

**NPL REPORT
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**The evaluation of the performance
of bandpass filters for filter
radiometry applications**

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The evaluation of the performance of bandpass filters
for filter radiometry applications

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Summary

The performance of a number of bandpass filters was evaluated in order to identify the most promising filters for application in UV/Visible/NIR filter radiometers. Two interference filters whose spectral responsivity peaks around 800 nm were shown to have the most promising characteristics and were selected for further long-term stability evaluations.

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CONTENTS

1.	Introduction.....	1
2.	Apparatus.....	1
2.1	Measurement of spectral transmission.....	1
2.2	Spatial uniformity of transmission.....	2
2.3	Measurement of the temperature coefficient of transmission.....	2
3	Results.....	3
3.1	Corion 360 nm bandpass filter.....	3
3.2	LR720 glass filter.....	6
3.3	The OCLI 800 nm bandpass filter	9
3.4	Barr Associates 800 nm bandpass filter.....	13
4.	Discussion.....	16
5.	Conclusions.....	17
6.	Acknowledgements.....	17
7.	References.....	17

1. Introduction

Any detector based measuring device whose spectral responsivity is limited to a well-defined wavelength range is called a filter radiometer. Filter radiometers are used extensively for the measurement of spectral irradiance and radiance generated by broadband sources [1]. These filter radiometers consist of an aperture which defines the area over which radiation is collected, a bandpass filter which restricts the range of wavelengths detected by the filter radiometer to the wavelength range of interest and a photodetector for converting the optical radiation passing through the filter into an electrical signal. At NPL, filter radiometers responding in the 400 nm to 900 nm wavelength range use 1337S silicon detectors which have an excellent performance (in terms of D^* , linearity of response, spatial uniformity of response, temperature coefficient of response and long term stability). The area-defining aperture is made of brass and provided its temperature is actively controlled, the area defined by the aperture is not expected (or indeed found) to change significantly with time. Optical filters, on the other hand, transmitting over narrow wavelength ranges are known to suffer from a number of problems. Two types of filters have been utilised in filter radiometer applications; filters based on coloured glassed and multi-layer dielectric (interference) filters. Clearly, the most critical component utilised in a filter radiometer is the bandpass filter. The bulk of the effort to identify ways of improving the performance of filter radiometers has therefore been directed towards identifying bandpass filters of improved performance.

The most important parameters determining the suitability of bandpass filters for application in filter radiometry are:

- i. Spectral transmission profile including high peak transmission, absence of “fine structure” in the filter transmission and low “out-of-band” transmission, i.e. transmission outside the filter bandpass.
- ii. Spatial uniformity of transmission
- iii. Variations in the filter transmission with ambient temperature
- iv. Long term stability

A total of 4 different bandpass filters were selected, one based on coloured glass technology while the others were based on multi-layer dielectric technology. A novel filter technology based on “subtractive filters” which was developed at NPL [2, 3] was not utilised as that filter technology is designed to address broadband filter applications rather than filter radiometer applications with narrow transmission bandwidths, typically 10 nm Full Width Half Maximum (FWHM). The filters were selected to transmit in different parts of the spectrum (360 nm to 800 nm). The aim of this report is to describe the procedure followed in the evaluation of these filters and present the results.

2. Apparatus

2.1 Measurement of spectral transmission

The spectral transmission of the bandpass filters was measured on the NPL filter transmission measurement facilities. The out-of-band transmission was measured on the modified UV/Visible detector spectral responsivity measurement facility [4].

2.2 Spatial uniformity of transmission

The spatial uniformity of response of the four bandpass filters was measured on the modified spatial uniformity of response measurement facility. The layout and operation of this facility when used to measure the spatial uniformity of response of detectors is described elsewhere [5]. When the facility is used to measure the spatial uniformity of transmission of filters, the “source” and “chopper” compartments are used in the same mode as when the spatial uniformity of response of detectors is being evaluated. The detector compartment, however, is modified significantly and the revised layout is shown in Figure 1. Pseudo-monochromatic radiation exiting the pinhole is collimated and re-imaged using a pair of identical optically-polished Off Axis Parabolic (OAP) mirrors. The filter is placed in the position of the real image of the pinhole. The filter is mounted on a computer controlled X-Y translation stage which displaces the filter in two orthogonal directions which are in the plane of the filter surface and perpendicular to the optical axis of the incident pseudo-monochromatic radiation. This means that the image of the pinhole sequentially illuminates different points on the filter aperture. Radiation passing through the filter is re-imaged onto the test detector (see Figure 1) with the aid of a spherical mirror and a beam-steering plane mirror. A beam splitter placed just before the filter splits a fraction of the incident radiation and directs it on the reference detector. The output of the reference detector is used to monitor variations in the radiant power within the incident beam and thus eliminate the effects of any drifts in the source output.

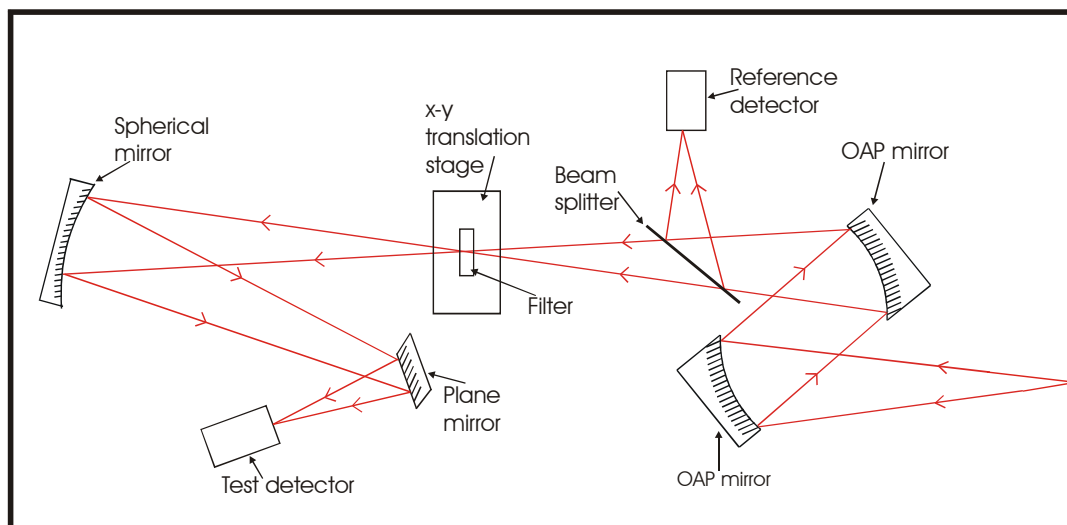


Figure 1: Layout of the modified “detector compartment” used for the spatial uniformity of transmittance of the filters.

2.3 Measurement of the temperature coefficient of transmission.

The transmission of the filters at different ambient temperatures was measured by mounting the filters inside a water jacket whose temperature was actively controlled by the temperature of the water circulating through it. The optical arrangement used was identical to the one shown in Figure 1, except that the position of the filter did not change during the test. Instead, the temperature of the water was changed in steps of 2 °C. The temperature coefficient of transmission was calculated from the slope of the plot of the filter normalised transmission versus temperature.

