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Citation: AIP Conf. Proc. **1531**, 833 (2013); doi: 10.1063/1.4804899
View online: http://dx.doi.org/10.1063/1.4804899
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1531&Issue=1
Published by the AIP Publishing LLC.

# Stability of Light-Emitting Diodes in the Solar UV Spectral Range

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**Abstract.** The development of compact, stable, portable, and robust monitoring sources based on state-of-the-art, commercially available UV light-emitting diodes (LEDs) is one of the tasks within the European Metrology Research Programme (EMRP) Project *Traceability for surface spectral solar ultraviolet radiation* aimed towards shortening the traceability chain and reducing the uncertainties of spectral solar UV radiation measurements in the wavelength range 280 nm to 400 nm. These sources will be used to maintain the spectral calibration of spectroradiometers while deployed at the solar UV measurement sites. As a first step, commercially available UV-LEDs have been selected and characterized with respect to their stability and spectral properties.

**Keywords:** UV-LEDs, Aging, Stability, Spectral properties, Solar UV.
**PACS:** 42.72.Bj

## UV-LEDS AND MEASUREMENT SETUPS

At the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig, Germany, UV-LEDs with the following peak wavelengths have been investigated (3 LEDs of each type, UVTOP series, flat emission window, TO-18 package): 285 nm, 299 nm, 310 nm, 333 nm, 342 nm, and 369 nm (Figure 1). Their spectral width (FWHM) is in the order of 10 nm – 14 nm.

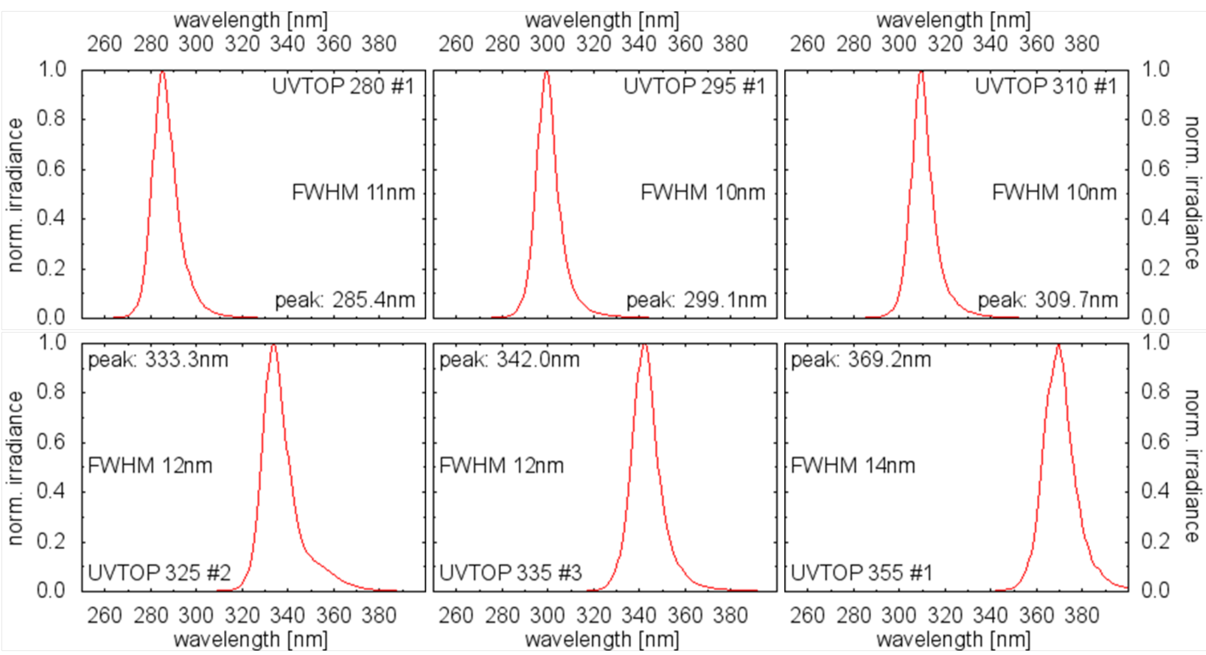


**FIGURE 1.** Normalized spectral irradiance of the UV-LEDs investigated at PTB.

A fully automated measurement setup with two rotary stages, carrying detectors and emitters, respectively, is used to monitor the stability of the constant-current (20 mA) driven UV-LEDs. All LEDs are mounted in separate

*Radiation Processes in the Atmosphere and Ocean (IRS2012)*
AIP Conf. Proc. 1531, 833-836 (2013); doi: 10.1063/1.4804899

holders, each equipped with a thermostat. The temperature, the forward voltage, and the current of each UV-LED are monitored. As monitor detector, a large area silicon photodiode, also equipped with a thermostat, has been used. In addition to the Si photodiode, a calibrated array spectroradiometer (Instrument Systems, CAS140CT) is used to monitor the stability of the emitted spectra.

