

Consultative Committee for Photometry and Radiometry (CCPR)
24th Meeting (19 - 20 September 2019)

Questionnaire on activities in radiometry and photometry

Reply from: Korea Research Institute of Standards and Science (KRISS)

Delegate: Dong-Hoon Lee

1. Summarize the progress in your laboratory in realizing top-level standards of:

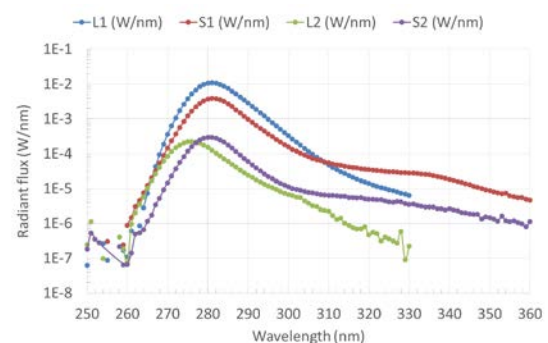
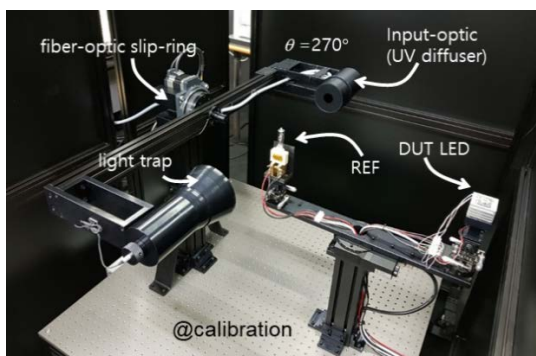
(a) broad-band radiometric quantities :

None.

(b) spectral radiometric quantities :

Gonio-spectroradiometer for UV LEDs

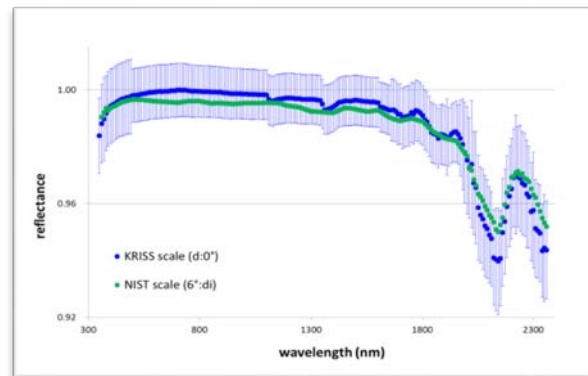
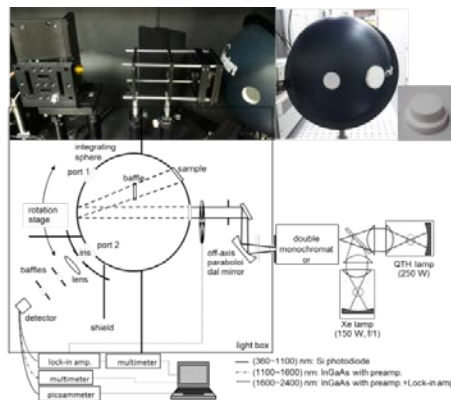
The measurement standards for total spectral radiance flux of LEDs and OLEDs was established based on an integrating sphere photometer from 350 nm to 850 nm. For UV LEDs, however, the integrating sphere photometer caused problems due to fluorescence from the coating material. Therefore, we developed a new instrument for measurement of total spectral radiant flux of UV LEDs based on a goniometer accompanied with a scanning double-grating spectroradiometer. The calibrated wavelength range is from 250 nm to 500 nm with a spectral bandwidth of 2.5 nm. By using a specially designed fiber-optic bundle slip-ring, a fully automated measurement of total spectral radiance flux could be completed within a few hours. The detailed uncertainty analysis is in progress. (Contact: Seongchong Park, spark@kriss.re.kr)



