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Optimization of Dielectric Parameters for the Design of Optical Bandpass Filters

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Abstract - *With the advent of technology, it is possible to design thin film optical bandpass filters for the desired wavelength and Full-Width Half Maximum (FWHM). A stack of high and low refractive index thin films of suitable thickness can result in the desired wavelength (as the amplitude of other wavelengths are attenuated and amplitude of the desired wavelength is amplified). The choice of the dielectric material, the thickness of the dielectric materials, and the stacking options of these dielectric materials affect the interference pattern. The proposed research work aims at developing optimization techniques for the selection of thin films and the number of layers to be deposited. In this paper, the design of the H alpha filter (656.3 nm), H beta (486.1 nm), and Carbon III (464.7nm) is discussed. The dielectric materials are Magnesium Fluoride and Zinc Sulphide. The impact of stacking and thickness on the attenuation of wavelengths is also studied.*

Keywords — *Central Wavelength (CWL), H alpha, H Beta, Full Wave Half Maximum (FWHM).*

I. INTRODUCTION

In nuclear fusion reactors, it is necessary to retrain the plasma within the chamber for a fixed duration of time. Hence, the plasma should remain unchanged in its form to avoid problems in the generation of power. However, due to unpredictable reasons, disruption does occur in plasma. These disruptions result in Hα, Hβ, and c3 emissions. Hence, the filters are to identify which atom is emitted, the amount of emission [27] and to avoid disruption. The optical bandpass filters are used to identify the emitted atoms since they can be used in the visible range of light (400-700nm). From the color of emitted atoms, the identification of emission can be made. For example, if the green color is emitted, it indicates that the wavelength lies between 495nm-570nm in the same way each color denotes a particular range of wavelength.

The major change lies in designing the optical bandpass filter in the nanometer range is to identify the material which can be used for filter design, where the material should not change its properties in the reactor. The next lies in the thickness of the filter; when the thickness of the filter is varied, then the amount of emission also varies. Hence, the thickness of the filter should be carefully determined to avoid the unwanted wavelength passing through the filter. The other is to identify the number of layers of coating that need to be done to design the filter. The two materials needed to be used as the high and low refractive index in the coating to form the number of layers in the filter design over the substrate to propagate the wavelength of H α (656.3nm), H β (486.1nm), and c3 (464.7nm) emission.

II. LITERATURE SURVEY

Pimenta et al. (2015) used Magnesium Oxide, Titanium Oxide, and Silicon Dioxide, Titanium Oxide combinations for the design of narrowband filters for biological systems. R. Kitsomboonloha et al. (2011) proposed a technique for varying the transmittance range by tuning the Plasmon characteristics. Gaillan H. Abdullah et al. (2020) used Titanium Oxide, and Silicon Dioxide for the design of filters for two sets of wavelengths. D. M. Beggs et al. (2009) proposed theoretical aspects for the design of a square-shaped transmission band. Saeed Al Rashid (2015) designed a narrow bandpass filter with Zinc Sulphide and Cryolite. He observed that the transmittance decreases as the number of layers in the stack increases.

From the literature is understood that the transmittance and hence the reflectance co-efficient are strongly dependent on the choice of the dielectric, thickness of the dielectric material, and number of stacks on the dielectric

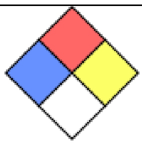
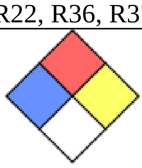
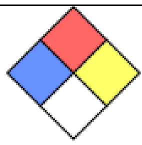
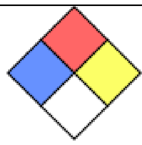
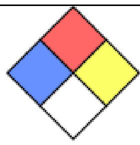
III. PROPOSED METHODOLOGY

In this paper, the number of layers used for the filter is reduced in number, nearly less than 10 layers are used for design, and the thickness of high and low refractive index materials are detected with more number of combinations out of which the best combination can be chosen for optical bandpass filter fabrication. The

A. Selection of Dielectric Material

In the above table, magnesium fluoride (MgF2) is used as a low refractive index material because of its above-mentioned properties. It is highly pure and insoluble in a plasma reactor, which prevents the filter from impurity formation and also avoids the mixing of impurities in the reactor. Zinc sulfide (ZnS) is used as a lower refractive index material because of their insoluble nature in the reactor of plasma, and they are highly suitable for optical coatings. The BK7 glass is used as a Major task in designing an optical bandpass filter lies in selecting the appropriate dielectric materials [1] for coating. The choice of these dielectric materials is based on the characteristics of these individual materials. The characteristics must be in such a way that they are not affected by temperature, moisture, the interaction between the layers, etc.; Table 1 shows the characteristics of different kinds of dielectric materials.