At the Bundesamt für Metrologie (METAS) in Bern-Wabern, Switzerland, the stability of UV-LEDs with peak wavelengths of 294 nm, 318 nm, 335 nm and 368 nm (4 LEDs of each type, UVTOP series, flat emission window, TO-39 package) were chosen for the studies.  The radiant flux of the UV-LEDs is measured by a temperature stabilized GaAsP trap detector. The temperature of the UV-LEDs is kept constant through a Peltier element. In addition, the forward voltage is monitored. The results obtained at METAS are similar to PTB's, therefore, mainly the results of PTB are discussed in the following.

## AGING BEHAVIOR

The aging behavior of the UV-LEDs measured at PTB is shown in Figure 2. Please note the different scales for the time and irradiance axes. The data obtained from the spectroradiometer (CAS, red crosses) and the Si diode (green crosses) correspond very well. It is obvious from these graphs, that the shorter the peak wavelength of the UV-LEDs, the shorter the lifetime (decrease in irradiance to 50% of the initial irradiance) is. These graphs also show that decreasing the temperature from 35°C to 25°C increases the irradiance. This behavior is expected due to several temperature-dependent factors, e.g., non-radiative recombination.

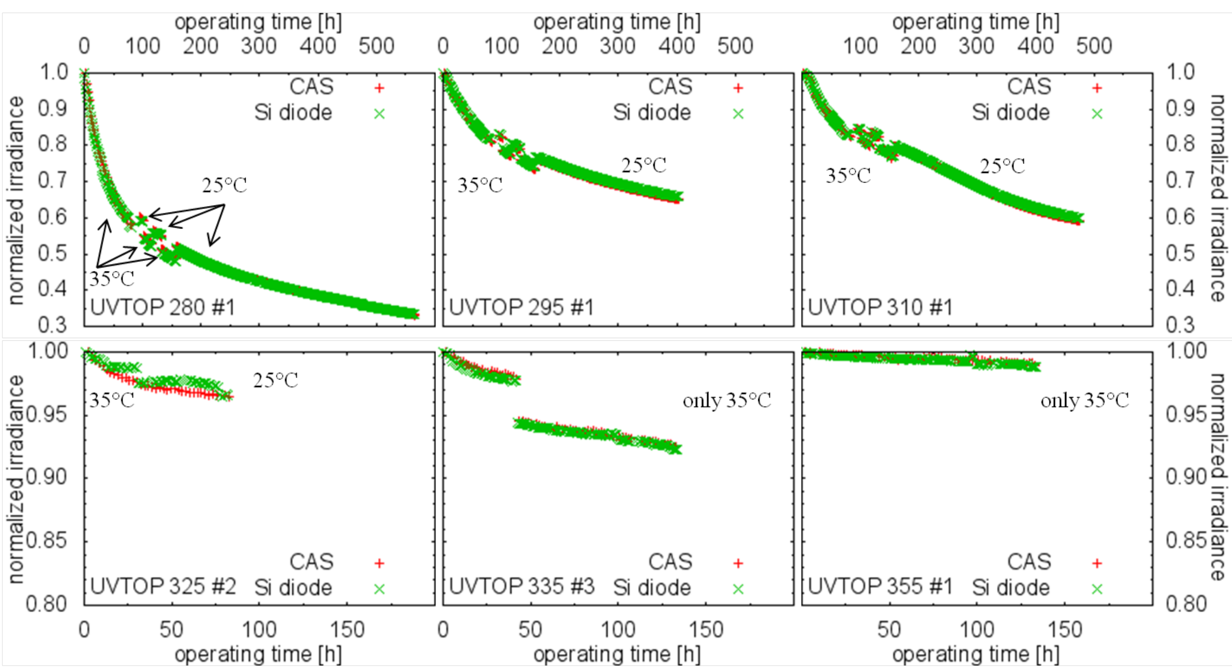


**FIGURE 2.** Aging behavior of the UV-LEDs measured at PTB. Side note: The difference between the Si and CAS measurement of device UVTOP 325 #2 (left graph in the lower row) is due to a problem of the measurement setup. The jump in irradiance seen in device UVTOP 355 #3 (middle graph in the lower row) is due to a change of the current source resulting in a different current level.