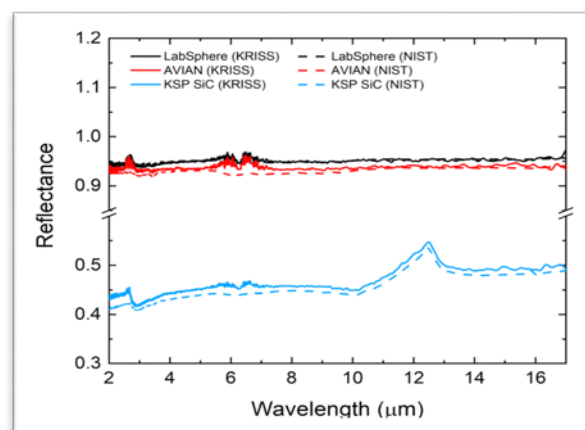
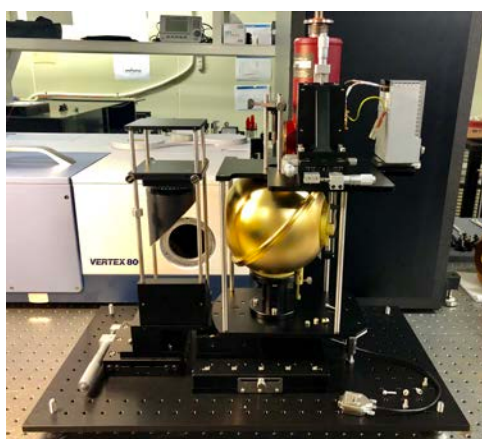
Spectral diffuse reflectance standards in the infrared

The primary standards for spectral diffuse reflectance at KRISS is based on the Sharp-Little technique in the geometry of (d:0°). The setup is recently improved to cover an extended wavelength range from 360 nm up to 2400 nm by adding new infrared detectors. The measurement uncertainty is evaluated to be in a range from 1.1 % to

2.5 % ($k = 2$) for a reference white standard, which varies with wavelength. In addition, a relative comparison method was also realized to link the primary standards to other samples in different measurement geometry (see bibliography No. 11). Based on these setups, the realized scale for spectral diffuse reflectance was compared with that of NIST by using a commercial standard reference material with a good agreement. (Contact: Jisoo Hwang, jhwang@kriss.re.kr)



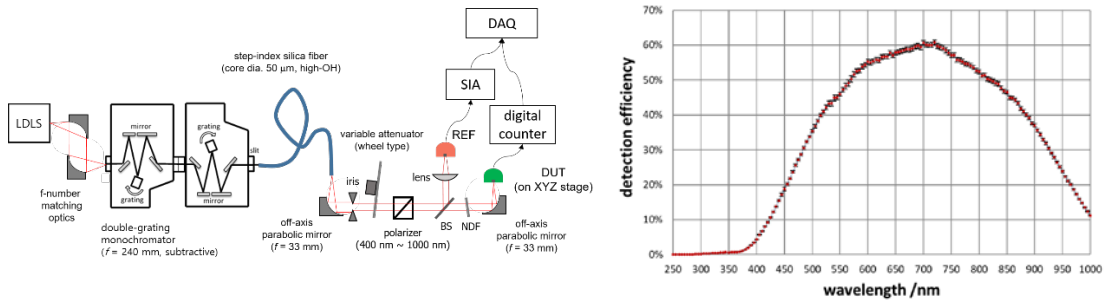
In the infrared beyond 2 μm , we developed a different primary standards based on the third Taylor method in the geometry of (8° :d). The setup consists of a gold-coated integrating sphere and a Fourier transform infrared (FTIR) spectrometer, which covers a wavelength range from 2 μm to 18 μm . In parallel, we are developing the gold-coated reference samples to disseminate the spectral diffuse reflectance in the mid-infrared, hopefully up to 25 μm in the future. The validation of the setup is being tested by using multiple samples calibrated at NIST, and the detailed uncertainty analysis is in progress. (Contact: Seon-Do Lim, sdlim@kriss.re.kr)



Detection efficiency of single photon detectors from 250 nm to 1000 nm

We improved the setup for measurement of detection efficiency (DE) of single photon detectors by direct comparison with a calibrated photodiode. By using a focused monochromatic beam, we could measure the DE of a free-space-coupled Si SPAD