TABLE 1 THE CHARACTERISTICS OF DIFFERENT KINDS OF DIELECTRIC MATERIALS.

Properties	Magnesium fluoride	Calcium fluoride	Silicon dioxide	Zinc sulfide	Lithium fluoride
Chemical formula	MgF2	CaF2	SiO2	ZnS	LiF
Molar mass	62.3018 g/mol	78.07 g·mol−1	60.08 g/mol	97.474 g/mol	25.939(2) g/mol
Solubility product (Ksp)	5.16·10−11	3.9 × 10−11 [1]			
Refractive index (nD)	1.37397	1.4338	1.544 (o), 1.553 (e)[1](p4.143)		1.3915
Structure	Structure	Structure	Structure		
Crystal structure	Rutile (tetragonal), tP6	cubic crystal system, cF12[2]	Coordination geometry: Tetrahedral (Zn2+) Tetrahedral (S2−)		Cubic
Space group	P42/mnm, No. 136	Fm3m, #225			Molecular shape: linear
Thermochemistry	Thermochemistry	Coordination geometry; Ca, 8, cubic F, 4, tetrahedral	Thermochemistry	Thermochemistry	Thermochemistry
Hazards	Hazards	Hazards	Hazards	Hazards	Hazards
R-phrases	R20, R22	R20, R22, R36, R37, R38			
NFPA 704	 0 3 0	 0 0 0	 0 0 0	 0 1 0	 0 2 0

B. Determining the Stack Order and Thickness of Thin Film Coating in Filters

The order of the stack and thickness of each layer can be determined from mathematical models through an iterative procedure. The following is the algorithm to find the transmittance and reflection coefficient of the required wavelength. From that, the absolute value of co-efficient used as a Major task in designing an optical bandpass filter lies in selecting the appropriate dielectric materials [1] for coating. The choice of these dielectric materials is based on the characteristics of these individual materials. The characteristics must be in such a way that they are not affected by temperature, moisture, the interaction between the layers, etc.; Table 1 shows the characteristics of different kinds of dielectric materials.

The refractive indices for each required wavelength of the dielectric material along with the substrate are constant values that are already available in existence.

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Algorithm:

Step 1: Choose the dielectric materials
Step 2: Initially begin with high refractive index material
Step 3: Keep the thickness of the material constant

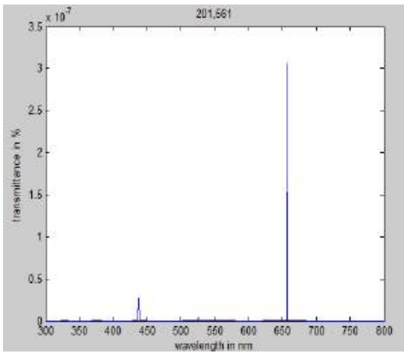
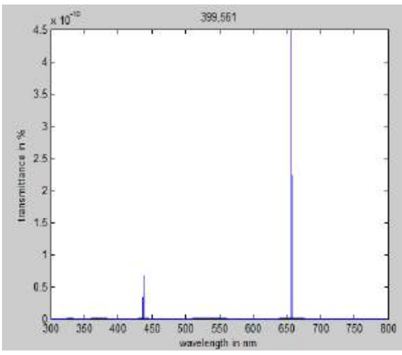
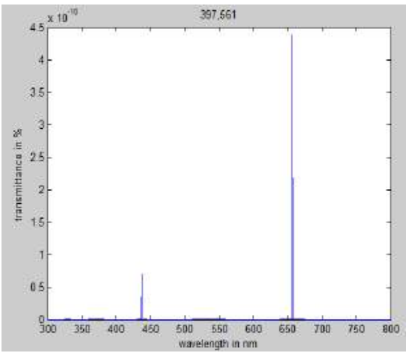
Step 4: Iteratively change the thickness of the other material and determine the transmittance and reflective co-efficient