For the to-be-built monitoring sources, the lifetime of the UV-LEDs is not primarily a limiting factor. It is more important that the irradiance levels are as constant as possible: the drift in irradiance is required to be 0.05% per hour or less. Table 1 shows the drift levels of the UV-LEDs after being operated for different times. The required drift level is achieved by almost all devices; however, the LEDs with the shortest wavelengths do not meet this requirement. For the operation of the monitoring sources, a solution could be to drive the LEDs with reduced current and/or lower temperature in order to achieve smaller drift levels.

**TABLE (1).** Drift in irradiance of the aged UV-LEDs.

| name | peak wavelength | operating time | temperature | drift required: 0.05% / h or less |
|---|---|---|---|---|
| UVTOP 280 #1 | 285 nm | 565 h | 25°C | -0.08% / h |
| UVTOP 295 #1 | 299 nm | 402 h | 25°C | -0.05% / h |
| UVTOP 310 #1 | 310 nm | 476 h | 25°C | -0.05% / h |
| UVTOP 325 #2 | 333 nm | 101 h | 25°C | -0.03% / h |
| UVTOP 335 #3 | 342 nm | 134 h | 35°C | -0.04% / h |
| UVTOP 355 #1 | 369 nm | 134 h | 35°C | -0.01% / h |
| | | | | |
| METAS 290 #1 | 294 nm | 55 h | 15°C | -0.12% / h |
| METAS 315 #2 | 318 nm | 50 h | 15°C | -0.02% / h |
| METAS 335 #2 | 335 nm | 60 h | 15°C | -0.02% / h |
| METAS 355 #2 | 368 nm | 50 h | 15°C | -0.02% / h |

## SPECTRAL PROPERTIES

As the devices are aging while being operated, it is possible that the emitted spectra are changing. While the peak wavelength is not changing during the aging, the centroid wavelength is slightly drifting to longer wavelengths and the spectral bandwidth is slightly increasing for most devices (see table 2). These observations are attributed to the individual devices; with the data at hand a general conclusion can not be drawn.

**TABLE (2).** Drift of the centroid wavelength to higher wavelengths and increase of the spectral width during aging.

| name | peak wavelength | temperature | shift in centroid wavelength | shift in FWHM |
|---|---|---|---|---|
| UVTOP 280 #1 | 285 nm | 25°C | $1.7 \cdot 10^{-4}$ nm / h | $0.9 \cdot 10^{-4}$ nm / h |
| UVTOP 295 #1 | 299 nm | 25°C | $0.8 \cdot 10^{-4}$ nm / h | $0.3 \cdot 10^{-4}$ nm / h |
| UVTOP 310 #1 | 310 nm | 25°C | $0.4 \cdot 10^{-4}$ nm / h | $<0.1 \cdot 10^{-4}$ nm / h |
| UVTOP 325 #2 | 333 nm | 25°C | $5.1 \cdot 10^{-4}$ nm / h | $6.1 \cdot 10^{-4}$ nm / h |
| UVTOP 335 #3 | 342 nm | 35°C | $5.4 \cdot 10^{-4}$ nm / h | $3.5 \cdot 10^{-4}$ nm / h |
| UVTOP 355 #1 | 369 nm | 35°C | $1.3 \cdot 10^{-4}$ nm / h | $7.8 \cdot 10^{-4}$ nm / h |

For the monitoring sources, another requirement is the level of spectral irradiance over the spectral range of 220 nm to 400 nm: at least 1 (mW/m$^2$)/nm for wavelengths below 330 nm and at least 5 (mW/m$^2$)/nm for wavelengths above 330 nm. The individual spectral irradiances of seven UV-LEDs after the aging process are shown in Figure 3. Using all these LEDs in the monitoring sources, we expect to reach the requirements for the spectral irradiance for almost all wavelengths (Figure 4, red curve: expected irradiance, black lines: required irradiance levels). To fill the missing gaps, additional LEDs have been bought with selected wavelengths (blue curves), which additionally will be investigated and used in the monitoring sources.

