Traceable Wavelength Calibration of a Monochromator Using a Fourier Transform Spectro*radio*meter

Stefan Winter, Thomas Fey, Ingo Kröger, and Fabian Plag

Physikalisch-Technische Bundesanstalt, Braunschweig, Germany
Stefan.Winter@PTB.de

The calibration of detectors with a spectral responsivity that differs from that of the reference detector requires an accurate traceable wavelength calibration of the monochromator system. For such detectors the wavelength uncertainty may even be the largest uncertainty component. Typically the wavelength calibration is performed with cw lasers or mercury pencil lamps. Its result though depends on the exact position of the optical image of the sources on the entrance slit. However, for this application the radiation that *exits* the monochromator is essential. We solve this challenge by using a radiometrically calibrated Fourier Transform Spectrometer (FTS) and, with this approach, reduce the wavelength uncertainty from 0.3 nm to 0.03 nm.

INTRODUCTION

An accurate traceable wavelength calibration of the monochromator system used for spectral responsivity measurements is important for the calibration of detectors with a spectral responsivity that differs from the reference detector, e.g. the calibration of photometers, UV detectors, or filter radiometers against silicon trap detectors. In these cases the wavelength uncertainty may be the largest uncertainty component. With a detailed uncertainty analysis it was shown that the wavelength uncertainty contributes more than 90 % to the combined uncertainty of relative quantities like the spectral mismatch index or the general $V(\lambda)$ mismatch index f_1' of photometers [1].

TRADITIONAL METHOD

Typically, the wavelength calibration of monochromators is performed with lasers or mercury pencil lamps. For these measurements the slits are reduced to a minimum width to ensure that the laser beam or the optical image of the pencil lamp enters the monochromator in the centre of the entrance slit and also to get a high resolution. While spectroradiometers have entrance optics with diffusers or integrating spheres and therefore do not show an important dependence of the centre wavelength on the uniformity of the irradiation, monochromators are optimized for high throughput and are very sensitive to a horizontal non-uniformity at their entrance. For the application of the monochromator a quartz halogen or a xenon lamp is imaged onto the entrance slit. It is thus not illuminated uniformly. In an extreme case this may lead to any centre wavelength within the range of the adjusted bandwidth (Full Width Half Maximum, FWHM). Especially if the application needs a high optical power, the slits must be opened wide and this leads to a large wavelength error. At the DSR facility of the authors a misalignment of the xenon lamp of 1 mm results in a wavelength offset at the exit of the monochromator of more than 0.6 nm.

A further problem of the calibration with pencil lamps is the limited number of usable spectral lines for the calibration and the need to interpolate between these lines. Typical monochromators are built up with a worm gear that rotates a gearwheel with the grating on its top. With very precise measurements as presented at the end of this paper, the periodical wavelength errors due to the mechanical errors of the worm gear may be made visible (Fig. 5).

A third issue is the influence of the spectral irradiance of the source on the centre wavelength of the radiation because the spectrum of the outgoing radiation is the product of the spectral irradiance of the source, the slit function of the monochromator and the reflectance of the components within the monochromator. Thus a peak of a xenon lamp influences the centre wavelength of wavelength settings of the monochromator close to the peak (Figs. 3+4).

Figure 1. Setup with the monochromator system on the left. Its monochromatic and parallel beam enters the FTS that stands on the right optical table at the place where usually the detectors (e.g. solar cells) were mounted.

To summarize, it can be concluded that it is not sufficient to calibrate a monochromator system with incoming radiation of a known wavelength. It is much more important to characterize the wavelength of the outgoing radiation at every wavelength and slit setting used individually.

