Novel subtractive band-pass filters based on coloured glasses.

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Abstract. A novel type of band-pass filter is proposed and demonstrated. The filter is based on replacing the mechanical shutter used in radiometric measurements with a long-pass coloured glass filter. The performance of the new filter was evaluated and is compared to the performance of band-pass filters based on multi-layer dielectric (interference) filters. The new filter is simple, robust, should exhibit little ageing in comparison with dielectric filters, has a very smooth transmission profile and can be designed to have very broad bandwidths with a near "top hat" transmission profile. It has excellent out-of-band rejection for wavelengths shorter than the peak, while out-of band rejection for wavelengths longer than the peak is likely to be inferior compared to interference filters. However the performance of subtractive band-pass filters should be sufficiently good to allow their adoption in a number of applications.

Introduction

Long-pass coloured glass filters are widely available throughout the UV, visible and NIR. These filters are characterised by very sharp cut-off regions and are used extensively in a number of applications, including the suppression of the out-of-band transmission of dielectric filters and as "order sorting" filters in grating monochromators. If short-pass filters were available, then the combination of a short-pass and a long-pass filter will result in a band-pass filter offering a number of advantages over multi-layer dielectric band-pass filters. However, short-pass coloured glass filters do not exist. To overcome this problem, the author proposed and experimentally demonstrated [1] a novel type of subtractive band-pass filter. This filter relies on using one long-pass coloured glass filter and replacing of the mechanical shutter used in radiometric measurements with a second long-pass coloured glass filter whose cut-off wavelength is shifted from that of the cut-off of the first coloured-glass filter. The effective transmission of this subtractive band-pass filter at a wavelength λ is the difference of the transmissions of the two coloured glass filters at the same wavelength. This means that the transmission of the subtractive band-pass filter at long wavelengths (where the transmission of the two component coloured glass filters is high) is going to be zero provided the transmission of the two coloured glasses are equal. This condition is satisfied by the GG, OG and RG-series of long pass coloured glasses which have internal transmission well in excess of 99.9% for wavelengths longer than their transmission edges.

Results

Consider the case when a detector is monitoring the output from a broadband visible source through, say, an RG630 Schott glass filter [2]. The internal transmission of a 6 mm thick sample of RG630 glass calculated from reference 2 is shown in figure 1. Assume that the amplified detector signal with the RG630 filter in the beam as being V_{RG630}. Now instead of closing the shutter for the dark signal the author proposes replacing the RG630 filter with another filter say an RG645. The internal transmission of a 6 mm thick sample of RG645 glass is also shown in figure 1. The amplified detector output will now give a different signal, V_{RG645}. Consider the properties of the difference between the two readings, V_{RG610}-V_{RG645}. Simple calculations show that the difference is equivalent to the zero-corrected reading when a filter is inserted in the beam which has a transmission profile equivalent to the difference in the spectral transmission between the RG630 filter and the RG645 filter. This transmission profile is shown by the green trace in figure 1. It is obvious from figure 1 that the technique results in a band-pass filter whose short wavelength edge is governed by the transmission characteristics of the RG630 glass while the long wavelength edge is determined by the characteristics of the RG645 coloured glass. In this particular case the resulting "subtractive" band-pass filter has a Full Width Half Maximum (FWHM) bandwidth of approximately 25 nm. Furthermore, because the transmission characteristics of the two coloured glasses are smooth, the transmission of the resulting band-pass filter also has a smooth profile, unlike the case for interference filters of similar transmission characteristics. It is important to remember that this process does NOT require a "dark signal" measurement since the stray light and drifts in the detector amplification system are common to the measurements made with the RG630 and RG645 filters and therefore the subtraction process eliminates their effects.

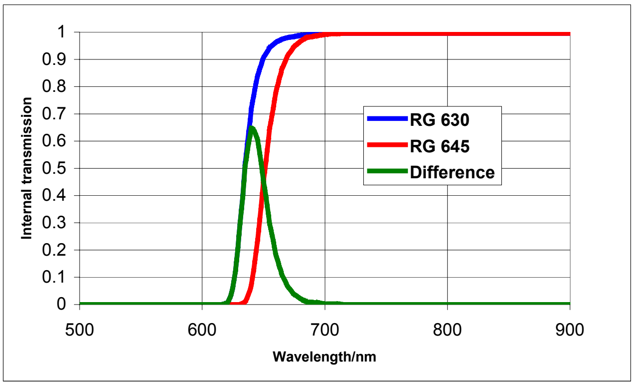

Figure 1. Transmission characteristics of a 6 mm thick RG630 glass (blue line), a 6 mm thick RG645 glass (red line) as well as the effective transmission characteristics of the subtractive band-pass filter resulting from this combination (green line).

Figure 2 shows (on a logarithmic scale) the experimentally measured (external) transmission characteristics of a 6 mm thick RG665 coloured glass filter, as well as the measured transmission of a 6 mm thick RG715 nm glass. Also shown in figure 2 is the transmission of the resulting subtractive band-pass filter. This filter peaks at 685 nm, has a FWHM bandwidth of approximately 35 nm, peak external transmission of 90% and a very smooth profile. Data shown in Figure 2 were plotted on a logarithmic scale in order to illustrate the out-of-band transmission of the subtractive band-pass filter. The subtractive filter has excellent blocking for all short wavelengths whereas the transmission for wavelengths longer than 800 nm appears to be lower than 0.1%. However, the effective transmission is lower than that 0.1% and this is confirmed by the broken line. The line is broken because the values of the measured transmission were negative at some wavelengths and negative values cannot be plotted on a logarithmic plot.

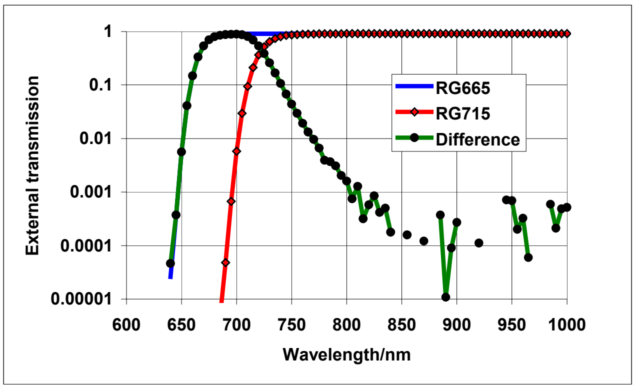

Figure 5: Experimentally measured external transmission characteristics of a 6 mm thick RG665 coloured glass filter, a 6 mm thick RG715 filter as well as the measured transmission of the resulting subtractive band-pass filter (note logarithmic scale).

The performance of the new subtractive band-pass filter was evaluated and was compared to the performance of band-pass filters based on multi-layer dielectric (interference) filters. The new band-pass filter is simple, robust, should exhibit little ageing compared to multi-layer dielectric filters, has a very smooth transmission profile and can be designed to have very broad bandwidths with near "top hat" transmission profiles. It has excellent out-of-band rejection for wavelengths shorter than the peak, while out-of band rejection for wavelengths longer than the peak is expected to be inferior compared to some multi-layer dielectric filters. However the performance of subtractive band-pass filters should be sufficiently good to allow their adoption in a number of applications. The experimental investigation of subtractive bandpass filters will be described and a number of potential applications of the subtractive band-pass of filters will be discussed.

Reference

1. E. Theocharous "Novel band-pass filters based on coloured glasses", *NPL report* No. COAM N3, March 2004.
2. Filter'99 Version 1.1US program available from Schott Glass Technologies Inc., Duryea, PA 18642, USA