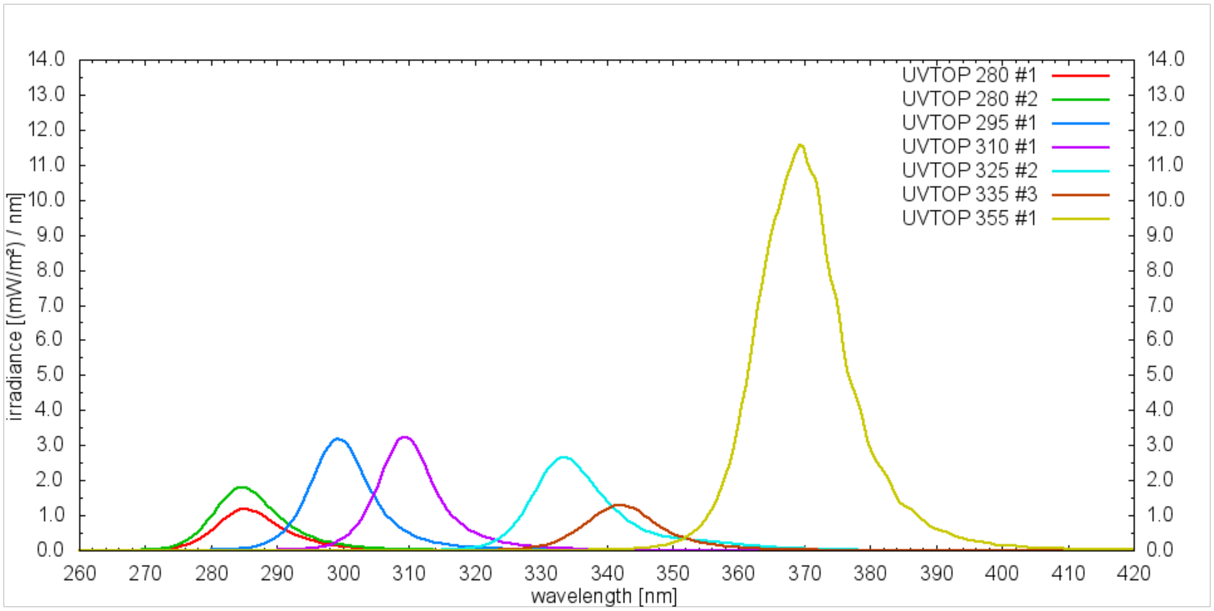


**FIGURE 3.** Individual spectral irradiance of seven aged UV-LEDs.

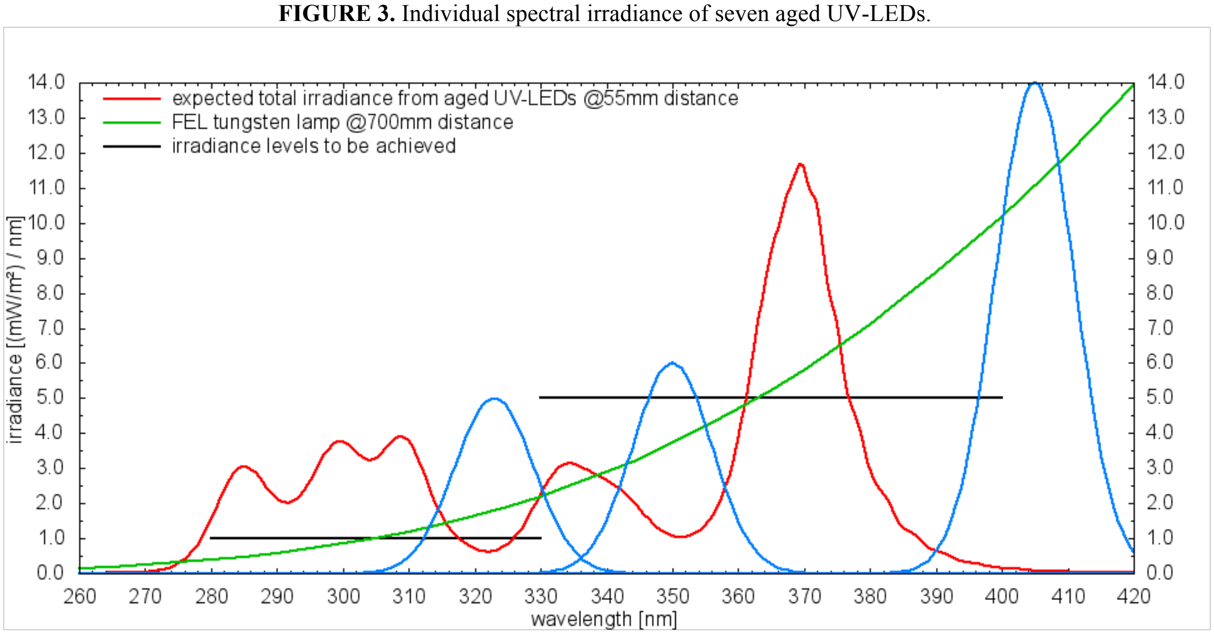


**FIGURE 4.** Expected total irradiance from the seven aged UV-LEDs of Figure 4 (red curve). Required irradiance levels: black lines. Additional UV-LEDs with selected wavelengths are needed (blue curves). For comparison: FEL spectral irradiance (green curve).

## ACKNOWLEDGMENTS

The work leading to this study was partly funded by the EMRP ENV03 Project "Traceability for surface spectral solar ultraviolet radiation". The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.