The UV Spectral Responsivity Scale of the PTB

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Abstract. A cryogenic radiometer based calibration facility utilizing monochromatized light of an argon arc plasma has been taken into operation. The rather high radiance of the plasma source allows to improve the accuracy of the UV spectral responsivity scale between 200 nm and 410 nm. A relative standard uncertainty between 0.1 % and 0.2 % was achieved. Three detectors can be calibrated simultaneously at a high degree of automation in order to make a relatively high throughput of secondary standard calibrations possible. Comparison with the PTB laser based cryogenic radiometer at five laser lines yielded excellent agreement.

Introduction

UV radiation is widely used in research and industry for lithography, non-destructive testing, water purification, environmental monitoring, atmospheric research, material curing, phototherapy and space-based astrophysical observation. The applications require the calibration of detectors with sufficient accuracy.

The PTB realisation of the spectral responsivity is based on cryogenic radiometers as primary detector standards. In the UV, it has proven a challenge to improve the accuracy of calibration because of the properties of available detectors. The spectral responsivity of Si trap detectors in the spectral range between 450 nm and 950 nm can be realized with uncertainties well below 0.1 % by calibration against a cryogenic radiometer at laser wavelengths and by interpolation of the spectral responsivity using a physical model. Due to the lack of a sufficiently accurate physical model for detectors in the ultraviolet spectral range, a calibration at laser wavelengths combined with the interpolation method does not lead to sufficiently low uncertainties. Consequently, a calibration with a light source tuneable over the whole wavelength range is mandatory. Thus a monochromator based design has been chosen for an improved UV calibration facility. A decisive property for attaining high radiant power at the detector is the spectral radiance of the light source.

Apparatus

The apparatus is a cryogenic radiometer calibration facility which contains a plasma arc as a light source combined with a monochromator for wavelength selection. The entire optical path is set up in gas- and light-tight monolithic boxes of black anodized aluminium. The cryogenic radiometer of type CryoRad II was manufactured by Cambridge Research & Instrumentation. This radiometer has a specified wavelength range between 0.2 µm and 50 µm and a time constant of 3.5 s.

A high-current argon arc plasma is used as the light source [1]. The argon gas of the plasma is electrically heated at a pressure of $2 \cdot 10^5$ Pa within a 100 mm long bore of 4 mm diameter. The discharge is driven by a stabilized direct current of 150 A. The heating power amounts to about 40 kW. The radiation of the argon plasma shows no line structure except between 350 nm and 400 nm where a slight line structure is superimposed on an intense continuum background (ratio 1:10).

A prism-grating double monochromator is used for selecting the wavelength. The rotation angles of the prism and the grating are measured by using absolute angle encoders. By this absolute measurement, the uncertainty of the wavelength determination can be attained completely, and the wavelength calibration can be obtained easily by using laser light at one known wavelength.

UV enhanced optics are essential for sufficient radiant power throughput even at 200 nm. The mirrors used have a special UV enhanced $AlMgF_2$ coating with more than 91 % reflectivity at 200 nm. The bandwidth is 1 nm, and Fig. 1 shows the measured radiant power for this bandwidth. The available radiant power of 1.5 µW/nm at 200 nm is greater than the radiant power at synchrotron UV radiation facilities [2], and in contrast to synchrotron sources, the radiant power of the argon plasma source increases above 200 nm, up to about 7 µW/nm around 300 nm.

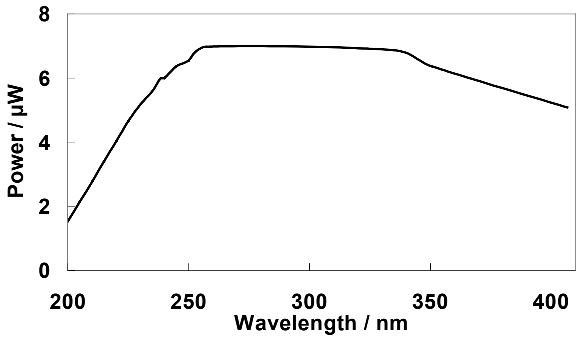

Figure 1. Measured radiant power at a bandwidth of 1 nm. The wavelength dependent power reaching the detector is shown.

Measurements and Discussion

Detectors are calibrated against the cryogenic radiometer at the same position in the beam path. Since the cryogenic radiometer measures the absolute radiant power, the responsivity of the secondary standard can be determined. A monitor detector can be used to correct for power variations between the radiometer and the detector measurement. Polarisation effects are corrected by measuring at three different angles of detector rotation. Detectors are calibrated at controlled temperature.

