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NEW SETUP FOR THE ABSOLUTE SPECTRAL RESPONSIVITY OF RADIATION THERMOMETERS WITH A SUPERCONTINUUM SOURCE

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Abstract:
This paper describes a new setup at National Metrology Institute of Japan (NMIJ) to measure spectral responsivities of radiation thermometers. We use a single monochromator and a supercontinuum source instead of a lamp. The spectral power, stability and special uniformities of the system were measured.

Keywords: thermodynamic temperature, radiation thermometer, supercontinuum source, spectral responsivity

1. INTRODUCTION

In high temperature region, thermodynamic temperature is measured with absolute radiometry which is traceable to a cryogenic radiometer via a silicon trap detector. When measuring absolute spectral responsivity of radiation thermometers, tunable lasers [1, 2] or monochromators with lamps [3] are used as light sources. The lamp-monochromator system is easily operated and is able to suppress spectral modulations caused by undesired interferences which are observed with a tunable laser. However, output power of the lamp-monochromator system is much lower than that of lasers because of low incidence efficiency of lamps into monochromators.

Supercontinuum (SC) sources are laser sources which emit broadly and continuously over extended spectral range. White light is generated from pulse lasers through nonlinear optical materials, such as photonic crystal fibers [4]. Recently, commercial SC sources with high power and wide wavelength ranges are available and their application to metrology was reported [5]. At National Metrology Institute of Japan (NMIJ), the SC-monochromator method for measuring absolute spectral responsivity of a radiation thermometer was proposed [6]. Here we report the setup and basic measurements of the new SC-monochromator system at NMIJ.

2. EXPERIMENTAL SETUP

Figure 1 shows a schematic diagram of the new setup to measure spectral responsivities of radiation thermometers at NMIJ. The SC source (SuperK Extreme EXR-15, NKT Photonics) covers a wavelength range of 450-2400 nm. The total output power is up to 6 W and can be controlled with a resolution of 0.1%. The white light exits from a single-mode fiber and is collimated to a Gaussian beam with a diameter of a few millimeter. The beam is focused to a few micrometer size spot at the slit of the monochromator with well-aligned lenses and mirrors. Therefore, unlike a lamp, both 100% incident efficiency and high wavelength resolution are achieved at the same time.

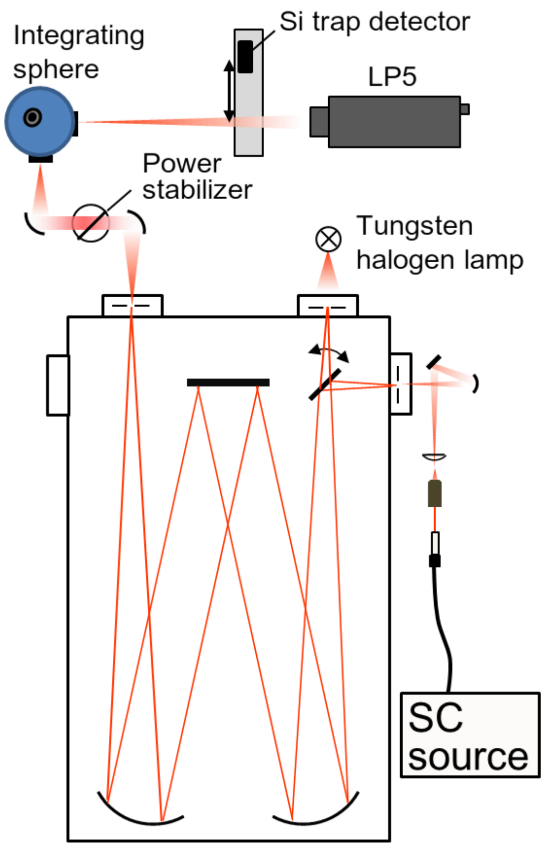

Fig. 1. The SC-monochromator based system for absolute spectral responsivity of radiation thermometers.

The single monochromator has the focal length of 1 m and the reciprocal linear dispersion of 0.8 nm/mm. Changing the slit widths, arbitrary band width can be obtained from picometer to sub-nanometer order. The entrance slit can be switched to that of the tungsten halogen lamp with the inside mirror. The outgoing light is focused into an integrating sphere with a silicon detector to monitor the spectral power. The integrating spheres with the diameter of 25 mm, 50 mm or 135 mm are selectable. The power stabilizer using angular dependence of Fresnel reflection is placed between the monochromator and an integrating sphere. The stabilizer controls the optical power according to the signal and temperature of the monitor detector with PID algorithm. The power is controlled with a resolution of a few 10^{-5} and a responsivity of a few Hz. The radiation thermometer (0.8 μm Linear Pyrometer 5; LP5) are focused to the output port of the integrating sphere. The absolute spectral responsivity of LP5 will be calibrated by the Si trap detector which is traceable to the cryogenic radiometer at NMIJ.