3 Results

3.1 Corion 360 nm bandpass filter

3.1.1 Spectral transmittance

Figure 2 shows that spectral transmittance of the Corion 360 interference filter in the 200 nm to 800 nm wavelength range. Peak transmittance values of about 50% are typical for UV transmitting filters. However, the out-of-band blocking of 10^3 is disappointing and discourages the adoption of this filter in UV filter radiometry applications.

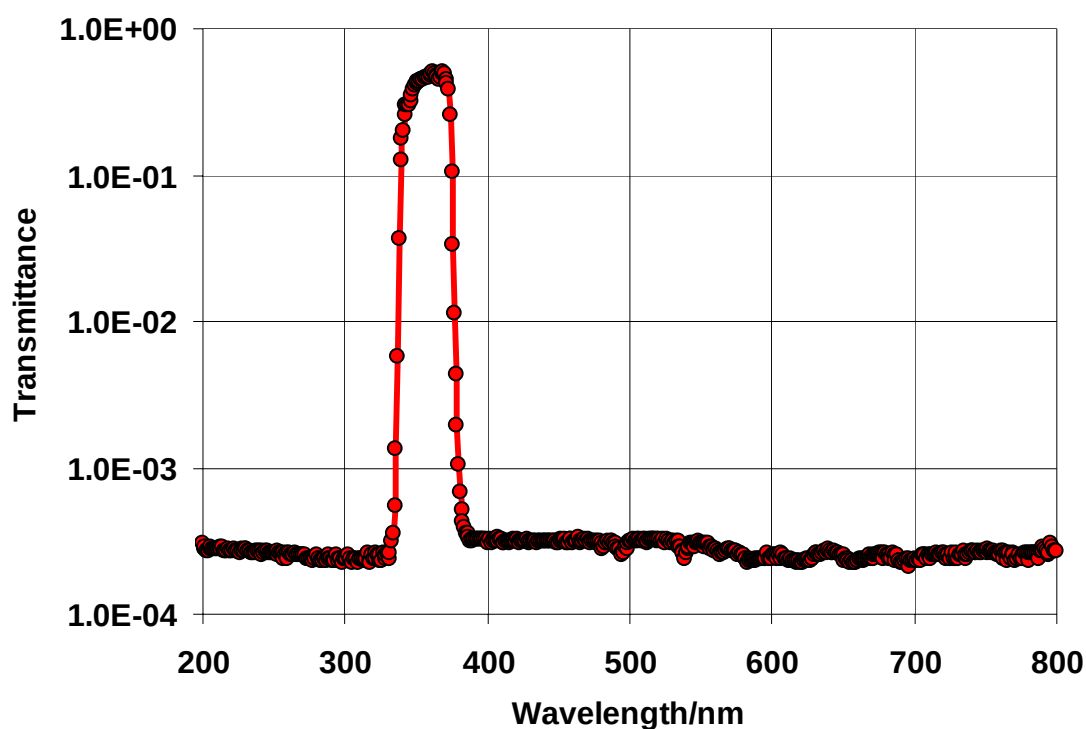


Figure 2: Spectral transmittance of the Corion 360 interference filter in the 200 nm to 800 nm wavelength range.

3.1.2 Spatial uniformity of transmission

Figure 3 shows the spatial uniformity of transmission of the Corion 360 interference filter. The transmittance of this filter varies by less than 1.5% over its entire clear aperture. Measurements shown in Figure 3 were done with a 380 μm beam diameter spot focused on the surface of the filter. The beam was incident on the filter in an F/4.7 cone.

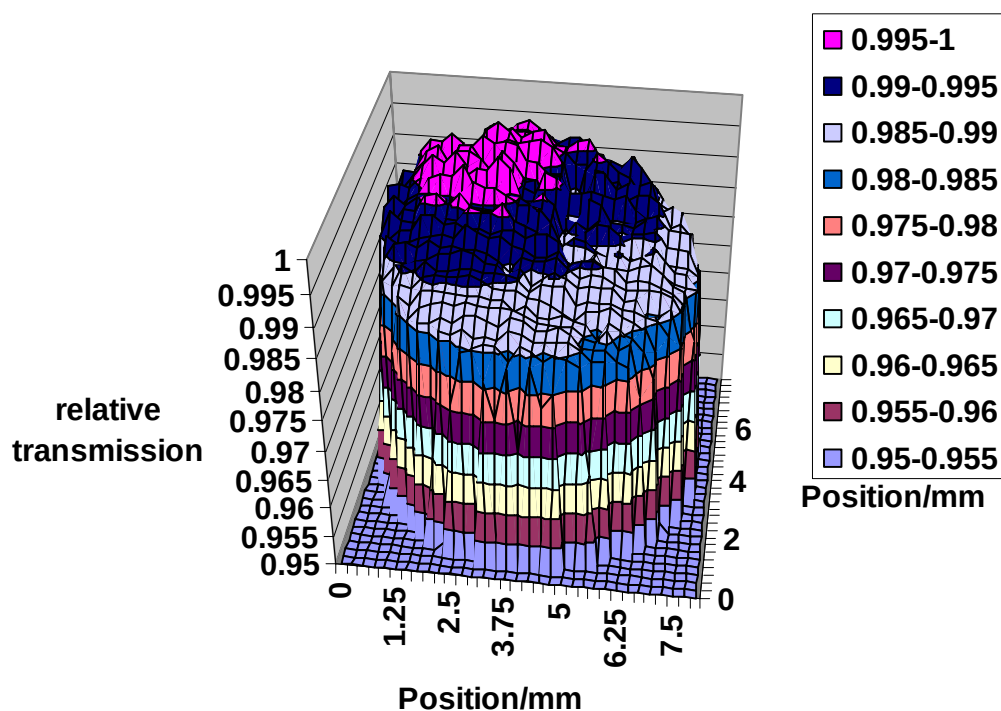


Figure 3: Spatial uniformity of transmission of the LR360 nm glass filter using a 0.38 mm diameter spot.

3.1.3 Temperature coefficient of response

Figure 4 shows the normalised transmission of the Corion 360 nm interference filter as its temperature was raised by 2 °C every 20 minutes from 20 °C to 30 °C. Using data shown in Figure 4, the normalised transmission of the Corion 360 nm interference filter was plotted at different temperatures and the results are shown in Figure 5. From the slope of the best straight line of this plot, the temperature coefficient of transmission of this filter was calculated to be 0.29% °C⁻¹.

