Consultative Committee for Photometry and Radiometry (CCPR)
23rd Meeting (22 - 23 September 2016)

Questionnaire on activities in radiometry and photometry

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

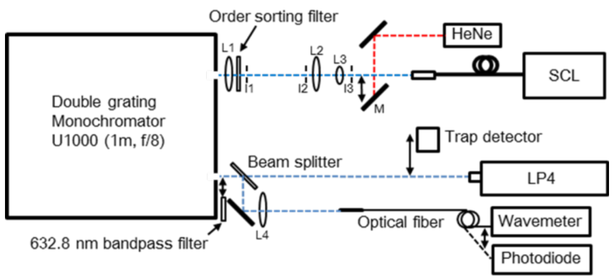
Delegate: Seung Kwan Kim

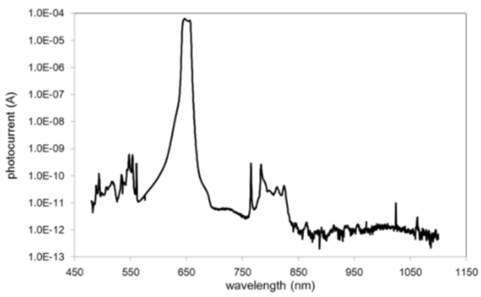
1. Summarize the progress in your laboratory in realizing top-level standards of:

   (a) broad-band radiometric quantities

<u>Improvement of radiation thermometer calibration</u>

Spectral responsivity measurement with high dynamic range is important to reduce the uncertainty of radiation thermometer calibration. We improved the spectral responsivity measurement of our high temperature radiation thermometer to have a dynamic range of more than 10^8 by utilizing a high power super-continuum laser (SCL) and a double grating monochromator. We also improved the wavelength accuracy of the monochromator to be less than 5 pm by measuring an absorption spectrum of water and oxygen in the air through a trap detector and a wavelength meter. As a result, we could reduce the dynamic range related uncertainty component down to 0.002 K from 0.5 K at 3021 K and the wavelength related uncertainty component down to 0.015 K from 0.3 K at 3021 K. We submitted the results to Metrologia this year.