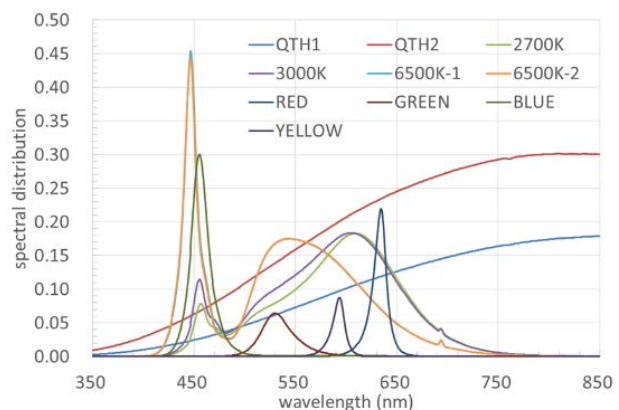
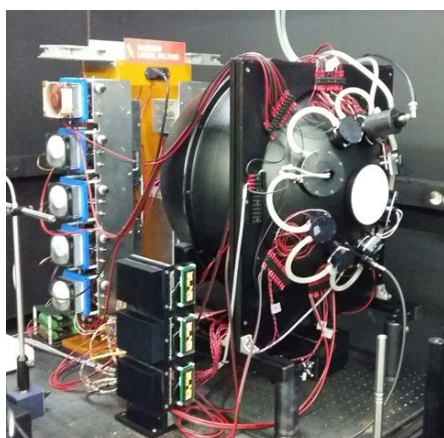
(single photon avalanche photodiode) in a wide wavelength range from 250 nm to 1000 nm with a typical uncertainty of less than 2 % as a relative expanded uncertainty ($k = 2$). The details of this work are published in Metrologia (see bibliography No. 3). (Contact: Dong-Hoon Lee, dh.lee@kriss.re.kr)

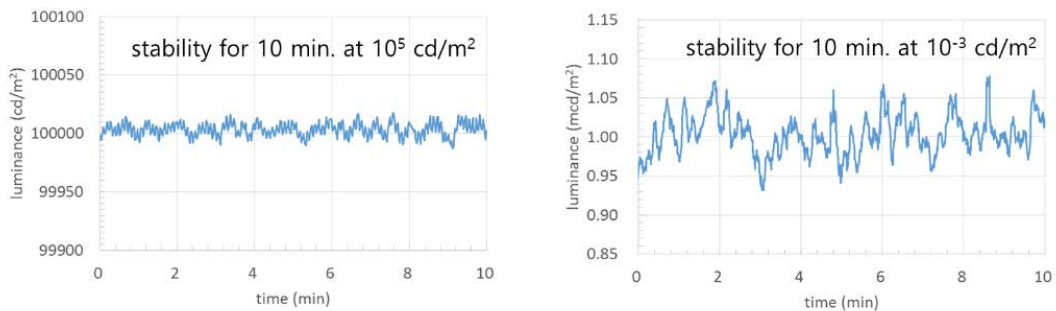


(c) photometric quantities :

High-dynamic-range luminance standard source

We developed a new integrating sphere-based source, whose luminance is variable in a range from 10^{-3} cd/m^2 to 10^5 cd/m^2 without changing its spectrum. Combining tungsten lamps and high-power LEDs with different CCTs, the source can generate 9 different spectra, which is continuously monitored with a built-in spectroradiometer. The luminance uniformity within the output port with a diameter of 50 mm was measured to be ± 0.4 %, and the temporal stability of luminance was less than 0.1 % for an hour. The source can be also used for linearity test of a luminance meter in the full range based on the flux addition method using two high-power LEDs inside. The typical calibration uncertainty of luminance meters by using this source is evaluated to be 1.6 % ($k = 2$) in the full dynamic range. (Contact: Seongchong Park, spark@kriss.re.kr)

