE AND THEIR EMISSIONS

There are three different wavelength ranges emitting three various radiations namely 4647nm, 4861nm and 6361nm which emits Halpha, hbeta and carbon emissions respectively.

1.1.3 ADVANTAGES AND DISADVANTAGES

Advantages:

The following are the advantages of optical filters

- Absorptive filters - Cost-effective; wide availability; scratch-resistant; excellent environmental and chemical resistance.
- Dichoric filters - Precise transmission; capability for thin filter; wide variety of simple or complex types possible.

Disadvantages:

The following are the disadvantages of optical filters:

- Absorptive filters - Poor transmission slope; not suitable for precision applications; heat-sensitive; breakdown after prolonged use; necessary thickness.
- Dichoric filters - Expensive; increased angle sensitivity; ineffective at blocking wide wavelength ranges.

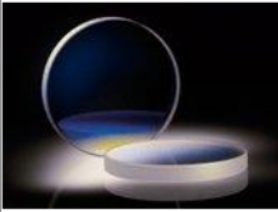
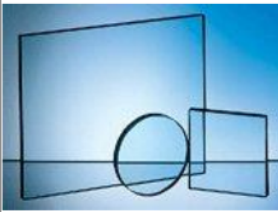
1.1.4 APPLICATIONS

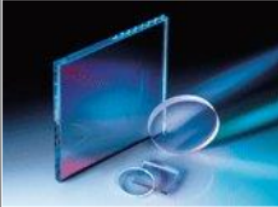
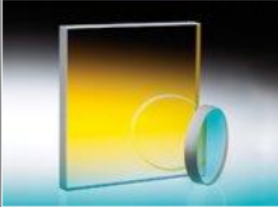
The following are the applications of Optical filters

- In structures for laser beam diagnostics with CCD-cameras
- Measurement of laser power, pulse energy and pulse duration
- Spectroscopy
- A set of bandpass filters for mercury lamps, laser lines, and different desires are available

1.2 TYPES OF OPTICAL FILTERS

To use a useful resource in information, the similarities and variations among the big variety of optical filters to be had today, recall ten of the maximum famous types. The following choice manual carries a short description, in addition to pattern product images.

Sample product image	Type of the filter
	BandpassFilters Bandpass filters have extremely narrow band (<2nm to 10nm) or broadband (50nm and 80nm) transmittance across the substrate. They are notably angle sensitive, thus care ought to be taken once mounting and putting them within an optical setup. hard sputtered filters ought to be chosen to maximise the transmission of designated wavelengths
	LongpassFilters Longpass filters transmit all wavelengths longer than the specified cut on wavelength. Longpass filters include cold mirrors, colored glass filters, and Thermoset ADC (optical cast plastic) filters.
	ShortpassFilters Shortpass filters transmit all wavelengths shorter than the specified cut off wavelength. Shortpass filters include IR cutoff filters, hot mirrors, and heat absorbing glass.
	HeatAbsorbingGlasses Heat absorbing glasses will transmit visible light and absorb infrared radiation. The absorbed energy is then dissipated as heat into the air around the glass. Forced air cooling is typically recommended to remove the excess heat. Heat absorbing glass can also be used as shortpass filters.

	Cold Mirrors Cold mirrors are specific types of dichroic filters designed to have high reflectivity in the visible spectrum while maintaining high transmission in the infrared. Cold mirrors are designed to be used in any application wherever heat build-up can cause harm or adverse effects.
	Hot mirrors Hot mirrors are specific types of dichroic filters designed to have high reflectivity in the infrared spectrum and high transmission in the visible. Hot mirrors are used primarily in projection and illumination systems.
	Notch Filters Notch filters are designed to stop a pre-selected bandwidth whilst sending all other wavelengths within the design range of the filter. Notch filters are accustomed to remove a single laser wavelength, or narrow band, from an optical system
	Color substrate filters Color substrate filters are factory-made from substrates with inherently totally different absorption and transmission properties across a specific spectral region. Color substrate filters are usually used as long pass and band pass filters. The boundary between transmission and interference is less sharp compared to some coating based mostly filters.
	Dichroic Filters Dichroic filters are coated with thin-films to achieve a desired transmission and reflection percentage across a given spectrum. They are often used as color filters (both additive and subtractive). Dichroic filters are slightly angle sensitive but are far more forgiving than interference filters



Neutral Density (ND) Filters

Neutral density (ND) filters are designed to reduce transmission evenly across a portion of a certain spectrum, UV, visible or IR. There are two main types of Neutral Density filters namely absorptive and reflective filters. The absorptive kind absorbs light that's not transmitted through the filter, whereas the reflective kind reflects it back toward the direction from which it had been incident. Special care ought to be taken once using the previous kind so as to make sure that any mirrored light doesn't interfere with the application setup. ND filters are usually accustomed forestall blooming or overexposure of cameras and alternative detectors.

1.3 KEYWORDS:

While filters share many of the same specifications with other optical components, there are a number of specifications unique to filters that should be understood in order to effectively understand and determine which filter is best for your application.

- **Central Wavelength**

Central Wavelength Center Wavelength (CWL), used in shaping band pass filters, describes the centre of spectral bandwidth over that the filter transmits. Traditional Coated Optical Filters have a tendency to acquire a most transmission close to the middle wavelength, while Hard Coated Optical Filters have a tendency to have a reasonably flat transmission profile over the spectral bandwidth.

- **Bandwidth**

Bandwidth is a wavelength range accustomed indicate a specific part of the spectrum that passes incident energy via a filter. It is likewise referred to as FWHM (Fig 1.1) Illustration of Centre Wavelength and Full width at half maximum.

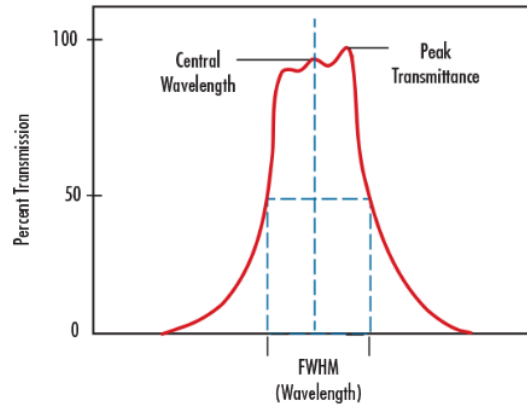


Fig 1.1 Centre Wavelength and Full Width at Half Maximum

- **Full Width-Half Maximum**

Full Width-Half Maximum (FWHM) describes the spectral bandwidth over which a bandpass clear out out will transmit. The higher and decrease restriction of that bandwidth is described on the wavelengths wherein the filter achieves 50% of the most transmission. For example, if the most transmission of the filter is 90%, the wavelengths at which the filter achieves 45% transmission will outline the higher and decrease limits of the FWHM. FWHM's of 10nm or much less are taken into consideration narrowband and frequently used for laser clean-up and chemical detection. FWHM's of 25 – 50nm are frequently utilized in gadget imaginative and prescient applications; FWHM's of greater than 50nm are taken into consideration broadband and commonly utilized in fluorescence microscopy applications.