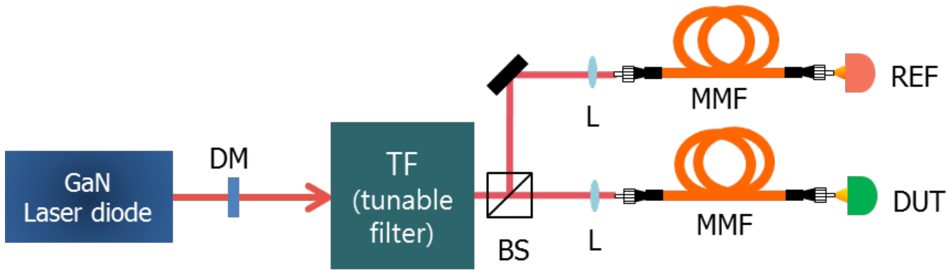


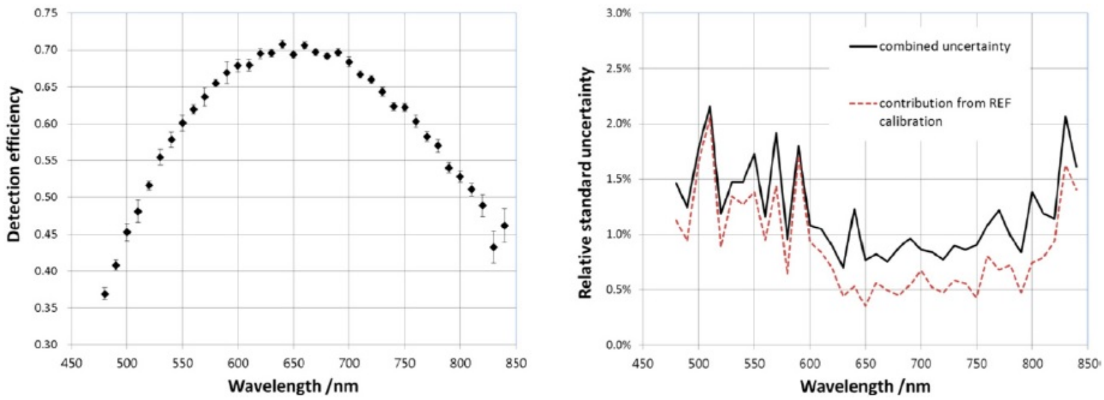


   (b) spectral radiometric quantities

<u>Calibration of detection efficiency of photon counting detector</u>

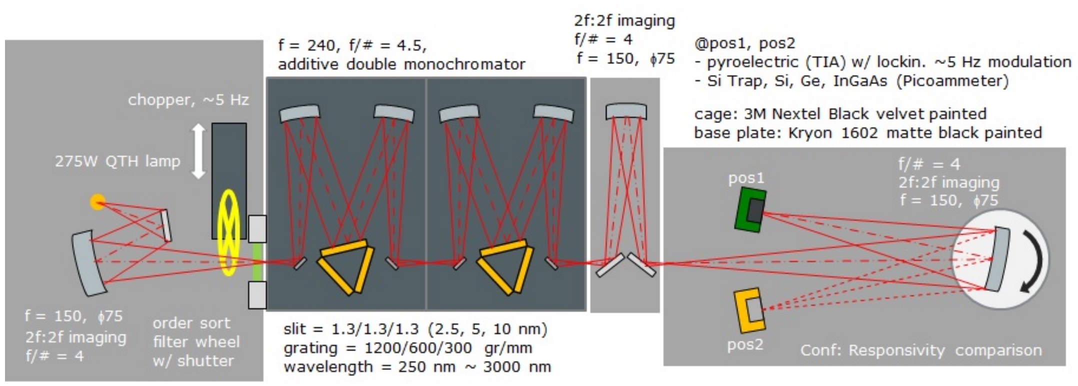
We developed a practical calibration method of the detection efficiency of photon counting detectors. In order to facilitate it, a switched integrating amplifier-based photocurrent meter that can measure photocurrent down to 100 femto ampere level was developed. The photon counting detector under test with a fiber-coupled input is directly compared with a reference photodiode without using any calibrated attenuator. The calibration was carried out in a wide wavelength range from 480 nm to 840 nm using a fluorescence from a GaN laser diode. The relative standard uncertainty of the detection efficiency was evaluated to be from 0.8 % to 2.2 % varying with wavelength. This work was reported at Single Photon Workshop in 2015 and published in Metrologia 2016. The work on the development of the switched integrating amplifier was also published in Applied Optics 2016.





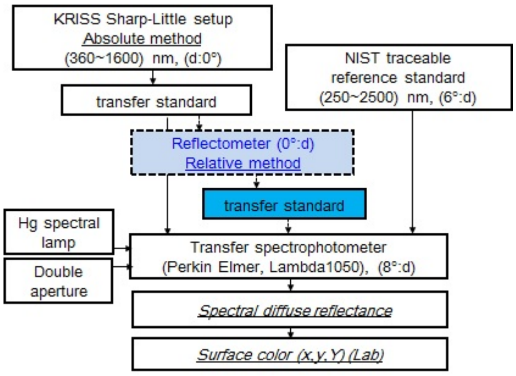
Re-establishment of NIR spectral responsivity scale using a pyroelectric detector

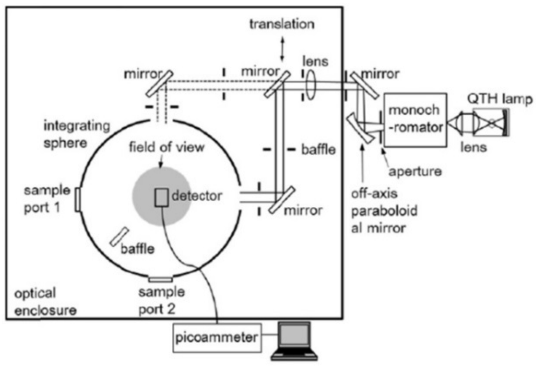
We constructed a new pyroelectric detector-based spectral responsivity comparator using a 275 W QTH lamp and an additive double monochromator that can produce more than 5 μW output power per 20 nm bandwidth (FWHM) from 800 nm to 1700 nm. Using this new comparator we achieved the expanded uncertainty of less than 1 % (*k*=2) when we scaled the spectral responsivity to the KRISS working standard InGaAs detector with the spectral responsivity of the KRISS Si trap detector. From this work, we can disseminate the spectral responsivity scale to industry through InGaAs detector-based certified reference material.



