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FILTERS TO THE BRAZILIAN EXPERIMENTAL SOLAR TELESCOPE: TEST REPORT.

Jenny Marcela Rodríguez Gómez
Wellington Guimarães
Braulio Fonseca Carneiro de Albuquerque
Luís Eduardo Antunes Vieira
Alisson Dal Lago

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1. INTRODUCTION

The optical filters can be used to attenuate or enhance an image, transmit or reflect specific wavelengths, and/or split an image into two identical images with controlled brightness levels relative to each other. A variety of filters are available, but in the field of the Brazilian Experimental Solar Telescope project four kind filter were studied, that are the Narrow band, bandpass, hot mirror and dichroic filters.

The narrowband bandpass and dichroic filters have been used in different fields that is fluorescence microscopy, flow cytometry, Raman spectroscopy, LIDAR, and spectral imaging. In this case will be used in the Brazilian Experimental Solar Telescope which is developed at INPE in the Space Geophysics Division (DID-DGE).

The Interference filters have the physical effect of the interference of light waves. Optical filters transmit a certain wavelength band, while other wavelength bands are being blocked. This selective transmittance of an optical filter is characteristic and therefore a quantitative measure of the optical filter. Bandpass filters transmit a certain wavelength band, i.e. are characterized by having a range of high transmittance (passband) bounded both towards the shorter and longer wavelengths by ranges of low transmittance. A special case is the edge filters Edge filters are characterized by having a range of high transmittance (passband) followed by a range of low transmittance (blocking range) or vice versa. There are two types of edge filters:

•Shortpass filters pass a shorter wavelength band i.e. have a range of high transmittance of shorter wavelengths than the blocking range.

•Longpass filters, on the other hand, pass a longer wavelength band, i.e. have a range of high transmittance of longer wavelengths than the blocking range.

These filters are usually characterize calculating the Full Width at Half Maximum (FWHM) were calculated in each filter when is possible and compared to theoretical values. Other value is calculated, it is the slope factor:

$$\%slope= \frac{\lambda 90\%\ of\ peak - \lambda 10\%}{\lambda 10\%}\ x100$$

this factor is related to the rate of change in the filter transmission from cut-off or cut-on, where λ90% of peak is the wavelength at which the transmittance is 90% of τmax (correspondingly λ10% wavelength where transmittance is 10% of τmax). τmax is the maximum value of spectral transmittance within the passband (peak transmittance)[1].

In general interference filters and a special type edge filters are characterize of short wavelengths pass and long wavelengths pass, which typical spectral curves are shown in Figure 1 and Figure 2.

[1]http://www.schott.com/d/advanced_optics/8c2cb5d1-4fa1-4b55-ad43-fef20ad89ad4/1.0/schott-optical-filters-2015-catalog-complete-en.pdf

Figure 1. Typical edge filter spectral curves [2]

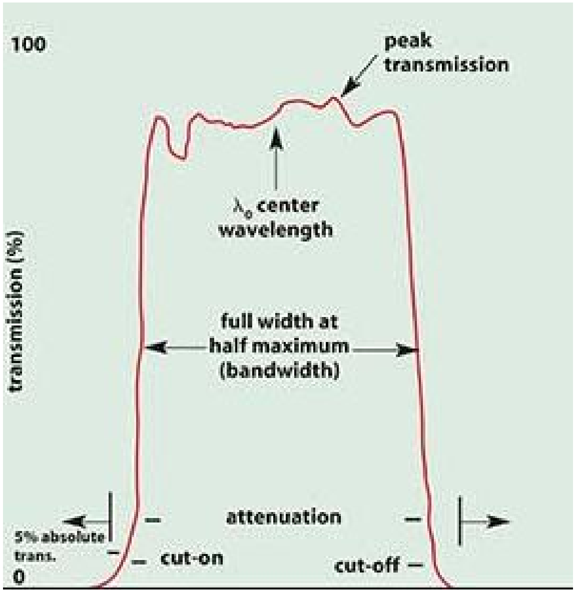
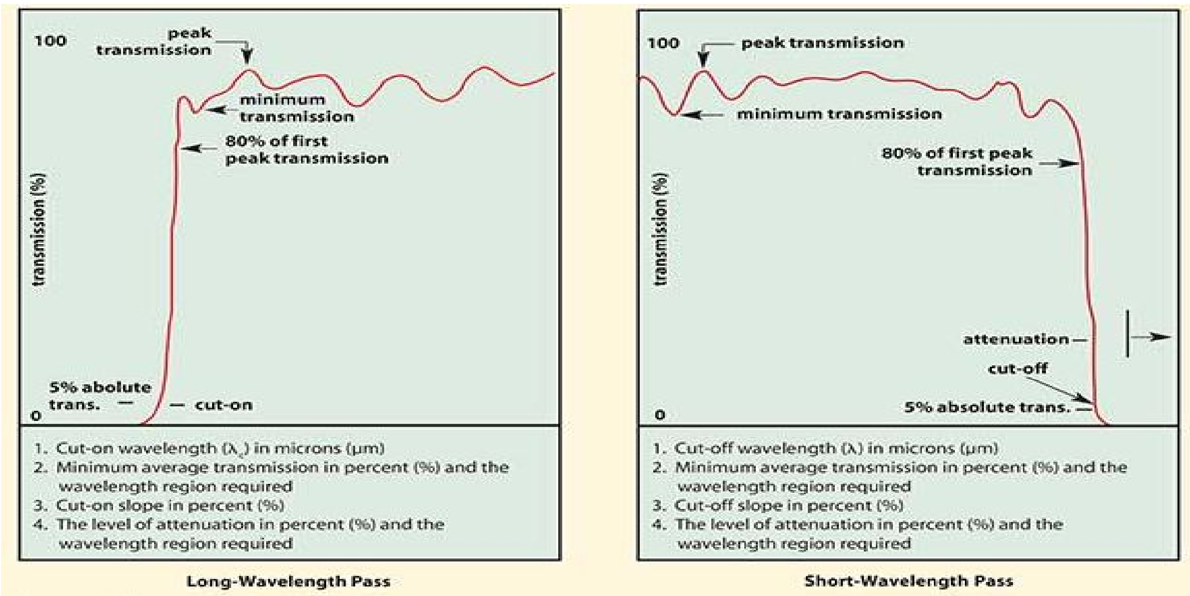


Figure 2. Long wavelength pass and short wavelength pass filters some characteristics[3].



The Ultra-narrowband optical filters made using modern plasma processes offer much improved transmission, temperature stability and out of band blocking as compared to legacy soft coating. As well as for cutting-edge astronomy and instrumentation application. In general Ultra-narrowband filters exhibiting square passbands for the NIR were pioneered during the telecom industry in the 1990's but,

2 https://www.photonics.com/EDU/Handbook.aspx?AID=25441
3 https://www.photonics.com/EDU/Handbook.aspx?AID=25441

until recently, have not been viable in large format sizes. Ultra-narrowband optical bandpass filters demonstrates the effect of shift with increasing temperature for a 659.2nm centered ultra-narrow. This particular filter exhibits an average shift < 4.2pm/°C from room temperature (27°C) to 105 °C. Lower values of temperature shift can be created on request by optimizing the design parameters[4].

The dichroic filters allows translate into minimal loss of light intensity and optimal instrument performance. It can be designed to work at any angle, and are ideal for use in applications such as fluorescence microscopy, flow cytometry, Raman spectroscopy. Also it allow to minimize distortion and maintain optimal performance in imaging. Ultra-flat dichroic filters can be custom specified with better than 0.1 wave PV / inch flatness when measured at 632.8 nm[5].

Some kinds of filter was analyzed in this report, for these reason the manufacturer informations are necessary. Some definitions[6] are need of analyze the measure in each filter:

Center Wavelength (CWL): The center of the passband for a bandpass filter. Another common definition is the average of the 50% of peak of each edge of a bandpass filter.

Optical Density (OD): The log (base 10) of transmittance (T). (T on a zero to unity scale).

$$\mathbf{OD = -log_{10}(T/100)}$$

A high optical density value indicates very low transmission, and low optical density indicates high transmission[7].

Ripple: Variations in transmission in the passband.

