Characterisation of optical filters for broadband UVA radiometer

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Abstract. Optical filters were characterized in order to know its suitability for use in broadband UVA radiometer head for spectral irradiance measurements. The spectral transmittance, the angular dependence and the spatial uniformity of the spectral transmittance of the UVA optical filters were investigated. The temperature dependence of the transmittance was also studied.

1. Introduction

Broadband ultraviolet (UV) radiometers usually consist of a radiometer head, a signal converter and a display unit. The detector head contains a photodiode, a spectral filter and an aperture. A diffuser is frequently used to improve the angular response and the spatial uniformity of the radiometer [1]. The spectral filter is used to shape the spectral response of the radiometer head to match the action spectrum of the actinic effect of interest [2]. The radiometer spectral responsivity is the product of the spectral responsivity of the detector and the spectral transmittance of the diffuser and optical filter. For UVA measurement, the required spectral response is a rectangular function from 315 nm to 400 nm and no response outside of this region. It is very difficult to find a commercial UVA meter with a perfect spectral match.

An UVA radiometer head is being assembled for the integrated irradiance measurements in the laboratory. In order to fully understand the response of such UVA meter head, some components properties are independently characterized. Considering the potential use in the device, some Hamamatsu G2119 GaAsP Schottky photodiodes and SUV-Detectors PtSi-n-Si Schottky photodiodes were previously investigated in terms of their spectral power responsivity, local responsivity and shunt resistance [3]. To define the effective area of the input flux for irradiance measurement, two precision apertures with cylindrical edge have been well characterized by using a non-contact technique used for area measurement [4].

In this paper, we present the optical characterization of a set of two UVA optical filters used to define the spectral bandpass measurement of the incident optical radiation in the radiometer head. The spectral transmittance of such filters was investigated inside and outside the specific region of UVA spectral region. The out-of-band transmittance effect was considered by using the spectral matching characteristic $f_1'$ of the filter as an indicator of the closeness to the spectral function of interest. The angular dependence and the spatial uniformity of the spectral transmittance of the UVA optical filters were also analyzed. One UVA optical filter was thermalized and the temperature dependence of the transmittance was analyzed.
2. Characterisation of optical filters

2.1. UVA optical filters
Two XUVA315 optical filters (27SA-01 and 27SA-02), figure 1, manufactured by Asahi Spectra Co. Ltd., were measured. Both filters are 25 mm in diameter and 4.5 mm thick and are made of a thin film deposited on a fused silica substrate mounted in an aluminum ring. According to the manufacturer, these filters are designed for isolating a broad band of UVA, with a transmission band from 315 nm to 400 nm.

![Figure 1. UVA optical filters](image)

2.2. Spectral regular transmittance measurements
The spectral regular transmittance of the UVA optical filters was measured using the laboratory spectrophotometer Varian Cary 5000. The spectrophotometer repeatability in wavelength is better than 0.005 nm, and the expanded uncertainty is estimated to be equal to 0.13 nm ($k = 2.02$).

The out-of-band spectral transmittance of the UVA optical filters was investigated in order to determine its ability to block radiation from wavelengths outside the actinic band function. Spectral scans were carried out in the spectral range from 200 nm to 800 nm and 0.1 nm step. The spectrophotometer bandwidth was 1 nm. The angle of incidence was normal or near normal. Measurements were carried out under dark environment conditions. The spectral regular transmittance of the UVA optical filters was measured at the temperature of 21 °C. The ambient temperature and the relative humidity were monitored during measurements and varied no more than 0.4 °C and 1.5 % ($1\sigma$), respectively.

The temperature dependence of the UVA filter transmittance was investigated by measuring the spectral transmittance of the 27SA-02 optical filter at a set of different temperatures ranging from 21 °C to 25 °C. Spectral scans were carried out in the spectral range from 250 nm to 450 nm and 1 nm step. The UVA filter thermalization was performed with a PID temperature controller acting on an annular thermoelectric Peltier element. The accuracy of the whole temperature controller is about 0.3 °C.

2.3. Angular dependence of the spectral transmittance
Measurements of the angular dependence of the spectral transmittance of the UVA optical filters was realized in the UV dedicated system. The experimental set-up optical radiation source is a mercury arc lamp and measurements were performed at a fixed wavelength of 365 nm. The angular dependence of the spectral transmittance was analyzed from the measurements of the photocurrent as a function of angle of incidence starting with the stable optical beam at normal incidence and further rotating the optical filter around the vertical axis. An automated rotator was used to position the optical filter. The
generated photocurrent by a silicon detector was amplified by a current-voltage converter and a digital multimeter was used to measure the voltage. The trans-impedance amplifier gain used for the test detector was typically $10^7 \text{ V/A}$.

