

New apparatus for the spectral radiant power calibration at CMS in Taiwan

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Abstract. A monochromator-based cryogenic radiometer (CR) facility has been established at the Center for Measurement Standards (CMS) in Taiwan, for calibrating the spectral radiant power responsivity of standard detectors. The design features of the new apparatus and uncertainty analysis are discussed. Presently the Si and Ge detectors can be calibrated in the spectral ranges 350 nm to 1100 nm and 800 nm to 1700 nm, respectively. The measured results of the Si and Ge detectors using the new apparatus were compared with the results in the NPL calibration reports to check the performance of the new apparatus. The agreement is better than 0.5 % for the Ge detector and 0.2 % for the Si detector.

1. Introduction

A new facility for the monochromator-based cryogenic radiometer [1,2] has been set up in the CMS in Taiwan. A monochromator-based cryogenic radiometer, rather than laser-based one, was established to calibrate the responsivity because of cost, convenience, and the flexibility of future applications. Instead of rotating the bellows to translate the CR and the transfer detectors as presented in Refs. 1 and 2, a linear translation stage is utilized to move the CR and the transfer detector to the focal position of the monochromator-source. The design of the new apparatus allows three detectors to be calibrated in a single measurement process to save time and liquid helium (LHe). The 1σ uncertainty of the Si detectors is approximately 0.2 % and that of the Ge detectors is 0.3 %.

2. Design features

Figure 1 presents the schematic overview of the new apparatus. The whole apparatus can be grouped into three categories - the CR, the detector stage, and the light source. The CR was manufactured by L-1 Standards and Technology, Inc. The hold time of LHe is well longer than 80 hours and the LN₂ for the cryostat can be refilled automatically. The relative standard uncertainty of the CR in radiant power measurement is less than 0.02 % for the monochromator-source.

The detector stage was originally designed by CMS and manufactured by L-1 Inc. The transfer detectors were placed on a holder inside a six-way reducing cross and connected to the feedthrough. It allows three detectors (depending on the size of the transfer detector) to be placed inside the cross. A thermistor was mounted on the holder to monitor the ambient temperature around the transfer detector. It showed that the ambient temperature was approximately 21.5°C during measurements. The welded bellows and linear translation stage were utilized to move the CR and the transfer detector to the focal position of the monochromator-source with an overall traveling length of around 31 cm. The X- and Z-axes of the XYZ manipulator were used to locate the center of and test the uniformity of the transfer detector. A flat fused quartz entrance window is placed in front of the welded bellows to eliminate the uncertainty from the window transmission.

A quartz-tungsten-halogen (QTH) lamp and an Xe lamp were used to cover the wavelength ranges from 400 nm to 1700 nm and below 400 nm, respectively. The F number of the monochromator is 4. After mirrors M1 to M4, the F number of the monochromator beam was about 13. Therefore, it could be absorbed totally by the CR (F/8). An aperture with a diameter of 1.9 mm was placed in front the exit port of the monochromator to make the spot diameter of the monochromator beam approximately 3 mm at its focal position.

3. Measured results and uncertainty analysis

To verify the performance of the new apparatus, the measurements of the spectral responsivity on two NPL-calibrated Si and Ge detectors were carried out. The measured procedures involved the photocurrent measurements of the detectors, radiant power measurements with the CR, and then obtaining the spectral radiant power responsivities of the detectors. The measured results of Si and Ge detectors against the apparatus were compared with the results in their NPL calibration reports. The discrepancy is

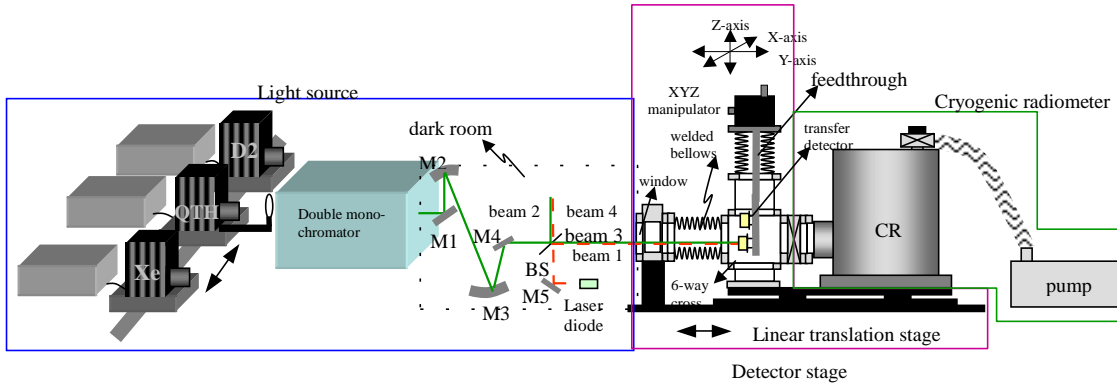


Figure 1. Schematic diagram of CMS new monochromator-based cryogenic radiometer for spectral radiant power calibration

