XX IMEKO World Congress
Metrology for Green Growth
September 9−14, 2012, Busan, Republic of Korea

SPECTRAL RESPONSIVITY MEASUREMENT OF KIM-LIPI STANDARD RADIATION THERMOMETER TRACEABLE TO ABSOLUTE CRYOGENIC RADIOMETER

*AdityaAchmadi[1], HelmiZaini[1], HidayatWiriadinata[1], Seung-Nam Park[2], GhufronZaid[1]**

[1] Research Center of Calibration, Instrumentation, and Metrology
Indonesian Institute of Sciences
(KIM-LIPI)
Gedung 420, Komplek Puspiptek Setu, Banten, Indonesia

[2]Division of Physical Metrology, KRISS, Daejeon 305-340, Korea

*Correponding author: ghufron@kim.lipi.go.id

Abstract: Measurement of spectral responsivity of KIM-LIPI standard radiation thermometer had been conducted. With several adjustments, the absolute cryogenic radiometer (ACR) setup was utilized as a primary spectral responsivity comparator to carry out the measurement. Output of double monochromator was redirected to enable the measurement. Additional voltmeter is installed in front of the available less accurate meter of the ACR setup to read the low level signal and provide analog output with enough accuracy. The setup provides a good quality of spectrally-selected light for this purpose without the need install a completely new spectral comparator facility. A dynamic range of up to 10^6 was achieved from the spectral responsivity measurement. The Full-width half maximum (FWHM) of the spectral response is 15 nm, which is 1 nm wider than the stated specification of the filter. Further work is being carried out to improve the accuracy of the monochromator wavelength scale.

Keywords: spectral responsivity, radiation thermometer, fixed-point, temperature

1. INTRODUCTION

The responsivity of photo-detectors to optical radiation is dependent of wavelength, temperature, bandwidth of detection and amount of incident radiation.[1] Spectral responsivity is the wavelength or spectral dependence of the detector electrical signal output in response to optical radiation input. It is quantified as the quotient of the detector output by a monochromatic radiation input at individual wavelength.[2] It is important to characterize the spectral responsivity of a detector to be able to optimally use it. A detector with too low a response at short wavelength should not be utilized at that wavelength. Conversely, a high spectral response at certain wavelengths should be sufficiently suppressed to avoid unwanted output from those wavelengths.

Radiation thermometer employs a photodetector with a band-pass filter attached to detect thermal radiation of an object and determine its temperature from it. The spectral response of the photodetector $S(\lambda)$ comes directly into the equation to determine the temperature[3] as shown in Equation 1 where r is experimentally measured ratio of detector signal, $L_\lambda(T_{90})$ and $L_\lambda[T_{90}(A_g)]$ are the spectral radiance of black body at wavelength λ at such measured temperature (T_{90}) and at temperature definition of freezing point silver respectively, Therefore, it is important to accurately determine the spectral response of radiation thermometer in order to have accurate temperature measurement.

$$r = \frac{\int L_\lambda(T_{90})S(\lambda)d\lambda}{\int L_\lambda[T_{90}(A_g)]S(\lambda)d\lambda} \quad (1)$$

This work describes the measurement of spectral responsivity of KIM-LIPI standard radiation thermometer by utilizing the absolute cryogenic radiometer setup to work as a primary spectral responsivity calibration facility. With this facility the standard radiation thermometer is compared to the reference calibrated detector, and then spectral responsivity of thermometer is calculated by using Equation 2, where $I_{LP4}(\lambda)$ and $I_D(\lambda)$ are photocurrent output of thermometer and reference detector respectively, $S_D(\lambda)$ and $S(\lambda)$ are known spectral responsivity of reference detector and obtained spectral responsivity of thermometer respectively.

$$S(\lambda) = \frac{I_{LP4}(\lambda)}{I_D(\lambda)} \times S_D(\lambda) \qquad (2)$$

The traceability of radiometry as reference detector and high quality spectral comparator are the most important factor to ensure the accuracy of spectral response measurement (see section 2). The reference detector can be traceable, via trapped-detector, to an absolute cryogenic radiometer as primary standar, with the monochromator as spectral light source selector calibrated by spectral line lamp.

2. TRACEABILITY

Figure 1 shows the detector-based traceability of the spectral responsivity of the radiation thermometer.