APPLYING AN FTS AS A FOURIER TRANSFORM SPECTRO*RADIO*METER

The solution to the above-mentioned issues is the spectral measurement of the radiation that comes out of the monochromator. One possibility would be to use an array spectroradiometer, but its wavelength uncertainty is too high and its wavelength must be first calibrated. Another idea could be to use wave-meters. They state the wavelength with a very high resolution and accuracy, but only for very narrow band sources such as cw-lasers. Thus we chose a system that is suitable for broad band light sources:

A Fourier Transform Spectrometer that can measure down to 200 nm was implemented (Fig. 1). At least an external HeNe laser that is coupled in from outside into the FTS on the same path as the radiation from the monochromator, must be used as a wavelength reference in air. This enables a wavelength uncertainty of the FTS smaller than 0.01 nm. The obtained values however are only valid for the peak wavelength at this step. After a radiometric calibration of the FTS against a standard lamp (Fig. 2), the radiometric centre wavelength can be determined. To estimate the uncertainty, the influence of a wrong distribution temperature was calculated. It was shown that a wrong distribution temperature of 3020 K instead of 3000 K would lead to an error in the centre wavelength of only 0.006 nm (parameters: radiation at 300 nm with an FWHM of 10 nm).

With this setup the spectral irradiance of the radiation behind the monochromator and its centre wavelength is determined with high wavelength accuracy (Fig. 3 - 5) and thus it can be corrected.

SUMMARY

With the integration of a radiometric calibrated FTS in the monochromator setup the uncertainty of the centre wavelength of the outgoing radiation could be reduced from 0.3 nm to 0.03 nm.

A further advantage of this method is that the unstabilized HeNe wavelength value (in vacuum) is recommended by the CIPM as a realization of the definition of the metre with a relative standard uncertainty of $1.5 \cdot 10^{-6}$ [2], while mercury lines are not recommended for this purpose by the CIPM.

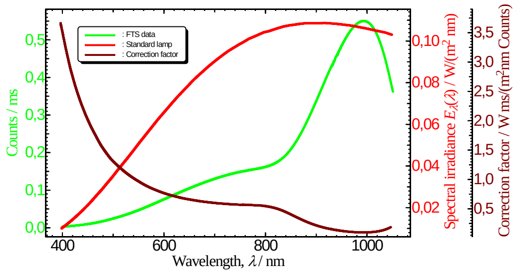

Figure 2. Result of the radiometric calibration of the FTS.

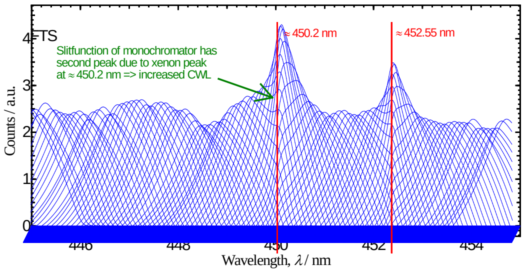

Figure 3. Spectral irradiance measured every 0.1 nm.

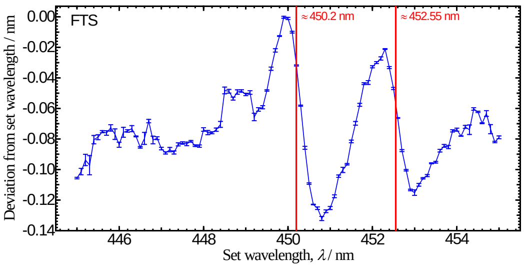

Figure 4. Deviation from the set wavelength. The xenon peaks lead to deviations of 0.14 nm (peak-to-peak).This is about 10 % of the FWHM of the monochromator output!

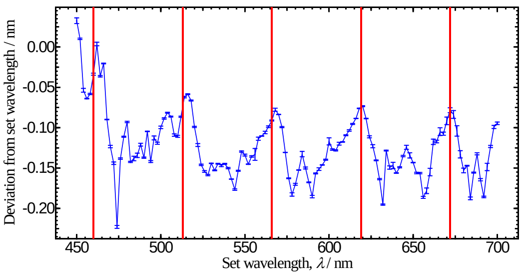

Figure 5. Deviation from the set wavelength. The red lines indicate the periodically identical position of the worm gear in the monochromator. The main wavelength deviations show the same periodicity, despite the superposition of other smaller effects (e.g. at 450 nm, see Fig. 4).

REFERENCES

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