Si photodiodes and trap detectors have been calibrated between 235 nm and 410 nm and PtSi photodiodes and trap detectors between 200 nm and 410 nm. The relative uncertainties of the Si detector calibrations are around 0.1 % whereas the relative uncertainties of the calibration of PtSi detectors are between 0.1 % and 0.2 % except at certain wavelength regions with a high spectral gradient of the responsivity (see Fig. 2). Therefore, PtSi detectors are used as secondary standards only at wavelengths below 250 nm.

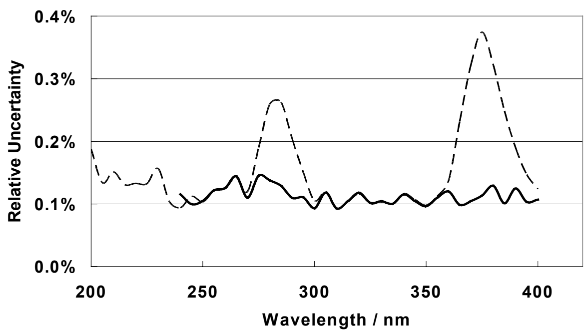

Figure 2. Relative standard uncertainties of the calibration of the spectral responsivities of trap detectors consisting of Si photodiodes (solid line) and PtSi photodiodes (dashed lines).

The calibrations were compared with measurements of the spectral responsivity at the laser based radiation thermometry cryogenic radiometer of the PTB [3] at five laser wavelengths (see Fig. 3), and good agreement was found. However, relative differences between the calibrations at both facilities are larger for PtSi detectors. This is caused by the poorer properties of these detectors.

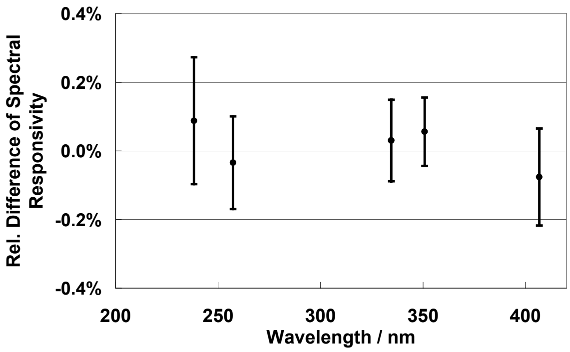

Figure 3. Relative differences of Si trap detector calibrations at the PTB radiation thermometry cryogenic radiometer at five laser wavelengths and at the new monochromator based cryogenic radiometer. The uncertainty bars indicate the standard uncertainties of the relative difference.

The new realisation of the UV spectral responsivity scale was found to agree well with the previous realisation at the PTB while being more accurate. Main contributions to the uncertainty of the calibrations are the noise and drift of the cryogenic radiometer, the fluctuations of the radiant power, stray light, and the uncertainty of the correction for the window transmittance.

The temporal drift of the cryogenic radiometer is independent of the radiant power and varies from measurement to measurement. Typical drift rates are not larger than 20 nW / 10 min presuming stable background conditions. The drift cannot be corrected completely. Being independent of the incident power, the relative significance of this contribution increases with decreasing power. This underlines the importance of having sufficient radiant power especially at short wavelengths around 200 nm.

The contribution to the relative uncertainty caused by the temporal instability of the argon plasma light source amounts to about $3 \cdot 10^{-4}$ to $7 \cdot 10^{-4}$.

The stray light was measured at different wavelengths. The largest uncertainty of $4 \cdot 10^{-4}$ was found at the shortest wavelength. The window transmittance is measured at all wavelengths before and after a calibration. Each calibration is corrected individually for the window transmittance at the assigned wavelength.

The wavelength uncertainty can become the dominant contribution to the uncertainty at certain wavelength regions with a larger spectral gradient of the spectral responsivity. This is only the case for PtSi detectors around 285 nm and 375 nm (see peaks in Fig. 2). Especially above 250 nm, Si photodiode detectors should be preferred.

Conclusion

The new calibration facility is now used to realize the PTB scale of the spectral responsivity between 200 nm and 410 nm. The accuracy of 0.1 % to 0.2 % of this facility has been proven. Since the apparatus offers a good throughput for high-accuracy calibrations it is also used to monitor the travelling detector standards during the CCPR key comparison K2.c.

References

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