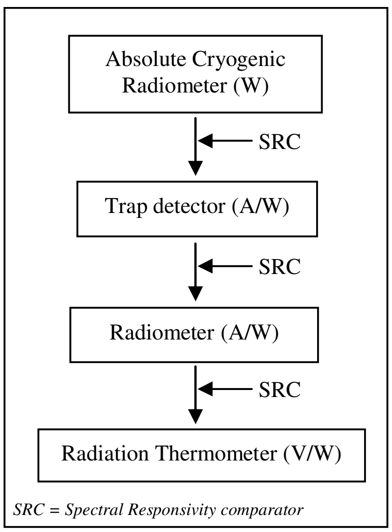


Figure 1. Detector-based Traceability of Radiation Thermometer

This is a detector-based method since the primary standard is a detector, i.e. an absolute cryogenic radiometer (ACR). The absolute cryogenic radiometer is used to determine the optical power of a light source with known electric power. It uses the electrical substitution technique. The optical power is equivalent to electrical power when each power causes the same temperature rise at the absorber.

The value of optical power is transferred to a trap detector in term of ratio, Ampere/Watt. It is then used to determine the spectral responsivity of radiometer using a spectral responsivity comparator. Dissemination of spectral responsivity of radiometer to radiation thermometer is performed using spectral responsivity comparator that basically the same with trap detector and radiometer.

The radiation thermometer and the radiometer are exposed interchangeably to the beam at the same wavelength. The measurement result of radiation thermometer is automatically corrected by the software based on the monitor detector.

At KIM-LIPI, the ACR system employs a 250 W quartz tungsten halogen lamp as a light source. It provides a continuous spectrum of optical radiation as compared to the discrete laser-based system. However, the laser-based system provides a higher power level. The ACR system utilizes a double monochromator with 600 grooves each mm.

In practice, initially electrical power is applied to the absorber so the total power is only from the electrical. And then optical power is applied whilst keeping the total power is unchanged, i.e. electrical power is reduced. The optical power is easily determined by subtracting the reduced electrical power from the new total power.

The ACR system employs a mechanical cooling system with which Helium gas is liquefied to reach an operational of 4 K. The use of Helium gas is much less expensive than liquid Helium. However, it requires longer time to reach the operational temperature, i.e. about three days. The main part of the mechanical cooling system is a compressor that is supported by a closed loop water chiller.

The ACR runs in the vacuum condition. Trap detectors attached to it is also in the same condition. The vacuum condition is necessary to prevent condensation in the ACR during cooling down process. The ACR is placed between two trap detectors on a rotation stage so they have the same optical length from the light source. However the comparison between the ACR and trap detectors takes more time due to the ACR large inertia.

3. MEASUREMENT SETUP

The spectral responsivity measurement was carried out by utilizing the light source and double monochromator of the absolute cryogenic radiometer (ACR) setup which is used primarily for the calibration of trap detector. The use of quality of spectrally-selected light. Also, there is no need to invest in a completely new setup for spectral responsivity comparator.

Modification is needed to the ACR setup as follows (Figure 2). Instead of going into the ACR, the output of the monochromator was redirected at 90 degree angle to the translator stage where a standard detector and the radiation thermometer are positioned. The standard detector was positioned at the focal length of the deflecting mirror in order to under-fill its aperture, whilst the radiation thermometer was positioned further away (about 60 cm from the focal length of the deflecting mirror) to achieve overfilled condition and also due to its bulky size. The exit slit of the monochromator was set at number 5, where the width is about 3.5 mm, in order to overfill the aperture of the thermometer which has an aperture stop of 1 mm.[4,5] A wider opening wouldn't affect the signal detected by the thermometer. This configuration provides light with 3 nm bandwidth.

To read the output of the thermometer, additional voltmeter was installed in front of the DVM integrated to the ACR. The ACR DVM has low accuracy and therefore would truncate the low signal of the thermometer output if fed directly to it. The analog output of the additional voltmeter provides high enough signal to be read by the ACR DVM before being recorded by the data acquisition software. The available ACR setup software does not allow modification of the programming code for direct reading of the additional DVM by the software.

Due to the presence of band-pass filter, having a peak wavelength of 650 nm and a full-width half-maximum (FWHM) of 14 nm, measurement was carried out at a limited range of wavelengths, i.e. 550 nm ~ 750 nm, at a step of 0.2 nm between 630 nm and 670 nm and a step of 1 nm for the rest of this range.

