REALIZATION OF THE SPECTRAL RESPONSIVITY SCALE IN KRISS

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Abstract: Korea Research Institute of Standards and Science (KRISS) realizes the spectral responsivity scale using a laser-based absolute cryogenic radiometer (ACR) as the primary standard. The ACR calibrates Si trap detectors, which serve as the working standards disseminating the scale through direct comparison. Outside the calibrated wavelength range of the trap detectors, a pyroelectric detector is used as the transfer standard. We present the recently renovated apparatus setup for establishing and maintaining the spectral responsivity scale in KRISS, as well as the measured characteristics of the new working standards.

1. INTRODUCTION

KRISS maintains an absolute cryogenic radiometer (ACR) since 1995, which is the primary standard for realizing the photometric and radiometric unit scales. In such a detector-based realization, it is the spectral responsivity scale that primarily propagates the high accuracy of the ACR to the optical detectors in application. The validity of the KRISS scale has been verified through participation in the related international comparisons [1,2].

Recently, we are renovating the apparatus setup for the primary radiometric standard and for the spectral responsivity scale. The issues to be achieved in the new setup are:

- to replace the used-up lasers and instruments,
- to replace the working standards of spectral responsivity,
- to extend the wavelength range of calibration using the ACR,
- to develop a laser-based spectral responsivity comparator,
- and to enable a computer-controlled measurement and data acquisition for better reproducibility and reliability.

We present in the following the realization of the spectral responsivity scale in KRISS with the up-to-date setup and standards.

2. APPARATUS SETUP

Three apparatus are used to establish and maintain the spectral responsivity scale: the primary radiometric standard apparatus including the ACR, the lamp-based responsivity comparator, and the laser-based responsivity comparator. The setup and features of these apparatus are described in this part.

2.1. Primary Radiometric Standard Apparatus

This apparatus is for calibrating the working standards of spectral responsivity using the ACR, and also for calibrating any detector under test (DUT) by comparison with the working standard at some discrete laser lines. Figure 1 shows schematically the apparatus setup, consisting of three beam-lines for different wavelength ranges.

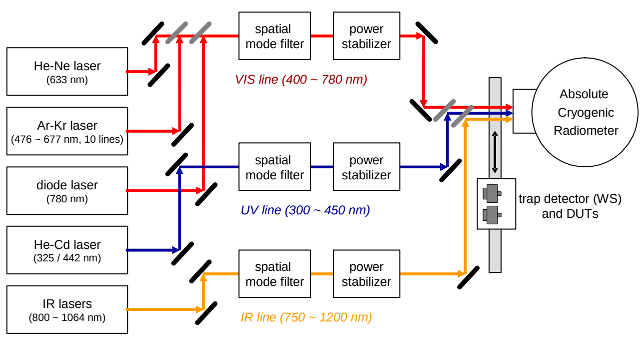

Fig. 1 *Schematic setup of the primary radiometric standard apparatus in KRISS.*

The ACR (Oxford Instruments, Radiox) measures the radiant power of a laser beam traceable to the electrical power standards. By alternatively positioning a detector mounted on a translation stage in the same beam path and reading its photocurrent, we absolutely calibrate the detector responsivity in A/W at the selected laser wavelength. The beam-line incident to the ACR as well as the particular laser in the beam-line can be selected using repositionable mirror mounts.

All the lasers used in the apparatus provide more than 5 mW radiant power at each emission wavelength. The output beam from the lasers is spatially filtered using a pinhole and power-stabilized using a feedback controlled modulator in the respective beam-line. As a result, a collimated beam with a Gaussian profile of a diameter smaller than 1.5 mm (1/e-width) is provided at the position of the detector and the ACR. The temporal power stability of the beam is measured to be smaller than 0.002 % (1σ) in a time scale of several tens of seconds. The calibration is typically performed at a power level of 0.1 mW.

2.2. Spectral Responsivity Comparators

The spectral responsivity of a calibrated detector is transferred to other DUTs by a spectral responsivity comparator. We have two types of the comparator in use; a lamp-based comparator using a tungsten-halogen lamp with a monochromator and a laser-based comparator using on tunable lasers. Note that the primary radiometric standard apparatus shown in Fig. 1 can also be used as a spectral responsivity comparator, but the available laser wavelengths are limited in that setup.

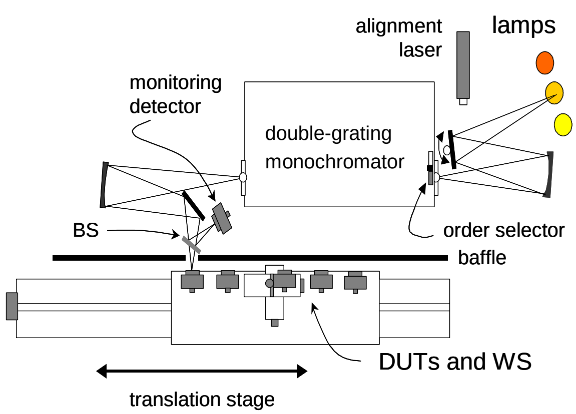

Fig. 2 *Schematic setup of the lamp-based spectral responsivity comparator in KRISS.*

Figure 2 shows the schematic setup of the lamp-based responsivity comparator. The apparatus can measure the responsivity ratio of up to 5 detectors simultaneously using a computer-controlled translation stage. The detectors are illuminated by light flux transmitted through a double-grating monochromator, which is focused at the detectors to a spot of 1.5-mm diameter with f/6. The photocurrent of the detectors is measured by an electrometer combined with a low-current switch. A 100 W tungsten-halogen lamp is used as light source whose radiant power is stable within 0.02 %. The actual comparator is optimized for a wavelength range 350 nm to 1100 nm providing a radiant power of several μW at 555 nm with a bandwidth of 4 nm.