Transmitted Wavefront Error (TWE): Distortion of the wavefront of a plane wave as it transmits through a filter. TWE is measured using an interferometer and the units are waves.

Angle of Incidence (AOI): The angle at which a filter is tilted relative to the primary ray. For example, an AOI of 0 means the primary ray is perpendicular to the plane of the filter.

[4] https://www.alluxa.com/learning-center/item/58-ultra-narrowband-optical-bandpass-filters-with-large-format-and-improved-temperature-stability

[5] http://www.alluxa.com/optical-filters/ultra-series-thin-films/dichroic-filters

[6] https://www.alluxa.com/white_papers/Flat-Top-Ultra-Narrow-Bandpass-Optical-Filters-Using-Plasma-Deposited-Hard-Oxide-Coatings.pdf

[7] https://www.edmundoptics.com/resources/application-notes/optics/optical-filters/

The characteristics of each filter are present following:

Table 1. Ultra Narrow band filter Lot 10-4080, information provided by the manufacturer: 0-2.4° AOI / Collimated, 630.352-0.6 OD4 4-Cavity Ultra Narrow 34 mm diameter on 5.93 mm thick FLAT Fused Silica substrate

Quantity	Characteristics
3 filters	**CWL**: 630.352 nm ± 0.1 nm (@ 0° AOI) **FWHM**: ≤ 0.6 nm (to be confirmed by design*) **Tabs** > 90% from 630.220 – 630.260 nm (for all angles) **Ripple** < 3% (for p & s –polarizations over full angle range) **90% Bandwidth** ≥ 0.465 nm* **3% Bandwidth** < 0.845 nm* **ODabs** > 4 blocking from 450 – 1000 nm out-of-band **TWE** < 0.125 waves P-V over the CA @ 632.8 nm (focusing / power term can be ignored) $\mathbf{n_{eff}}$ > 1.7* **Clear Aperture (CA)** > 27 mm

Table 2. Bandpass filter 4445_630-10 OD3 BP Lot 6-5997, information provided by the manufacturer: 0° AOI / collimated, 630-10 OD3 Bandpass Filter 25.4 mm (+0/-0.2 mm) diameter on 2.98 mm thick Fused Silica

Quantity	Characteristics
3 filters	**CWL**: 630.24 nm nominal **FWHM** < 10 nm **Tabs** > 95% from 630.22 - 630.26 nm Difference between p- and s- polarizations < 2% for angles 0-4.5° Collimated (for above range) **ODabs** > 3 from 400 - 600 nm and 660 - 1000 nm **Typical transition** < 2% as defined from FWHM to OD3 **TWE** < 0.125 waves P-V @ 632.8 nm over CA (power subtracted) **Parallelism** < 30 arc sec **Surface Quality** 40-20 **CA** > 22.86 mm

Table 3. Dichroic filter - 4444_605 LP Dich Lot 7-4697, 45°, information provided by the manufacturer : 45° AOI / Collimated, 605 LP Dichroic 50.8 mm (+0/-0.2 mm) diameter on 5.93 mm thick Flat Fused Silica (#68)

Quantity	Characteristics
3 filters	**Tave** > 93% from 620 - 700 nm (Tabs > 90%) Difference between s- and p- transmission is < 5% from 620 - 700 nm **Rave** > 94% from 470 - 590 nm (Rabs > 90%) **Slope** < 3% as defined between 90% to 10% Transmittance (for Ave Polarization) **TWE** < 0.125 waves P-V @ 632.8 nm over CA (power subtracted) **Parallelism** < 30 arc sec **Surface Quality** 40-20 **CA** > 45.72 mm centered

Table 4. Collimated hot mirror filter - 4443_700 SP Dich Lot 7-4725, 45°, information provided by the manufacturer: 45° AOI / Collimated, Hot Mirror 50.8 mm (+0/-0.2 mm) diameter on 5.93 mm thick Flat Fused Silica (#68)

Quantity	Characteristics
3 filters	**Tave** > 95% from 400 - 690 nm (Tabs > 88%) Difference between s- and p- transmission is < 4% from 450 - 690 nm **Rave** > 97% from 710 - 1200 nm (Rabs > 88%) **Slope** < 3.6% as defined between 90% to 10% Transmittance (for Ave Polarization) **TWE** < 0.125 waves P-V @ 632.8 nm over CA (power subtracted) **Parallelism** < 30 arc sec **Surface Quality** 40-20, best effort to 20-10 over CA **CA** > 45.72 mm centered

In this report was present the results of these tests in the laboratory DEA-ETE, under supervision of Dr. Braulio Fonseca Carneiro de Albuquerque. In the following section the methodology description will be present.

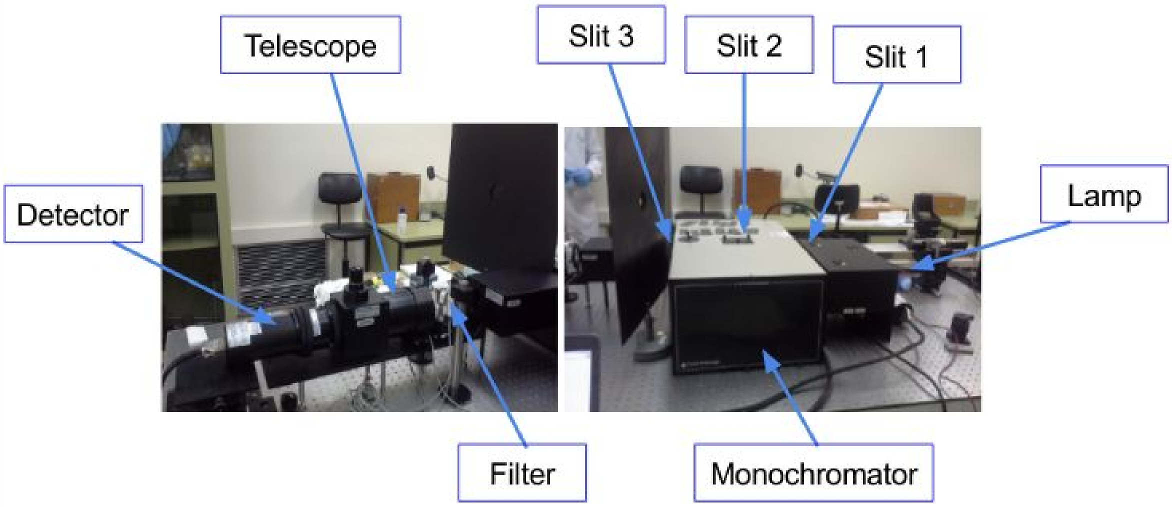
2. METHODOLOGY

The test consisted in measured the transmittance in each filter using the setup shown in Figure 6 and 7. We considered the incident angle at 0° to measure the transmittance in each filter. Also, the clear aperture (CA) was considered from the manufacturer specifications for each filter.

Materials

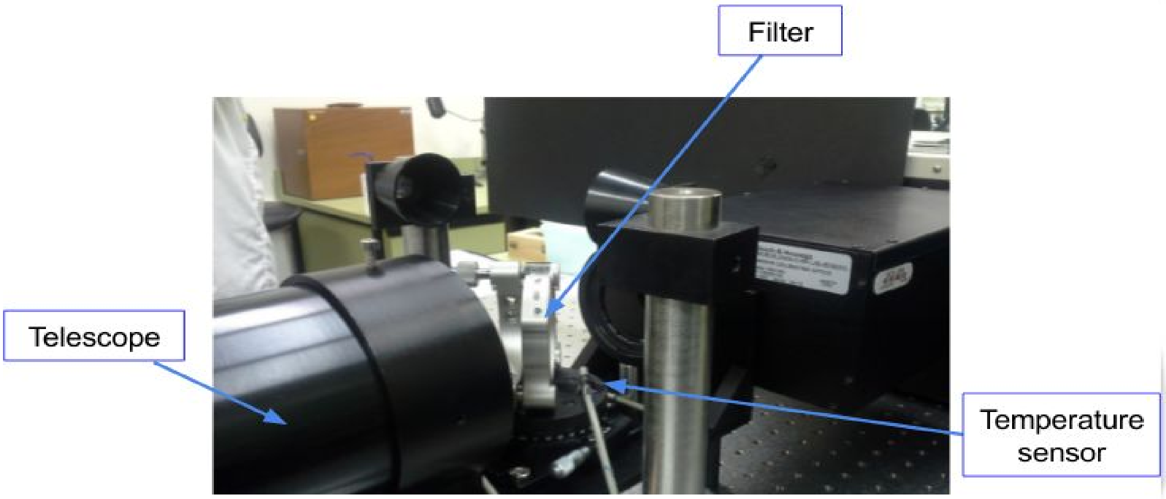
- Telescope
- OL 750-D Monochromator-controller and detector
- OL 410-200 Precision lamp source
- HOBO data logger
- Softwares: OL 750-D and HOBO data logger (4 ext channels)

Figure 3. General view of the workbench and description of the components[8]



[8] This setup was developed to Guimarães W.