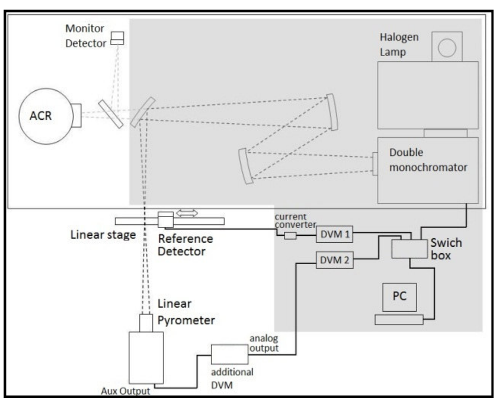


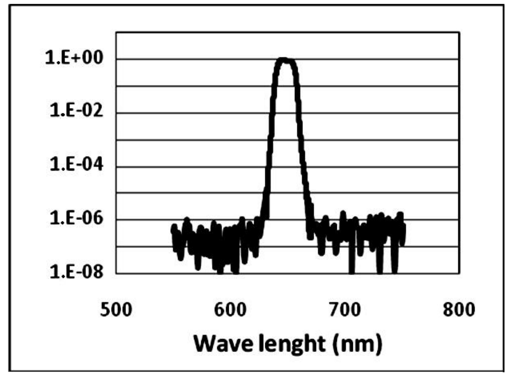
Figure 2. Spectral response measurement setup, the gray area is the ACR facility that used in measurement.

Dark signal was measured at each wavelength step with three different approaches; first, the dark signal was obtained with room lighting off; second, with the thermometer aperture completely blocked; and third by measuring a black cavity positioned at the focal length of the deflecting mirror.

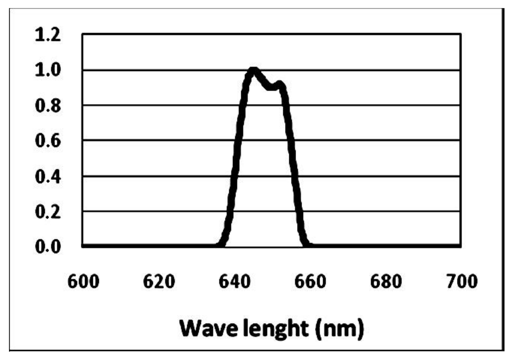
4. RESULTS AND DISCUSSION

Figure 3 shows result of spectral responsivity measurement. The result shows that the measurement setup is able to provide a dynamic range of up to 10^6. At longer wavelengths, photodetector has higher responsivity and a blackbody produces higher spectral radiance[6] and therefore it is important to suppress the unwanted signal.

.



(a)



(b)

Figure 3. Spectral response measurement result of LP4 (a) logaritmic scale (b) linear scale

The dynamic range provides enough suppression of the signal outside the thermometer center wavelength of 650 nm. The Full-width half maximum (FWHM) of the spectral response is 15 nm, which is 1 nm wider than the stated specification of the filter.

The dark signals obtained from three different approaches of measurement were used in the above calculations with a difference in the order of 1 mK.

Further work is being carried out to improve the accuracy of the respon spectral measurement due to the wider FWHM of measurement result.

5. CONCLUSIONS

This work shows the spectral responsivity measurement of KIM-LIPI standard radiation thermometer which is important to enable the measurement of temperature and cross-check values of fixed point temperatures.

The work also shows that a spectral responsivity comparator can be established without a completely brand new setup. Instead, a setup providing spectrally-selected light can be utilized for this purpose. Being a primary standard, the absolute cryogenic radiometer setup has the advantage in high quality spectrally-selected light.

The constructed setup is able to provide a dynamic range of up to 10^6, with The FWHM is 1 nm wider than the stated specification of the filter.

Investigation should be conducted to improve the accuracy and consistency of the spectral response measurement.

6. REFERENCES

[1] Dereniak, E.L., Growe, D.G., '*Optical Radiation Detectors*,' 2nd Edition, London: John Wiley & Sons, 1984.

[2] International Commission on Illumination (CIE), '*Determination of the spectral responsivity of optical radiation detectors*' CIE Publication No.64, 1984.

[3] BIPM,*'Supplementary Information for the International Temperature Scale of 1990',* BIPM,1997

[4] McPherson, 'Instruction Manual Model 2035 Scanning Monochromator'.

[5] KE Technologie GmbH, *'Linearpyrometer LP4 Operating Instructions'*, KE Technologie GmbH, 2006.

[6] DeCusatis, Casimer, '*Handbook of Applied Photometry*,' 3rd Edition, New York, Springer-Verlag, 1998.