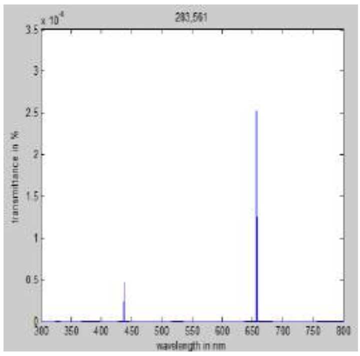
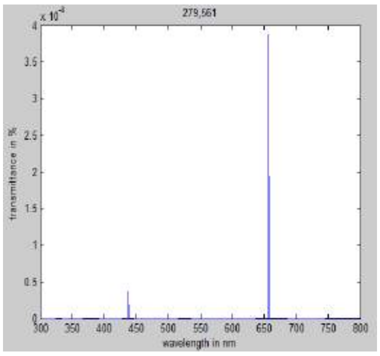
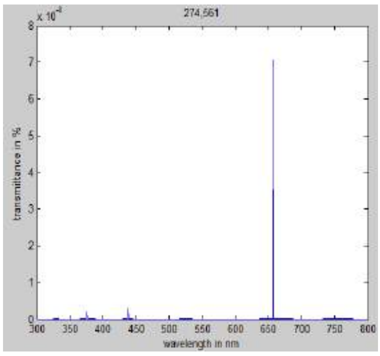
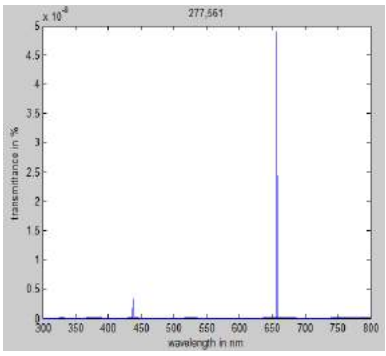
Step 5: If the transmittance is within the acceptable range for the desired wavelength, stop the process. Else continue with step 4.

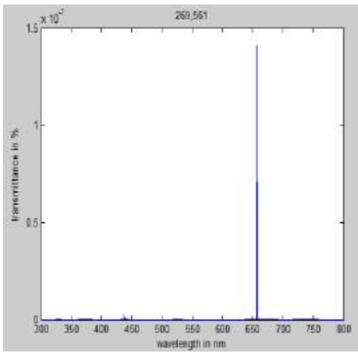
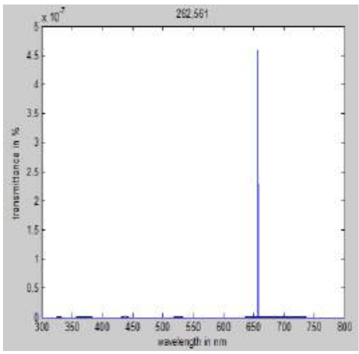
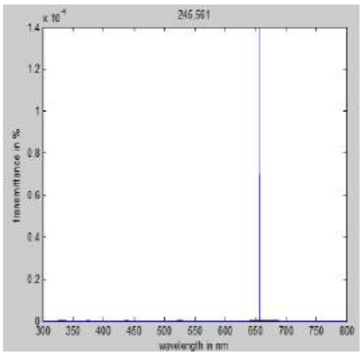
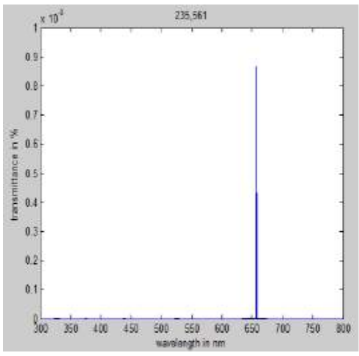
IV. RESULTS AND DISCUSSION

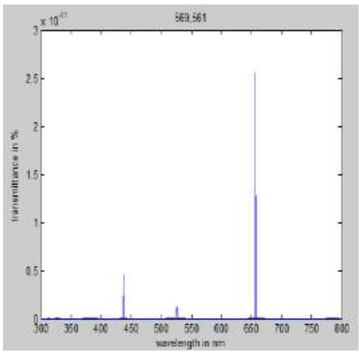
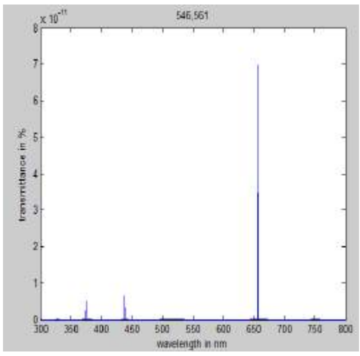
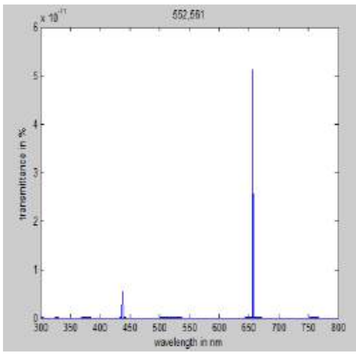
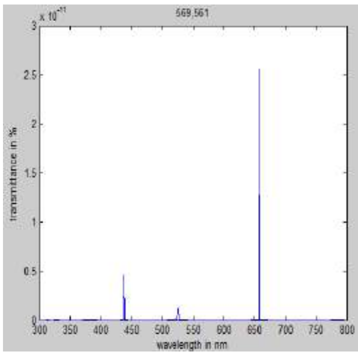
The obtained outputs for each required wavelength of H alpha, H beta, and C III emission are given in table 2,3,4. Here, a different combination of thickness values is obtained for each wavelength. The same combination of layers of low and high refractive index is used for the coating of the optical bandpass filter. Nearly 1000 output waveforms were obtained for each wavelength.