Figure 4. Highlight near to the filter setup



An optical filter is a medium that only allows the passage through it of light with certain properties, suppressing or attenuating the remaining light. The attenuation of the filtered signal is measured by the optical transmittance of the filter medium or its inverse, the absorbance. The transmittance is the fraction of incident light with a specific wavelength, which traverses a sample of matter. In this report, we were measuring the transmittance in each filter and the results are present in the following section.

3. ANALYSIS OF RESULTS

The transmittance was measured in each filter and the results are present in this section. It calculates the Full Width at Half Maximum (FWHM) and the center, in all cases where it is possible. The % slope was calculated, 90% bandwidth and 3% bandwidth. The optical density (OD) was calculated to ultra narrow filter and the band pass filter. Also, the data were interpolated for these analyses. The absolute and relative error was calculated in each case, when it is possible. These procedures were obtained using the Matlab software.

3.1. ULTRA NARROW BAND FILTERS: 4446_630.272-0.6 OD4 - LOT 10-4080: 0-2.4° AOI / Collimated, 630.352-0.6 OD4 4-Cavity Ultra Narrow 34 mm diameter on 5.93 mm thick FLAT Fused Silica substrate

Figure 5. Transmittance measured in ultra narrow filter 1. Lot # 10-4080 Envelope 1

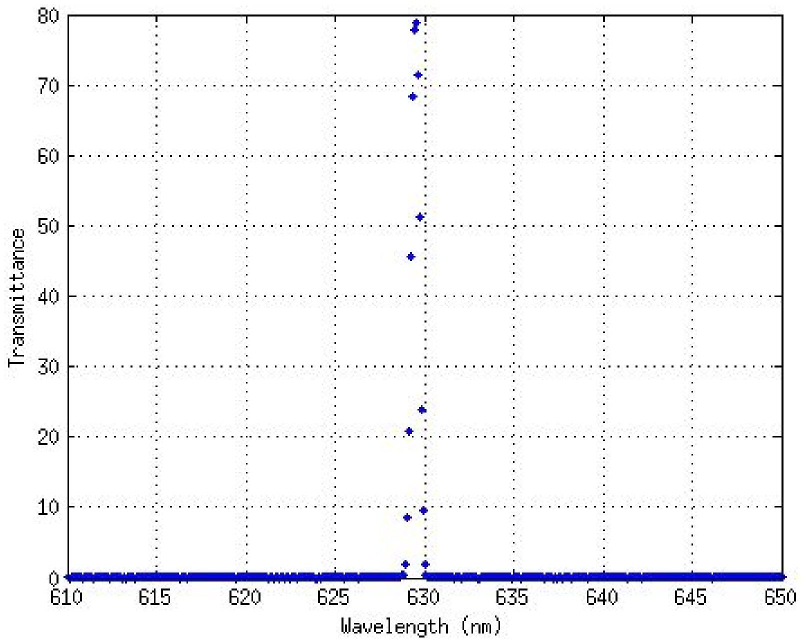


Table 5. Theoretical values, calculated values from measurements of ultra narrow filter 1. Lot # 10-4080 Envelope 1 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	629.5 nm	0.85 nm	0.13 %
Full Width at Half Maximum (FWHM)	0.57 nm	0.56 nm	0.01 nm	1.75 %
Transmittance maximum value	89.92	78.90		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.76 %
3% Bandwidth	0.92 nm	1.1 nm	0.18 nm	19.56 %
OD abs > 4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.15 1.56 4.46		

Figure 6. Transmittance measured in ultra narrow filter 2. Lot # 10-4080 Envelope 12

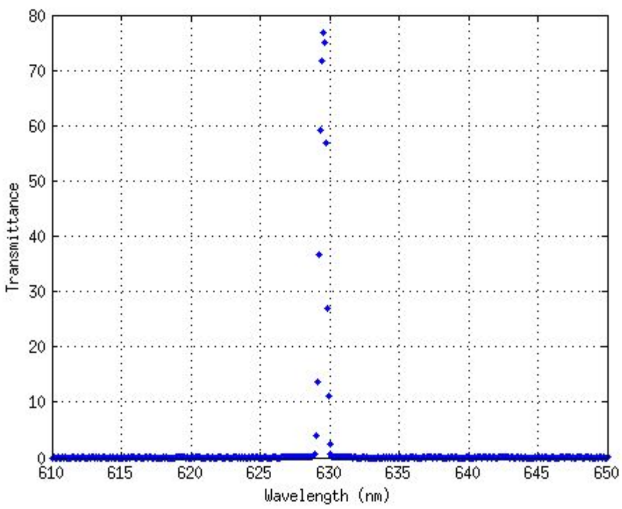


Table 6. Theoretical values, calculated values from measurements of ultra narrow filter 2. Lot # 10-4080 Envelope 12 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	629.5 nm	0.85 nm	0.13 %
Full Width at Half Maximum (FWHM)	0.57 nm	0.55 nm	0.02 nm	3.51 %
Transmittance maximum value		76.82		
90% Bandwidth	0.34 nm	0.20 nm	0.14 nm	41.17 %
3% Bandwidth	0.92 nm	1.00 nm	0.08 nm	8.69 %
OD abs >4 blocking from 450 nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.73 0.74 4.92		

Figure 7. Transmittance measured in ultra narrow filter 3. Lot # 10-4080 Envelope 13

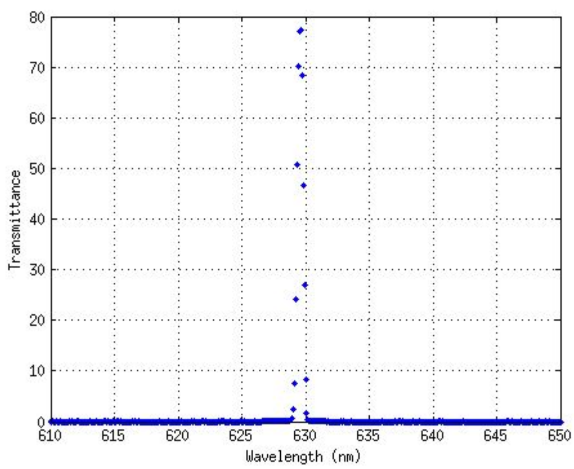


Table 7. Theoretical values, calculated values from measurements of ultra narrow filter 3. Lot # 10-4080 Envelope 13 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	629.6 nm	0.75 nm	0.11%
Full Width at Half Maximum (FWHM)	0.57 nm	0.58 nm	0.01 nm	1.75%
Transmittance maximum value		77.25		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.76%
3% Bandwidth	0.92 nm	1.1 nm	0.18 nm	19.56%
OD abs >4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.44 0.70 4.31		

Figure 8. Transmittance measured in ultra narrow filter 4. Lot # 10-4080 Envelope 105

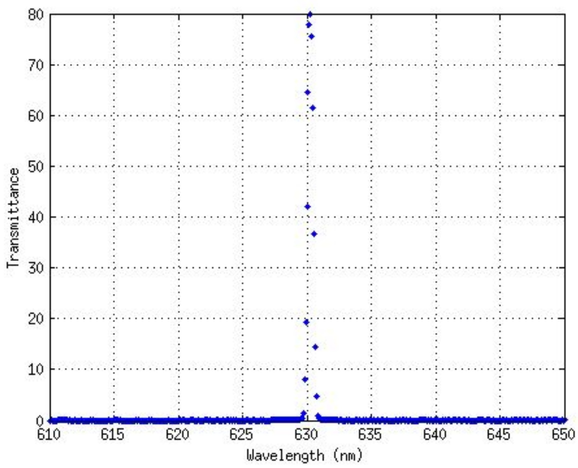


Table 8. Theoretical values, calculated values from measurements of ultra narrow filter 4. Lot # 10-4080 Envelope 105 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	630.3 nm	0.05 nm	0.008%
Full Width at Half Maximum (FWHM)	0.57 nm	0.59 nm	0.02 nm	3.50%
Transmittance maximum value		79.79		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.76%
3% Bandwidth	0.92 nm	1.10 nm	0.18 nm	19.56%
OD abs >4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.56 0.61 5.05		

