OP55

DEVELOPMENT OF 2π TOTAL SPECTRAL RADIANT FLUX STANDARDS AT NIST

Yuqin Zong[1] and Haiping Shen[2]
[1] National Institute of Standards and Technology, Gaithersburg, Maryland, USA
[2] Fudan University, Shanghai, CHINA
yuqin.zong@nist.gov

Abstract

We have developed a new, reflector lamp based 2π transfer standard for total spectral radiant flux (TSRF) scale in the spectral range from 360 nm to 1100 nm. Correlated colour temperature of the standard lamp is 3000 K. Spectral aging rate is ±0.3 % for 24 h operation time. The 2π standard lamp has a near Lambertian beam pattern. Relative expanded uncertainty (k=2) of the 2π standard lamp is between 1.3 % (in the visible region) and 2.9 % (in the ultraviolet region).

Keywords: 2π standard lamp, total spectral radiant flux, integrating sphere, spectroradiometer.

1 Introduction

Integrating spheres equipped with a spectroradiometer are commonly used for measurement of light emitting diodes (LEDs) and solid-state lighting (SSL) products for total spectral radiant flux to obtain photometric, radiometric, and colorimetric quantities. Such sphere-spectroradiometer measurement systems are typically calibrated against total spectral radiant flux standards. There are two types of measurement geometries: 4π and 2π. In a 4π geometry a light source is placed at the centre of a sphere. While in a 2π geometry the light source is mounted on a port of a sphere. Depending on the measurement geometry, a 4π or 2π total spectral radiant flux standard is required for calibration of such a sphere-spectroradiometer system.

A 4π total spectral radiant flux standard, based on a 75 W quartz tungsten halogen lamp, was developed in 1997 at NIST which covered the spectral range from 360 nm to 830 nm [1] and was extended to 300 nm to 1100 nm in 2011 with expanded uncertainties between 1 % to 3 % (k=2) depending on the wavelength range.

For measurement of 2π LEDs (such as high-power LEDs) and 2π SSL products a 2π geometry sphere is more convenient than a 4π geometry sphere. Hence 2π geometry spheres are preferred by calibration laboratories and recommended by many national and international standard testing documents. However, 2π total spectral radiant flux standards are not available from National Metrology Laboratories at present time. To address the urgent need we recently developed a compact 2π total spectral radiant flux standard based on a 20 W tungsten halogen reflector lamp. The 2π standard lamp covers the spectral range from 360 nm to 1100 nm.

2 Description of a 2π standard lamp for total spectral radiant flux

Similar to a 4π standard lamp, an ideal 2π transfer standard lamp for TSRF should have a smooth spectral power distribution, high correlated colour temperature (CCT) (>3000 K), low aging rate, high reproducibility, and good long term stability.

A 2π sphere is typically small (less than 0.5 m diameter typically), thus, a small, low wattage lamp is preferred as a 2π standard lamp. Several tungsten halogen reflector lamps have been evaluated to see if they are feasible to be used as 2π transfer standards. Currently we use a compact (37 mm diameter), 12 V, 20 W tungsten halogen aluminium reflector lamp as the 2π transfer standard. The nominal CCT of the reflector lamp is 3000 K and total luminous flux is 250 lm. The rated average life of the reflector lamp is 2000 h and it allows to be operated in any orientation. A custom lamp housing with a four-wire socket is designed for operating this standard lamp.

The ideal beam pattern for a 4π standard lamp is isotropic. In contrast, the ideal beam pattern for a 2π standard lamp is Lambertian. Unfortunately commercial tungsten halogen reflector lamps with a large beam angle are not available. Therefore, we replaced the window of the 20 W tungsten halogen aluminium reflector lamp with an optical diffuser to convert its narrow beam pattern to a near Lambertian beam pattern. A photograph of the modified tungsten halogen aluminium reflector lamp (the 2π TSRF transfer standard) and a lamp housing are shown in Figure 1.