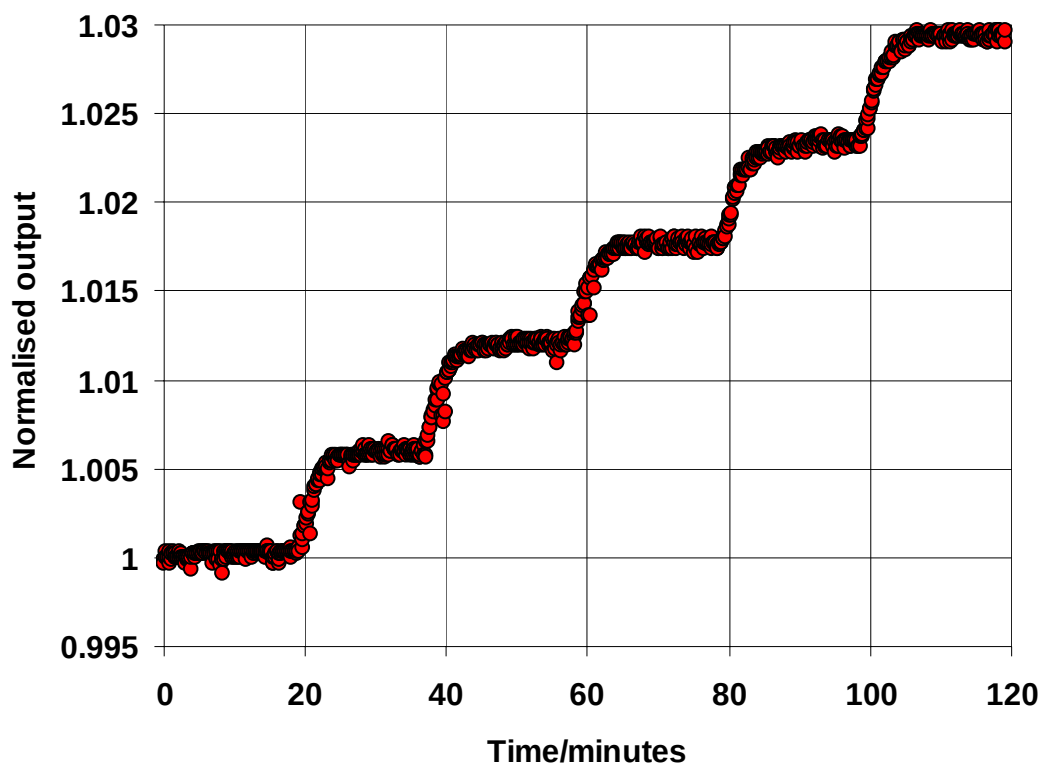


Figure 4: Normalised transmission of the Corion 360 nm interference filter as its temperature is raised by 2 °C every 20 minutes from 20 °C to 30 °C.

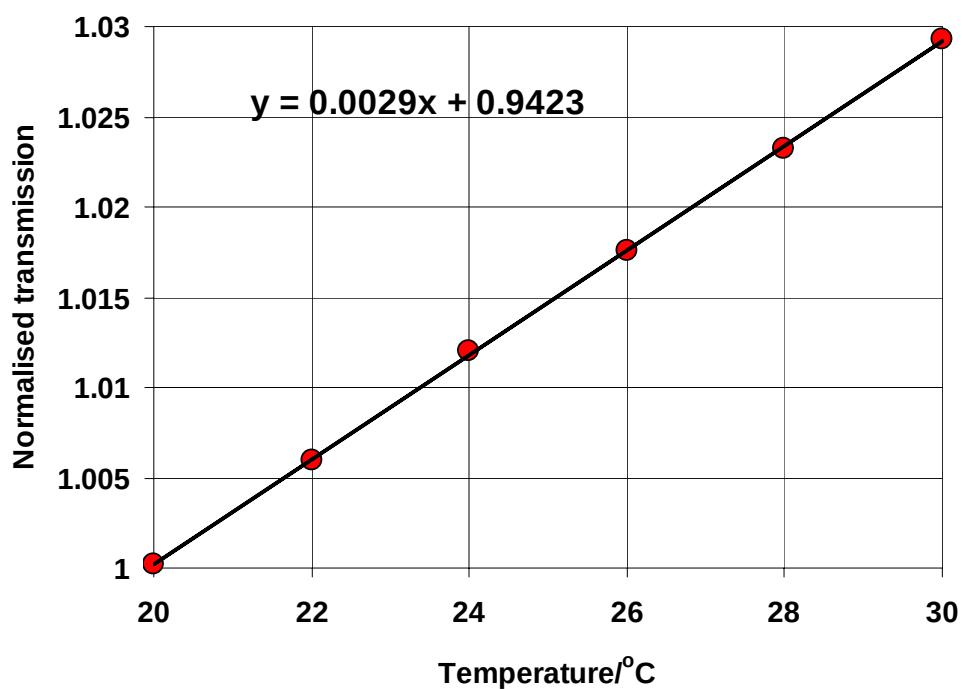


Figure 5: Normalised transmission of the Corion 360 nm interference filter at different temperatures. From the slope of the best straight line, the temperature coefficient of transmission of this filter is calculated to be 0.29% °C⁻¹.

3.2 LR720 glass filter

The spectral transmittance of the 720 nm glass filter in the 200 nm to 1200 nm wavelength range is shown in Figure 6. The plot shows that the maximum transmission of this filter is low (less than 14%) but the transmission profile is smooth. These characteristics were expected due to the “glass” nature of this filter.

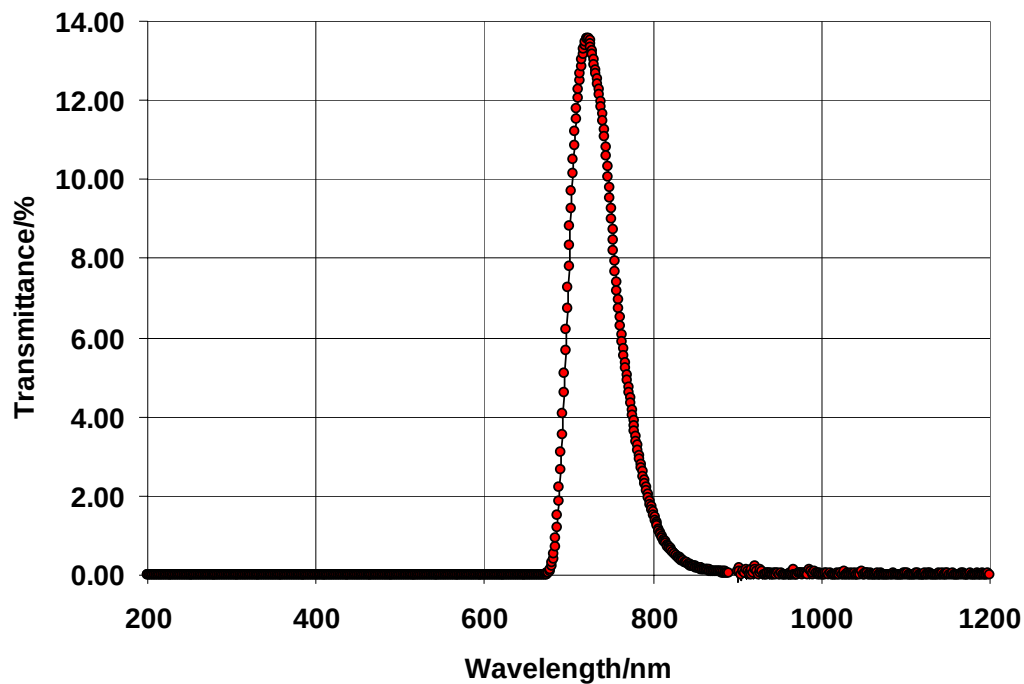


Figure 6: Spectral transmittance of the LR720 nm glass filter in the 200 nm to 1200 nm wavelength range.

