Using of the white lasers at the spectral responsivity scale realisation

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The Russian national standards for detector calibrations at wavelengths from 250 nm up to 14000 nm are realized at the All-Russian Research Institute for Optical and Physical measurements (VNIIOFI) at 2014. It based on the CryoRad-III System from L-1 Standards and Technology, Inc. (USA). Facility for spectral responsivity measurements with using the white laser as a source of radiation is presented. Results of monochromatic power measurements in the spectral range from 0.4 to 1.6 um are presented.

Figure 1 shows the VNIIOFI facility for realizing the primary standard of radiant power. The main parts of the facility are: (i) the radiation source unit with the optical system, which focus the radiation on the input slit of the monochromator; (ii) the aspherical optical unit with a thermostabilized housing, which project the radiation from the monochromator output slit on the input of the radiometer or detector to be calibrated; (iii) the cryogenic vacuum chamber with the absolute cryogenic radiometer (ACR) manufactured by L-1 Standards and Technology, Inc. (USA); (iv) the vacuum chamber with detectors to be calibrated; (v) the vacuum chamber with input window, which binds the cryogenic chamber with the ACR and detectors vacuum chamber to a single vacuum space; (vi) the positioner, on which the ACR and detectors vacuum chambers are located. The cooling, vacuum, and measurements control systems are not shown on Figure 1.

The halogen lamp (5) for the wavelength range from 0.25 μm to 2.5 μm, and the blackbody with the temperature range from 1200 K to 3400 K for the wavelength range from 2.5 μm to 14.0 μm are used as radiation sources. The spectral lamp and the He-Ne laser are used for monochromator wavelength calibration and for the optical system alignment, respectively. Radiation of sources is directed to one of the double monochromator input slits, in front of which the shutter (7) controlled by the computer and the filter wheel (8), are located. The unit (9) with replaceable apertures is arranged behind the monochromator output slit. The chopper (10) is placed after the aperture unit. Monochromator technical characteristics allow creating radiation with the spectral bandwidth from 6 nm to 48 nm, depending on the wavelength in the range from 0.25 μm to 14 μm.

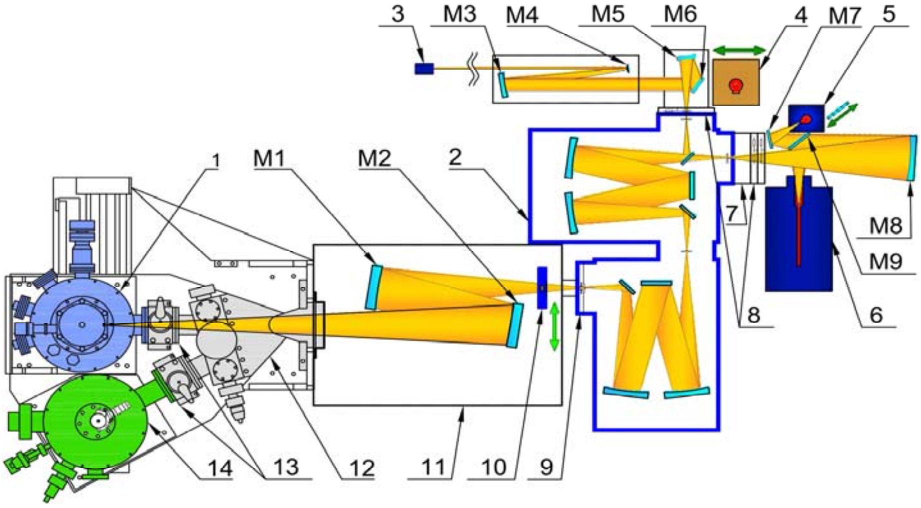

Figure 1. VNIIOFI facility for realizing the primary standard for radiant power
1 – ACR; 2 – McPherson's double monochromator; 3 –white light laser; 4 – spectral lamp; 5 – halogen lamp; 6 –blackbody with temperature of 3400 K; 7 – shutter; 8 –filters unit; 9 – replaceable apertures module; 10 –chopper; 11 – aspherical optical unit with thermostabilized housing; 12 – vacuum chamber with input window; 13 –vacuum valves; 14 – vacuum chamber for detectors under calibration; M1, M2 – off-axis parabolic mirrors; M3, M4, M5, M8 – spherical mirrors; M6, M7, M9 – plane mirrors.