Figure 1 – Photograph of the 2π TSRF transfer standard lamp and its lamp housing

Beam pattern of the 2π standard lamp is symmetric. Figure 2 shows a measured beam profile of the 2π standard lamp which is close to that of a Lambertian source.

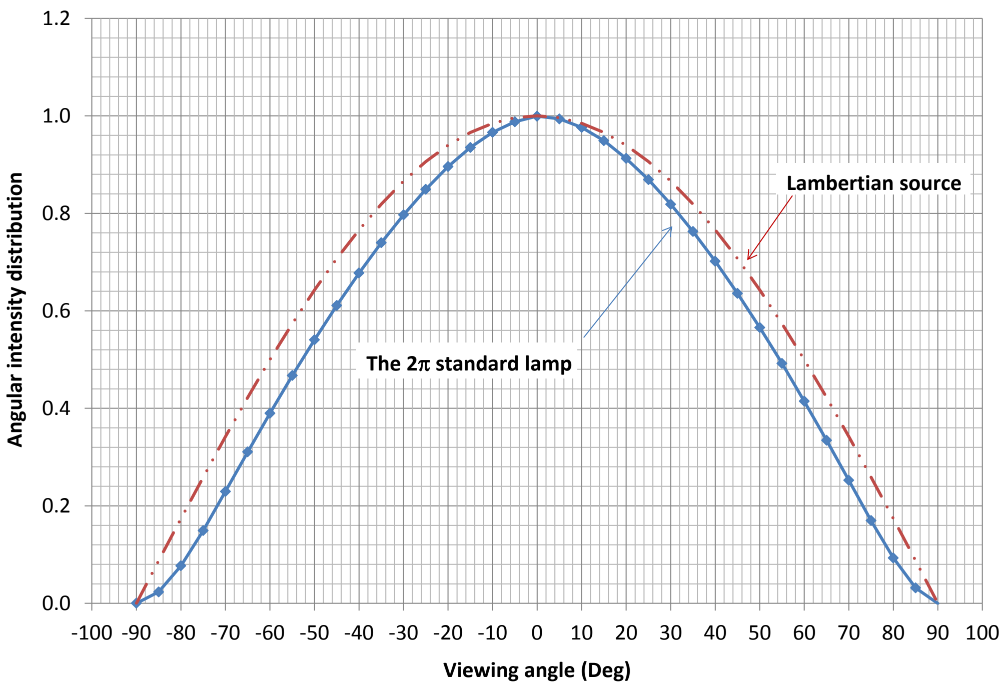

Figure 2 – Measured beam profile of the 2π standard lamp

Aging curves of spectral radiant intensity of the 2π standard lamp at four wavelengths of 430 nm, 555 nm, 720 nm, and 830 nm are shown in Figure 3. The starting points at t = 0 are set to be 1.000 for 430 nm, 1.005 for 555 nm, 1.010 for 720 nm, and 1.015 for 830 nm, so that the curves are not overlapped. The aging curve for CCT is shown in Figure 4. After an initial stabilization time (approximately 10 min) spectral radiant intensity changes slowly over time due to aging. Change of the spectral radiant intensity is within ±0.3 %, and the change of CCT is less than 2 K for 24 h operation.