TABLE 2. OUTPUT CHARACTERISTIC OF H ALPHA EMISSION

H APLHA WABVELENGTH (656.3nm)			
s.no	Tl	Th	Output obtained wavelength
1.	201	561	
2.	399	561	
3.	397	561	

H APLHA WABVELENGTH (656.3nm)			
s.no	Tl	Th	Output obtained wavelength
4.	283	561	
5.	279	561	
6.	274	561	
7.	277	561	

H APLHA WABVELENGTH (656.3nm)			
s.no	Tl	Th	Output obtained wavelength
8.	269	561	
9.	262	561	
10.	245	561	
11.	235	561	

H APLHA WABVELENGTH (656.3nm)			
s.no	Tl	Th	Output obtained wavelength
12.	569	571	
13.	546	561	
14.	553	571	
15.	569	561	

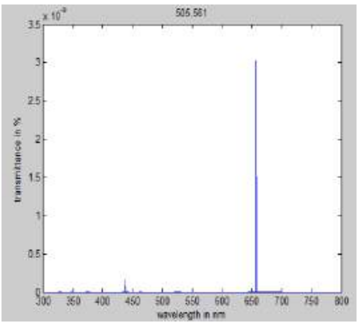
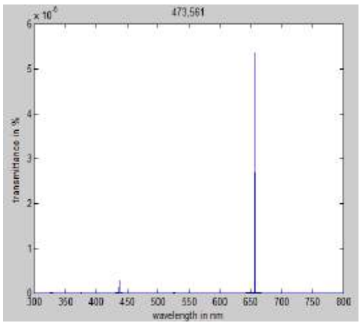
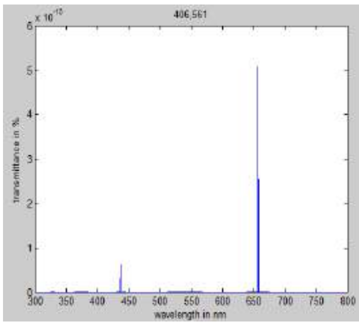
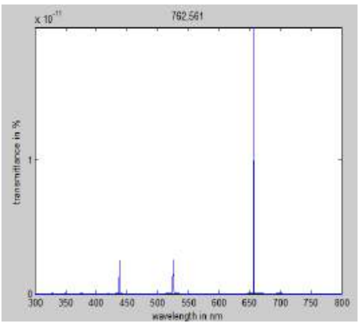
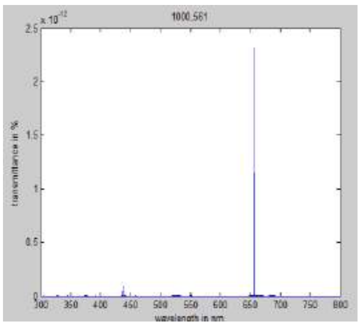
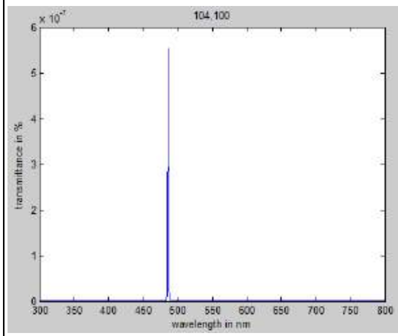