3.2.2 Spatial uniformity of transmission

Figure 7 shows the spatial uniformity of transmission of the LR720 glass filter using a 0.38 mm diameter spot. Non-uniformities in the transmission of 10% are evident. This very large variation in the spatial uniformity of transmission of this filter prohibits its adoption in high performance filter radiometer applications.

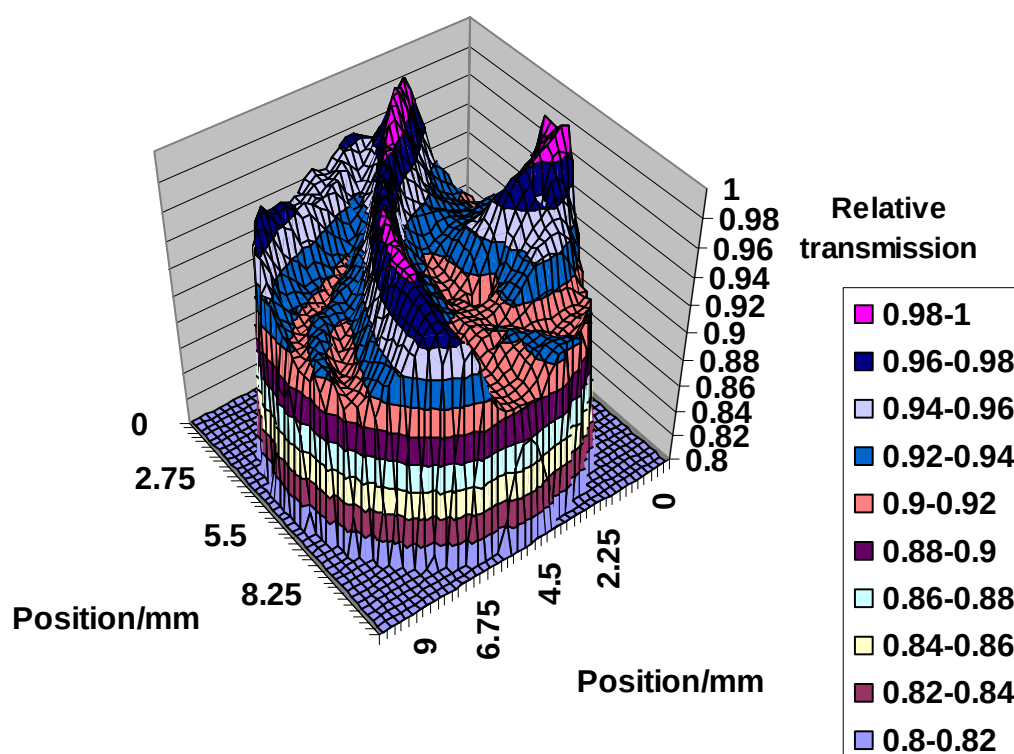


Figure 7: Spatial uniformity of transmission of the LR720 glass filter using a 0.38 mm diameter spot. Non-uniformities in the transmission of 10% are evident.

3.2.3 Temperature coefficient of response

Figure 8 shows the normalised transmission of the LR720 glass filter as its temperature was raised by 2 °C every 20 minutes from 20 °C to 30 °C. Using data shown in Figure 8, the normalised transmission of the LR720 glass filter was plotted at different temperatures and the results are shown in Figure 9. From the slope of the best straight line of this plot, the temperature coefficient of transmission of this filter is calculated to be 0.05% per °C increase in temperature. This is surprisingly low for a glass filter.

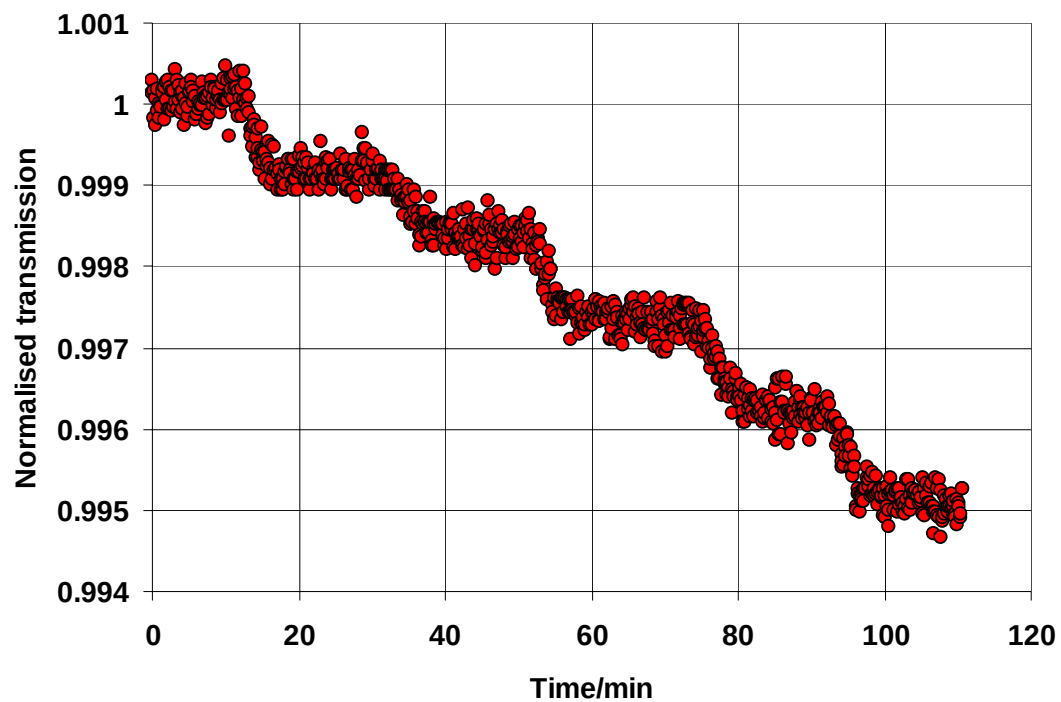


Figure 8: Normalised transmission of the LR720 nm glass filter as its temperature is raised by 2 °C every 20 minutes from 20 °C to 30 °C