- **Blocking Range**

Blocking Range is a wavelength interval used to indicate a spectral place of energy that is attenuated via way of means of the filter (Figure 2). The diploma of its blocking off is generally laid out in phrases of optical density.

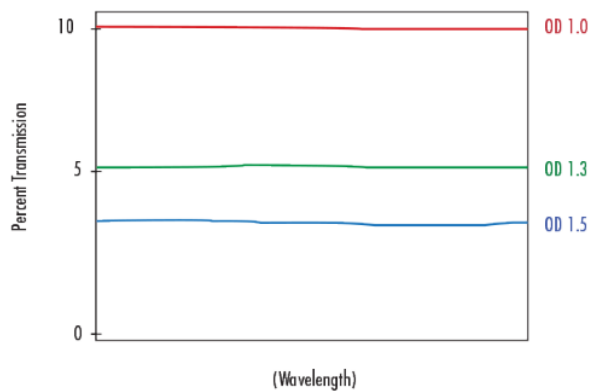


Fig 1.2 Blocking Range

- **Slope**

Slope is a specification regularly described on aspect filters, inclusive of shortpass or longpass filters, to explain the bandwidth over which the clear out transitions from excessive blockading to excessive transmission. Given because the percentage of the cut-wavelength, slope may be unique from lots of beginning and stop points. We can also say that the slope is defined as the gap from the 10% transmission factor to the 80% transmission factor. For example, a 500nm longpass clear out with a 1% slope could be anticipated to transition from 10% transmission to 80% transmission over a 5nm (1% of 500nm) bandwidth.

- **Optical Density**

Optical Density (OD) describes the quantity of energy blocked or rejected through a filter. A excessive optical density value suggests low transmission, and occasional optical density suggests excessive transmission. Optical densities of 6 or extra are used for severe blocking off wishes together with Raman spectroscopy or fluorescence microscopy. Optical densities of 3.0– 4.0 are ideal for laser separation and clean-up, device vision, and chemical detection, while optical densities of 2.0 or much less are best for colour sorting and keeping apart spectral orders.

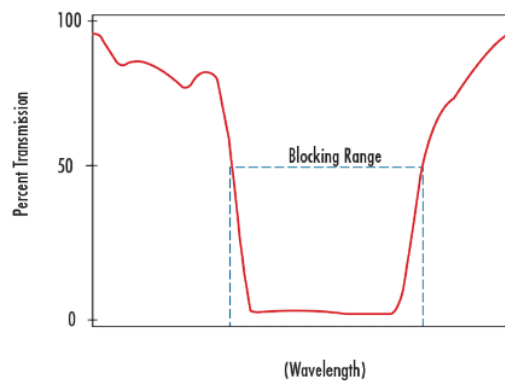


Fig 1.3 Optical Density

- 29 • **Transmittance**
The ratio of the normal components of transmitted and incident irradiance or, alternatively, the ratio of the total transmitted beam power to the total incident beam power is called transmittance and this is represented in percentages.

CHAPTER 2

LITERATURE SURVEY

¹¹ **B.A. Belyaev, V.V. Tyurnev and V.F. Shabanov (2014)** have proposed to design an optical bandpass filter with equalized passband ripples of a given magnitude. Their filter is product of dielectric materials, accommodates coupled half-wavelength resonators and multilayer mirrors. They have proposed a filter layout which starts with the synthesis of the multimaterial filter prototype whose mirrors encompass quarter-wavelength layers. In the prototype, the optimal refractive indices of the layers are obtained by a special optimization based on universal rules. The thicknesses of the mirrors' layers withinside the very last filter are computed the usage of derived formulas. They have used silicon-air bandpass filter with a functional bandwidth of 1%.

⁵⁰ **Haoyan Wang, Lin Yang and Lei Zhang (2019)** put forward a low-loss optical bandpass filter with narrow bandwidth demonstrated their distinguished performance in comparison with a third-order microring resonator using the Scattering Matrix method. The Scattering matrix method is a general computation for the analysis of electromagnetic propagation with respect to orthogonal modes ranging from low frequencies to RF/Microwave frequencies and frequencies within the optical region.

⁵¹ **Yi-Jun Jen and Meng-Jie Lin (2018)** have proposed a multilayer narrow bandpass filter that consists of silver and silicon thin films is designed using the admittance tracing method. Owing to the low loss of silicon in the infrared range, the peak transmittance at a wavelength of 950 nm exceeds 85%. In order to eliminate the sidebands that are adjoining to the passband, a compact four-layered shape is proposed to generate an angle-insensitive spectrum. In fabrication, a silver-silicon multilayer is deposited alternatively as a multilayer structure

³¹ **Gaurav Dwivedi, Nancy Sharma, Vemuri Sri Ranga Sai Praveen Kumar, Sunita Parinam, Mukesh Kumar, Neelam Kumari, Vinod Karar and Ami Sharma (2016)** propose an alternate stack of 26 layers using Alumina and

Silica which is designed and fabricated to realize optical bandpass filter at 660 nm wavelength for 45° angle of incidence with Alumina selected as high refractive index material and Silica as low refractive index material . Designed filter was fabricated in e-beam vacuum coating plant on BK-7 glass substrate under reactive oxygenated environment. The fabricated optical filter is characterised with the help of UV-Vis-NIR spectrophotometer to obtain the transmittance spectrum in the visible range which is around 400-800 nm.

¹ **Manoj Niraula, Jae Woong Yoon, and Robert Magnusson (2015)** have proposed an experimental bandpass filter fashioned in a single patterned silicon layer on a quartz substrate. Its performance corresponds to bandpass filters requiring 15 traditional Si/SiO₂ thin-film layers. An experimental filter presented exhibits a transmittance of ~72%, bandwidth of ~0.5 nm, and low sidebands spanning ~100 nm. The proposed technology is integration-friendly and opens doors for further development in various disciplines and spectral regions where thin-film solutions are traditionally applied.