Radiation from the monochromator output slit is directed using two off-axis parabolic mirrors (M1, M2) to the entrance window of the vacuum chamber (12), which forms a common vacuum volume for the ACR and detectors to be calibrated. The vacuum valves (13) are located between the common vacuum chamber with the input window, the radiometer cryogenic chamber (1), and the detectors vacuum chamber (14). The rotation stage, on which five detectors can be placed, is located in the detector vacuum chamber.

The Si photodiode trap detector, the set of InGaAs photodiodes, and the InSb–CdHgTe two-color detector are used as transfer standards. The ACR and the detectors vacuum chambers are attached to the common vacuum chamber with the optical window using a flexible Y-bellows, which makes unnecessary measurements of the optical window transmittance. Automatic translation stage, on which the ACR and detectors vacuum chambers are arranged, allows to expose the ACR or detectors to radiation according to the measurements program. Monochromatic radiation, whose radiant power is measured by the ACR, is directed to the detector to be calibrated.

The main part of the facility is the ACR, the cavity nonselective thermal detector with electrical substitution. The principle of electrical substitution consists of heating the receiving cavity to the same temperature as it is heated by optical radiation and precise measuring the electric power, which gives heating equivalent to that due to optical radiation. Thus the accuracy of calibration against electrical substitution radiometers is determined by electric power measurements that are substantially more accurate than direct temperature measurements of a radiating cavity.

The ACR is a complex cryo-vacuum and electronic system that includes a vacuum system for the radiometer cryostat internal volume, a cavity, a heat sink, a cooling and temperature stabilizing system, and an electronic measurement system. The radiometer cryostat internal volume is evacuated to the pressure of 10^{-7} mbar measured by the vacuum gauge with the measurement range from the atmospheric pressure to 10^{-8} mbar. The radiometer cavity is cooled down to 3 K using the mechanical cooling system connected to the helium compressor.

Actually, electric heating is performed in the optical phase as well as in electric phase. In the optical phase, the cavity temperature T_{OPT} can be calculated as follows:

$$T_{OPT} = S \cdot (P_{EL.OPT.} + P_{BG}), \qquad (1)$$

where T_{OPT} is the cavity temperature, S is the cavity transformation coefficient, $P_{EL.OPT.}$ is electric power provided to the cavity substitution winding at the optical phase, P_O is the measured optical power, P_{BG} is the background radiation power.

In the electric substitution phase, the radiometer cavity temperature T_{SUB} can be calculated as follows:

$$T_{SUB} = S \cdot (P_{EL.SUB.} + P_{BG}), \qquad (2)$$

where $P_{EL.SUB.}$ is electric power provided to the cavity substitution winding at the substitution phase. The cavity temperatures at the optical phase T_{OPT} and the substitution phase T_{SUB} are assumed to be equal. In this way,

$$P_O = P_{EL.SUB} - P_{EL.OPT.}. \qquad (3)$$

The ACR specification is presented in Table 1.

Table 1. Specification of the ACR

Parameter	**Value**
Cavity absorptance	0.9999
Wavelength range, μm	0.2…25.0
Acceptance angle, degrees	7
Aperture diameter, mm	7
Receiver thermal response time, s	< 10
Dynamic range, μW	1…500
Noise at 30 second integration, nW	< 10

The relative standard uncertainty of power measurements in the wavelength range from 0.25 μm to 14 μm is from $8.8 \cdot 10^{-4}$ to $1.9 \cdot 10^{-2}$.

Comparison of spectral responsivity scales between the VNIIOFI and the PTB were performed using the Si trap detector and the laser with power of 300 μW at 0.633 μm as radiation source. Comparison results showed agreement of the spectral responsivity scale within 0.01 %.

As can be seen from Table 1 the high power levels are required in order to perform accurate measurements of optical power with an absolute cryogenic radiometer. The solution of this problem in the spectral range from 0.39 to 2.40 μm is using of a white laser "supercontinuum" - the WhiteLase Supercontinuum 400-4 laser system from Fianium Ltd.

A special collimator with a focusing system was designed and manufactured in order to match the laser radiation with a monochromator. This system transforms the laser beam with a diameter of 5 mm to a parallel beam of 30 mm in diameter. There is a focusing system consisting of a flat mirror and a spherical mirror after the second mirror of the collimator. The laser radiation is formed into a solid angle filling the aperture angle of the monochromator with help of this focusing system. Figure 2 shows this special collimator with a focusing system.