Figure 9. Transmittance measured in ultra narrow filter 5. Lot # 10-4080 Envelope 108

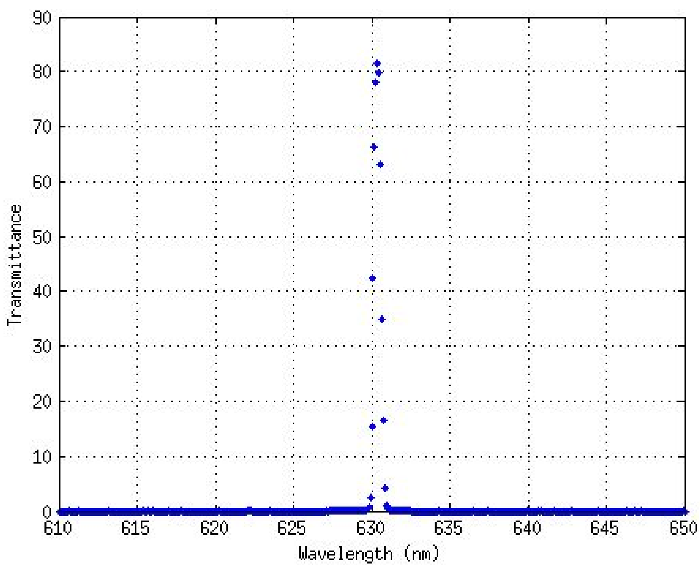


Table 9. Theoretical values, calculated values from measurements of ultra narrow filter 5. Lot # 10-4080 Envelope 108 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	630.4 nm	0.05 nm	0.007%
Full Width at Half Maximum (FWHM)	0.57 nm	0.58 nm	0.01 nm	1.75%
Transmittance maximum value		81.52		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.76%
3% Bandwidth	0.92 nm	1.0 nm	0.08 nm	8.69%
OD abs >4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.03 0.79 4.10		

The last filter of this type is measured three times and the results are present following:

Figure 10. Transmittance measured in ultra narrow filter 6. Lot # 10-4080 Envelope 13 (first measure)

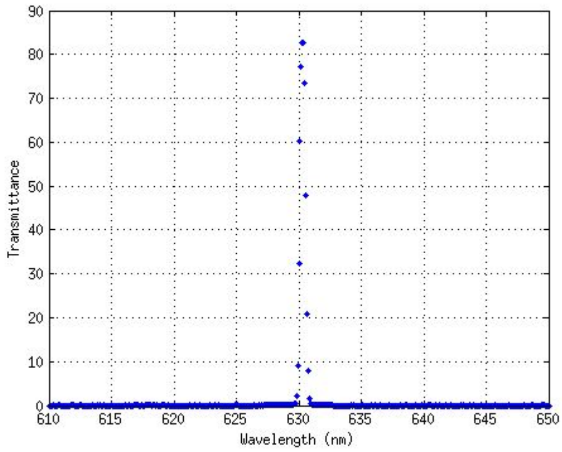


Figure 11. Transmittance measured in ultra narrow filter 6. Lot # 10-4080 Envelope 13 (second measure)

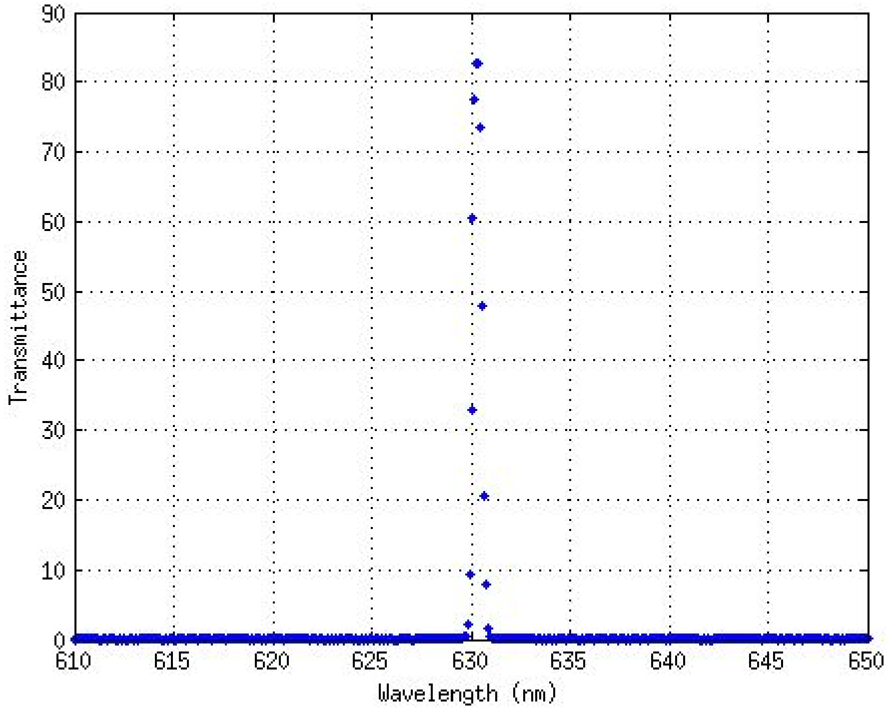


Figure 12. Transmittance measured in ultra narrow filter 6. Lot # 10-4080 Envelope 13 (third measure)

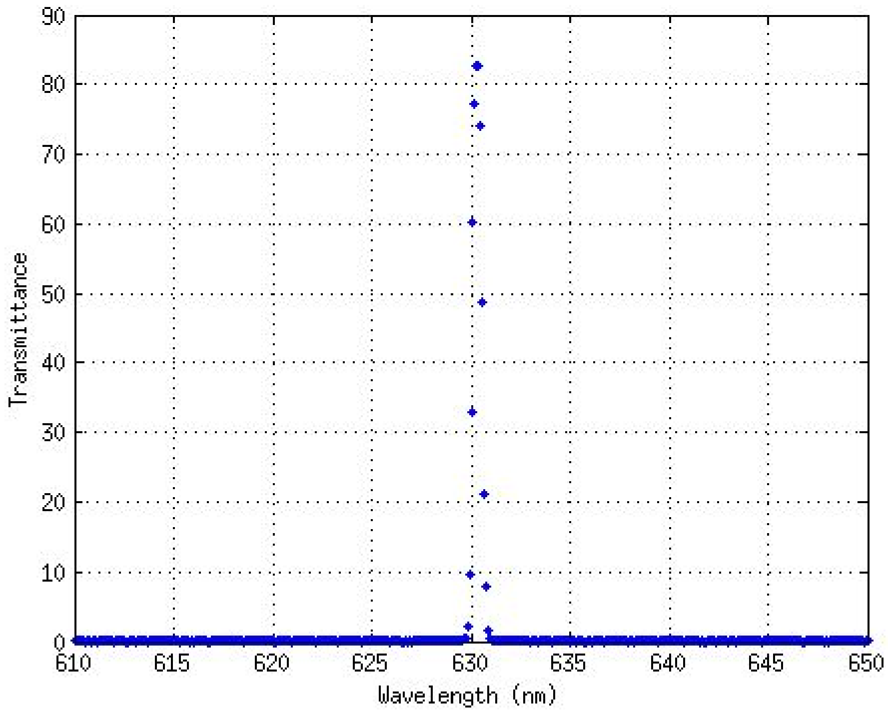


Table 10. Theoretical values, calculated values from measurements of ultra narrow filter 6. Lot # 10-4080 Envelope 13 (first measure) and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	630.3 nm	0.05 nm	0.008%
Full Width at Half Maximum (FWHM)	0.57 nm	0.59 nm	0.02 nm	3.50%
Transmittance maximum value		82.69		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.75%
3% Bandwidth	0.92 nm	1.10 nm	0.18 nm	19.56%
OD abs >4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.58 0.78 4.74		

Table 11. Theoretical values, calculated values from measurements of ultra narrow filter 6. Lot # 10-4080 Envelope 13 (first measure) and error calculation.