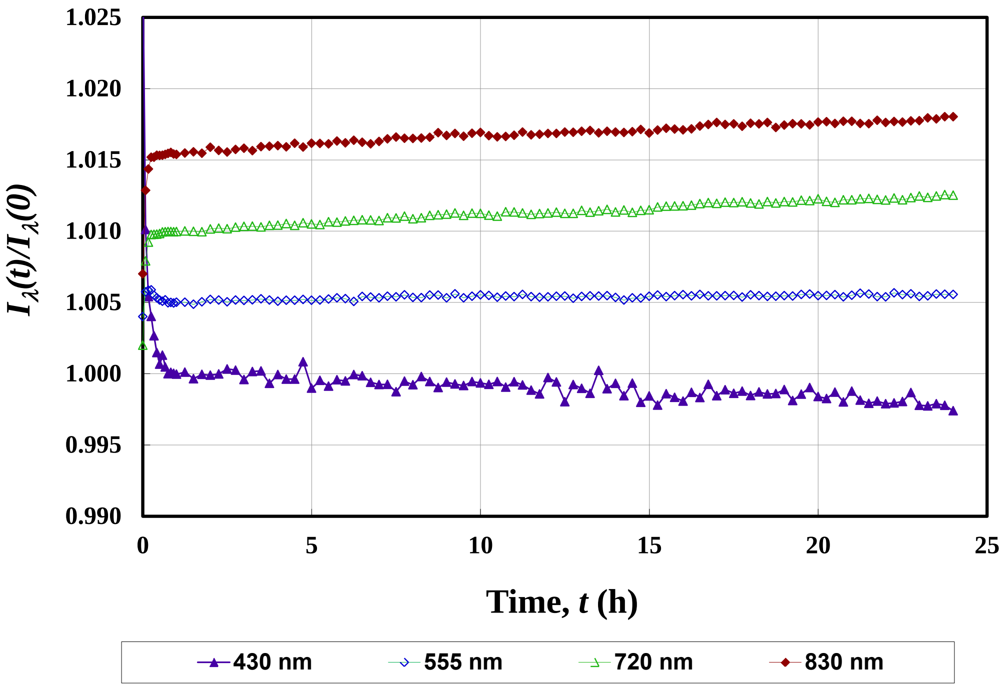

Figure 3 – Aging of spectral radiant intensity over 24 h operation time

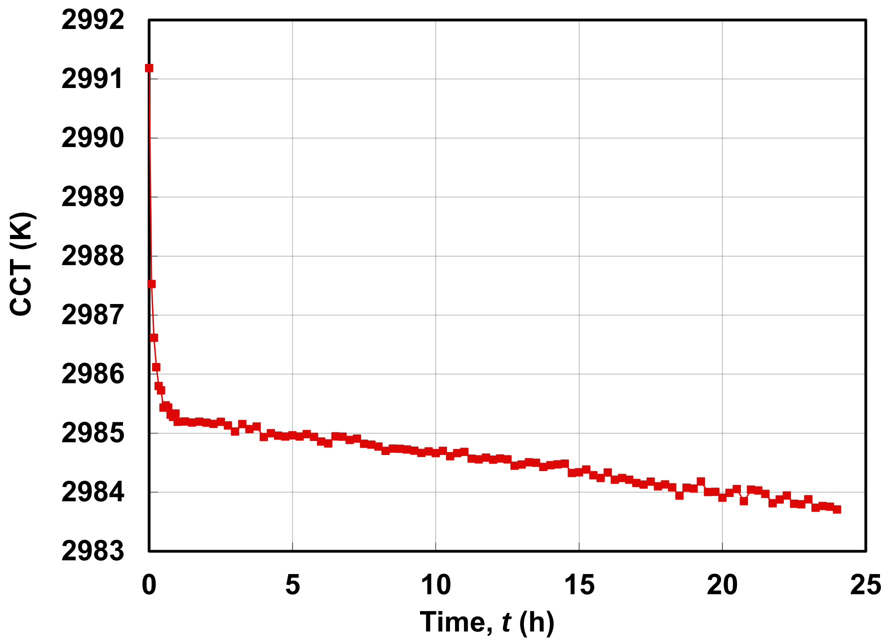

Figure 4 – Aging of CCT over 24 h operation time

3 Calibration of 2π TSRF standard lamps

A 2π TSRF standard lamp is calibrated using a way similar to that used for calibration of a 4π TSRF lamp. To determine the TSRF, a 2π standard lamp is first measured at many angles using a gonio-spectroradiometer for the relative spectral radiant intensity distribution, $I_{\lambda,\mathrm{rel}}(\lambda,\theta,\varphi)$. The scaling of $I_{\lambda,\mathrm{rel}}(\lambda,\theta,\varphi)$ is set arbitrarily, but is fixed during measurements of the lamp at every angle so that relative change of the lamp's intensity with different angles is measured accurately. After the measurements of $I_{\lambda,\mathrm{rel}}(\lambda,\theta,\varphi)$, the 2π TSRF standard lamp is then calibrated for total luminous flux, Φ_v , using the NIST 2.5 m absolute integrating sphere [2] to determine the scaling factor, k_scale. The TSRF, $\Phi_\lambda(\lambda)$, is obtained using Equations 1 and 2,