Improvement of spectral diffuse reflectance scale transfer

We are developing a relative spectral diffuse reflectance (SDR) measurement setup in order to calibrate our spectrophotometer with low uncertainty and to accommodate the artifacts of CCPR-K5. Since it was not easy to directly measure general samples with our primary standard setup using Sharp-Little method, we have used a transfer standard to calibrate our spectrophotometer but the uncertainty could not have been reduced further because its size and geometry were limited by the primary standard setup. By adopting a relative SDR setup we can overcome the size and geometry limitation to reduce the uncertainty and have capability to accommodate general samples. We finished constructing the relative SRD setup and obtained promising result where the difference between NIST and KRISS traceable measurement was less than 0.2 % in visible range. We submitted the intermediate results to Metrologia this year where we describe the design, theoretical analysis, experimental results and the uncertainty evaluations in detail.

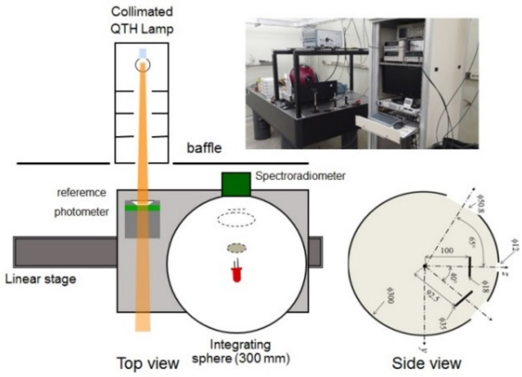


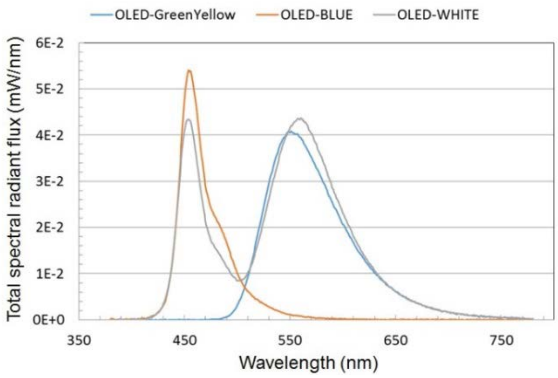


(c) photometric quantities

<u>Establishment of total spectral radiant flux standard for LED and OLED</u>

We established the standard system to provide measurement service for total spectral radiant flux for LED and OLED in the wavelength range from 350 nm to 850 nm. It uses a spectral irradiance standard lamp and a total luminous flux standard lamp to scale the total spectral radiant flux. The overall uncertainty is about 3 % (k=2) in a whole range when we use the DUT size within 25 mm by 25 mm. We transferred the technology of building up the total spectral radiant flux testing system to the LED manufacturing division in Samsung Electronics and helped them to open a standard laboratory traceable to KRISS.





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

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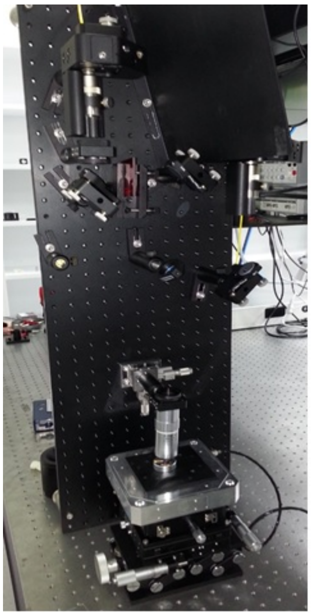
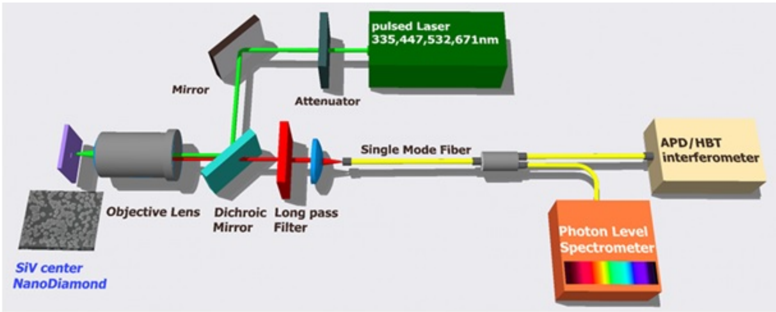
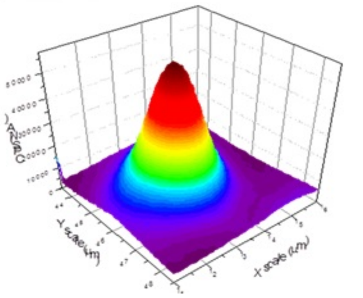
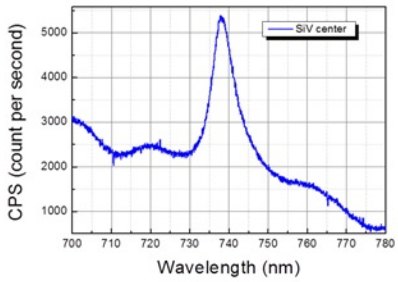
Development of single photon source based on Si vacancy center in nano-diamond