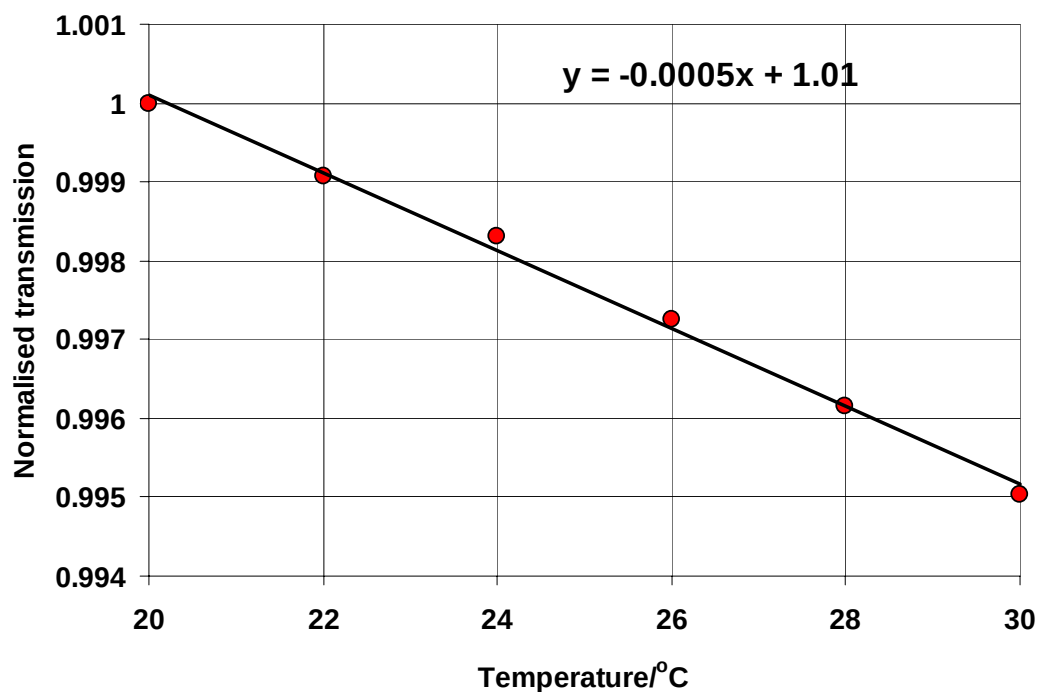


Figure 9: Normalised transmission of the LR720 glass filter at different temperatures. The transmission of this filter decreases by 0.05% per °C increase in temperature.

3.3 The OCLI 800 nm bandpass filter

3.3.1 Spectral transmittance

Figure 10 shows the spectral transmittance of the OCLI 800 nm interference filter in the vicinity of the filter bandpass. This filter exhibits a peak transmission of about 45%. While the edges of this filter profile are relatively sharp and smooth, (no fine structure), the transmission of this filter does not resemble the (highly desirable) “top-hat” shape. Figure 11 shows the transmittance of the same filter in the 400 nm to 1200 nm wavelength range plotted on a logarithmic plot to highlight the out-of-band blocking characteristics of this filter. Figure 11 indicates that the filter has good out-of-band rejection which is better than 1 part in 10^5 for most of the wavelength range examined. However, this filter exhibits a surprisingly high transmittance in the 650 nm to 770 nm wavelength range. This was surprising since radiation of wavelength shorter than the peak can be effectively blocked using long-pass colour glass filters (e.g. RG780 filter). Measurements of the out-of-band transmission for longer wavelengths were completed on the modified detector spectral responsivity facility and show that the transmission is lower than 10^{-5} .

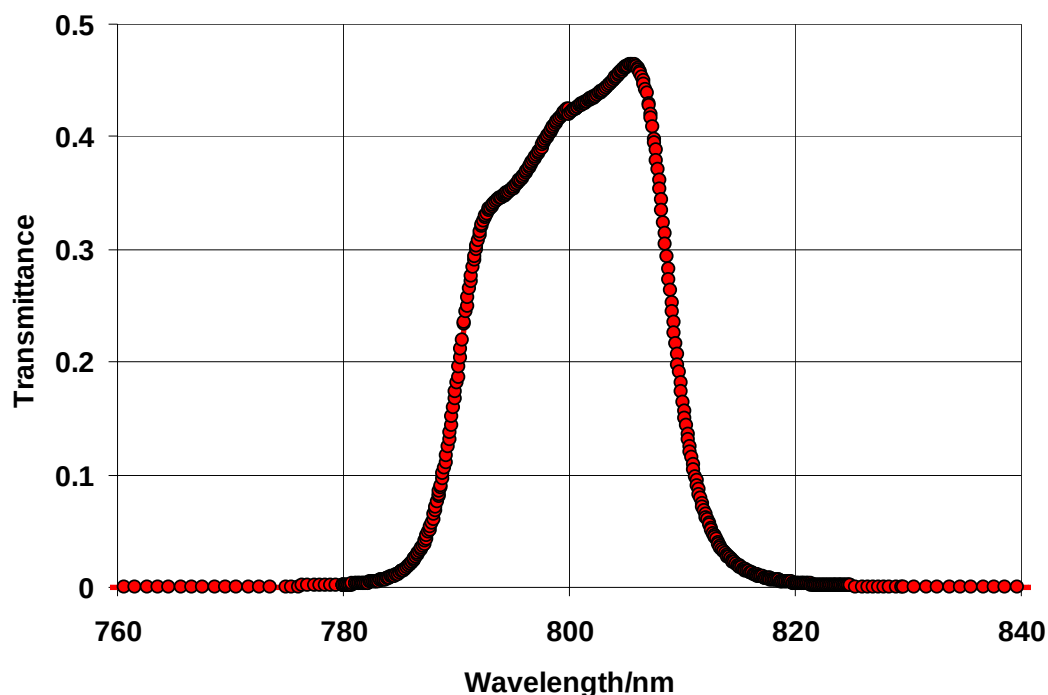


Figure 10: Spectral transmittance of the OCLI 800 nm interference filter in the 760 nm to 840 nm wavelength range.

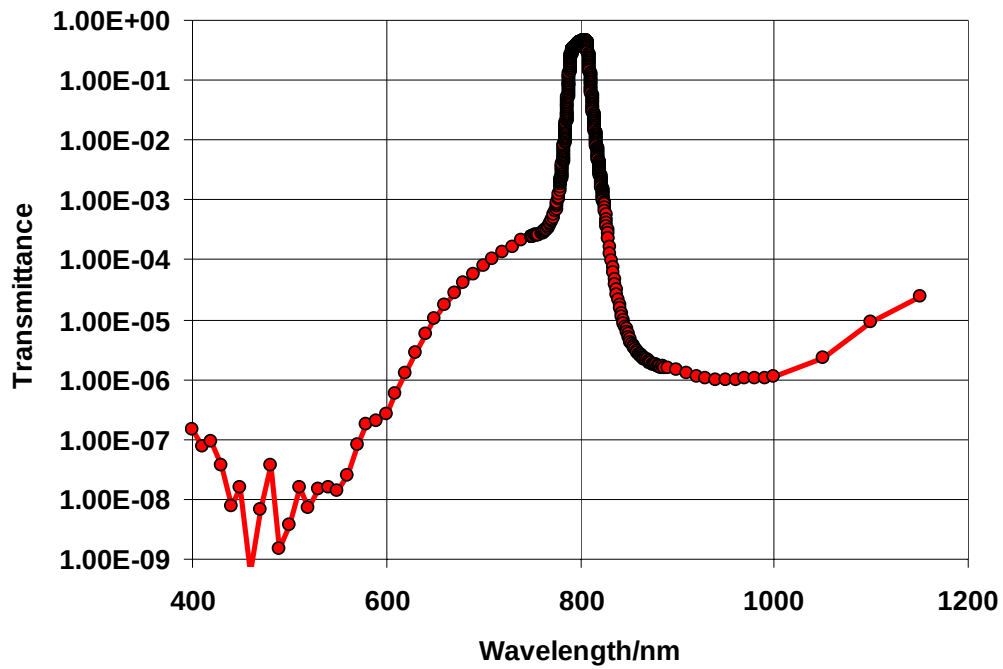


Figure 11: Spectral transmittance of the OCLI 800 nm interference filter in the 400 nm to 1200 nm wavelength range.