2.4. Spatial uniformity measurements
Spatial uniformity measurements of spectral regular transmittance of UVA optical filters were performed in the spectral power responsivity facility adapted for this purpose. The experimental set-up optical radiation source is a mercury arc lamp. The measurement was performed in power mode. The generated photocurrents were amplified by a current-voltage converter and two digital multimeters were used to measure the voltage. The trans-impedance amplifier gain used for the test detector was typically $10^7 \text{ V/A}$. The measurement of spatial uniformity of spectral regular transmittance of UVA optical filters was performed at 365 nm. The diameter of the incident beam was equal to 1.0 mm. The spatial uniformity of optical filters was investigated by performing a scan of a $(12 \times 12)$ mm² area on the surface of each optical filter with a pitch of 0.5 mm.

3. Measurements results
3.1. Spectral regular transmittance
The UVA optical filters 27SA-01 and 27SA-02 showed spectral regular transmittance at 365 nm equal to 96.27 % and 96.30 %, respectively. In the pass band of interest, it was calculated a relative difference of 2.6 % between their spectral transmittances. The in-band transmittance does not match ideally to the UVA function and moreover both optical filters presented out-of-band transmittances below 315 nm, as can be seen in the figure 2. Both optical filters had undesirable leakages out-of-band transmittance with a peak at 760 nm. Up to 730 nm, the average out-of-band blocking of the optical filter 27SA-01 and 27SA-02 is $3.3 \times 10^{-5}$ to $2.7 \times 10^{-5}$ relative to the bandpass, respectively.

![Figure 2](image-url)

**Figure 2.** Spectral regular transmittance measured of the UVA optical filters inside and outside the passband.
Additionally, the relative differences between the measured spectral regular transmittance of the optical filters and the nominal spectral regular transmittance declared by the manufacturer Asahi Spectra were evaluated. In the pass band of interest, the optical filters showed a maximum relative difference equal to 9 %, approximately.

3.2. Temperature dependence
Within the passband, the spectral transmittance of the 27SA-02 optical filter was measured from 21 °C to 25 °C. The temperature stability was better than 0.1 °C. Figure 3 shows the temperature coefficient of the UVA filter transmittance as a function of wavelength and the region of the inflection points is the most sensitive to changes in temperature [5]. The typical temperature coefficient around the wavelength of 365 nm is about $1.2 \times 10^{-2} \, ^\circ\text{C}^{-1}$. Maximum temperature coefficients of transmittance were observed at the edges of the spectral band.

![Figure 3. Temperature coefficient of the UVA filter transmittance.](image)

3.3. Angular dependence of the spectral transmittance
The generated photocurrent was evaluated at different angles of incidence (0°, 5°, 10°, 15°, 20°, 25° e 30°) of the monochromatic beam at 365 nm. No significant variation of $T$% depending on the angle of incidence ($\Delta T \%/° = 0.06 \%$) was observed.

3.4. Spatial uniformity
The spatial uniformity of spectral regular transmittance of the XUVA315 optical filter (27SA-01) was investigated. The spatial nonuniformity was calculated with a relative expanded uncertainty of $5 \times 10^{-4}$ ($k = 2$). Figure 4 shows the measured spatial uniformity of the spectral regular transmittance of the UVA optical filter.
4. Discussion

A set of UVA optical filters was evaluated by its ability to block radiation of wavelengths outside the band of interest. Both optical filters had undesirable out-of-band leakage in the near-infrared region, what may imply in a measurement overestimation by the assembled UVA meter head. The choice of photodiodes for use in the construction of the UVA meter head have already been made based on a previous study [3]. The best choice among the analyzed photodiodes, considering the out-of-band transmittance of the optical filters peaked at 760 nm, proved to be the GaAsP Schottky photodiodes due to the suppression of radiation above 650 nm and the high shunt resistance. The spectral responsivity of the UVA meter head based on a single GaAsP photodiode was preliminarily calculated as the product of its components characterized separately. The contribution of the out-of-band response of the UVA meter head in the short and long wavelength band was estimated to be only 5.8 % and 5.3 % of the total signal using a continuous spectral lamp as radiant source, respectively. Nevertheless, the presence of the transmittance outside the band of interest may imply the need to use blocking filter to reduce this effect. If the use of the blocking filter is not possible, the out-of-band responsivity must be considered in order to apply a correction, if significant. Assuming a UV radiant source with no flux out-of-band, the effect of the outer band response can be easily corrected by measuring the dark current.

5. Conclusion

The study of the optical characteristics of the UVA optical filters is an important step in the full characterization of the broadband UVA radiometers. Measurements were realized in order to characterize UVA optical filters for being used in the construction of a broadband ultraviolet radiometer for use as a transfer standard. The next step is to investigate some others optical characteristics functions of these UVA optical filters prior to use in radiometric measurements such as its spectral reflectance. As a further remark, filters and photodiodes should be individually selected to achieve a better realization of the UVA spectral function since the use of suitable components can contribute to lower the measurement uncertainty.

Figure 4. Spatial uniformity of the spectral regular transmittance of XUVA315 27SA-01 optical filter at 365 nm. The transmittances are normalized to the center of the active area.
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