less than 0.5 % for the Ge detector and 0.2 % for Si detector. The error sources include the bandwidth effect, wavelength accuracy, and stray light of the monochromator; the uniformity, polarization effect, and output current accuracy of the transfer detector; the measured accuracy of the radiant power of the CR. Table 1 lists the uncertainty budget and the conditions of the estimation.

Table 1. Uncertainty budget of the monochromator-based spectral radiant power responsivity calibration

Source	relative standard uncertainty
Power measurement CR (monochromator-source)	0.02 %
Bandwidth effect	0.0001 % (Si; 400 nm-1000 nm)
($\Delta=1.5$ nm for Si)	0.01 % (Si; other range)
($\Delta=3.5$ nm for Ge)	0.001 % (Ge; 800 nm-1500 nm)
	0.04 % (Ge; other range)
Wavelength accuracy	0.03 % (Si; 400 nm-1000 nm)
(± 0.1 nm for Si)	0.2 % (Si; other range)
(± 0.2 nm for Ge)	0.05 % (Ge; 800 nm-1500 nm)
	0.3 % (Ge; other range)
Uniformity	0.02 % (Si)
(0.3 mm deviation from the center of the diode)	0.08 % (Ge)
Polarization (F/13, 0.2° incident angle)	0.01 %
Current measurement	0.0005 %
Repeatability	0.05 % (Si; 400 nm-1100 nm)
	0.1 % (Si; <400 nm)
	0.05 % (Ge; 970 nm-1550 nm)
	0.1 % (Ge; other range)
Total	0.07 % (Si; 400 nm-1000 nm)
	0.23 % (Si; other range)
	0.11 % (Ge; 970 nm-1550 nm)
	0.33 % (Ge; other range)

The error associated with the bandwidth can be calculated using the following method.

$$R_m(I_o) = \int_{I_o-\Delta}^{I_o+\Delta} R(I - I_o)S(I)dI$$

where $R_m(\lambda)$ is the measured responsivity, $R(\lambda)$ is the real responsivity, $S(\lambda)$ is the slit function of the monochromator, and Δ is the bandwidth of

the monochromator. $S(\lambda)$ is assumed to have a symmetrical tri-anguluar function around λ_o , and the bandwidth error ϵ can thus be expressed as

$$e = \frac{R_m(I) - R(I)}{R(I)} \approx \frac{\Delta^2}{12R_m(I)} \frac{d^2R_m(I)}{dI^2}$$

Conclusion and outlook

Only the spectral range from 350 nm to 1700 nm was considered. The Si and Ge detectors used in this work were not calibrated directly using the NPL primary system, so the uncertainties in the NPL reports are relatively large. Hence, a further intercomparison is required to precisely study the consistency with other relative primary standards. The future works will include extending the measurement range below 350 nm and over 1700 nm, and applying the monochromator-based CR to establish another apparatus for measuring the spectral irradiance/radiance of light sources.

References

- 1.L. P. Boivin and K. Gibb, Monochromator-based cryogenic radiometry at the NRC, *Metrologia*, 32, 565-570, 1995/1996.
- 2.C. A. Schrama, R. Bosma, K. Gibb, H. Reijn, and P. Bloembergen, Comparison of monochromator-based and laser-based cryogenic radiometry, *Metrologia*, 35, 431-435, 1998.
- 3.Peter V. Foukal, C. Hoyt, H. Kochling, and P. Miller, Cryogenic absolute radiometers as laboratory irradiance standards, remote sensing detectors, and pyroheliometers, *Applied Optics*, 29, 988-993, 1990.
- 4.R. U. Datla, K. Stock, A. C. Parr, C. C. Hoyt, P. J. Miller, and P. V. Foukal, Characterization of an absolute cryogenic radiometer as a standard detector for radiant-power measurements, *Applied optics*, 31, 7219-7225, 1992.

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