$$\Phi_\lambda(\lambda) = k_\mathrm{scale}\int_{\varphi=0}^{2\pi}\int_{\theta=0}^{\frac{\pi}{2}} I_{\lambda,\mathrm{rel}}(\lambda,\theta,\varphi)\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\varphi\,, \tag{1}$$

$$k_\mathrm{scale} = \frac{\Phi_\mathrm{v}}{K_\mathrm{m}\int_{\lambda=0}^{\infty}V(\lambda)\int_{\varphi=0}^{2\pi}\int_{\theta=0}^{\frac{\pi}{2}} I_{\lambda,\mathrm{rel}}(\lambda,\theta,\varphi)\sin\theta\,\mathrm{d}\theta\,\mathrm{d}\varphi\,\mathrm{d}\lambda}\,, \tag{2}$$

where K_m (=683 lm/W) is the maximum spectral luminous efficacy, $V(\lambda)$ is the spectral luminous efficiency, and θ and φ are polar coordinates of the gonio-spectroradiometer. As indicated in the above two equations, the scaling of $I_{\lambda,\mathrm{rel}}(\lambda,\theta,\varphi)$ is cancelled, and the absolute scale of $\Phi_\lambda(\lambda)$ is determined by total luminous flux, Φ_v, making $\Phi_\lambda(\lambda)$ consistent with the NIST luminous flux scale. Thus, the TSRF scale realized at NIST is based on both the NIST spectral irradiance scale and NIST total luminous flux scale.

The gonio-spectroradiometer used for the calibration is shown in Figure 5. It is composed of a 3-axis scanning mechanism, a fast, cooled (-10° C), charge-coupled device (CCD) array spectroradiometer, and a motion control/data acquisition computer. The 3-axis scanning mechanism consists of a short arm for the lamp holder (used to set up the orientation of a standard lamp), a long arm for rotation of the irradiance head of the spectroradiometer around the θ axis, and a lamp holder which rotates around the φ axis. The dead angle of θ due to the mechanism of the lamp holder is ±3 degrees (that is, θ covers from 0 to 177 degrees). For measurement of 2π lamps the required scanning angle, θ, is only from 0 to 90 degrees, thus the dead angle does not cause any problem. Both scanning motors for θ and φ axes stop when an optical measurement takes place. The total measurement time for a 2π standard lamp is approximately one hour with a scanning angle interval of 5 degrees for θ and 10 degrees for φ.

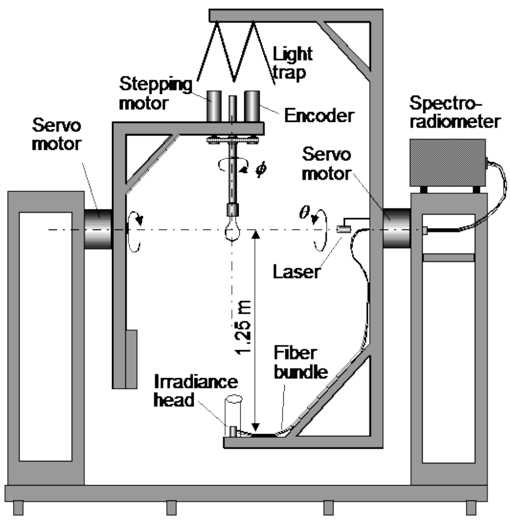

Figure 5 – Illustration of the NIST gonio-spectroradiometer

An irradiance head (a 15 mm diameter UV-VIS-NIR diffuser) is mounted on one end of the long arm (for θ) with a rotation radius of 1.25 m, and a light trap is mounted on the other end of the long arm. A hood is mounted on the irradiance head to minimize the errors arising from scattered ambient stray light. The irradiance head has an approximate cosine response within the field of view limited by the hood.