	Theoretical values	Calculated values	Absolut e error	Relative error
Center Wavelength (CWL)	630.352 nm ± 0.1	630.3 nm	0.05 nm	0.008%
Full Width at Half Maximum (FWHM)	0.57 nm	0.59 nm	0.02 nm	3.50%
Transmittance maximum value		82.73		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.76%
3% Bandwidth	0.92 nm	1.10 nm	0.18 nm	19.56%
OD abs >4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.74 0.78 4.89		

Table 12. Theoretical values and calculated values from measurements of ultra narrow filter 6. Lot # 10-4080 Envelope 13 (third measure) and error calculation.

	Theoretical values	**Calculated values**	**Absolute error**	**Relative error**
Center Wavelength (CWL)	630.352 nm ± 0.1	630.3 nm	0.05 nm	0.008%
Full Width at Half Maximum (FWHM)	0.57 nm	0.59 nm	0.02 nm	3.50%
Transmittance maximum value		82.68		
90% Bandwidth	0.34 nm	0.30 nm	0.04 nm	11.76%
3% Bandwidth	0.92 nm	1.10 nm	0.18 nm	19.56%
OD abs >4 blocking from 450nm to 627 nm and from 630 nm to 1000 nm	610 nm - 628.8 nm 628 nm - 630 nm 630 nm - 650 nm	4.62 0.77 4.84		

Using the three measures made under the last filter, the standard deviation was calculated to check our results.
The standard deviation of transmittance maximum value σ = 0.0265
The standard deviation of FWHM value σ = 0
The standard deviation 90% Bandwidth σ = 0
The standard deviation 3% Bandwidth σ = 0

Summary

The Center Wavelength (CWL), Full Width at Half Maximum (FWHM), Optical density (OD), 90% and 30% bandwidth are according to values informed by the manufacturer. The ultra narrow band filter have center wavelength (CWL) at 630.272 nm ± 0.1 nm at temperature (23-25°). In these measurements the temperature was chosen at 35° where the filter should have center wavelength (CWL) at 630.352 nm. The error rate is below 20% in each considered cases. The repeatability of the measures confirms our results and validate our experimental setup.

3.2. BANDPASS FILTERS: 4445_630-10 OD3 BP LOT 6-5997: 0 ° AOI / collimated, 630-10 OD3, 25.4 mm (+0/-0.2 mm) diameter on 2.98 mm thick Fused Silica

Figure 13. Transmittance measured in bandpass filter 7. Lot # 6-5997 Envelope 2

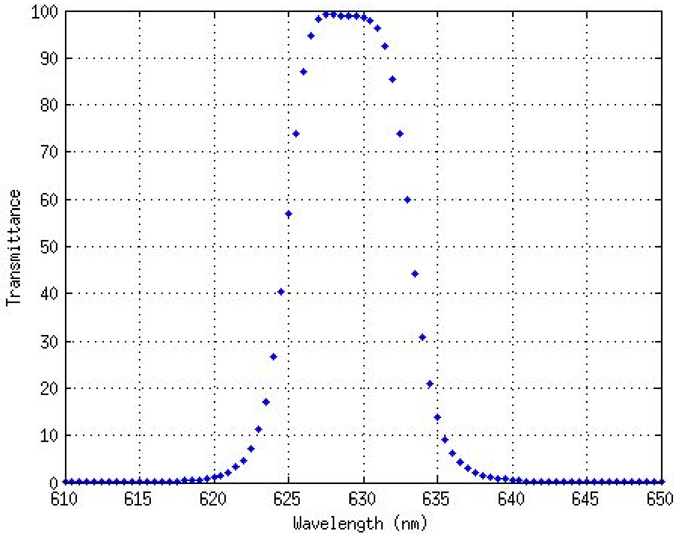


Table 13. Center a Full Width and Half Maximum (FWHM) manufactured, measured informations bandpass filter 7. Lot # 6-5997 Envelope 2 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.24 nm ± 0.1	628.0 nm	2.24 nm	0.35%
Full Width at Half Maximum (FWHM)	8.06 nm	8.55 nm	0.49 nm	6.07%
Transmittance maximum value		99.18		
OD abs> 3 from 400 nm to 600 nm and from 660 nm to 1000 nm	610 nm - 618 nm 618 nm - 640 nm 640 nm - 650 nm	3.35 0.89 3.30		

Figure 14. Transmittance measured in bandpass filter 8. Lot # 6-5997 Envelope 4

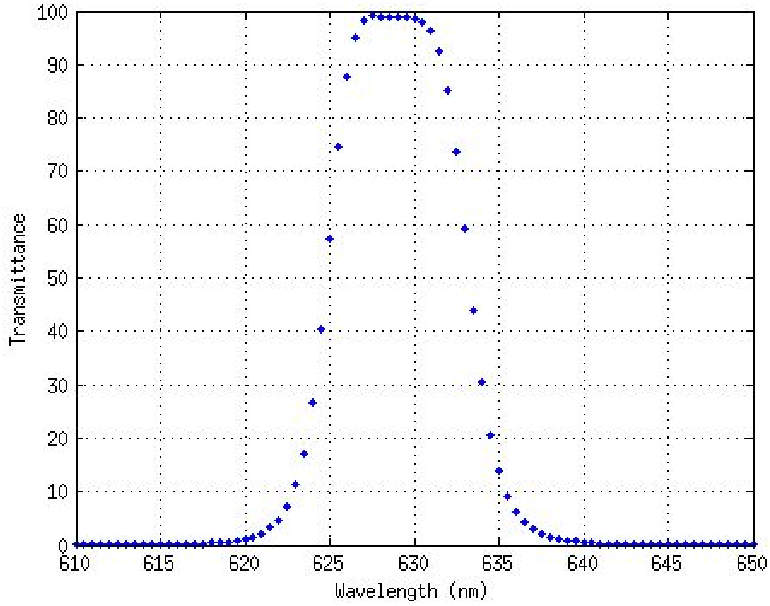


Table 14. Center a Full Width and Half Maximum (FWHM) manufactured, measured informations in bandpass filter 8. Lot # 6-5997 Envelope 4 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.24 nm ± 0.1	627.5 nm	2.74 nm	0.43%
Full Width at Half Maximum (FWHM)	8.06 nm	8.55 nm	0.49 nm	6.07%
Transmittance maximum value		99.17		
OD abs> 3 from 400 nm to 600 nm and from 660 nm to 1000 nm	610 nm - 618 nm 618 nm - 640 nm 640 nm - 650 nm	3.36 0.89 3.30		

Figure 15. Transmittance measured in bandpass filter 9. Lot # 6-5997 Envelope 5

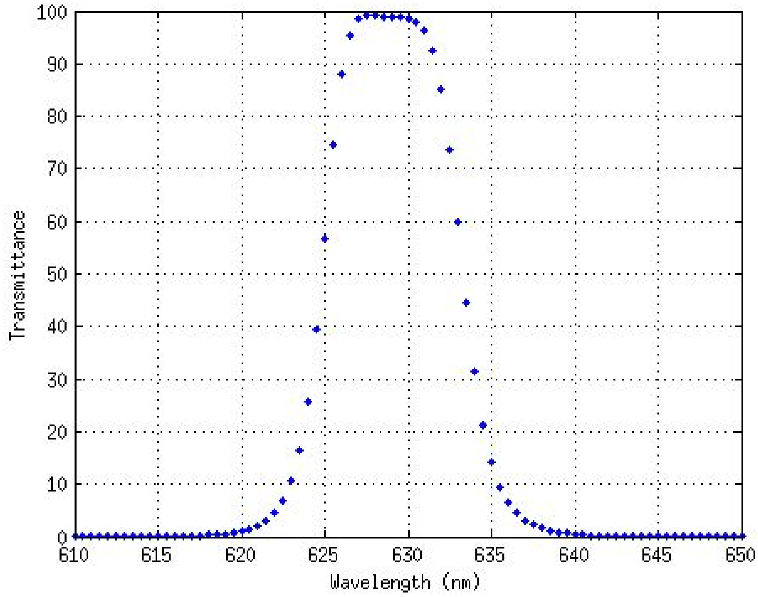


Table 15. Center a Full Width and Half Maximum (FWHM) manufactured, measured informations in bandpass filter 9. Lot # 6-5997 Envelope 5 and error calculation.