The relative spectral responsivity of LP5, the output spectral power stability and special uniformity of radiance at integrating spheres were evaluated using this SC-monochromator based system.

3. RESULTS

Figure 2 shows relative spectral responsivities of LP5 with the SC source (100 % output power) and the tungsten halogen lamp. The spectral responsivities were measured through 200 μm slits and the integrating sphere with the 25 mm diameter. The spectral radiance of the SC source is two or more magnitudes higher than that of the tungsten halogen lamp. Although the ratio of signals between in-band and out-of-band wavelength is about 10^3 when using the SC source and the integrating spheres, a ratio of more than 10^6 can be obtained when the radiation thermometer focuses to the exit slit of the monochromator. Therefore, the absolute calibration with an integrating sphere and the Si trap detector and the relative measurement without them will be chosen in appropriate wavelength regions.

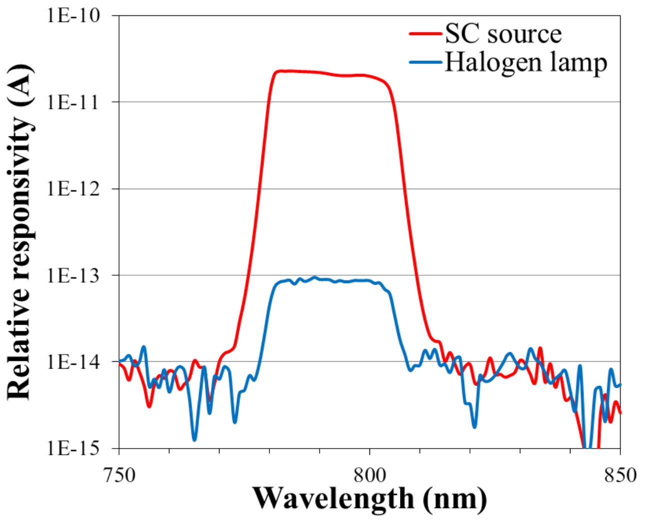

Fig. 2. Relative radiance responsivities of LP5 with the SC source (red line) and the tungsten halogen lamp (blue line).

Since the SC source generates white light with the nonlinear optical effect, the optical power of output light widely fluctuates in even a few minutes, within a range up to ±3% in an hour. Therefore, it is necessary to maintain a constant output at the integrating sphere in order to decrease uncertainty of all measurements using this system. Figure 3 shows radiance stability of the system with 50% output power at 795 nm, which are standardized by the mean values. It was measured with LP5 facing the integrating sphere which has 50 mm in diameter in 15 minutes. The fluctuation range with no control is about ±0.2%, which is not negligible for continues measurements of spectral responsivity, so the output power must be controlled with a feedback method. On the other hand, by controlling the output power with the stabilizer, the stability was improved to less than ±0.03%, which is almost equivalent to the noise levels of the radiation thermometer and the photodiode.

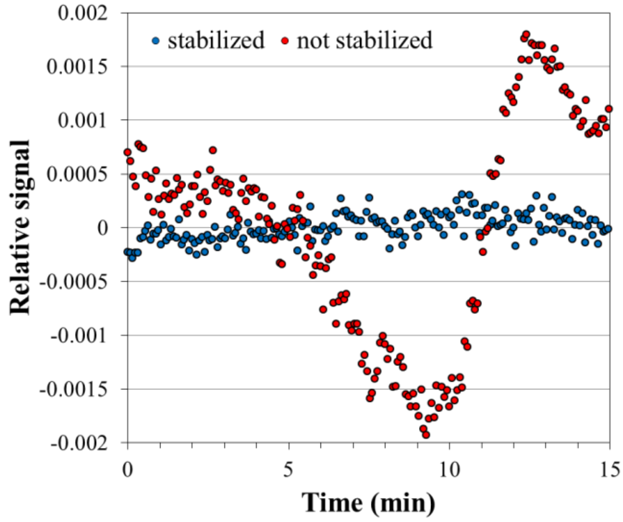

Fig. 3. Relative stability of the LP5 signal viewing the integrating sphere radiance at 795 nm.

