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Study of Applying Fiber Based Laser with the Primary Standard for Optical Power and Improvement of Spectral Responsivity Scales in Near IR Range

Zhang Jing^{*a}, Teo Jia Jie^b, Huang Xuebo^a

^aNational Metrology Centre (NMC), Agency for Science, Technology and Research (A*STAR)
1 Science Park Drive, Singapore 118221

^bSchool of Electrical and Electronics Engineering, Nanyang Technological University,
Singapore 639798

**Email: zhang_jing@nmc.a-star.edu.sg*

ABSTRACT

A fiber optics based 1310nm laser was applied with the primary standard cryogenic radiometer for optical power measurement to extend NMC's spectral responsivity scale toward infrared wavelength. The absolute optical power was measured and two absolute transfer standard detectors (InGaAs based trap detectors) were calibrated at 1310nm. The measurement setup is described and the measurement uncertainty was analyzed. The advantages of using fiber optics based laser sources are discussed in the paper. With the new calibration capability, the uncertainty of the spectral responsivity in the range from 900nm to 1640nm in NMC will be improved.

Keywords: Spectral responsivity scale, cryogenic radiometer, infrared wavelength, fiber based laser, trap detector

1. INTRODUCTION

The primary standard for optical power is a cryogenic radiometer operating at an absolute temperature of ~13 K, based on thermal equivalence between optical and electrical heating. Combined with a group of intensity stabilised lasers, it is capable of measuring laser power with very low uncertainty. In the past ten years, a krypton ion laser and a He-Ne laser were used for visible and near IR wavelengths (476.2nm to 799.3nm) with the cryogenic radiometer to calibrate the absolute transfer standard detectors for spectral responsivity scales in NMC[1]. Recently, we set up a Ti:Sapphire tunable laser (700nm to 1100nm) and a 1310nm fiber laser with the primary standard for optical power measurement system. With the new setup, the InGaAs trap detector based absolute transfer standard was established at 1310nm.

2. MEASUREMENT OF OPTICAL POWER AND CALIBRATION OF TRAP DETECTORS

Figure 1 shows the schematic diagram of the spectral responsivity scale measurement system. The laser was collimated and aligned with the absorbing cavity in cryogenic radiometer. The absolute transfer standards - trap detectors - were installed on a movable stage in front of the cryogenic radiometer. The laser power was measured by the cryogenic radiometer. Then the trap detectors moved in to the optical path and the photo currents generated in the trap detectors were measured. By linking the photo currents and optical powers measured, the responsivities (A/W) of the trap detectors were calculated.

2. 1 Applying fiber optics laser sources with cryogenic radiometer

The laser outputs from the krypton ion laser, the He-Ne laser and the Ti:Sapphire tunable laser were in free space. The laser beams were reshaped and high order modes were filtered out by using a space filter with 0.1mm hole. Then the laser beams were collimated and entered the cryogenic radiometer. The fiber based laser in the system takes the advantage of stable and Gaussian-like beam profile (Fig. 2) from the single mode fiber, which has better beam quality than free space laser sources and eliminates the extra components in the system for improving the beam profile. Another advantage of using fiber based laser source is the convenience of changing the laser source and bringing the laser into the optical path through the optical fiber and a collimator. Minor adjustments are needed to fine tune the lenses to achieve the desired optical path and beam position.

