A Radiometer for Precision Coherent Radiation Measurements

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ABSTRACT

A radiometer had been designed for precision coherent radiation measurements and tested for long-term repeatability at wavelengths of 488 and 633 nm. The radiometer consists of a single high-quality PN silicon photodiode maintained in a nitrogen atmosphere with a quartz window designed to eliminate interference problems. Ratio measurements between the radiometer and an absolute type detector were made over a period of 215 days. At 0.5 mW, the standard deviations were 0.008 and 0.009 % at 488 and 633 nm respectively. The maximum deviations from the mean were 0.016 and 0.015 % at the respective wavelengths. The high precision, simplicity, and portability of the radiometer make it an excellent transfer standard for radiometric measurements.

1. INTRODUCTION

The need for reliable and precise radiometric transfer standards has been emphasized by the recent development of high accuracy cryogenic radiometers [1]. In order to utilize this high accuracy capability, the precision of a transfer standard should be at least an order of magnitude better than most portable radiometers currently available. We have constructed and tested a nitrogen filled, wedged window radiometer (WWR) for coherent radiation measurements using a Hamamatsu [2] 1337-1010B PN silicon photodiode of the type found to be most stable by Korde and Geist [3].

2. DESCRIPTION OF THE EXPERIMENT

The laser based comparator facility used to determine the long-term stability of the wedged window radiometer is shown schematically in Figure 1. Two lasers, a 9 mW helium-neon laser and a 15 mW air-cooled argon laser were used as sources in the facility. Basically, the optical system consists of a laser power stabilizer, spatial filter, beam expanding telescope, wedged beam-splitter, and a monitor detector. The monitor detector was a Hamamatsu PN silicon photodiode similar to the type used in the WWR. Although the monitor diode was not protected by a window, its short-term (< 4 hours) stability when measured against a QED-200 absolute radiometer (see below) was <0.02 %. The laser power stabilizer was a Cambridge Research and Instrument Company model LS-100 [2], a commercial version of the stabilizer described by Fowler, et al [4]. The maximum peak-to-peak variation of the laser power over a 30-minute period was 0.05 %.
 Absolute spectral response measurements made in the comparator facility were generally based on commercially available 100% quantum efficient three-detector devices [5] (the United Detector Technology model QED-200 [2]). Ratio measurements between the WWR and one of the QED-200 devices were made to determine the long-term stability of the WWR. The acquisition of data was facilitated by the use of a computer programmed to measure the QED or WWR photocurrent followed by a measurement of the monitor detector photocurrent. The ratio of the two photocurrents was then computed. A measurement sequence consisted of 150 repeats of the measurement of the ratio over a time span of about 30 minutes. The 150-measurement sequence of the QED to monitor detector ratio was followed immediately by a 150-measurement sequence of the WWR to monitor detector ratio. The ratio of the average of these two measurement sequences represents one data point in the long-term stability discussion in Section 3. The integration time for a single photocurrent measurement was 160 msec. All measurements on the WWR were made (a) at an ambient temperature of $24 \pm 0.5$ °C., (b) with a laser beam diameter of approximately 4 mm, and (c) with the laser beam normal to and centered on the WWR photodiode.

Figure 2 is a cross-section drawing of the WWR. A windowless Hamamatsu 1337-101OB PN type silicon photodiode is sealed at one end of a heavy-wall black plastic tube with epoxy cement. A quartz wedged window is also sealed with epoxy cement to the other end of the tube. The tube is filled with high purity nitrogen of 99.998% minimum purity as certified by the manufacturer and then sealed by using two glass stop-cock valves. The nitrogen gas pressure in the tube is slightly above 1.0 X $10^5$ N/m² (1 atm.). The window is 25 mm in diameter with a minimum thickness of 3 mm and a wedge angle of 3.8 degrees. Also, the end of the plastic tube to which the window is sealed is cut at an angle of 3.8 degrees ($\Phi$ in Fig. 2). The window is sealed to the end of the plastic tube at an orientation such that neither plane of the window is parallel to the surface of the photodiode. This minimizes interference effects which cause variations in the quantity of radiation received by the photodiode.

3. STABILITY OF THE WEDGED WINDOW RADIOMETER

The long-term stability of the WWR was determined over a period of 215 days at 633 nm and 40 days at 488 nm. Figure 3 is a plot of the deviations of all WWR to QED measurement-sequence ratios at 0.5 mW from their respective mean at 488 and 633 nm. The maximum deviations were -0.016 and +0.015% at the two wavelengths respectively. Each data point in Figure 3 represents a ratio of the average of 150 measurements of the WWR photocurrent to the average of 150 measurements of the QED photocurrent. The standard deviation for each 150-measurement sequence was calculated and the average of these standard deviations is 0.013%. The long-term repeatability of the WWR to QED ratios i.e., the standard deviation of the ratio differences in Figure 3, is 0.008% at 488 nm and 0.009% at 633 nm.
4. CONCLUSION

The wedged window radiometer, which was designed for coherent radiation measurements, maintains a PN type photodiode in an environment free of water vapor that can effect the internal quantum efficiency of PN photodiodes [3] and uses a quartz protective window designed to eliminate interference problems. Ratio measurements between the wedged window radiometer and the QED over a period of 40 days at 488 nm show the repeatability (1 sigma) of the differences between each measurement sequence ratio from the mean of the respective ratios to be 0.008 %. At 633 nm over a period of 215 days, the repeatability (1 sigma) of the ratio differences was 0.009 %. This repeatability was determined at 0.5 mW. The maximum deviations of the ratios from the mean of all ratios at the respective wavelengths were - 0.016 and + 0.015 % at 488 and 633 nm respectively.

Since the WWR is not an absolute radiometer, it must be calibrated using an absolute standard. Such standards include (a) the 100 % quantum efficient detector radiometer (QED), (b) a self-calibrated silicon photodiode [6] [7], (c) a cryogenic absolute radiometer [8], (d) a cavity-type electrically calibrated radiometer [9], and (e) an electrically calibrated pyroelectric radiometer (ECPR) [10]. The reported absolute accuracies of these standards range from 0.01 % for the cryogenic radiometer to 0.7 % for the ECPR.

If the WWR were calibrated to the highest accuracy using the cryogenic absolute radiometer, it is not unreasonable to expect the calibration to have an absolute uncertainty of 0.02 to 0.03 %. If this is achievable, the WWR would surpass other radiometers described in the literature in the area of cost, ease of use, long-term stability, portability, and accuracy.

Our measurements on the WWR have demonstrated that silicon photodiodes are unique for use in high precision radiometric measurements. The numerous studies conducted on silicon photodiodes over the past decade have shown that while they have limitations like any other photodetector, they are highly reliable if handled, maintained, and used properly.

5. REFERENCES

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Figure 1. Laser based detector calibration facility for 488 and 633 nm wavelengths.
Figure 2. Cross-section of the wedged window radiometer.
A, black opaque plastic; B, silicon photodiode;
C, quartz wedged window; D, glass stop-cock valve;
E, epoxy cement; F, BNC connector; $\phi$, 3.8 degrees
Figure 3. Deviation of all WWR to QED ratios at 0.5 mW from their respective mean at 488 and 633 nm. Each data point represents the average of a 150-measurement sequence. The standard deviations are 0.008 and 0.009 % at 488 and 633 nm respectively. The error bar of ± 0.014 % (+ 1 sigma) indicates the average standard deviation of all measurement sequences.