3.3.2 Spatial uniformity of transmission

Figure 12 shows the spatial uniformity of transmission of the OCLI 800 nm interference bandpass filter. The transmittance of this filter varies by approximately 3 % over the entire clear aperture of this filter. Measurements shown in Figure 12 were completed with a 380 μm beam diameter spot focused on the surface of the filter. The beam was incident on the filter in an F/4.7 cone.

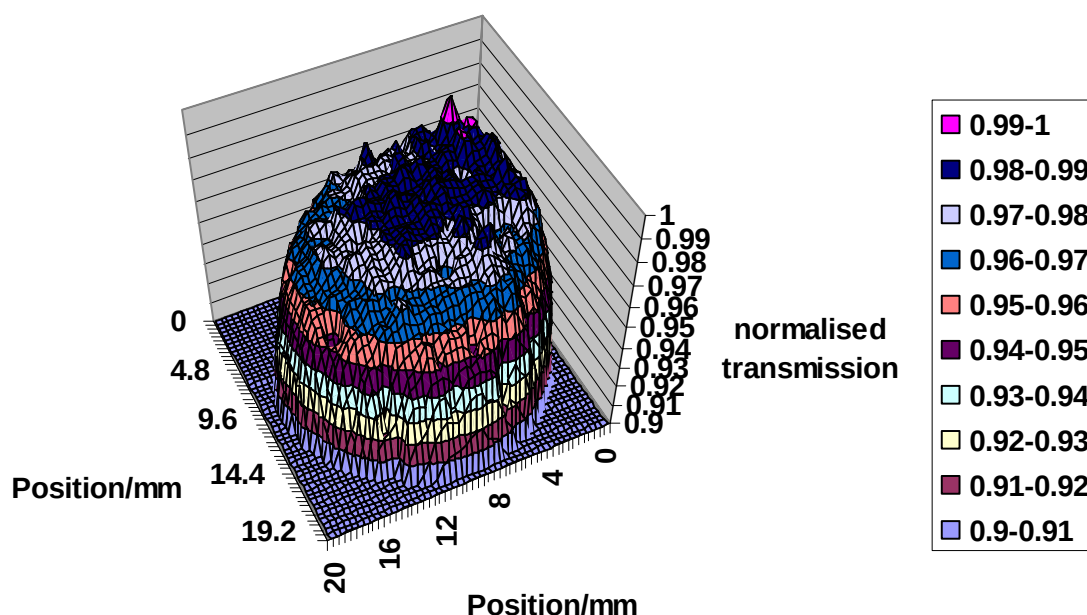


Figure 12: Spatial uniformity of response of the OCLI 800 nm filter using a 0.38 mm diameter spot.

3.3.3 Temperature coefficient of response

Figure 13 shows the normalised transmission of the OCLI 800 nm interference filter as its temperature was raised in steps of 2 °C every 20 minutes from 21.7 °C to 31.7 °C. Figure 13 also shows the value of the filter temperature at different times. Using data shown in Figure 13, the normalised transmission of the OCLI 800 nm interference filter was plotted at different temperatures and the results are shown in Figure 14. Taking the slope of the best straight line of this plot, the temperature coefficient of transmission of this filter is calculated to be -0.56% per °C increase in temperature. The negative sign indicates that the transmission of this filter decreases with increasing temperature.

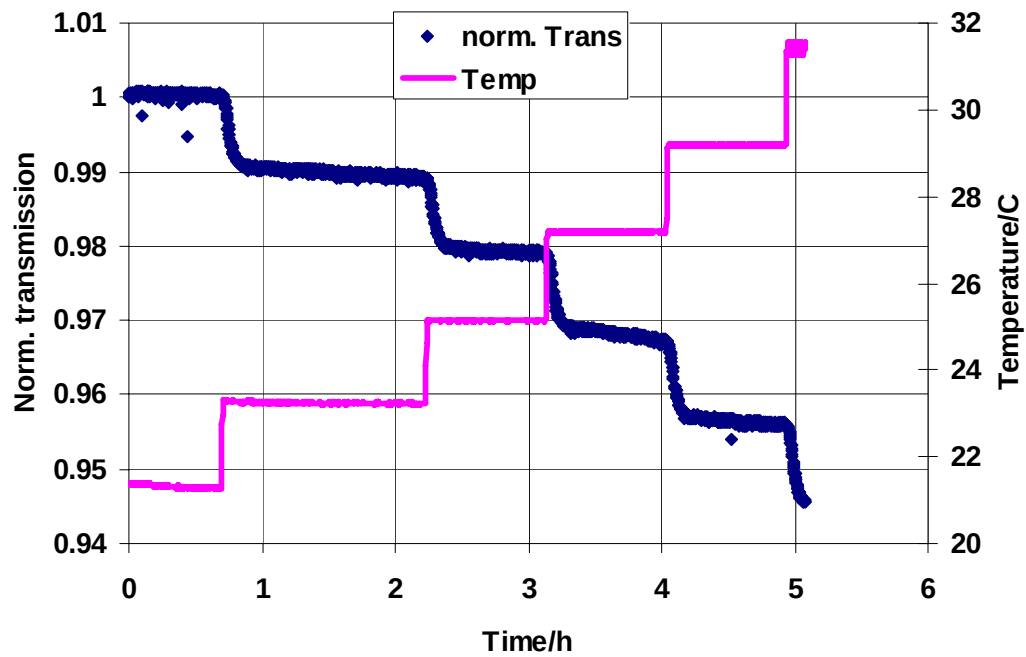


Figure 13: Normalised transmission of the OCLI 800 nm filter at different temperatures.