We built up a single photon generator using a nano-diamond sample having Silicon vacancy centers. Its configuration is a confocal microscope to focus pump photons at 671 nm to a single isolated Silicon vacancy center and collect fluorescence photons from it through a photon-counting detector or a photon level spectrometer. We succeeded in obtaining fluorescence photons from a single isolated Silicon vacancy center and capturing the spatial image with a size of less than 0.6 μm in FWHM. We also succeeded in measuring its spectrum showing the fluorescence photons with a zero phonon line at 738 nm. We are now carrying out g(2)(τ) measuring experiment to demonstrate single photon generation. The intermediate results were reported at QCMC 2016.









Development of Mid-IR tunable optical source based on OPO

Increasing demand for calibration and test of detectors, cameras, and spectrometers in IR wavelength range beyond NIR makes us start preparing radiometric tools to expand our capability to MIR range. Our initial research work is to develop tunable narrow band optical sources in MIR range based on optical parametric oscillator technology. So far, we succeeded in obtaining the laser output mechanically tunable between 2.6 μm and 3.5 μm from an OPO cavity with a fan-out grating type MgO:PPLN pumped by a single longitudinal mode Nd:YAG laser at 1064 nm. In addition, we developed a tunable single longitudinal mode Tm-doped fiber ring laser in 2 μm range in order to pump a ZGP crystal to obtain OPO output between 4 μm and 8 μm. The tunable fiber laser development was published in IEEE Journal of Photonics in 2016.

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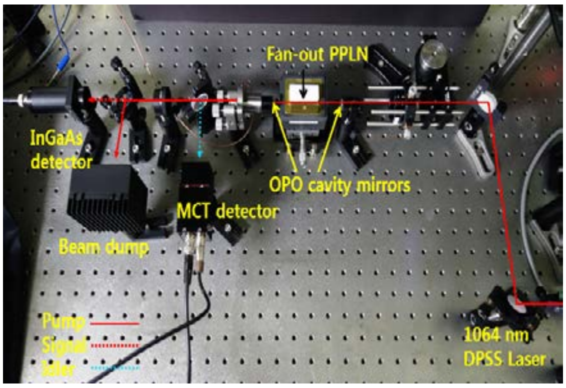