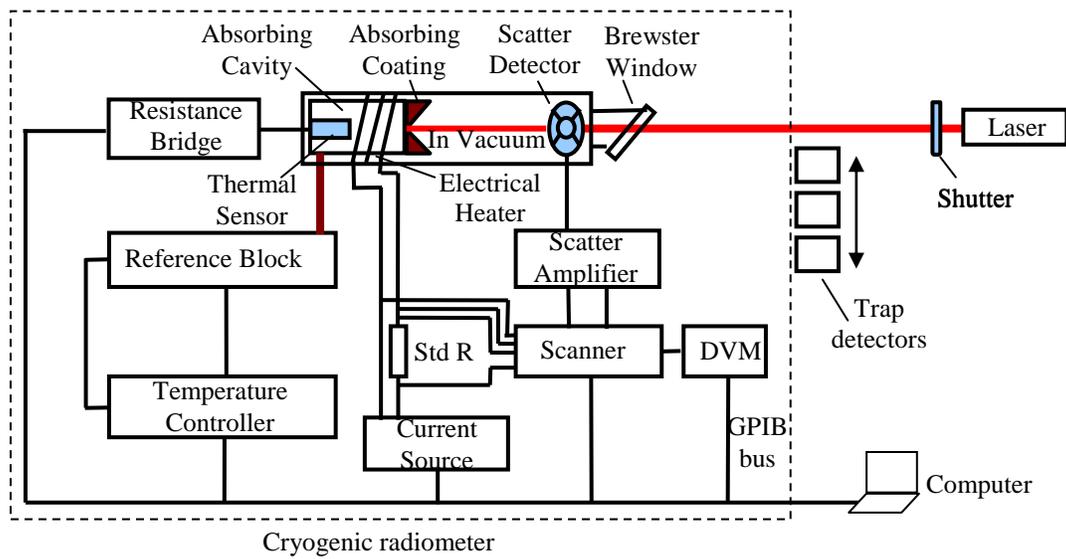


Fig. 1 Schematic structure of NMC's Cryogenic Radiometer Facility

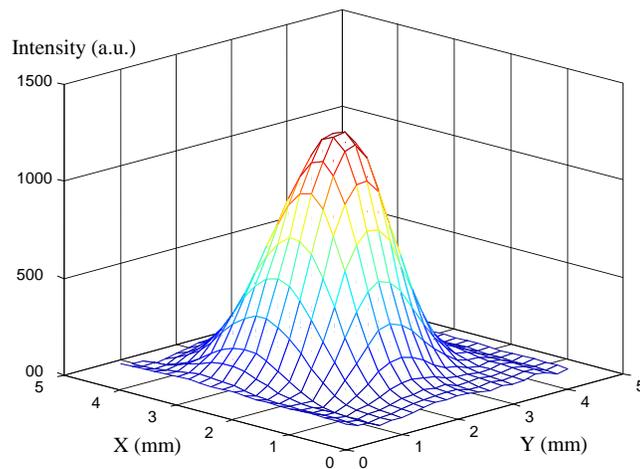


Fig. 2 Beam profile of 1310nm laser.

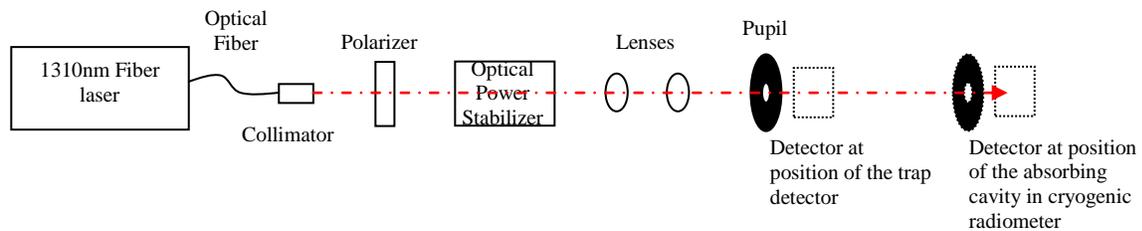


Fig. 3 Laser beam characterization

Figure 3 shows the laser setup for 1310nm measurement. The 1310nm source was a fiber laser source. We set the output power to be around 5mW at the output APC port. A single mode polarization maintained fiber was used to connect the laser into the optical path. As the laser exiting from a single mode fiber was divergent, a collimator was used to collimate the laser and the beam size was about 1mm diameter. The optical power stabilizer stabilized the fiber laser power output to be around 0.3mW with less than 0.005% fluctuation. The lenses placed after the stabilizer enlarged the collimated laser beam to a size of around 3mm diameter at the position of the trap detector. The pupil in front of the trap detector blocked the scattered light.

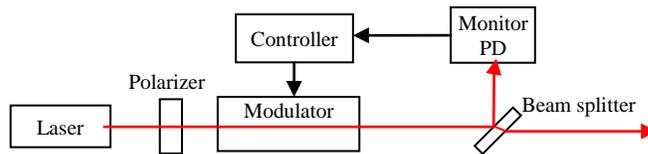


Fig. 4 Schematic structure of laser power stabilization system

2. 2 The stability of the laser power

The schematic structure of optical power stabilizer is shown in Fig. 4. The monitor photodetector detects the optical power and feedbacks to the controller of the optical modulator so that the power fluctuation of the laser can be decreased. In 1310nm laser measurement, the laser power fluctuation was measured to be 0.05% within 1 min period without the optical power stabilizer. With the optical power stabilizer, the laser power fluctuation decreased to <0.005% within 1 min. The power fluctuation within one hour was less than 0.01%.