The CCD array spectroradiometer is placed on the fixed frame of the gonio-spectroradiometer. A 1.5 mm core diameter, 5 m long quartz fiber bundle is used to couple the rotating irradiance head to the stationary array spectroradiometer. The twisting effect of the fiber bundle on the responsivity of the spectroradiometer was tested to be less than 0.1 %. The spectroradiometer is calibrated against two FEL spectral irradiance standard lamps [3] when the long arm for the irradiance head is rotated to be horizontal (θ =90°).

The signal response nonlinearity of the spectroradiometer was characterized and corrected. In addition, the spectroradiometer was also characterized and corrected for errors from stray light using the stray-light correction matrix method [4]. The stray-light corrections are applied for all optical measurements including the standard FEL lamp measurements (for relative spectral irradiance responsivity calibration) and the 2π standard lamp measurements at every rotation angle. The correction for stray-light errors is critical for reducing the uncertainties in the UV region.

4 Uncertainty of 2π TSRF standard lamps

The uncertainty of a 2π TSRF standard lamp is analysed following the international recommendation [5] and is shown in Table 1.

Table 1 – Uncertainty budget for a 2π TSRF standard lamp

Component	Type	Standard uncertainty (%)							
		360 nm	380 nm	400 nm	450 nm	555 nm	750 nm	950 nm	1100 nm
Scaling factor, k_{scale}, i.e., total luminous flux of a standard lamp	B	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Total uncertainty of the reference FEL lamps	B	0.54	0.51	0.48	0.43	0.35	0.27	0.22	0.19
Performance of the gonio-spectroradiometer	B	0.63	0.36	0.26	0.22	0.22	0.32	0.51	0.84
Calibration of the gonio-spectroradiometer	B	0.91	0.60	0.34	0.25	0.25	0.25	0.33	0.59
Measurement of a standard lamp	A	0.53	0.52	0.29	0.25	0.25	0.25	0.30	0.39
Reproducibility and long term stability of a standard lamp	A	0.50	0.35	0.30	0.25	0.25	0.25	0.30	0.40
Combined relative uncertainty (%)		1.46	1.10	0.81	0.69	0.65	0.65	0.81	1.21
Expanded relative uncertainty of total spectral radiant flux (%) (*k*=2)		**2.9**	**2.2**	**1.6**	**1.4**	**1.3**	**1.3**	**1.6**	**2.4**

5 Summary

We have extended the TSRF transfer standard lamps from 4π to 2π. The new 2π standard lamp is a near Lambertian source. It has a CCT of 3000 K and covers the spectral range from 360 nm to 1100 nm with the uncertainty from 1.3 % to 2.9 % depending on the wavelength region. The aging rate is ±0.3 % for 24 h operation time.

References

[1] ZONG, Y. and OHNO, Y. 2007. Realization of total spectral radiant flux scale and calibration service at NIST. CIE 26th Session – Beijing 2007, D2 179-182.

[2] OHNO, Y. and ZONG, Y. 1999. Detector-Based Integrating Sphere Photometry, Proc., 24th Session of the CIE, 1999, 1, Part 1, 155-160.

[3] YOON, H. W., GIBSON, C. E., and BARNES, P. Y. 2002. Realization of the National Institute of Standards and Technology detector-based spectral irradiance scale, Appl. Opt., 2002, 41, 5879-5890.

[4] ZONG, Y., BROWN, S. W., JOHNSON, B. C., LYKKE, K. R., and OHNO, Y. 2006. Simple spectral stray light correction method for array spectroradiometers, Appl. Opt., 2006, 45, 1111-1119.

[5] ISO 1993. Guide to the Expression of Uncertainty in Measurement.