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Liquid nitrogen cryostat for predictable quantum efficient detectors

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Abstract. We present the design and testing of a cryostat to be used with induced junction photodiodes of the Predictable Quantum Efficient Detector (PQED). Long-term reflectance measurements indicate that possible ice growth on the photodiodes at the temperature of liquid nitrogen (LN) is significantly reduced from earlier PQED cryostat designs.

1. Introduction

The predictable quantum efficient detector [1-4] consists of two induced junction photodiodes, which are mounted in a wedged trap configuration to minimise the specular reflectance losses. PQEDs are typically operated at room temperature, where uncertainty of internal quantum deficiency (IQD) of around 100 ppm is achieved. We have also operated PQEDs in liquid nitrogen cryostats to cool the induced junction photodiodes. The cooling reduces dark current, improves the mobility of charge carriers, and therefore reduces the IQD of the photodiodes according to the predictions of photodiode models [5-6]. However, when we cooled the PQEDs in commercially available cryostats, the reflectance of the detector changed temporally [1]. This is due to the growing ice layer on top of silicon photodiodes [7-8].

In this work, we present the design of a new cryostat for operating PQEDs at 79 K temperature. The cryostat is compatible with various versions of the PQED photodiodes. For testing purposes, photodiodes with 310 nm oxide layer from the first production batch of the PQED [9], referred here as round-1, were installed. Long-term reflectance measurements at 79 K indicate that the icing effect is greatly reduced in the new cryostat. In addition, the results of responsivity measurements of round-1 PQED are given. This is useful for the comparison of photodiode responsivity models.

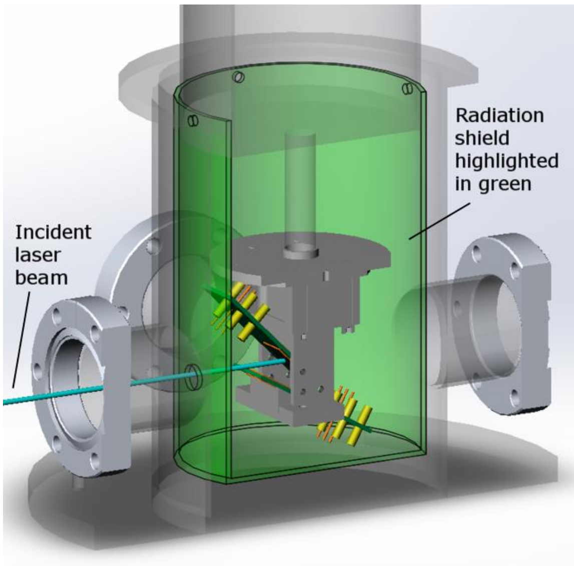

Figure 1. Schematic drawing of the cryostat. The radiation shield has an aperture of 10 mm in diameter for the incident laser beam to reach the photodiodes.

2. Cryostat

The schematic drawing of the cryostat design is shown in figure 1. The temperature of the photodiode holder (the central grey part in figure 1) can be increased and the radiation shield enclosing the photodiodes serves as a cold trap. In addition, the cryostat is equipped with a heatable charcoal getter to trap permeated gases. We pumped the cryostat by using a turbomolecular pump together with a mechanical backing pump. The pumping system is similar as used in the previous publication [1], but the achieved vacuum is 68 µPa, a factor of ten better.

3. Measurement results

Before cooling with liquid nitrogen, the cryostat was baked at 80 °C for 20 hours. Figure 2 shows the reflectance measured over 21 hour time period at LN temperature. Measurements were performed using a stabilized argon ion laser operated at the wavelength of 488 nm. The reflectance has a rate of change around 0.2 ppm/h, which is a factor of five smaller than that previously reported in [1].

Before cooling down the photodiodes, the responsivity of the round-1 PQED was measured at room temperature against a PQED that is similar to those characterized in [2] and [3]. The obtained IQD values for the round-1 photodiodes at room temperature are around 0.2% as shown in table 1. Due to the problems of the packaging and circuitry of chip carriers in the round-1 photodiodes, attempts to determine the IQD values at LN temperatures were not successful at 488 nm wavelength. During comparison measurements against the cryogenic radiometer at the CMI, the IQD of 0.2% at 79 K was obtained for the wavelength of 476 nm. An earlier result was 0.6% for the wavelength of 760 nm in measurements performed at PTB on a similar PQED with one of the photodiodes slightly displaced from its chip carrier [9].

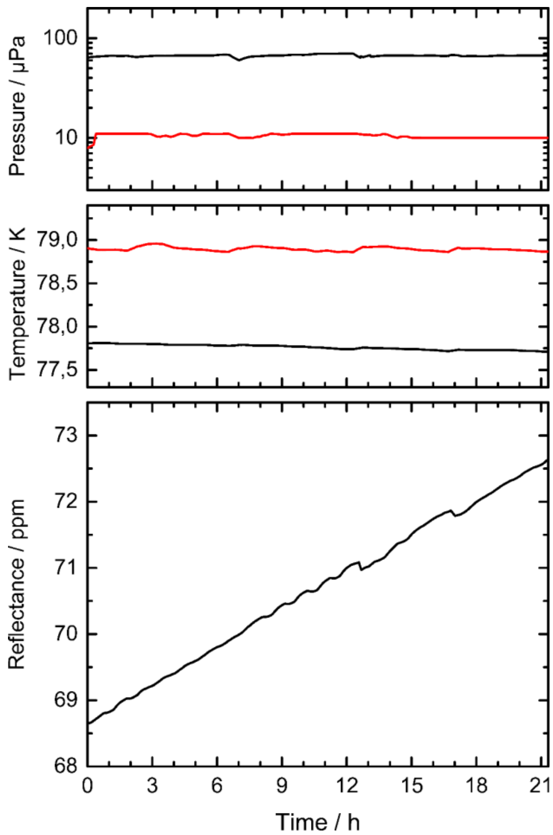

Figure 2. Measured absolute reflectance over 21 hour time period at LN temperature. Pressure was monitored with gauges near the cryostat (black line) and the turbomolecular pump (red line). Platinum sensors were used to measure temperature close to the N_2 vessel (black line) and close to the photodiodes (red line).

Table 1. Measured IQD of the PQED constructed of round-1 photodiodes at various reverse bias voltages and power levels at room temperature. The uncertainties are given at 95% confidence level.

Optical power (μW)	Bias voltage (V)	IQD (%)
100	-5	0.186 ± 0.015
240	-5	0.195 ± 0.021
100	-10	0.195 ± 0.020

4. Conclusions

We have developed a custom designed cryostat for operating the PQEDs at LN temperatures. The device can minimise the growth of ice layers on the photodiodes and therefore achieve a rate of change of reflectance of about 0.2 ppm per hour. This can facilitate the demonstration of the potential near zero IQD with an uncertainty of around 10 ppm predicted for the cooled PQEDs. It is essential that the stability of reflectance is monitored during such measurements of PQEDs at low temperatures.

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