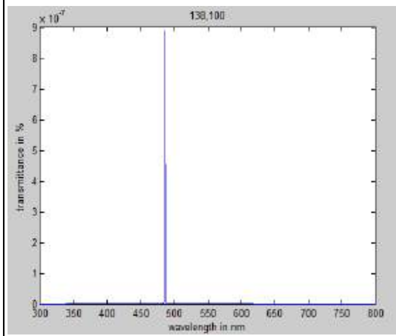
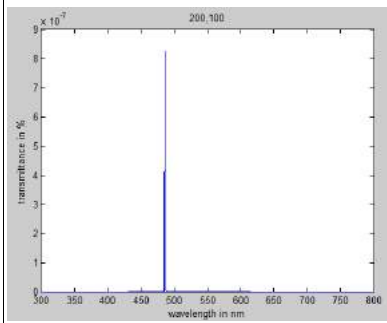
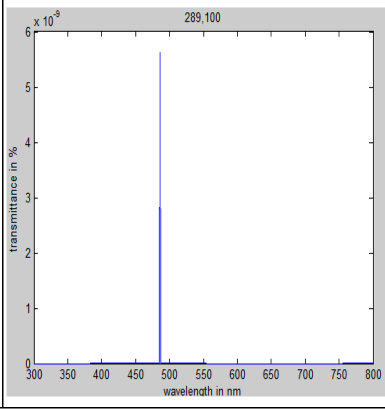
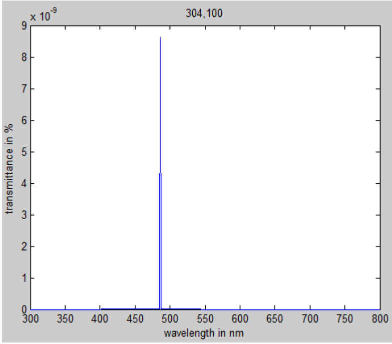
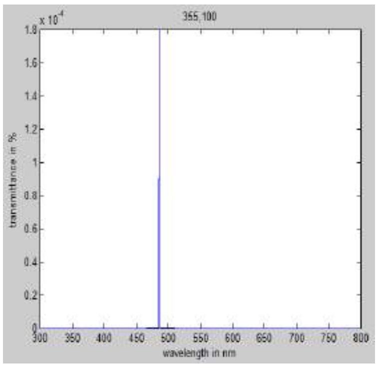
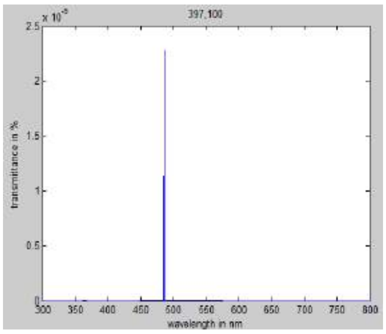
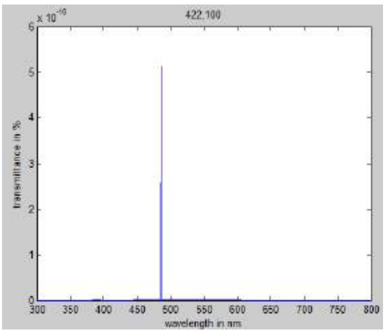
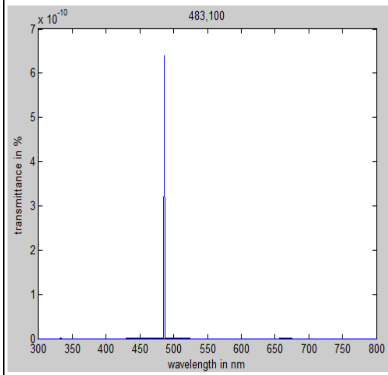
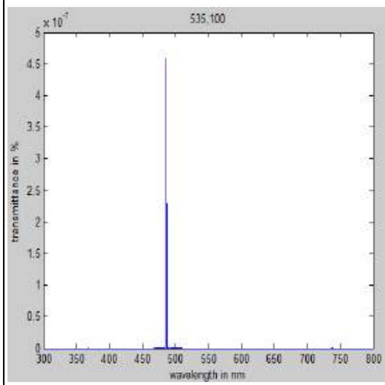
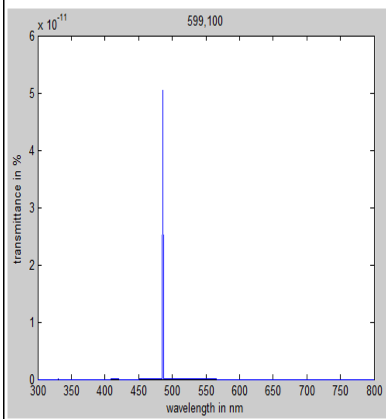
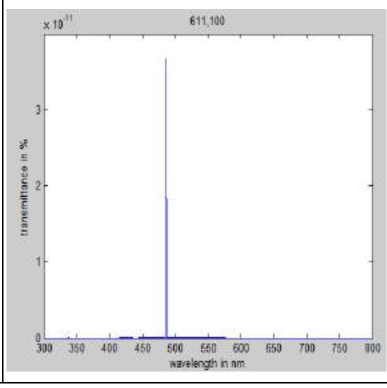
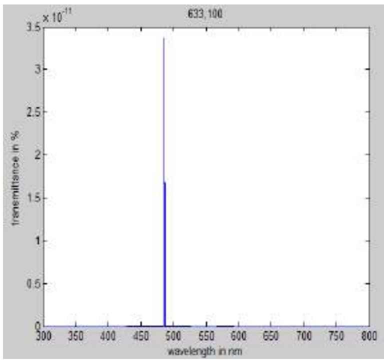
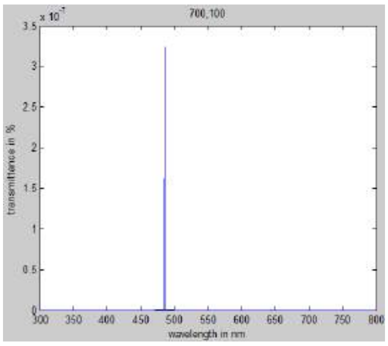
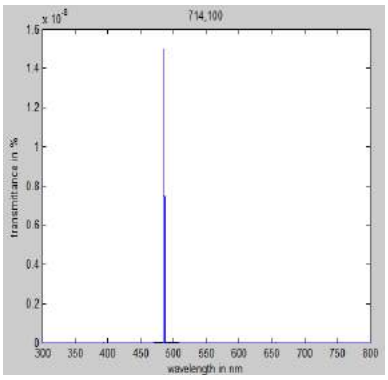
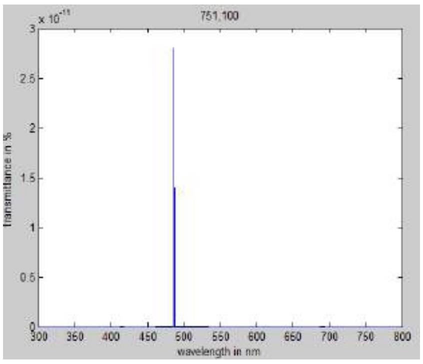
H APLHA WABVELENGTH (656.3nm)			
s.no	Tl	Th	Output obtained wavelength
16.	505	561	
17.	473	561	
18.	406	561	
19.	762	561	
20.	1000	561	