³⁵ **Qinghua Wang, Bingtao Gao, Michaela E Raglione, Huixin Wang, Baojia Li, Fatima Toor, Mark A. Arnold, Hongtao Ding (2019)** have mentioned that the aim is to provide a comprehensive review of THz band pass meta-materials related to several areas. First, the design fundamentals and geometrical patterns of THz band pass meta-materials are summarized. Second, fabrication methods are reviewed, including typical micro- and nano fabrication techniques and laser micromachining techniques. More importantly, for these meta-materials different engineering methods are reviewed for tuning and modulation of the THz transmission resonance. Both passive and active modulation methods are included in this discussion. The passive method involves changes in the geometrical pattern of the filter material and the active method performs in situ modulation of properties by applying an external physical field. Finally, the potential applications and prospects for future research of THz band pass meta-materials are discussed.

Hanh Hong Mai (2020) ¹⁷ proposes a new construction design of a distributed Bragg reflector (DBR) filter and a Fabry–Pérot (FP) filter. It uses needle technique as a synthesis method. This optimized DBR and FP filter has a proper number of layers with controlling thickness $\text{TiO}_2/\text{SiO}_2$. They are utilized to transmit only a certain narrow band of wavelengths while blocking the others. As a proof of this concept, the filters are designed to selectively transmit only a very narrow band of wavelength at 780 nm which is the near infrared (NIR) fluorescent emission from Alexa Fluor 750 dye. The obtained results show that the optimized filters represent advanced spectral performance. It can be used to improve the sensitivity and the imaging contrast in fluorescence microscopy.

²⁷ **A.Beheshti Asl, A.Rostami, I.S. Amir (2020)** ²⁵ propose a band pass THz filter based on multilayer meta-materials is proposed, designed and simulated numerically. The functional behavior (filtering property) of the bilayer meta-surface is investigated considering a single bilayer cylinder in the periodic system. The cylinders are the basic elements in the unit cell. ²⁵ Then we show that the increase in the number of cylinders will increase the bandwidth. Also, the center frequency is tunable through changes in the dimension of the basic element. ²⁷ The main advantages of the proposed structure help us to realize terahertz filters are wideband, tunable, and easy to build. It is shown that the bandwidth of the proposed band pass filter is about 1 THz and the amount of transmittance is close to 93%.

¹ **Jing Wan, Jiangyun Miao, Jinwen You, Linlin Xu, and Xinyue Xie (2020)** ¹ propose a silicon optical filter utilizing multiple semi-rings to realize optical filtering. The structure of such filters is simple, adjustable, and integrated. By changing the number and spacing distance of semi-rings, the properties of the optical filter can be flexibly adjusted to meet different application requirements. Research results show that the optical filter has a 3 dB bandwidth of 2.52 nm, a free spectral range of 11.33 nm, and a finesse of 4.50. The silicon optical filter with multiple semi-rings is compared with a Mach–Zehnder-interferometer-based optical filter with the traditional structure, and it shows better performance. To the best of our knowledge, our work provides a new method for finding adjustable optical filters with compact structure and good performance.

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Jeoung, Chan-Gwoun , Kang, Young Kim, Sun-Youb –Jin (2007) say that The recent, a large capacity of telecommunication networks is required in order to it is in proportion to capacity of information communication increase and to satisfy a demand because of the demand about Internet, a multimedia service of internet, Video of internet protocol(VoIP), Audio/Video streaming. As a result, Dense Wavelength Division Multiplexing (DWDM) technologies are emerging to be a prevailing the method of solving it without additional optical fiber network building and high-speed equipment. Therefore this thesis proposed the optical filter of fiber/multilayer slab coupled structure combining it to multilayer slab waveguide by polishing the cladding of one side of fiber to design the optical filter having these functions. When a separation distance of fiber and slab was $3\mu\text{m}$, The optical filter proposed as the simulation result was satisfied with a DWDM filter characteristic with FWHM of 0.1nm on TM mode and TE mode as 32nm polarization independence in a communication window of $1.3\mu\text{m}$ when center wavelength was each $\lambda_0=1.274755\mu\text{m}$ and $\lambda_0=1.30591\mu\text{m}$.

1

Mingzhi Lu, Wenzao Li, and Elliott R. Brown (2011) present We propose a multilayer complementary metamaterial structure fabricated on a crystal quartz substrate measuring between 100 and 700 GHz. The concept of a second-order terahertz bandpass filter is realized by this structure, and it offers a superior quality factor, steepness of skirts, and out-of-band rejection. Physical limitations on the quality factor and insertion loss have also been studied, including the skin depth of the metal and the optical phonon resonance in quartz. Based on these factors, a series of higher frequency filters has been designed, and simulation results are provided.

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Xinrong Wang and Hiroshi Masumoto (1998) have proposed a Thirty one layer $\text{TiO}_2/\text{SiO}_2$ optical filters with graded refractive index profiles were fabricated by helicon plasma sputtering at room temperature. Multilayer films were deposited on glass (BK7) and Si (100) substrates simultaneously and sequentially. The measured transmittance spectrum exhibited a reflectance of 99.8% at a central wavelength of 730 nm and high transmittance over the wavelength region outside of the reflected band as a result of the suppression of the sidelobes. The experimental transmittance spectrum corresponded almost completely with that

calculated based on the optical multilayer film theory and using the measured refractive indices of TiO₂, SiO₂ and TiO₂–SiO₂ composite films. Transmission electron microscopic observations confirmed the expected microstructure of the filter.

Minoru YAMADA, Yasuhiro YAMANE (1996) presented a generalized design method for an optical filter consisting of a dielectric multilayer structure is proposed to get an arbitrary profile of the wavelength dispersion of reflectivity or transmittance. The basic concept of the method lies in the fact that the wavelength dispersion of the reflectivity is approximately determined by taking the inverse Fourier transformation of the refractive index profile of the multilayer structure. Construction of a filter with only three different values of refractive index is described.

M.A. Butt S.A. Fomchenkov, A. Ullah, M. Habib R.Z. Ali (2016) report a design for creating multilayer dielectric optical filters based on TiO₂ and SiO₂/MgF₂ alternating layers. We have selected Titanium dioxide (TiO₂) for high refractive index (2.5), Silicon dioxide (SiO₂) and Magnesium fluoride (MgF₂) as a low refractive index layer (1.45 and 1.37) respectively. Miniaturized visible spectrometers are useful for quick and mobile characterization of biological samples. Such devices can be fabricated by using Fabry-Perot (FP) filters consisting of two highly reflecting mirrors with a central cavity in between. Distributed Bragg Re-flectors (DBRs) consisting of alternating high and low refractive index material pairs are the most commonly used mirrors in FP filters, due to their high reflectivity. However, DBRs have high re-flectivity for a selected range of wavelengths known as the stopband of the DBR. This range is usually much smaller than the sensitivity range of the spectrometer. Therefore, bandpass filters are required to restrict the wavelength outside the stopband of the FP DBRs. The proposed filter shows high quality with an average transmission of 97 % within the passbands and the transmission outside the passband is around 3 %. Special attention has been given to keep the thickness of the filters within the economic limits. It can be suggested that these filters are exceptionally promising for florescence imaging and narrow-band imaging endoscopy.