Although the lamp-based comparator is practical with its wide wavelength coverage and ease of use, the low power level limits the accuracy of comparison. To supply these shortcomings, we are building a spectral responsivity comparator with tunable lasers that replace lamp and monochromator. A continuous-wave (CW) dye laser and a CW Ti:Saphire laser will be used in the visible and near-infrared wavelength range, respectively, which is planned to be set-up at the end of 2006. For the infrared range 1250 nm to 1600 nm, where InGaAs or Ge photodiodes are used, we developed a CW optical parametric oscillator (OPO) that uses a MgO:PPLN crystal to convert the pump laser beam at 532 nm to the signal and idler beams in the infrared. More than 1 mW output power at the idler wavelengths ranging from 1260 nm to 1620 nm is achieved. Application of the CW-OPO for responsivity comparison of InGaAs detectors is the subject of our current work.

3. SILICON TRAP WORKING STANDARD

We replaced the working standard up to the present, a biased three-element reflection-type Si trap detector (Grasby Optronics, QED200), because of its reduced quantum efficiency at wavelengths longer than 700 nm and the high dark current caused by biasing. The new working standard is a self-constructed transmission-type trap detector consisting of four Si photodiodes (Hamamatsu, S1337-11). The main advantage of such a transmission-type is that the transmission can easily be measured at the laser wavelengths and compared to the theoretical model [3]. This means that, in practice, any change of the absolute responsivity can easily be checked only by a transmission measurement without operating the ACR. Note, however, that the trap detector of this type is polarization-dependent, so that this working standard is exclusively used for the well-characterized laser beam.

As a working standard applicable also in the lamp-based spectral responsivity comparator, we additionally constructed a polarization-independent three-element reflection-type trap detector using large-area Si photodiodes (Hamamatsu, S6227-01).

We designate the transmission-type and reflection-type trap detector as T-trap and R-trap, respectively. These two working standards of spectral responsivity are simultaneously calibrated against the ACR and regularly compared each other in the primary radiometric standard apparatus.

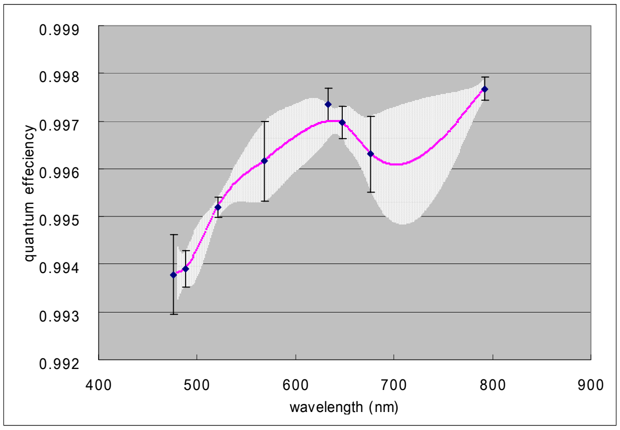

Fig. 3 *Spectral quantum efficiency of the T-trap working standard resulted by a cubic spline interpolation of the ACR measurements at 9 wavelengths (symbols with error bars: measured data, line: interpolated data, white area: standard uncertainty of the interpolated data).*

The trap working standards are calibrated against the ACR at 8 selected laser wavelengths from 476 nm to 792 nm in November 2005. The spectral responsivity scale with a 1-nm interval is then established through a cubic spline interpolation of the measured values and uncertainties [4]. Figure 3 shows the result for an example of the T-trap, where, for better visibility, the spectral quantum efficiency is plotted instead of the spectral responsivity. The spectral (external) quantum efficiency η and spectral responsivity S is related by the equation

$$S = \eta \frac{e}{hc} \lambda \ . \qquad (1)$$

Note that the uncertainty of the ACR measurements in Fig. 3 varies with the wavelength, resulting in expanded uncertainties (k = 2) from 0.04 % at best (520.8 nm) to 0.17 % at worst (568.2 nm). The high accuracy of the ACR with the expected uncertainty lower than 0.02 % is not fully achieved yet, mainly due to the noise of the ACR. The improved measurement software capable of effectively averaging out the noise is expected to solve this problem and achieve a higher accuracy. The next calibration planned in September 2006 should also be performed including the UV and IR beam-lines in Fig. 1.

4. PYROELECTRIC TRANSFER STANDARD

In order to transfer the spectral responsivity scale outside the calibrated wavelength range of the trap detectors, an electrically calibrated pyroelectric radiometers (ECPR, Laserprobe, Rs-5900) is used as the transfer standard. Calibrated at 633 nm at a radiant power of 0.1 mW, the responsivity of the ECPR should not vary more than 1 % in a wavelength range 250 nm to 2000 nm. The calibration uncertainty at 633 nm is smaller than 0.5 % (k = 2).

Due to the low accuracy of the ECPR mainly caused by the spatially and spectrally dependent reflectance of the pyroelectric sensor, we are going to replace the pyroelectric transfer standards to the calibrated photodiodes (Si and InGaAs). However, this can be realized only when the spectral responsivity comparator can cover the required wavelength range in the UV and IR. It is our next goal to introduce the photodiode-based higher-accuracy transfer standard for the wavelength range 300 nm to 1600 nm.

5. SUMMARY

We presented how the spectral responsivity scale is realized in KRISS. The apparatus setup is recently renovated, and some work is still in progress. By using the transmission-type trap detector, we expect to cross-check the absolute calibration using the ACR by measuring the transmission of the trap. Currently, an extension of the wavelength range of absolute calibration in the UV down to 325 nm and in the IR up to 1064 nm, as well as an extension of responsivity comparison in the IR up to 1600 nm is in preparation.

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