TABLE 3. OUTPUT CHARACTER ISTIC OF H BETA EMISSION

H beta emission (486.1nm)			
S.no	Tl	Th	Output wavelength for h beta
1.	104	100	
2.	138	100	
3.	200	100	
4.	289	100	

H beta emission (486.1nm)			
S.no	Tl	Th	Output wavelength for h beta
5.	304	100	
6.	355	100	
7.	397	100	
8.	422	100	

H beta emission (486.1nm)			
S.no	Tl	Th	Output wavelength for h beta
9.	483	100	
10.	535	100	
11.	599	100	
12.	611	100	

H beta emission (486.1nm)			
S.no	Tl	Th	Output wavelength for h beta
13.	633	100	
14.	700	100	
15.	714	100	
16.	751	100	

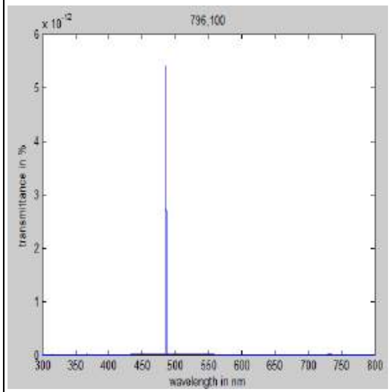
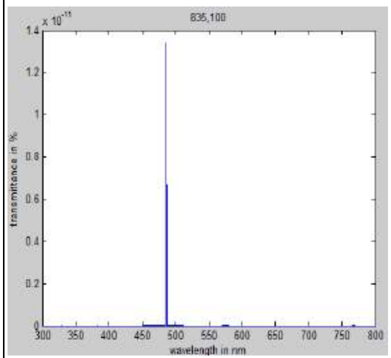
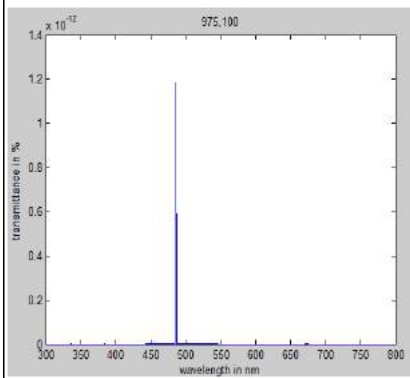
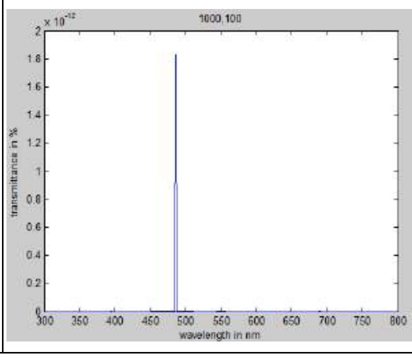
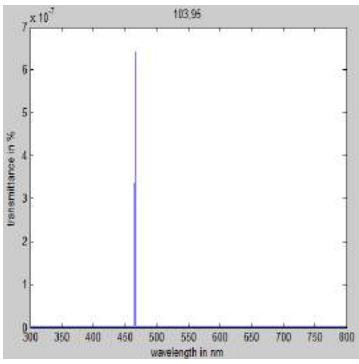
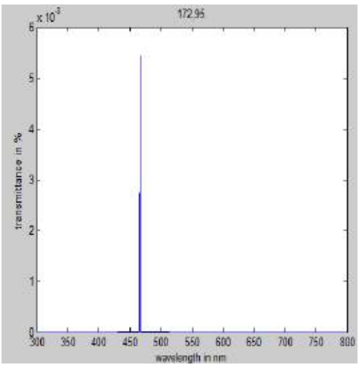
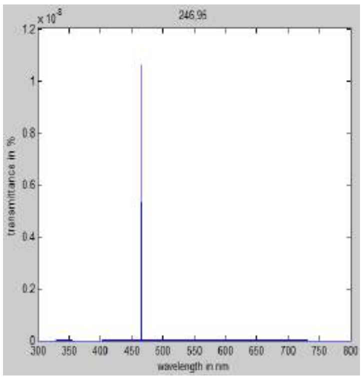