Ph. Refregierm (1990) demonstrated ²⁴ a method of constructing optimal multicriteria filters for optical pattern recognition is presented. In the particular case of synthetic discriminant function filters, this method is illustrated for double-optimization criteria, and filters that are not overspecialized are obtained, in contrast with traditional techniques. Furthermore, a rigorous comparison between different filters, with respect to the considered criteria, is provided with this approach.

²⁴ **Thomas Begou, Fabien Lemarchand, Frédéric Lemarquis, Antonin Moreau, Julien Lumeau (2019)** ¹ present a thorough description of high-performance thin-film optical filters with high flatness. These components can combine several tens or hundreds of layers and are manufactured using plasma-assisted reactive magnetron sputtering. Stress compensation is achieved using dual-side coatings with appropriate spectral function. Examples are described of highly reflecting mirrors at 515 nm with 15 nm flatness peak-to-valley up to and over 75 mm diameter aperture, narrow bandpass filters, and filters with broadband controlled transmission.

¹ **Yanhan Zhu, Subash Vegesna, Vladimir Kuryatkov, Mark Holtz, Mohammad Saed, and Ayrton A. Bernussi (2012)** ¹ report a Bandpass filter based on double-stacked metamaterial layers separated by an air gap for operation at terahertz frequencies. Several stacking configurations were investigated designed for a ~0.5 THz center frequency. The filters exhibited improved spectral transmission properties when compared with conventional ones based on single metamaterial layers. 3 dB bandwidth of ~78 GHz and sidelobe suppression ratio >16 dB were determined when symmetric or asymmetric double layers were stacked. We demonstrate that superior frequency selectivity can be achieved when metamaterial layers with different unit cells are used. Good agreement was found between measured and simulated transmission response.

¹**J. M. Slaughter, Brian S. Medower, R. N. Watts, C. Tarrio, T. B. Lucatorto, and Charles M. Falco (1994)** report the results of extreme-ultraviolet reflectance measurements and structural characterization of multilayer mirrors made by sequential sputter deposition of Si and B₄C. Compared with Si/Mo multilayers, Si/B₄C have a much narrower bandpass ($\delta\lambda$) and better off-peak rejection but lower peak reflectance (R_0). Mirrors with three different designs gave the following results: $R_0 = 0.275$ and $\delta\lambda = 0.31$ nm at 13.1 nm and normal incidence; $R_0 = 0.34$ and $\delta\lambda = 1.1$ nm at 18.2 nm and 45°; and $R_0 = 0.30$ and $\delta\lambda = 2.0$ nm at 23.6 nm and 45°. These multilayers exhibited excellent stability on annealing at temperatures up to 600°C.

¹**Adriana Szeghalmi, Michael Helgert, Robert Brunner, Frank Heyroth, Ulrich Gösele, and Mato Knez (2009)** propose an Al₂O₃ and TiO₂ thin films have been deposited on Si wafers, quartz, BK7 glass, and polycarbonate substrates by atomic layer deposition (ALD). The refractive indices and growth rates of the materials have been determined by spectroscopic ellipsometry and transmission electron microscopy. The influence of substrate temperature and precursor on the refractive indices has been investigated. The refractive index of TiO₂ significantly increases with temperature, whereas the Al₂O₃ films are temperature insensitive. The films deposited using H₂O₂ as oxygen source show a slightly higher refractive index than the films prepared with H₂O. Multilayer narrow-bandpass filters and broadband antireflective coatings have been designed and produced by ALD.

¹**Alain Jody Corso, Paola Zuppella, Piergiorgio Nicolosi, David L. Windt, E. Gullikson, and Maria Guglielmina Pelizzo (2011)** say that Novel capping layer structures have been deposited on periodic Mo/Si multilayers to optimize reflectance at 30.4 nm. Design, deposition and characterization of such coatings are presented. Most of the structures proposed show improved performance with respect to standard Mo/Si multilayers and are stable over time. Reflectance at 121.6 nm and in the visible spectral range have been also tested to explore the applicability of such coatings to the Multi Element Telescope for Imaging and Spectroscopy (METIS) instrument, a coronagraph being developed for the ESA Solar Orbiter platform

I.Wakabyashi; O. Yokoyama T. Koizumi K. Miyauchi (2000) presents a design method and examples of dielectric multi-layer bandpass filters with Butterworth characteristics for three-media system in the optical wavelength range. The external medium of the filter is air, BK-7, or Si while the filter itself consists of SiO₂/sub 2/ and TiO₂/sub 2/ layers. The percentage bandwidth is below 10 percent. The angle of incidence is below 30 degrees with s and p polarized ray. Attenuation characteristics of designed filters agree well with design objectives.

Haojie Chang Weixing Sheng Jie Cui Jie Lu (2020) propose a multilayer dual-band bandpass filter with two independent paths combined between common input and output ports is proposed in this letter. Slot-coupled resonators and hairpin-line resonators form the two passbands centered at 2.4 and 5 GHz with 3-dB fraction bandwidth of 8% and 8.8%. Discriminating coupling is used in this letter to introduce a transmission zero (TZ) at third harmonic, validated by synthesis equations. And more TZs located at sideband of both passbands are obtained by source-load coupling. All these TZs contribute to high selectivity and extended stopband. The proposed filter is fabricated through a multilayer substrate to validate the design. Both simulated and measured results are in good agreement.

Gaillan H.Abdullah , Bushra. R.Mahdi, Farah .G (2013) present three designs band-pass filter with different number of layers are presented. These designs are concerned with a theoretical study on optoelectronics. physics to design and These designs consist of two material TiO₂ / SiO₂ as high / low index. analyze band-pass filter The wavelength range from 600 to 850nm and the design wavelength 700nm. The results show that the effects of angle of incident on the characteristics curve Transmission vs. wavelength for each design. The resulting design approach to push pulse durations further into the single-cycle regime.