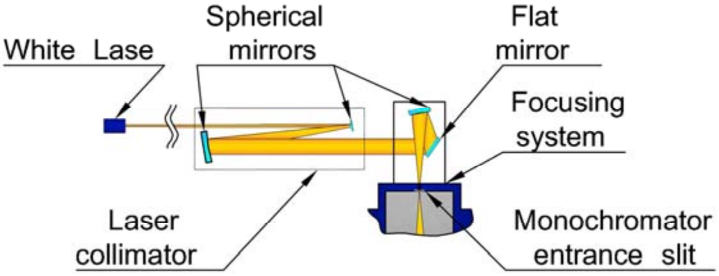

Figure 2. Laser collimator with focusing system

The measurements of the spectral power levels in the spectral band of 6 nm in the input of the monochromatic source based on a white laser in the spectral range from 380 to 1600 nm were performed. The results of these measurements are given in Table 2 and in Figure 3.

Table 2. The results of measurements of monochromatic source power

Wavelength λ, nm	Laser source power $P_{LASER}(\lambda), uW$	Wavelength λ, nm	Laser source power $P_{LASER}(\lambda), uW$
380	1,11	1000	22,70
400	72,05	1050	39,26
410	662,70	1100	40,25
450	358,95	1150	45,88
500	281,49	1200	48,20
550	289,58	1250	49,38
600	156,19	1300	48,46
650	85,74	1350	41,46
700	49,75	1400	23,78
750	22,22	1450	30,81
800	8,76	1500	51,61
850	7,00	1550	24,69
900	8,71	1600	19,85
950	14,09		

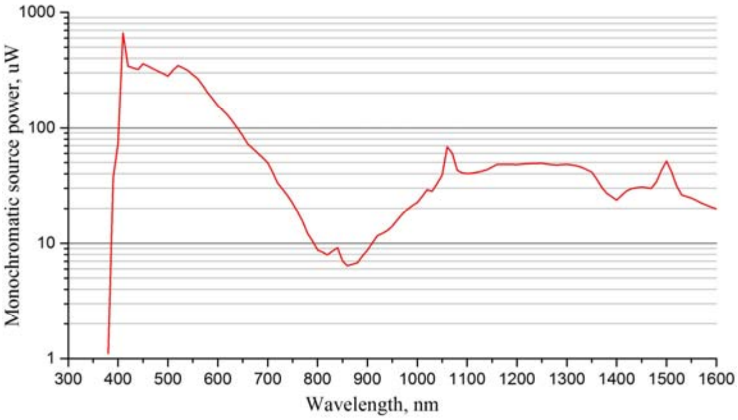

Figure 3. Monochromatic source power with spectral band width of 6 nm

Except that the measurements of the spectral power level in the spectral band of 6 nm in the output of the monochromatic source based on a halogen lamp as a source in the spectral range from 380 to 1600 nm were performed. The results of the comparison of the spectral power levels at using as a source a white laser or halogen lamp are given in Figure 4.

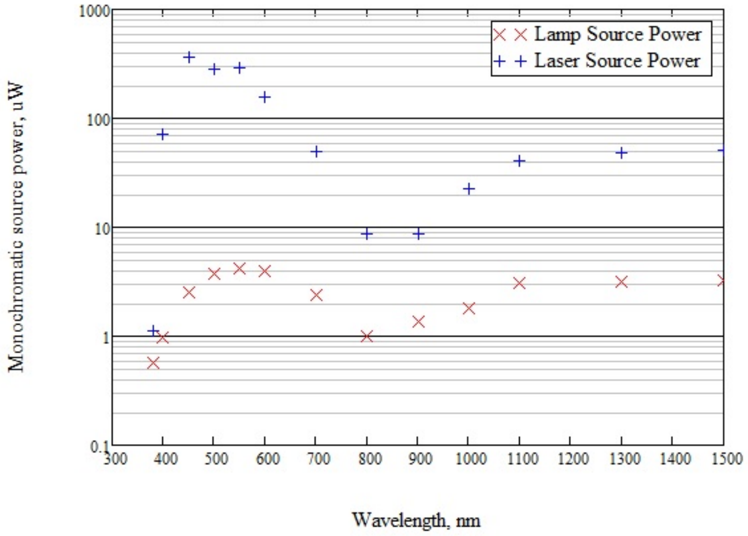

Figure 4. Comparision of power levels using the Laser Source Power and Lamp Source Power

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