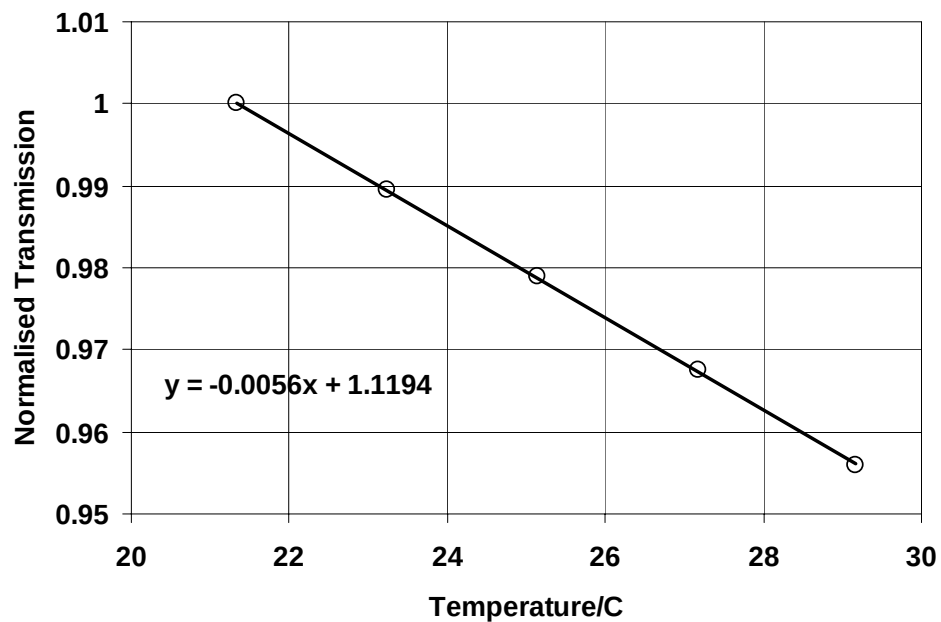


Figure 14: Normalised transmission of the OCLI 800 nm interference filter at different temperatures. The transmission of this filter decreases by 0.56% per °C increase in temperature.

3.4 Barr Associates 800 nm bandpass filter

3.4.1 Spectral transmittance

Figure 15 shows the spectral transmittance of the Barr Associates 800 nm interference filter in the vicinity of the filter bandpass. This filter exhibits high peak transmission (greater than 80%) combined with sharp edges. Figure 16 shows the transmittance of the same filter in the 200 nm to 1200 nm wavelength range plotted on a logarithmic plot to highlight the out-of-band blocking characteristics of this filter. Figure 16 indicates that the filter has good out-of-band rejection which is better than 1 part in 10^5 for wavelengths shorter than the peak (limited by the digitisation of the spectrophotometer used). Measurements of the out-of-band transmission for longer wavelengths were completed on the modified detector responsivity spectral responsivity facility which shows that the transmission is lower than 10^{-6} .

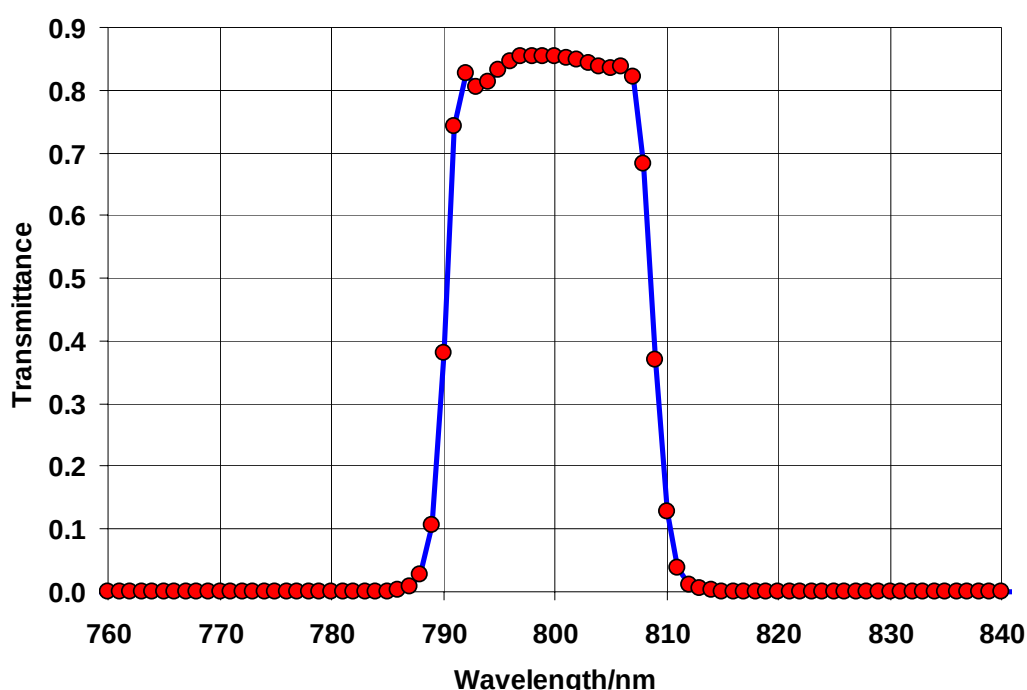


Figure 15: Spectral transmittance of the Barr Associates 800 nm interference filter in the 760 nm to 840 nm wavelength range.

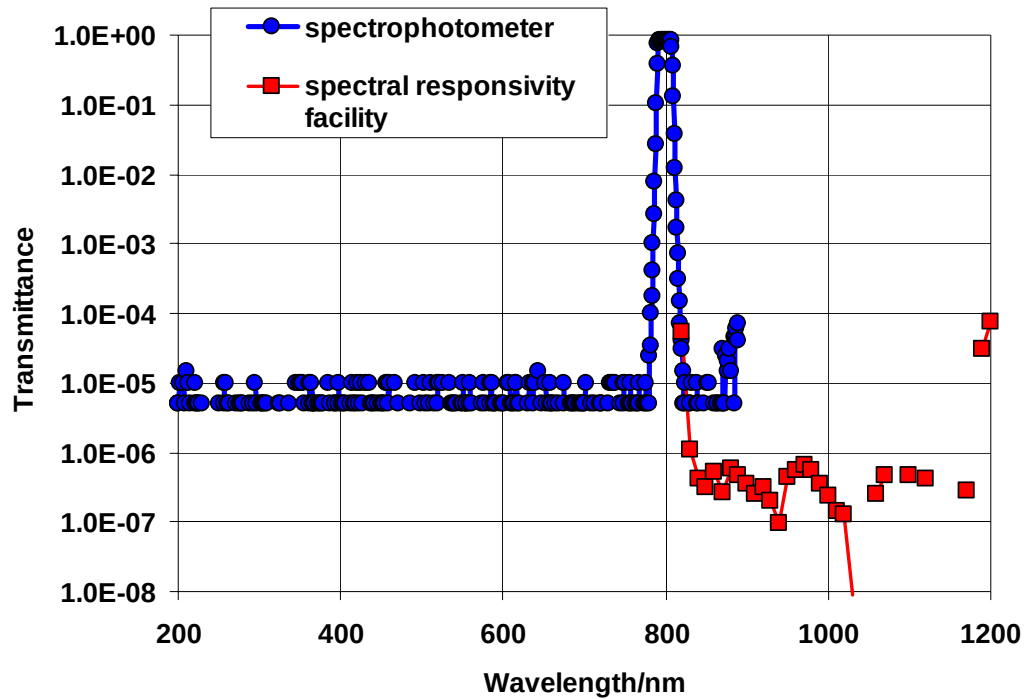


Figure 16: Spectral transmittance of the Barr Associates 800 nm interference filter in the 200 nm to 1200 nm wavelength range.