B. A. Belyaev Vladimir Tyurnev V. F. Shabanov (2014) mentions that Optical bandpass filters usually represent multi-layer dielectric structures in which the layers with high and low refractive indices alternate. In the case when the mirror layers have a thickness multiple to the quarter wavelength, their reflectance is the

largest. In this case, they do not disturb the resonant frequencies of resonators, while the stopbands have an identical depth on both sides of the passband. The optical filters, the multilayer mirrors in which contain only the quarter wavelength layers and are fabricated from two materials, have a substantial disadvantage consisting of the high optical passband ripple. It is related to the impossibility of a smooth fine tuning of the reflectance of such mirrors both between resonators and on the input and output of the filter. The prototype filter contains resonators in the form of half wave-length dielectric layers with a low refractive index, each of which is separated from the next resonator or from free space on the input and output of the device by a multilayer dielectric mirror consisting of quarter wavelength layers.

H. Arabshahi and M. Asmari (2010) propose that their filters are designed to work for wavelength in the range of 1550 - 1600 nm. Our calculation results show good convergence rate and higher performance in comparison with results based on genetic algorithm. The calculated result for band pass filter layers of SiO_2 and SnTe have also shown that the transmittance parameter is about 0.994. The results for narrow filters show that the values of S and P reflectance parameter are in fair agreement with other methods and average transmittance parameter is about 0.985 which is 25% better than flip-flop results.

Vemuri SRS Praveen Kumar, Mukesh Kumar, Neelam Kumari, Vinod Karar and Amit L Sharma (2019) report the fabrication of a high reflective filter with excellent uniformity for demanding optical interference filters. To achieve this, films were deposited in different batches at three different angular positions using electron beam deposition technique. The coatings were carried out using indigenously designed flat jig holder without shapers. Fourteen alternating layers of high and low refractive index films were deposited on BK7 substrates of dimensions 186×150 mm by using aluminum dioxide (Al_2O_3) and silicon dioxide (SiO_2) evaporation grade granuals. Individual layers in the stack were deposited at quarter wave optical thickness at a wavelength of 550 nm. To examine the optical properties of multilayer optical films, Gonio-spectrophotometer was used. Roughness and thickness of all the samples were evaluated using Stylus Profilometer and Coherence Correlation interferometer. Surface properties such

as wettability, adhesion and hardness were studied. Additionally, to investigate the change in chemical bonding and structural properties of the coating materials used for evaporation before (bulk powdered material) and after deposition of thin films (material left in the crucible after deposition process), FTIR and XRD studies were carried out.

⁴⁵ **Muhammad H. Asghar, Muhammad Shoaib, Frank Placido, Shahzad Naseem (2008)** propose a ⁵³ **Complex multilayer** skinny **film filters for optical** packages organized and characterised on this work. E-beam reactive evaporation approach has been used as a deposition process. In the primary stage, optimized character movie layers of TiO₂, Ta₂O₅, and SiO₂ are deposited and characterised optically and structurally earlier than the deposition of multilayered structures. The filter designs are primarily based totally upon 33 layered SiO₂/TiO₂ and SiO₂/Ta₂O₅ configurations on glass substrate. These designs are optimized to attain wideband transmission withinside the seen spectrum. After deposition, the 2 filter configurations are characterised optically and structurally the use of spectrophotometry, atomic pressure microscopy (AFM), X-ray diffraction (XRD) and scanning electron microscopy (SEM). SiO₂/Ta₂O₅/glass filter has been determined touchy to deposition situations considering that excessive ¹⁴ absorption is determined in multilayered configuration for the as-deposited samples. Post-deposition annealing of the filter withinside the temperature variety one hundred fifty to 250°C turned into additionally executed with the intention to examine the impact of temperature on absorption and spectral traits of the filter. Comparison of the 2 filter configurations turned into additionally executed to investigate ¹⁴ their suitability for optical packages. Adhesion of the 2 filters turned into determined to be superb via way of means of way of tape-peel test.

¹⁰ **ZHANG Jin-sheng, ZHANG Jin-long, NING Yong-qiang, WANG Li-Jun (2013)** say that cccording to the special requirements of space communication, a 1 555 nm high transmittance and broad band-pass filter was designed and prepared to operate under high temperature and high humidity environments. TiO₂ and SiO₂ were selected as coating materials to produce a large refractive index difference and the Quarter-wave Optical Thickness (QWOT) film was designed based on the design theory. Then, the nonQWOT film was optimized by using the needle

optimization and double sided coating by Optilayer software. The monitoring technique in the experiment was combined with direct monitoring and indirect monitoring, and the method were also discussed. A filter film with a transmittance of 97% in the center wavelength and a halfwidth of 50 nm was manufactured under electron beam evaporation by ion assisted. Experiments show that the wavelength shift of the filter film is only 0.2 nm in a high temperature of 100 °C and a low temperature of 30 °C for 3 hours each. Moreover, the film maintains high stability and reliability, which meets the requirements of space communication.

¹
Mukesh Kumar, Neelam Kumari, Amit L. Sharma, Vinod Karar, and R K Sinha (2019) designed a multilayer band pass filter using 11 layers of alternate TiO₂ and SiO₂ were fabricated on a BK7 substrate using ion assisted electron-beam deposition technique. The filter was designed to have maximum transmission at 545 nm (Green) with adequate bandwidth to allow maximum energy transmission in the green wavelength band. The fabricated filter was found to have a bandwidth of 45 nm with a peak transmission of 91.5% at 545 nm.

³¹
D. Caputo, E. Parisi M. Carpentiero, A. Nascetti, G. de Cesare, M. Tucci, F. Pavanello (2015) presents the design, fabrication and characterization of a system based on thin film technology for the selective detection of the natural fluorescence of Ochratoxin A. To this aim, the system optically couples an amorphous silicon photosensor with a long pass multi-dielectric filter, deposited on glass substrates. In particular, the filter rejects the wavelengths coming from the excitation source (centered at 340 nm) and transmits the emission spectrum (centered at 465 nm) of the mycotoxin, reducing therefore the background noise. The basic structure of the a-Si:H photosensors is a p-type/intrinsic/n-type stacked junction, deposited by Plasma Enhanced Chemical Vapor Deposition at temperatures ranging from 210 to 300 °C. Its responsivity at 465 nm is equal to 185 mA/W. The long pass filter is an interferential filter, constituted by alternating layers of TiO₂ and SiO₂. It has been designed by using a freeware software, and deposited by electron beam Physical Vapor Deposition at 250 °C. A very good agreement between modeled and experimental data of transmittance and reflectance has been achieved. In particular, transmittance of the filter varies by

almost four orders of magnitude between 360 nm and 400 nm, showing its suitability in rejecting the excitation light.