	Theoretical values	Calculated values	Absolute error	Relative error
Center Wavelength (CWL)	630.24 nm ± 0.1	627.5 nm	2.74 nm	0.43%
Full Width at Half Maximum (FWHM)	8.06 nm	8.54 nm	0.48 nm	5.95%
Transmittance maximum value		99.26		
OD abs> 3 from 400 nm to 600 nm and from 660 nm to 1000 nm	610 nm - 618 nm 618 nm - 640 nm 640 nm - 650 nm	3.32 0.89 3.24		

Summary

For this set of filters the Central Wavelength (CWL), Full Width at Half Maximum (FWHM), Optical Density (OD) were calculated from the measured data. They are are according to values informed by the manufacturer. The error rate is below 10% in each considered cases.

3.3. HOT MIRROR FILTERS: 4443_700 SP DICH LOT 7-4725, 45°:45° AOI / Collimated, 50.8 mm (+0/-0.2 mm) diameter on 5.93 mm thick Flat Fused Silica (#68)

In each filter the %slope was calculated, transmittance maximum value, 90% transmittance, 10% transmittance and FWHM

$$\%slope= \frac{\lambda 90-\lambda 10}{\lambda 10}\ x100$$

Figure 16. Transmittance measured in hot mirror filter 1. Lot # 7-4725

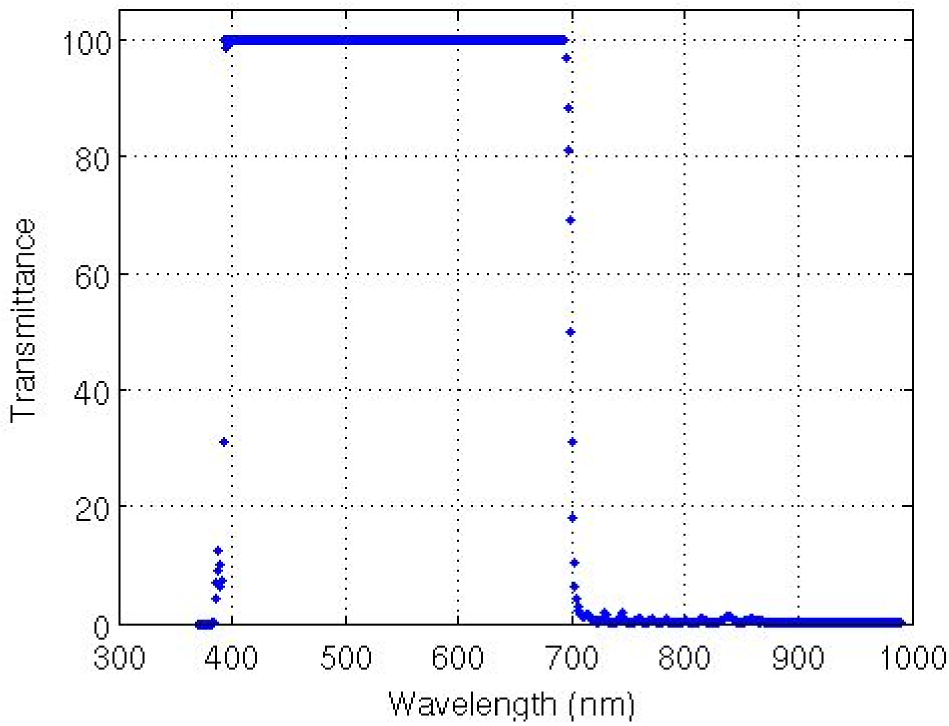


Table 16. Calculated informations from measured data of hot mirror filter filter 1. Lot # 7-4725.

	Theoretical values	Calculated values
Full Width at Half Maximum (FWHM)		306.53 nm
Transmittance maximum value		105.26
90% transmittance		94.70
10% transmittance		10.52
Wavelength 90% transmittance		393 nm
Wavelength 10% transmittance		389 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	1.02%

Figure 17. Transmittance measured in hot mirror filter 2. Lot # 7-4725

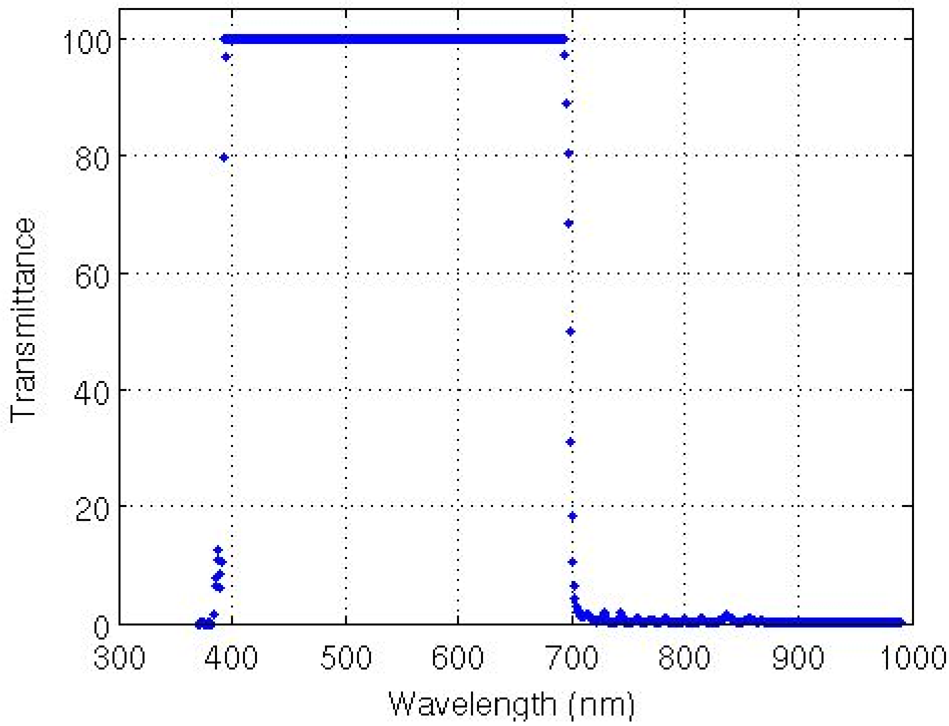


Table 17. Calculated informations from measured data in hot mirror filter 2. Lot # 7-4725.

	Theoretical values	Calculated values
FWHM		306.24
Transmittance maximum value		105.45
90% transmittance		97,02
10% transmittance		10,87
Wavelength 90% transmittance		395 nm
Wavelength 10% transmittance		387 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	2.06%

Figure 18. Transmittance measured in hot mirror filter 4. Lot # 7-4725

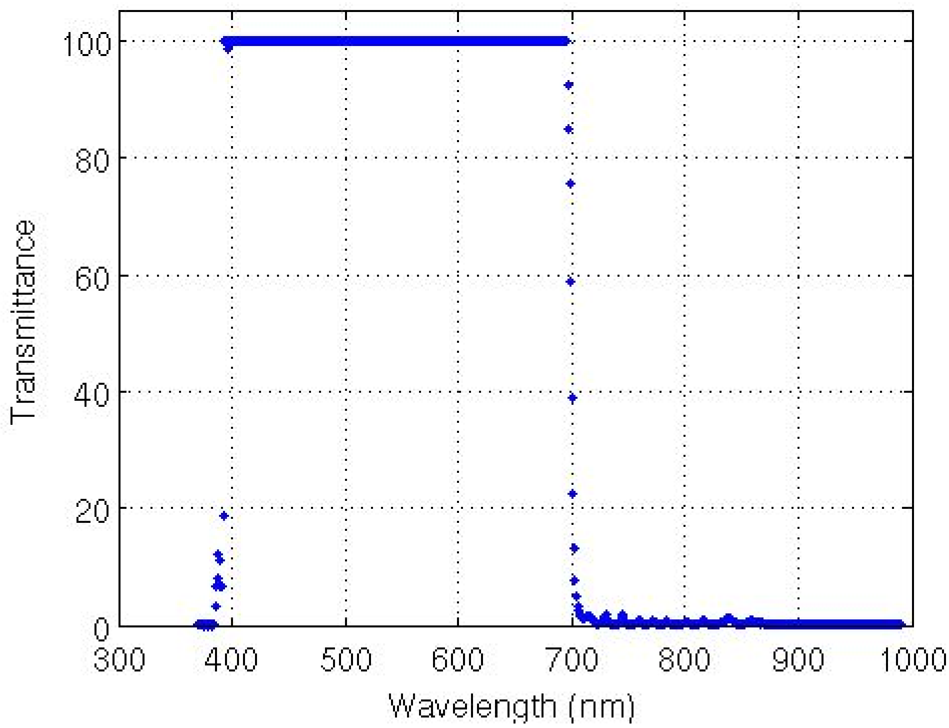


Table 18. Calculated informations from measured data in hot mirror filter 4. Lot # 7-4725.