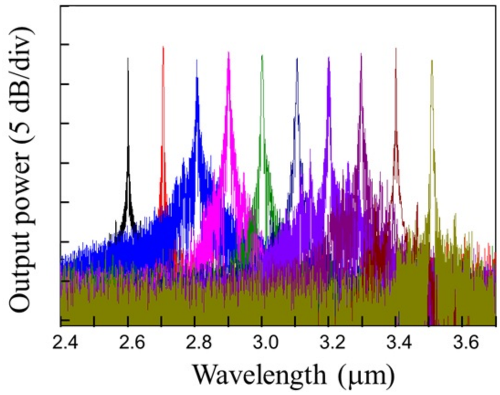

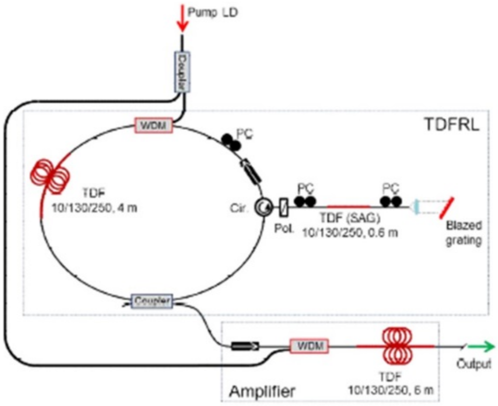

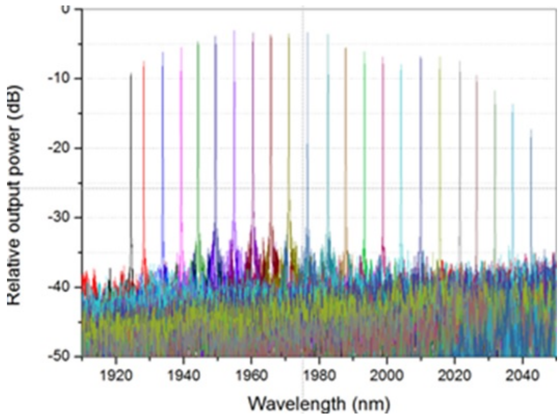

3. What work in PR has been/will be terminated in your laboratory, if any, in the past /future few years? Please provide the name of the institution if it has been/will be substituted by a DI or accredited laboratory.

   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 is increasing demand for calibration and test of detectors, cameras, spectrometers, and spectral reflectance/emissivity of materials in mid- and far-infrared range from the sectors of remote sensing and material science. Although the quantities are already listed in the CMC service categories, no explicit activity exists currently within CCPR. 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?

   - Primary standards for few photon-level radiometry
   - Scale realization and dissemination in the UV (< 300 nm) and mid/far-IR (> 3 μm)
   - Research on optical properties of materials (analysis and synthesis)

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?

   - Calibration of quantum efficiency of single photon counters as a function of wavelength
   - Development of single photon sources
   - Spectral responsivity scale for UV (< 300 nm) and IR (> 1600 nm): realization, dissemination, and validation of scale
   - Spectral reflectance scale for UV (< 300 nm) and IR (> 1600 nm): realization, dissemination, and validation of scale

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 2014)?

[1] Sun Do Lim, Jae-Keun Yoo and Seung Kwan Kim, *Widely Tunable Watt-Level Single-Frequency Tm-Doped Fiber Ring Laser as Pump for Mid-IR Frequency Generation*, IEEE Photon. J. 8 (3), 1502006 (2016).

[2] Hee Jung Lee, Seongchong Park, Hee Su Park, Kee Suk Hong, Dong-Hoon Lee, Heonoh Kim, Myoungsik Cha and Han Seb Moon, *Wavelength-scanning calibration of detection efficiency of single photon detectors by direct comparison with a photodiode*, Metrologia 53, 908-917 (2016).

[3] Seongchong Park, Kee-Suk Hong and Wan-Seop Kim, *Switched integration amplifier-based photocurrent meter for accurate spectral responsivity measurement of photometers*, Appl. Opt. 55 (9), 2285-2293 (2016).

[4] Helmi Zaini, Jae-Keun Yoo, Seongchong Park and Dong-Hoon Lee, *Indoor calibration method for UV index meters with a solar simulator and a reference spectroradiometer*, Int. J. Metrol. Qual. Eng. 7, 101 (2016).

[5] Kee-Suk Hong, Seongchong Park, Seung-Kwan Kim, Seung-Nam Park and Dong-Hoon Lee, *Realization of the Spectral Responsivity Scale based on an Absolute Cryogenic Radiometer*, J. Kor. Phys. Soc. 67 (12), 2045-2058 (2015).

[6] Jisoo Hwang and Ki-Lyong Jeong, *Surface Color Measurement Uncertainties*, J. Opt. Soc. Kor. 19 (6), 649-657 (2015).

[7] Seung Kwan Kim, Dong-Hoon Lee and Seung-Nam Park, *APMP supplementary comparison on fiber optic power responsivity APMP.PR-S2*, Metrologia Tech. Suppl. 52, 02002 (2015).

[8] Khaled Mahmoud, Seongchong Park, Seung-Nam Park and Dong-Hoon Lee, *An imaging spectrophotometer for measuring the two-dimensional distribution of spectral reflectance*, Metrologia 51, S293-S301 (2014).

[9] S. D. Lim, A. M. Karmalawi, S. G. R. Salim, M. A. Soliman, B. H. Kim, D. H. Lee, Y. S. Yoo, *A Method to Improve the Temperature Distribution of Holder Around the Fixed-Point Cell Position*, Int. J. Thermophys. 35, 1169-1179 (2014).

[10] Gen Jung Kim, Yong Shim Yoo, Bong Hak Kim, Sun Do Lim and Jong Hyun Song, *A small-size transfer blackbody cavity for calibration of infrared ear thermometers*, Physiol. Meas. 35, 753-762 (2014).