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Tatiana Amotchkina, Michael Trubetskov, Marcus Schulz, Vladimir Pervak

(2019) say that the mid-infrared (MIR) spectral region has become more and more interesting for bio-medical laser applications since large organic molecules exhibit their fundamental vibrational and rotational modes in this range. In this rapidly developing research area, high-quality optical interference coatings are highly demanded. In many laser systems, it is required to separate initial high-power near-infrared beams originated from a driving laser from lower power MIR components emerged in a nonlinear crystal through a nonlinear process (for example, frequency difference generation). The corresponding multilayer dichroic filters reflecting the radiation in the near-infrared range and transmitting the MIR radiation are required. The coatings exhibit desired reflectance and phase in a near-infrared range and high transmittance in a required MIR region. The acceptable levels of reflectance and transmittance, width of the high-reflectance and high-transmittance ranges, polarization states as well as the angle of incidence are dependent on the laser setup. Along with the specified spectral performance, non-optical properties such as good adhesion, low mechanical stress, thermal stability, are of outmost importance. Low stress is crucial in order not to deform the laser beam wave front of the entire laser system and to avoid thermal lensing. Therefore, the choice of the appropriate evaporation materials and optimization of the high-vacuum deposition processes on the one hand and selection of optimal design solutions on the other hand are key elements in development of advanced multilayer optics for laser systems.

CHAPTER 3

AIM AND SCOPE OF PRESENT INVESTIGATION

3.1 EXISTING METHODOLOGY

²¹ An experiment was held to design a two-layered filter with a specified design. The wavelengths of the $[\text{Er}_2\text{O}_3/\text{TiO}_2]^6$ film was 514, 524, 540 and 980 nm. Those values are controlled by controlling the film thickness. The filters consist of two (6 pairs) Bragg reflecting mirrors which is enclosed by a cavity $[\text{Er}_2\text{O}_3]^6$. These materials are designed and fabricated to obtain a wavelength of 514 nm. These two films were prepared using the corresponding targets. 1. Optical transmittance and 2. Photographs of those prepared films. All layers in this mirrors have a thickness of a quarter of wavelength, $(\lambda/4n)$, which was 51.0 nm for TiO_2 and 65.6 nm for Er_2O_3 . Where n corresponds to the refractive index of the both the materials or either one at their designed wavelength. The optical resonance cavity had a thickness of 131.2 nm, resulting in a total thickness of 5129 nm. ⁴⁹ Er_2O_3 and TiO_2 films were first grown for aligning the rate of the deposition, by measuring the transmission spectra, and by calculating the wavelength dispersion of the refractive indexes from the Fabry oscillations. Then, it was grown to achieve a resonance wavelength of 514 nm. The deposition time was fixed at 90 min. Uniform films were obtained with high transmittance value with maximum of 80% of values. The thickness of TiO_2 and Er_2O_3 films were 40 and 73.5 nm, which is measured by a α step. And corresponding to those thickness, their deposition rates are 0.44 and 0.82 nm/min resp. Those films when examined by the XRD spectrum and those of the TiO_2 films when prepared without heating the substrate provides us the almost amorphous. The spectrum when heated at 400 °C with the substrate, reveals the crystalline nature of the films as peaks which corresponds to their anatase structure. At first, the thin film of the Er_2O_3 is prepared without heating the substrate. And at the wavelength of 222 the film exhibits the peaks. The spectrum of the prepared thin films at the substrate is of 400 °C. It is found that the crystallinity of the prepared films is firmly depended on the substrate's temperature, which exhibits peaks at four various wavelengths as 222, 413, 512 and 514. These two films which can act as a magnet-Optics bandpass filter, were

prepared using the magnetron sputtering deposition method. By controlling and varying the film thickness and the deposition time respectively, the deposition was performed 26 times to prepare the multilayer films. The FESEM image of the thin film reveals the presence of the 26 layers on a uniform film. That uniform film has a thickness of 1480 nm which is 129 nm lower than that of the designed thickness of the film, which achieves a thickness difference of 3.3%. The film, it has a light reddish-brown colour also is transparent in nature. The film gives out the transmittance at the wavelength of 460 and 520 nm which is lower than 20%, and a high transmittance of 490 nm which is about 70%. The highest transmittance is about 80%, which is centred around 490 nm. These are again shifted towards the shorter wavelengths compared with the designed value as 514 nm. In addition to that, the film's thickness is also altered as per the designed value. Thus the wavelength shift can be attributed to the low crystallinity and variations in the thickness of the two films Er₂O₃ and TiO₂.

3.2 PROPOSED METHODOLOGY

In this project, we propose to build a successfully working Optical Band pass filter using the elements Silicon Dioxide (SiO₂) and Titanium Dioxide (TiO₂) stacked in alternate layers using a BK7 Glass as substrate. The following is the specifications used in this project.

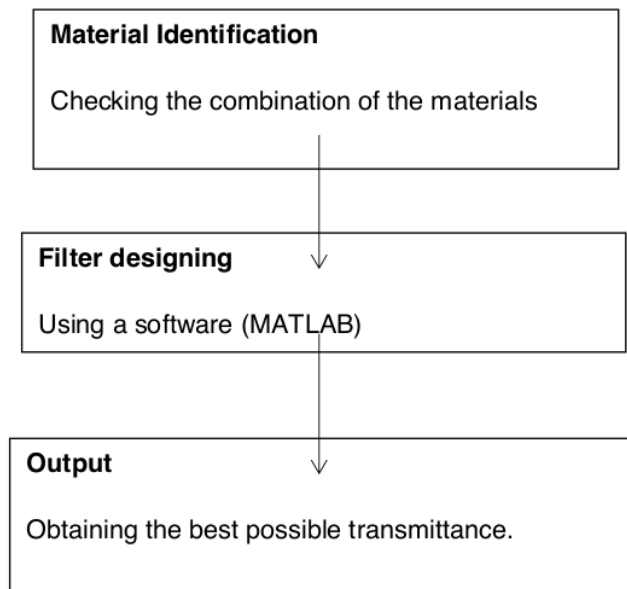
3.2.1 SPECIFICATIONS

- Software Used : MATLAB (R2019b)
- Wavelength range : 400-700nm
- Wavelength used : 4647nm
- Elements used : Silicon Dioxide (SiO₂) and Titanium Dioxide (TiO₂)
- Substrate used : BK7 Glass
- Refractive index of SiO₂ at 4647nm : 1.4665
- Refractive Index of TiO₂ at 4647nm : 2.7771
- Refractive Index of BK7 Glass : 1.4595
- High refractive index material (m₂) : TiO₂
- Low refractive index material (m₁) : SiO₂
- Thickness of High refractive index material (t_h) : 82nm

- Thickness of Low refractive index material (t_l) : 8nm
- Number of layers (N) : 4
- Combination used : $m_2^*m_1^*m_1^*m_2^*m_1^*m_1^*m_2^*m_2$

Since this is a software project, a software called MATLAB (MATrix LABoratory) is used to design the optical band pass filter. MATLAB is a programming, numerical computation platform developed by MathWorks. It is a flexible platform which allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages.