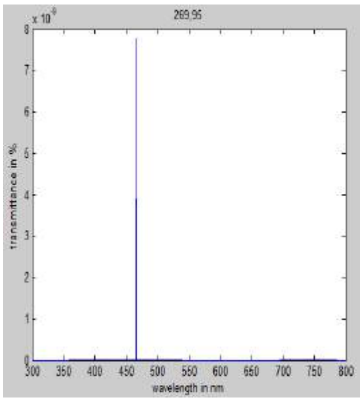
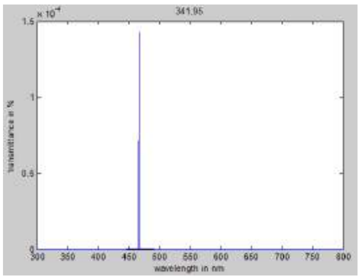
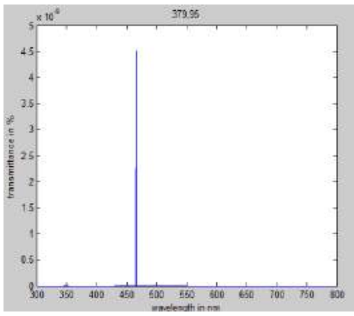
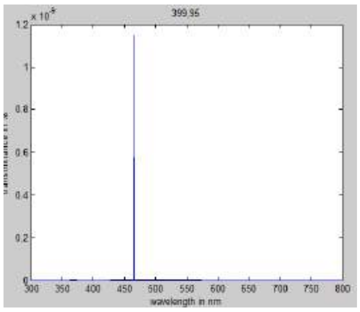
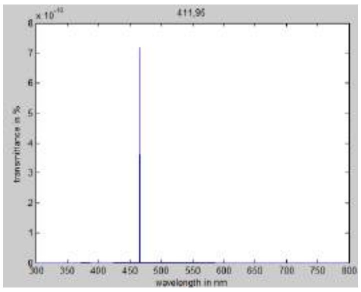
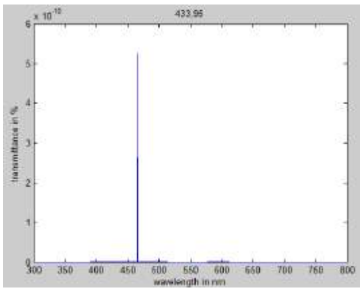
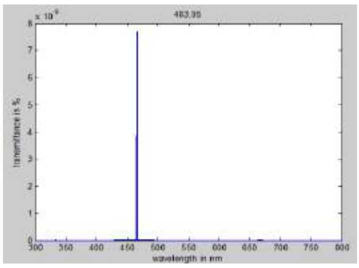
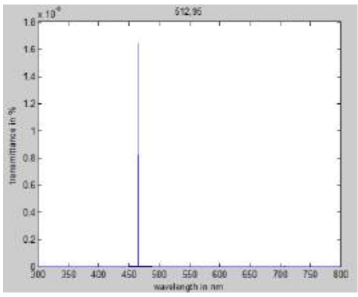
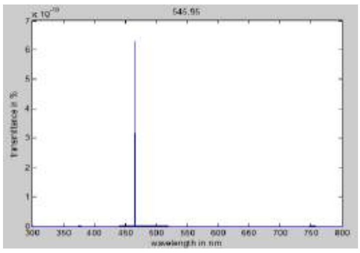
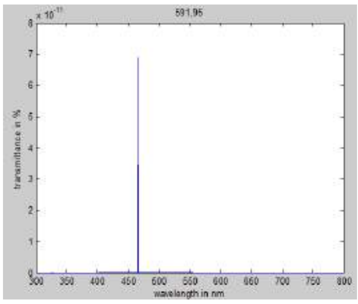
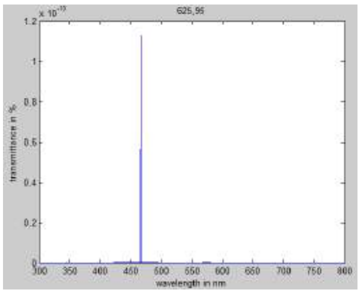
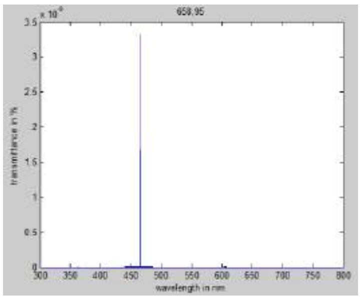
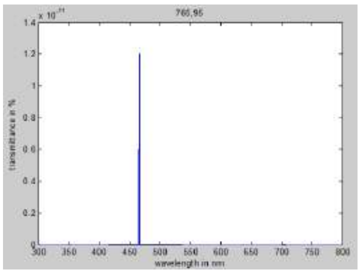
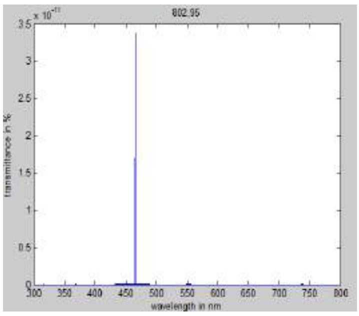
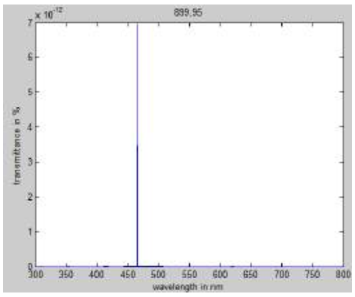
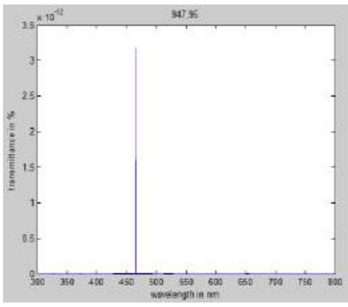
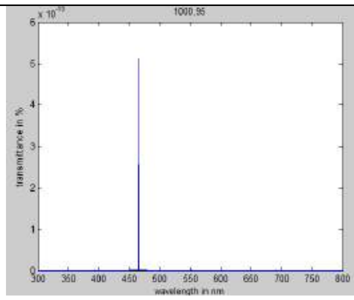
H beta emission (486.1nm)			
S.no	Tl	Th	Output wavelength for h beta
17.	796	100	
18.	835	100	
19.	975	100	
20.	1000	100	