	Theoretical values	Calculated values
FWHM		306.89
Transmittance maximum value		105.41
90% transmittance		98.78
10% transmittance		11.27
Wavelength 90% transmittance		396 nm
Wavelength 10% transmittance		389 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	1.79%

Summary

The Full Width at Half Maximum (FWHM) and transmittance maximum value were calculated in each case, 90% and 10% transmittance and the wavelength correspond to these values. The %slope was calculated in each filter using the measured data. Just the %slope value was informed by the manufacturer, then in these cases the error calculation are not possible. Only was possible to check and compared the value to the slope, and evaluated if our values are in the intervals reported. In all cases these values are in according to the reported values.

3.4. DICHROIC FILTERS: 4444_605 LP DICH LOT 7-4697, 45° : 45° AOI / Collimated, 50.8 mm (+0/-0.2 mm) diameter on 5.93 mm thick Flat Fused Silica (#68)

Figure 19. Transmittance measured in LP Dichroic filter 2. Lot # 7-4697

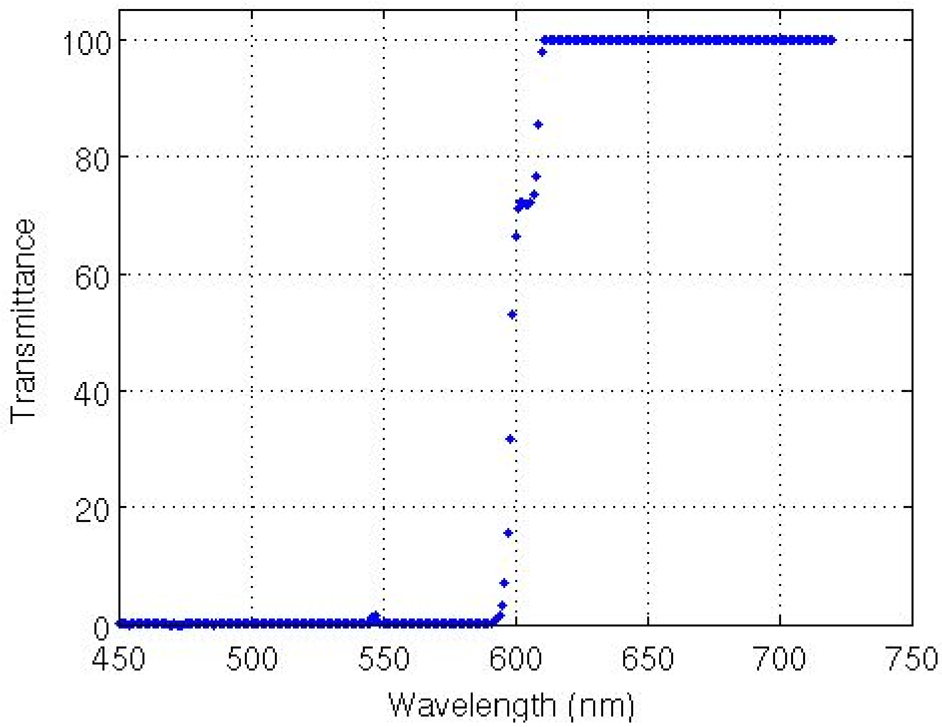


Table 19. Calculated informations from measured data in LP Dichroic filter 2. Lot # 7-4697.

	Theoretical values	**Calculated values**
Transmittance maximum value		107.45
90% transmittance		98.11
10% transmittance		15.55
Wavelength 90% transmittance		610 nm
Wavelength 10% transmittance		597 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	2.17%

Figure 20. Transmittance measured in LP Dichroic filter 3. Lot # 7-4697

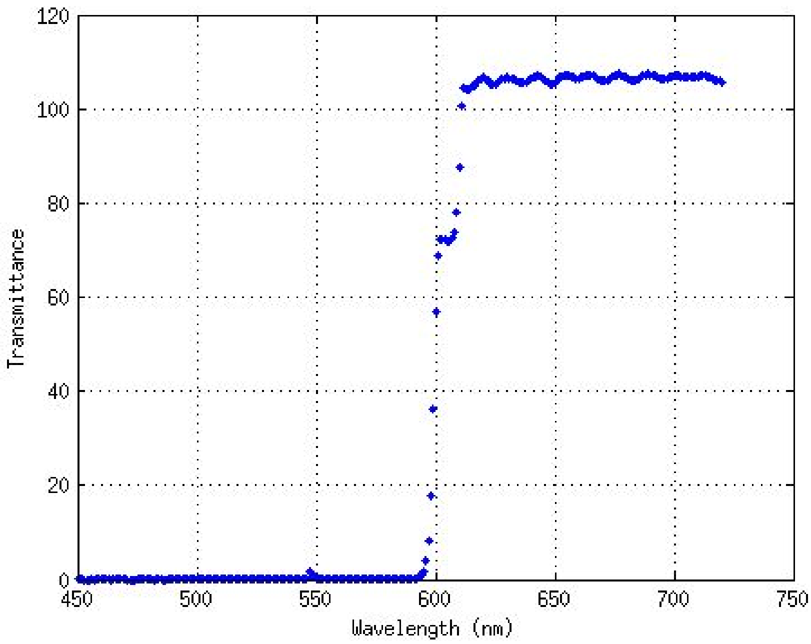


Table 20. Calculated informations from measured data in LP Dichroic filter 3. Lot # 7-4697.

	Theoretical values	Calculated values
Transmittance maximum value		107.36
Wavelength of transmittance maximum		677 nm
90% transmittance		87.75
10% transmittance		8.13
Wavelength 90% transmittance		610 nm
Wavelength 10% transmittance		597 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	2.17%

Figure 21. Transmittance measured in LP Dichroic filter 3. Lot # 7-4697 second measure

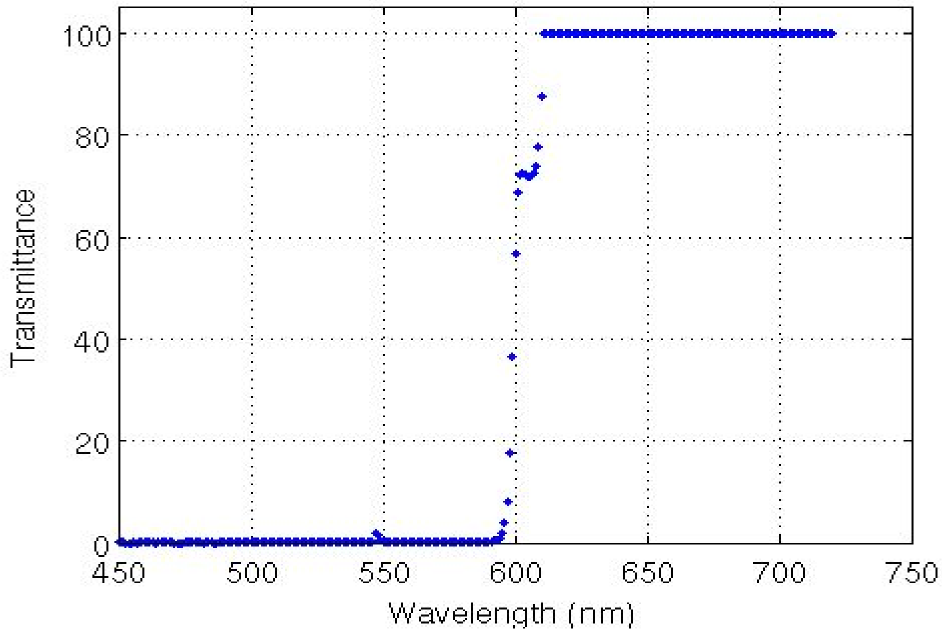


Table 21. Calculated informations from measured data LP Dichroic filter 3. Lot # 7-4697.