3.3 WORKFLOW OF THE PROJECT



There are a total of three steps to complete the project namely Material Identification, Filter Designing and Output. The first step is called Material Identification where we tried various combinations of oxide elements which goes well on sync. By doing so, we got to the conclusion to use SiO₂ and TiO₂. This is done by comparing the refractive indices and measure the upward or downward trend of transmittance. If the transmittance is somewhere around the range where we can work on altering other factors, they're the elements which are used.

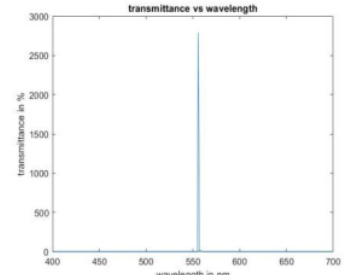
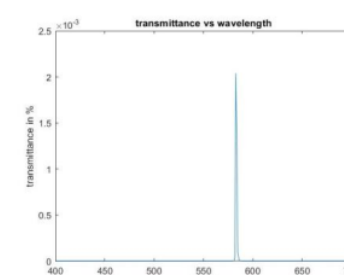
Once we find the two elements, the next step is to design the filter using the MATLAB software where the source code is written with all the required parameters as input and an output ⁴¹graph with wavelength (nm) in x axis and transmittance(%) in y axis. Then the wavelength is set as 4647nm and set the refractive indices of the elements with respect to 4647nm. Then, the layers are set along with their combinations. Finally, the thickness of high and low refractive indices are altered in a fashion to get the best possible transmittance below 100. Transmittance can never be 100% and if that happens, it's technically wrong.

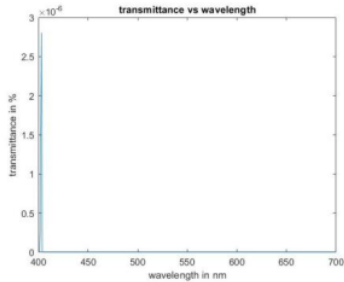
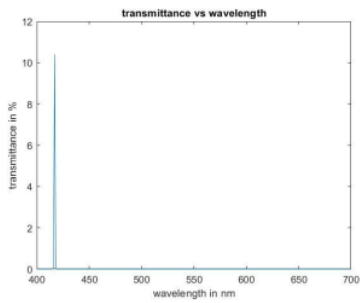
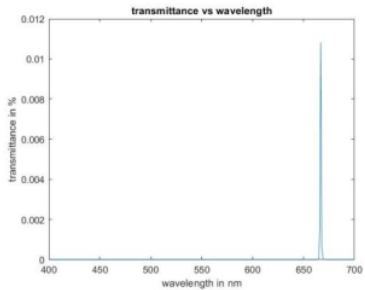
CHAPTER 5

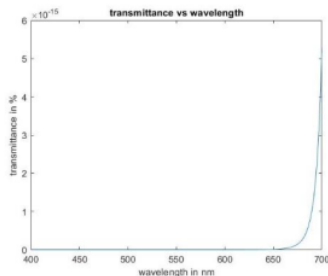
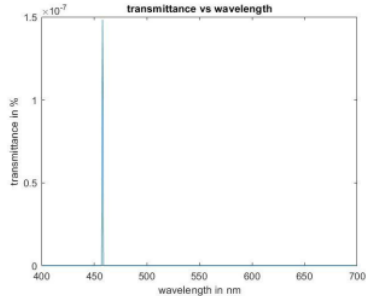
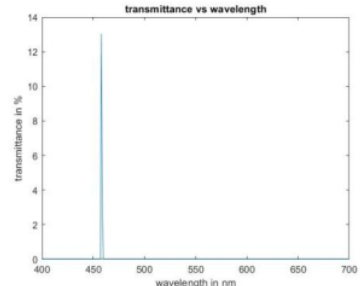
RESULT AND PERFORMANCE ANALYSIS

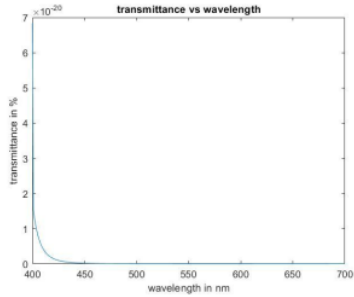
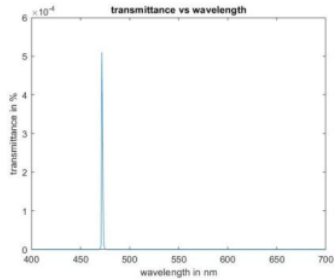
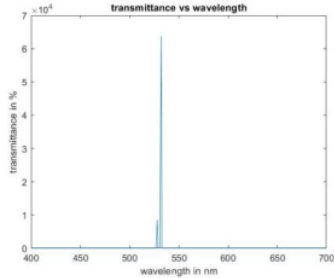
Many combinations were experimented by varying the thickness of higher and lower refractive index, but none of them produced an appropriate peak in our desired transmittance. All the inappropriate results are attached below in a tabular column which were obtained during the process.

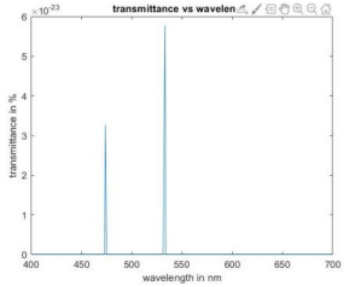
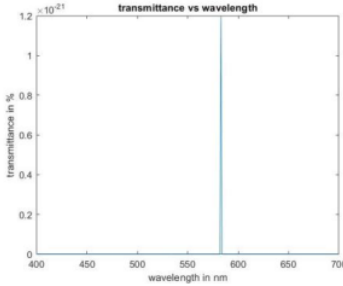
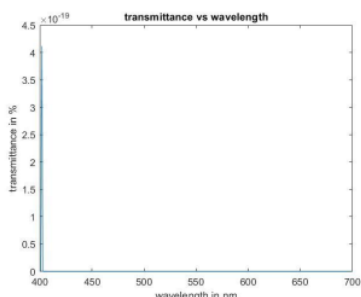
TABLE 1.1 PERFORMANCE ANALYSIS