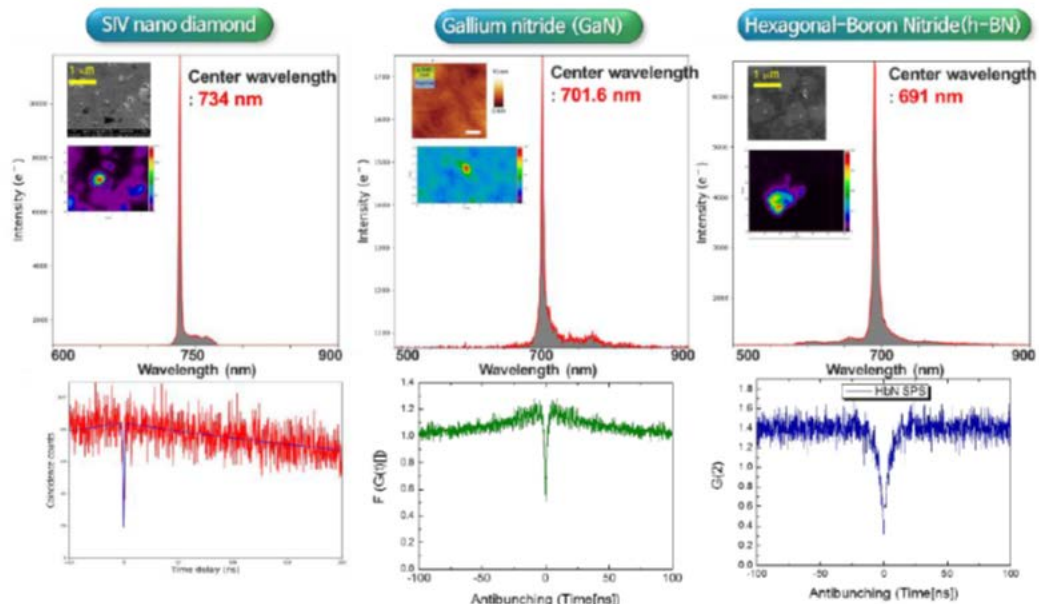




2. What other work has taken place in your laboratory in scientific or technological areas relevant to the CCPR?

Radiometric sources of single photons

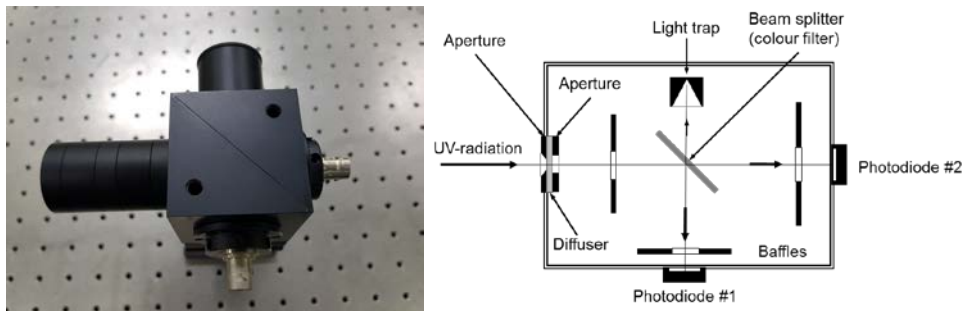
We are continuously developing single photon sources based on solid state single emitters such as isolated impurities in nano-sized crystals, which should be applicable for quantum radiometry. Recently, we realized and tested sources based on Si vacancies in nano-diamonds emitting the zero photon line (ZPL) at 734 nm, defects in gallium nitride at 701.6 nm, and defects in hexagonal-boron nitride at 691 nm. The spectral bandwidth of all the ZPLs are less than 4 nm in room temperature, and the values of $g^{(2)}$ measured with a Hanbury-Brown-Twiss interferometer were less than 0.5 in CW pumping for all three sources. We are currently testing these sources for calibration and characterization of single photon detectors. (Contact: Kee-Suk Hong, hongi2011@kriss.re.kr)



Dual-photodiode radiometer as a new instrument concept

We developed a new design of radiometer, which can simultaneously measure both centroid wavelength and irradiance of a light source without recording its spectrum as

long as the light source has a finite spectral bandwidth. It consists of two photodiode separated with a beam splitter in its basic construction, and can be calibrated by measuring the spectral responsivities of two photodiodes against the spectral irradiance at the input aperture. The concept was realized for a UVA irradiance meter, which provides a practical and accurate solution for testing UV LED sources and UV-filtered lamps. The first results were published in the CIE session 2019 (see bibliography No. 2). (Contact: Dong-Joo Shin, djshin@kriss.re.kr)



3. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.

None.

4. What are present, new or emerging needs of users of your services that are not being supported sufficiently by current CCPR activities or initiatives? In the light of this information please suggest desirable changes in the future working program of the CCPR.

There are increasing demands from remote sensing and material science sectors for calibration and test of detectors, cameras, spectrometers, and spectral reflectance/emissivity of materials in mid- and far-infrared range beyond 2 μm . Although the related quantities are listed in the CMC service categories, the radiometry in this wavelength range is not effectively covered by current CCPR activities. Formation of a task group to initiate a working program in the mid- and far-infrared radiometry is suggested.

5. What priorities do you suggest for new research and development programmes at NMIs in the area of Photometry and Radiometry?