Spatial non-uniformity of an integrating sphere is one of the most important components when comparing a radiation thermometer and a trap detector. This is because the spatial uniformity is supposed at the radiance-irradiance conversion, which is necessary to calibrate the absolute responsivity from the trap detector. The results of spatial non-uniformity measurements are shown in Fig. 4. At the 25 mm sphere, the radiance increase on the upper side and near the first irradiance area of incident light, and the non-uniformity was about ±0.2%. Generally, as the sizes of integrating spheres become larger, the spatial uniformity gets better while the optical throughput becomes smaller. At the 50 mm sphere, the spatial non-uniformity was reduced to less than ±0.1%. The non-uniformity of the 135 mm sphere was smallest in the measurements, which is less than ±0.08% inside the exit port. The non-uniformity of the integrating spheres leaves room for reduction by improving positions and angles of the incident light.

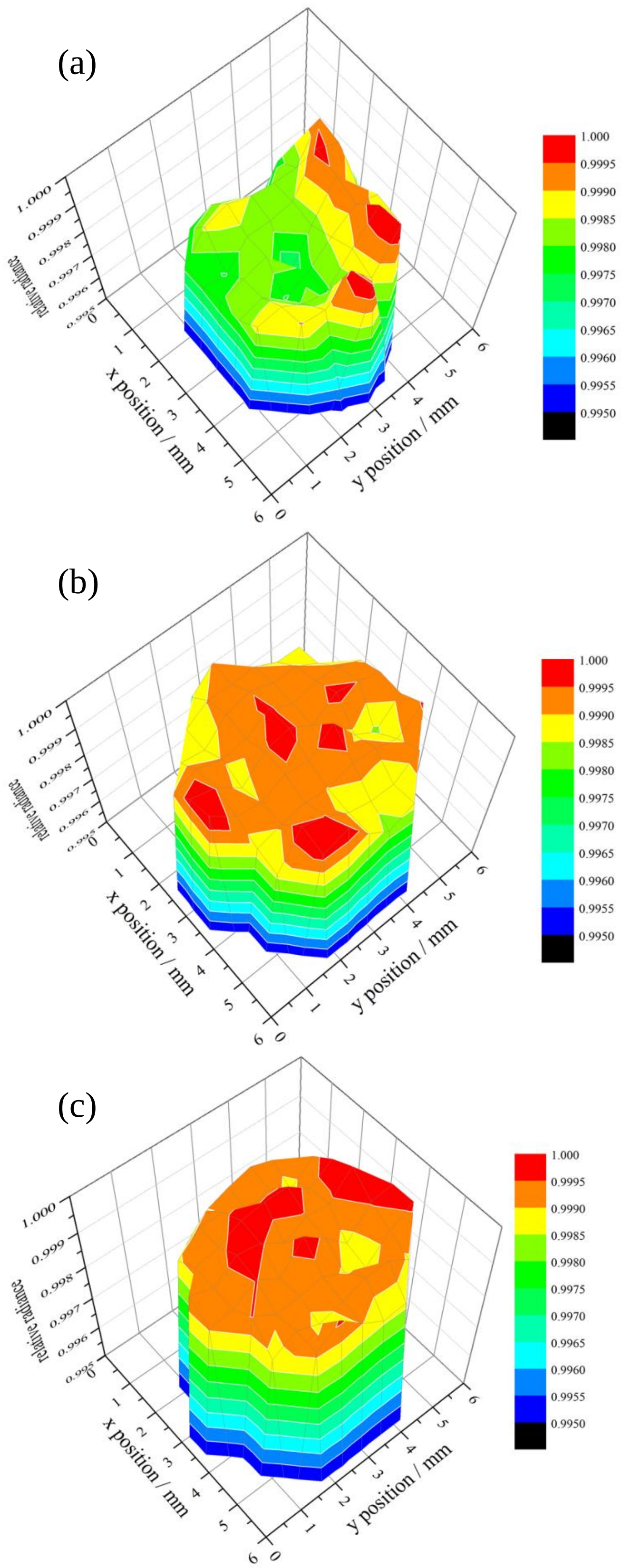

Fig. 4. Non-uniformity of radiance at the exit port of the integrating spheres with diameters of 25 mm (a), 50 mm (b) and 135 mm (c).

4. CONCLUSIONS

The new setup with the SC source to measure spectral responsivities of radiation thermometers at NMIJ and its fundamental performance were shown. The SC light is successfully coupled to the monochromator, and then two or more magnitudes higher radiance than that of the tungsten halogen lamp was measured. The power stability of less than ±0.03% was achieved with the P. I. D. control of the power stabilizer. The non-uniformity of radiance at the exit port of the integrating spheres was measured, which was less than ±0.08% at the largest sphere.

5. REFERENCES

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