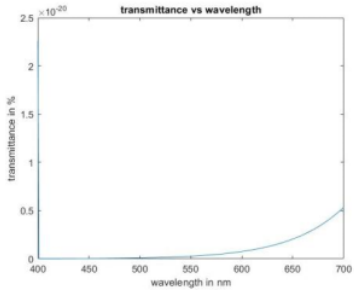
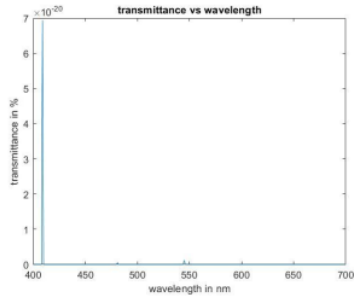
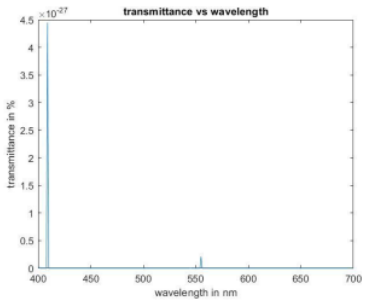
wavelength	Refractive index of SiO ₂ and TiO ₂	Th – TI ratio	No. of layers	Output Waveforms
4647nm	1.4565 (SiO ₂) 2.7771 (TiO ₂)	100:8	4	x=556 y=2789 
4647nm	1.4565 (SiO ₂) 2.7771 (TiO ₂)	105:15	4	X=583 Y=0.002039 

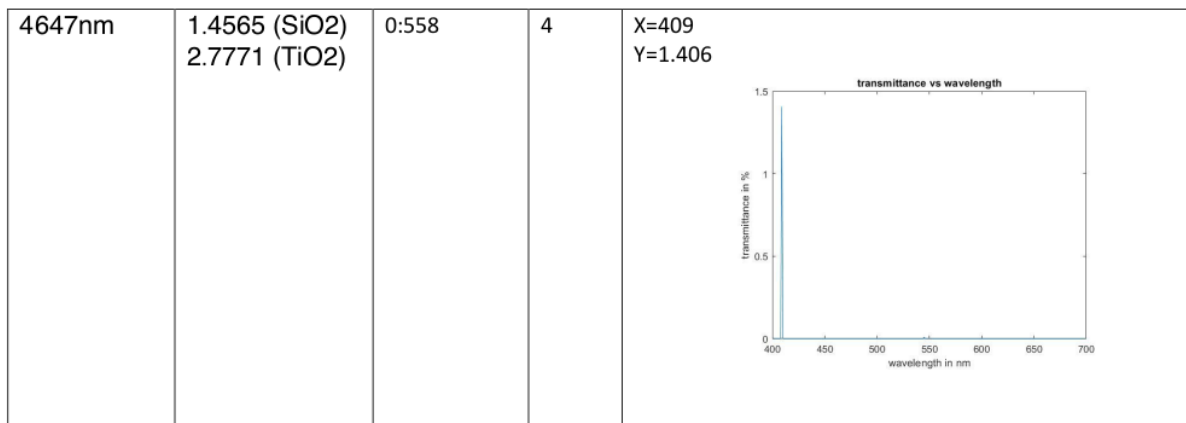
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	145:15	4	X=403 Y=2.806 e ⁻⁰⁶ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	150:5	4	X=417 Y=10.4 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	120:15	4	X=667 Y=0.01082 

4647nm	1.4565 (SiO2) 2.7771 (TiO2)	135:15	4	X=700 Y=5.253 e ⁻⁰⁷ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	165:25	4	X=458 Y=1.483 e ⁻⁰⁷ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	165:5	4	X=458 Y=13.04 

4647nm	1.4565 (SiO2) 2.7771 (TiO2)	65:35	4	X=400 Y=6.832 e ⁻²⁰ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	85:15	4	X=472 Y=0.0005098 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	95:5	4	X=532 Y=63790 

4647nm	1.4565 (SiO2) 2.7771 (TiO2)	256:545	4	X=533 Y=5.777 e ⁻²³ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	420:545	4	X=583 Y=1.196 e ⁻²¹ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	4200:55	4	X=402 Y=4.118 e ⁻¹⁹ 

4647nm	1.4565 (SiO2) 2.7771 (TiO2)	26:55	4	X=700 Y=5.342 e ⁻²¹ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	260:558	4	X=409 Y=6.936 e ⁻²⁰ 
4647nm	1.4565 (SiO2) 2.7771 (TiO2)	2600: 558	4	X=409 Y=4.445 e ⁻²⁷ 



As per the proposed methodology, MATLAB was used as the platform to design an optical bandpass filter using SiO₂ and TiO₂ oxide materials. By changing various combinations of t_h and t_l , the perfect output was presented as a linear progressing peak in the bandpass filter with transmittance of 94.15% with a thickness values as 82nm and 8nm with wavelength of 4647nm.

WAVELENGTH = 456 nm

TRANSMITTANCE = 94.15%

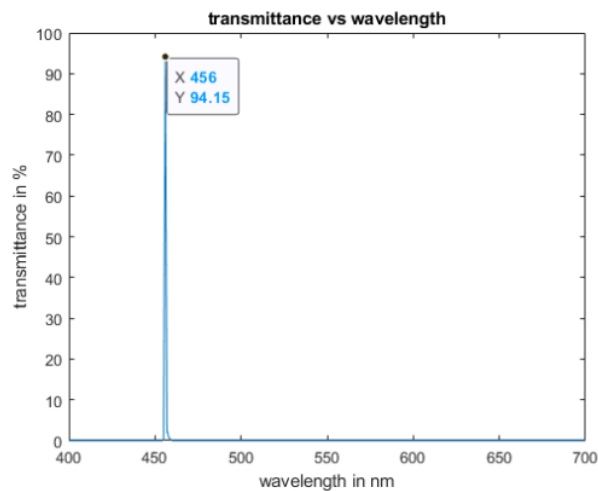


Fig 1.4 Output Waveform

CHAPTER 6

CONCLUSION

Thus, our conclusion describes that our project is to design an optical band pass filter to fabricate a multilayer structure using oxide materials. After analysing so many varieties of oxide materials with their refractive index, we have chosen TiO₂ and SiO₂ into account to work with. A glass substrate is used for fabricating the materials together. Once we have chosen the two materials. The next step is to design the filter using MATLAB software, in which we have got the required parameters in the source code as input and the output graph with wavelength(nm) and transmittance (%) in their X and Y axis respectively. The wavelength is set as 4647nm and their refractive index is set according to the wavelength. The thickness of the higher and lower refractive index is altered in such a way to get the best transmittance below 100. We tried out so many combinations by varying the thickness values with setting up the wavelength as constant. But none of them provided an appropriate peak in our desired wavelength. And at last, we have got our desired transmittance at 94.15% at a wavelength of 456 nm with thicknesses as 82nm and 8nm. And thus we got out output wavelength as desired.

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