2. 3 The alignment and scattering measurement

A silicon-based quadrant detector in the cryogenic radiometer measures the scattered light in the cavity and assists the alignment of the laser with the cryogenic radiometer at the wavelengths of 1000nm or less. The silicon-based detector has poor response at wavelengths above 1000nm. In order to align the laser at above 1000nm wavelength with the cryogenic radiometer and measure the scattered light, external components are needed. The Physikalisch-Technische Bundesanstalt (PTB) developed a spectral responsivity scale in the spectral range 960nm to 1550nm in 2000 [2]. The measurement of the scattered light was performed outside the cryogenic radiometer, using a germanium (Ge) photodiode and a spherical mirror with a central hole of the same diameter as the hole of the quadrant photodiode in front of the cavity.

Similar to PTB's method, we performed the alignment and the scattered light measurement outside the cryogenic radiometer. We used 1000nm laser as the reference beam to do the alignment and then aligned 1310nm laser to the same optical axis. The beam spot size and position of 1310nm were adjusted to be the same as those of the beam at 1000nm. The scattered light was measured with a InGaAs detector out of the cryogenic radiometer. The detector had an active area of 10mm diameter. The photodetector was placed at the position of the trap detector and then at the position of the absorbing cavity in cryogenic radiometer to measure the optical powers, respectively. The difference between the two optical powers was the scattered light. A second pupil was used in front of the detector at the position of the absorbing cavity in cryogenic radiometer to simulate the entrance of the absorbing cavity. By comparing the scattered light measured at the wavelength of 1000nm with the detector outside the cryogenic radiometer and the silicon-based quadrant detector inside the cryogenic radiometer, the size of second pupil was determined. The scattered light at 1310nm was measured to be 0.2% (+/-0.1%) of the total power. The scattered light amount was used to adjust the trap detector calibration result.

2. 4 Trap detectors calibration result

The absolute transfer standard - the trap detector - is a reflection type which consists of three single InGaAs photodiodes electrically connected in parallel while oriented in the way that the incoming laser beam is reflected by the surfaces of the photodiodes five times before leaving (Fig. 5). This unique structure minimizes the reflection of incoming laser power.

The wavelength of the 1310nm laser source was measured to be 1308.456nm +/- 0.005nm. The optical power was measured with the cryogenic radiometer and two InGaAs trap detectors were calibrated. Table 1 shows the calibration

results and the trap detectors responsivity after scattered light adjustment. Before doing the scattered light adjustment, the responsivities of trap detector 1 and 2 were 1.0116A/W and 1.0185A/W, respectively. After scattered light adjustment, the responsivity of trap detector 1 at 1308.456nm was 1.0096A/W with the uncertainty of 0.10%, and the responsivity of trap detector 2 at 1308.456nm was 1.0096A/W with the uncertainty of 0.10%.

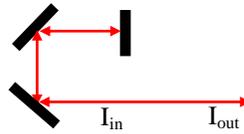


Fig. 5 diagram of a trap detector

Table 1. The spectral responsivities and the measurement uncertainties.

Calibration At 1308.456nm	Trap Detector 1	Trap Detector 2
Measured Responsivity (A/W)	1.0116	1.0185
Responsivity (A/W) After Scattering Adjustment	1.0096	1.0165
Uncertainty (%)	0.10	0.10

Before we developed the capability of direct calibration with cryogenic radiometer at 1310nm, we calibrated the trap detectors at the wavelengths of up to 799.3nm, and then extrapolated the responsivity up to the wavelength of 900nm. The trap detectors were used to calibrate the secondary standards up to the wavelength of 900nm. The spectral responsivity scale was further expanded by calibrating the secondary standards (Si and InGaAs detectors) through a relative transfer standard - cavity pyroelectric detector (CPD). As the CPD was a spectrally flat detector i.e., its spectral responsivity was independent of wavelength, once calibrated at a specified wavelength, its spectral responsivity values at other wavelengths were all known with 0.25% uncertainty [3]. The calibration uncertainty of the spectral responsivity of the secondary standard in the range from 900nm to 1640nm in NMC was 1.5-1.9%.

With the calibration capability available at 1310nm, the spectral responsivity scale of the trap detectors will be used to calibrate the secondary standards (InGaAs photodetector) directly in IR range. Then the secondary standard responsivity scale will be extended to 1640nm by comparing the responsivity between the secondary standard detector and a cavity pyroelectric detector with a flat spectral responsivity within the range. Without calculating the absolute values of the cavity pyroelectric detector, the estimated uncertainty of the spectral responsivity scale in the range from 900nm to 1640nm will be improved from 1.5% to 0.4%.

3. CONCLUSION

The absolute transfer standards for optical power measurement at National Metrology Centre (NMC) were directly calibrated at near infrared wavelengths laser by using fiber laser at 1310 nm with cryogenic radiometer. With the new absolute spectral responsivity value at 1310nm, the calibration uncertainty of the spectral responsivity scale in NMC is estimated to be improved greatly in the near infrared wavelength range.

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