- Realization of primary standards for photon-based radiometry
- Development of LED-based standard lamps
- Realization of standards in the UV (< 300 nm) and mid/far-IR (> 2.5 μm)
- Metrology for imaging-based photometry and radiometry

6. Are there any research projects where you might be looking for collaborators from other NMIs or are there studies that might be suitable for collaboration or coordination between NMIs?
- Operation of cryogenic radiometer with a tunable source from 250 nm to 2100 nm
 - Radiometry and metrology with single photon sources
 - Spectral diffuse reflectance standards in the mid-infrared range from 2 μm to 18 μm
 - Out-of-plane BRDF measurement from 410 nm to 1600 nm
 - Development of detector-based absolute radiation thermometers
 - Study on visual appearance in high-dynamic-range (HDR) conditions
7. Have you got any other information to place before the CCPR in advance of its next meeting?
- None.
8. Bibliography of radiometry and photometry papers of your laboratory since the last CCPR (September 2016)?
- 1) C.-S. Lee, J. S. Hwang, D.-H. Lee, *Chromatic dependence of the contrast sensitivity function of the phantom array effect*, Proc. of 29th Session of the CIE, CIE x46:2019, 962-964 (2019)
 - 2) D.-J. Shin, S. Park, K. Jeong, D.-H. Lee, *Reference radiometer in a dual-photodiode design for calibration of UVA irradiance meters*, Proc. of 29th Session of the CIE, CIE x46:2019, 1243-1248 (2019)
 - 3) In-Ho Bae, Seongchong Park, Kee-Suk Hong, Hee Su Park, Hee Jung Lee, Han Seb Moon, Joseph Steven Borbely, Dong-Hoon Lee, *Detection efficiency measurement of single photon avalanche photodiodes by using a focused monochromatic beam tunable from 250 nm to 1000 nm*, Metrologia **56**, 035003 (2019)
 - 4) In-Ho Bae, Sun Do Lim, Jae-Keun Yoo, Dong-Hoon Lee, Seung-Kwan Kim, *Development of a mid-infrared CW optical parametric oscillator based on fan-out grating MgO:PPLN pumped at 1064 nm*, Current Optics and Photonics **3**, 33 (2019)
 - 5) J H Gene, S D Lim and S K Kim, *Low repetition rate passively mode-locked thulium-doped fiber laser for LIDAR system*, Journal of Physics: Conf. Series **1065**, 032006 (2018)
 - 6) J. Gene, S. K. Kim, S. D. Lim, *Sub-megahertz mode-locked thulium-doped fiber laser*, Laser Phys. Lett. **15**, 085102 (2018)
 - 7) Jinhwa Gene, Seung Kwan Kim, Sun Do Lim, *Validity analysis of Holmium-doped fiber as saturable absorber for passively Q-switched Thulium-doped fiber laser*, J. Lightwave Tech. **36**, 2183-2186 (2018)

- 8) Abdallah Mohamad Karmalawi, Saber Gomaa Rabie Salim, Yong Shim Yoo, Mohamed Amin Soliman, Bong Hak Kim, and Sun Do Lim, *Evaluation of Co-C, Ni-C, Re-C and δ (MoC)-C Fixed Points Fabricated at KRISS*, Int. J. Precis. Eng. Man. **19**, 481-486 (2018)
- 9) Khaled Mahmoud, Seongchong Park, Dong-Hoon Lee, *Development of a new linearly variable edge filter (LVEF)-based compact slit-less mini-spectrometer*, Journal of Physics: Conf. Series **972**, 012026 (2018)
- 10) Kee Suk Hong, Seongchong Park, Jisoo Hwang, Errol Atkinson, Peter Manson, Dong-Hoon Lee, *Spectral responsivity measurement of photovoltaic detectors by comparison with a pyroelectric detector on individual nano-second laser pulses*, Metrologia **54**, 355-364 (2017)
- 11) Jisoo Hwang, Dong-Joo Shin, Ki Ryong Jeong, *Integrating sphere-based relative methods for reflection measurements*, Metrologia **53**, 1231-1242 (2016)
- 12) Yong Shim Yoo, Gun Jung Kim, Seongchong Park, Dong-Hoon Lee, Bong-Hak Kim, *Spectral responsivity calibration of the reference radiation thermometer at KRISS by using a super-continuum laser-based high-accuracy monochromatic source*, Metrologia **53**, 1354-1364 (2016)