TABLE 4. OUTPUT CHARACTERISTIC OF C3 EMISSION

carbon emission (464.7nm)			
s.no	tl	th	The output waveform of c3 emission
1.	103	95	
2.	172	95	
3.	246	95	
4.	269	95	
5.	341	95	
6.	379	95	
7.	399	95	
8.	411	95	
9.	433	95	
10.	483	95	

carbon emission (464.7nm)			
s.no	tl	th	The output waveform of c3 emission
11.	512	95	
12.	545	95	
13.	591	95	
14.	625	95	
15.	658	95	
16.	765	95	

carbon emission (464.7nm)			
s.no	tl	th	The output waveform of c3 emission
17	802	95	
18.	899	95	
19.	947	95	
20.	1000	95	

V. CONCLUSIONS

In this paper, Magnesium Fluoride and Zinc Sulphide are chosen as the dielectric materials for the design of H alpha, H beta, and Carbon III filters. The impact of the choice, thickness, and stack order of dielectric material on the transmittance and reflection coefficient is studied. The various combinations of thickness for each wavelength of emission are obtained with more than a thousand waveforms. Out of which, the best thickness value can be utilized for the fabrication of optical bandpass filters. The required wavelengths of H Alpha, H Beta, and C3 emission are obtained through the simulation results and verified in the visible range of light (400-700nm). As the deposition of Magnesium Fluoride and Zinc Sulphide results in undesirable residues, other dielectric materials can also be explored.

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