	Theoretical values	**Calculated values**
Transmittance maximum value		106.19
Wavelength of transmittance maximum		689 nm
90% transmittance		86.92
10% transmittance		8.17
Wavelength 90% transmittance		610 nm
Wavelength 10% transmittance		597 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	2.17%

Figure 22. Transmittance measured in LP Dichroic filter 9. Lot # 7-4697

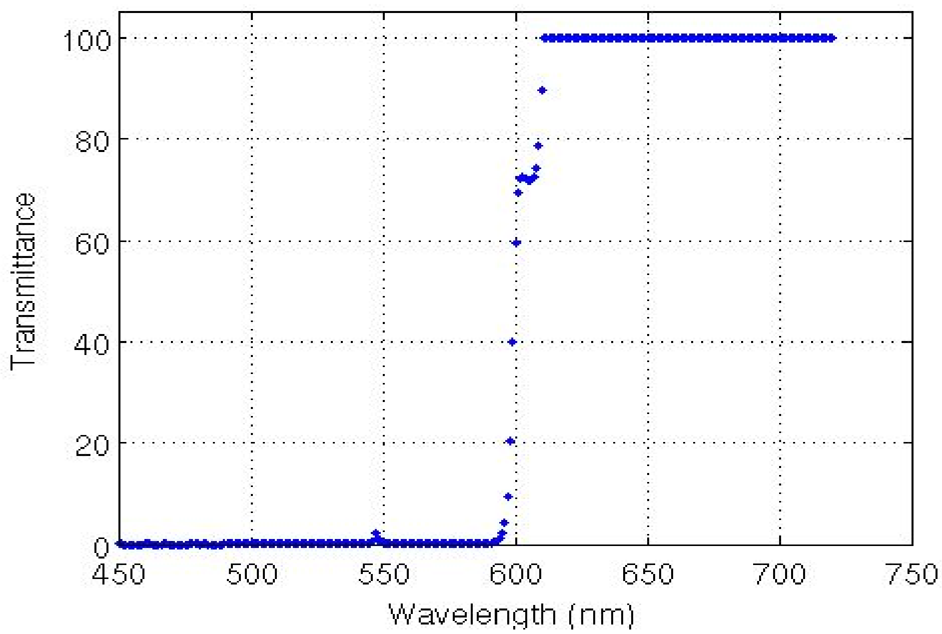


Table 22. Calculated informations from measured data LP Dichroic filter 9. Lot # 7-4697.

	Theoretical values	Calculated values
Transmittance maximum value		107.32
Wavelength of transmittance maximum		677 nm
90% transmittance		89.82
10% transmittance		9.40
Wavelength 90% transmittance		610 nm
Wavelength 10% transmittance		597 nm
Slope as defined between 90% to 10% Transmittance	Slope < 3.0%	2.17%

Summary

The Dichroic filters were characterize measured the transmittance maximum value, wavelength of transmittance maximum, the 90% and 10% transmittance and wavelength related to these transmittance. Also, the %slope were calculated and these values are in according to the manufacturer's specifications. In this case the error analysis is not possible to obtain due to we have no theoretical values.

4. CONCLUSIONS

The ultra narrow band filters were characterized through the Central Wavelength (CWL), 90% and 3% bandwidth, Full Width at Half Maximum (FWHM), transmittance maximum value and the Optical Density (OD). All measured are in according to the values informed to the manufacturer. Also the OD are the important measure specifically for this filter, because the main characteristic “ultra narrow band”, is completely checked with this parameter, in all filters the high transmission are related to the low optical density (628 nm - 630 nm), and the lower transmission with the high optical density in two intervals: 610 nm - 628.8 nm and 630 nm - 650 nm. On the other hand, the rate error is less to the 20% in all cases confirm our measurements.

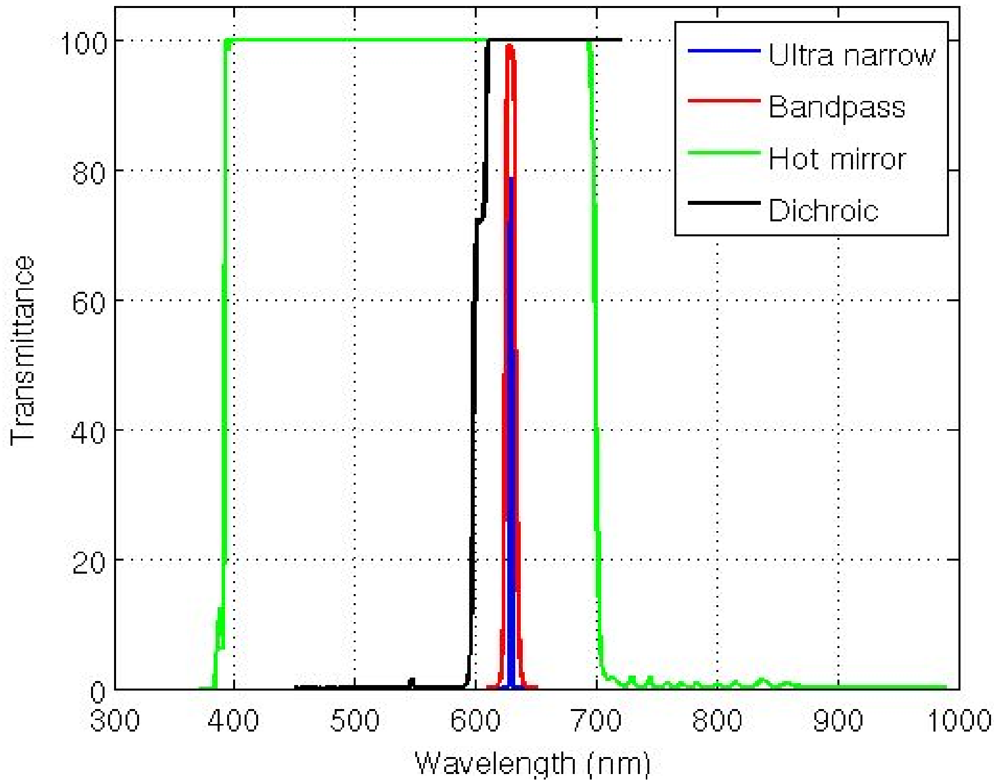
The band pass filters were characterized using the following measurements: the Central Wavelength (CWL), Full Width at Half Maximum (FWHM) and Optical Density (OD). The measurements are in according to the theoretical values. The OD were checked in three differents intervals: 610 nm - 618 nm, 618 nm - 640 nm and 640 nm - 650 nm. In all cases the relationship between OD and transmission have physical sense and are in according to the manufacturer's specifications. Also, the measurements shown an error less of 10% compared to the theoretical values informed by the manufacturer.

The Hot mirror filters were characterized to calculate the Full Width at Half Maximum (FWHM), transmittance maximum value, 90% and 10% transmittance and the wavelength correspond to these values and the %slope, but in this case the error analyze were not conducted due to the lack of theoretical values informed by the manufacturer.

The Dichroic filters were characterized checked these characteristics: the transmittance maximum value, wavelength of transmittance maximum, the 90% and 10% transmittance and wavelength related to these transmittance. Also, the %slope were calculated, but as in the previous case the error analyze it was not done.

The filters studied and test in this report present the expected characteristics to the developed to The Brazilian Experimental Solar Telescope project. The following Figure 23 shows the performance of all filters, each of them cut a specific interval in wavelength, it allows remove wavelengths that are not of interest in the solar telescope.

Figure 23. Ultra narrow, band pass, hot mirror, and dichroic filters.



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