Calibration of a modular trap detector system towards a new realization of the luminous intensity unit

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A modular photometric trap detector system has recently been developed at PTB. All parts of the detector are now completely calibrated. As a result, the new traceability chain for the realisation of the luminous intensity unit can be established for a first time. This contribution shows the results of the individual calibration steps. Improvements in the measurement setup used for carrying out most of the calibration steps in the traceability chain are described and the resulting effect on the measurement uncertainty is shown. The remaining steps along the way towards this new realization of the luminous intensity unit and its implications are discussed.

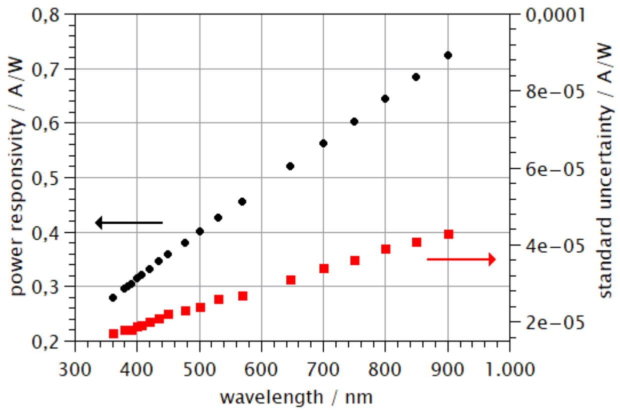

Figure 1. Power responsivity of the trap detector (black symbols) calibrated against the cryogenic radiometer with a preliminary standard uncertainty (red symbols)

THE MODULAR DETECTOR APPROACH

The individual steps within the improved calibration strategy for realising the luminous intensity unit at PTB have been shown and described previously [1]. The modular detector system was developed specifically for this purpose. Its suitability for realising the traceability chain were checked beforehand based on thorough characterizations at the TULIP setup [2].

All necessary calibrations of the detector system have now been accomplished, which provides a glance of the final uncertainty achievable while following the new calibration strategy.

CRYOGENIC RADIOMETER-BASED CALIBRATION OF THE TRAP DETECTOR

The trap-detector was calibrated with respect to the spectral power responsivity at the laser-based cryogenic radiometer facility of PTB. It has been designed and is operated in a way to ensure the lowest possible uncertainties. The facility is equipped with a common Brewster window which means that cryogenic radiometer and trap-detector are irradiated through the same window. Thus, the correction for and the uncertainty contribution arising from the measurement of the transmittance of the Brewster window can be avoided. The detector cavity of the cryogenic radiometer and the trap-detector were irradiated at the same position with respect to the laser beam. Thus, the uncertainty contribution arising from the scattered radiation around the laser beam is drastically reduced. The calibration was carried out at 19 wavelengths covering the spectral range from 360 nm to 900 nm. The results are shown in Figure 1.

The spectral power responsivities at the 19 wavelengths need to be interpolated for further calibrations at the TULIP setup. Since silicon photodiodes are known for their aging and the measurements were done over the course of 5 months, the data points need a correction for this effect. As this detector was measured only once at this uncertainty level, the specific aging correction function is not available yet. Nevertheless, a correction will be estimated with a conservative uncertainty contribution based on known aging rates of similar trap detectors with the same type of photodiodes.

CALIBRATION OF THE PHOTOMETRIC FILTER

The realisation of the luminous intensity unit requires adapting the spectral responsivity of the detector system to the photometric standard observer. For this purpose, the modular trap detector system includes a $V(\lambda)$ filter. The filter transmittance is measured relatively to a precision aperture deposited on a window as described in [1]. The measurements were carried out using the femtosecond laser system at the TULIP setup. The results are shown in Figure 2.

The major contributions to the uncertainty were yielded by the measurements of the laser wavelength with a spectrometer and the signal to noise ratio of the measured signals, combining the stability of the laser system and the electrical measurement. These uncertainty components of the filter transmittance contribute directly to the measurement uncertainty of the spectral irradiance responsivity of the photometric trap detector system and to the respective uncertainty of the luminous responsivity.

IMPROVING THE CALIBRATION

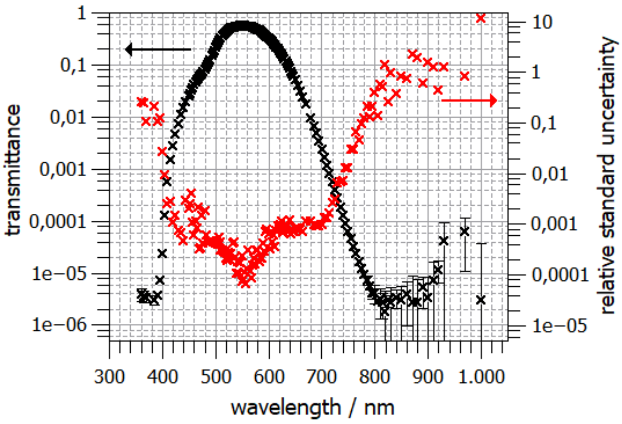

Figure 2. Spectral transmittance of the photometric filter plotted on a logarithmic scale (black symbols) and the corresponding relative standard uncertainty (red symbols).

UNCERTAINTIES

To enable a lower uncertainty of these calibration steps we have done improvements on the TULIP facility. As an additional radiant source, a mode-locked picosecond laser system tuneable from 230 nm to 2300 nm has been installed and is characterized for calibration of the trap detector.

The picosecond laser offers several advantages for the measurements compared to the femtosecond system. The picosecond laser beam has a maximum spectral bandwidth of 0.5 nm within the spectral range of interest. This means that no bandpass additional limiting monochromator is needed. In addition, the wavelength of such a narrow spectral distribution can be measured directly by a laser spectrum analyser with an improved uncertainty compared to the conventional spectrometer that is used for measuring the wavelength of the femtosecond laser.

The measurements of the filter transmission determining the spectral irradiance responsivity of the trap detector system are repeated following the upgrade of the TULIP setup by the picosecond laser system. The results of the new measurements will be compared to the existing ones.

REALIZATION OF THE LUMINOUS INTENSITY UNIT

Considering the above-mentioned measurements, the detector system can be ascribed with the spectral irradiance responsivity values and the associated uncertainties including correlations. Based on these values, the luminous responsivity can finally be assigned.

A comparison between the current realization of the luminous intensity unit at PTB and the results obtained following the discussed calibration steps will be done. Nevertheless, this is just a first step towards implementing a new strategy for the traceability of the luminous intensity unit at PTB.

Before implementing this new strategy, a thorough investigation of the new realization needs to be done with respect to the stability of this radiometric detector-based approach. This includes establishment of a network of calibrated detectors, determining their individual aging rates, implementing regular calibration of the multiple detectors, apertures, filters and a long-term observation of the values resulting from the new calibration strategy compared to the values of the unit currently maintained by a group of standard incandescent lamps.

REFERENCES

1. P. Schneider et al., Improved calibration strategy for luminous intensity, J. Phys.: Conf. Ser., 972, 012016, 2017
2. M. Schuster et al., Validation of short-pulse-laser-based measurement setup for absolute spectral irradiance responsivity calibration, Applied Optics, 53, 13, 2815-2812, 2014