3.4.2 Spatial uniformity of transmission

Figure 17 shows the spatial uniformity of transmission of the Barr Associates 800 nm interference bandpass filter. The transmittance of this filter varies by 2% over the entire clear aperture. Measurements shown in Figure 17 were done with a 380 μm beam diameter spot focused on the surface of the filter. The beam was incident on the filter in an F/4.7 cone.

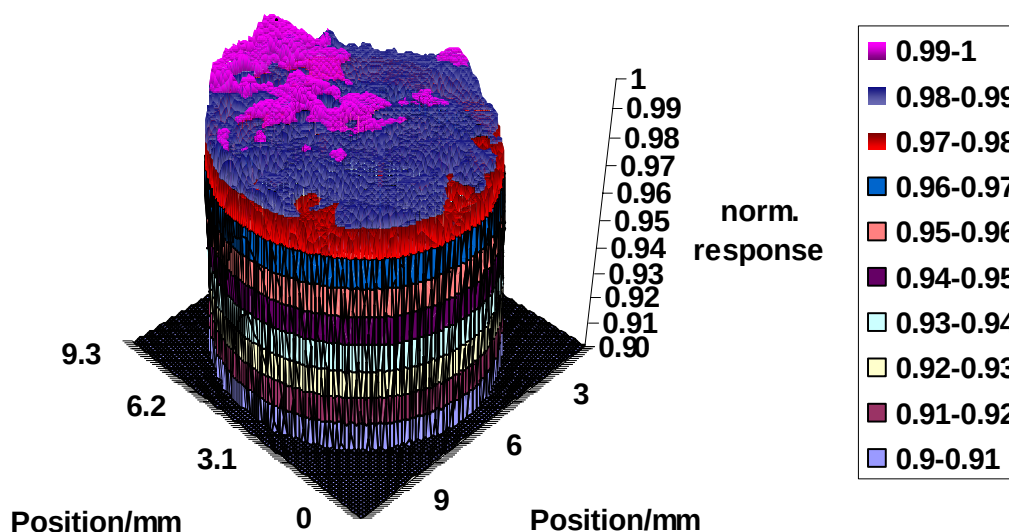


Figure 17: Spatial uniformity of response of the Barr Associates 800 nm interference filter, 0.38 mm diameter spot.

3.4.3 Temperature coefficient of response

Figure 18 shows the normalised transmission of the Barr Associates 800 nm interference filter as its temperature is raised in steps of 2 °C every 20 minutes from 21.2 °C to 29.2 °C. Figure 18 also shows the value of the filter temperature at different times. Using data shown in Figure 18, the normalised transmission of the Barr Associates 800 nm interference filter was calculated to change by less than -0.05 % per °C change in temperature in the 21.2 to 29.2 °C temperature range.

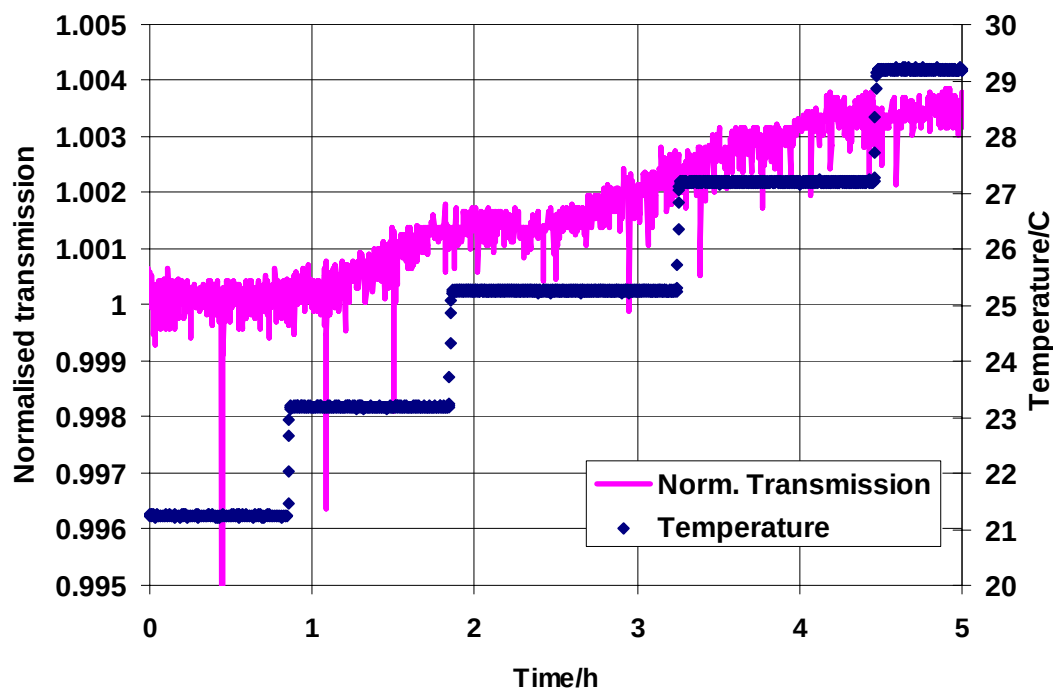


Figure 18: Normalised transmission of the Barr Associates 800 nm filter at different temperatures. The transmission of this filter increases by less than 0.05% per °C increase in temperature.

4. Discussion

The glass structure of the LR720 glass filter means that it should exhibit good long-term stability and robustness. Furthermore, the temperature coefficient of transmission is low (0.05% per °C). However, the relatively low value of its peak transmission (less than 14%) combined with the large spatial non-uniformity of transmission (10%) and relatively wide bandwidth lets this filter down. The characteristics of at least two of the other filters evaluated are clearly superior. The LR360 nm interference filter is let down by the relatively high transmission outside the filter bandpass and the relatively high temperature coefficient of transmission (0.29% per °C). Peak transmission of approximately 50% is typical for narrow-band UV filters.

The performance of the two 800 nm bandpass filters is far superior to the other filters examined and both are more suited to applications in filter radiometry, provided their long term stability is good (the long term stability of these filters is currently being evaluated). The spatial non-uniformity of transmission of both filters was less than 3% over their active areas (although the diameter of the Barr filter was only about 9 mm compared to about 21 mm for the OCLI 800 nm filter). The Barr Associates 800 nm filter had a clear advantage because of its high peak transmission (greater than 80%, compared with 45% for the OCLI 800 nm filter). One of the biggest advantages offered by the Barr Associates 800 nm bandpass filter is the very low temperature coefficient of transmission which is less than 0.05% per °C, compared with a value of 0.56 % per °C for the OCLI 800 nm bandpass filter. The overall performance of both filters was good (with the possible exception of the high temperature coefficient of

transmission of the OCLI 800 nm filter) so both filters were selected for further, long-term stability evaluations, which are currently being completed.

5. Conclusions

The performance of the OCLI 800 nm bandpass filter and the Barr Associated 800 nm bandpass filter was shown to be superior to that of the other filters evaluated so both these filters were selected for further long-term stability evaluations which are currently being completed.

6. Acknowledgements

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7. References

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