# Planar Absolute Radiometer Operating at Room Temperature for Replacing NIST’s Legacy Laser Calorimeter

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**We have developed a Planar Absolute Radiometer for Room Temperature (PARRoT) that will replace the legacy C-series calorimeter in free-space continuous-wave laser power measurements at the National Institute of Standards and Technology (NIST). PARRoT measures laser powers between 100 µW and 250 mW from ultraviolet to near-infrared using the electrical power substitution method with active background compensation. Its expanded uncertainty ($k = 2$) reaches 0.13% at laser powers >2 mW. PARRoT’s response was compared against a transfer standard silicon trap detector and against the C-series calorimeter. On average these comparisons agreed to better than 0.008% and 0.05%, respectively.**

## INTRODUCTION

After first lasers became commercially available in the 1960’s, West *et al.* [1] at the National Institute of Standards and Technology (NIST) started the development of laser calorimeters to meet the needs of laser-power meter calibrations. The C4-series calorimeters were completed in 1974 [2] and they have been used for calibrating customer detectors at NIST for the past 46 years.

The C-series calorimeter performs free-space laser power measurements with an expanded uncertainty ($k = 2$) of 0.84%, with one measurement cycle taking approximately 15 minutes. Recently, the Laser Interferometer Gravitational-wave Observatory (LIGO) [3, 4] has indicated need for an order of magnitude lower calibration uncertainty at a few 100 mW range.

In this work, we introduce a Planar Absolute Radiometer for Room Temperature (PARRoT) [5], shown in Fig. 1, that will replace the legacy C-series calorimeter. PARRoT is more robust, twice as fast, and it has over a factor of 6 lower measurement uncertainty compared to the C-calorimeter.

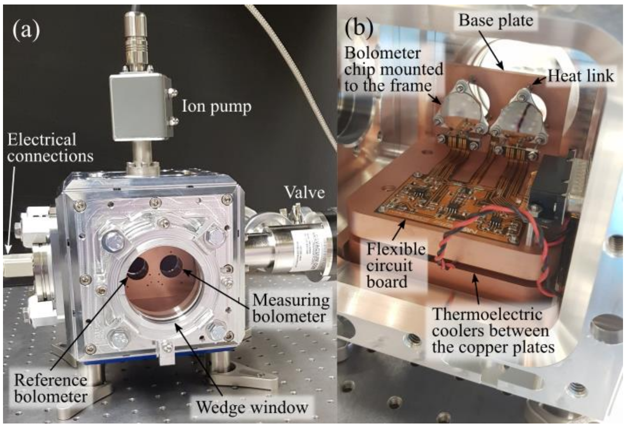

**Figure 1.** Front side of the radiometer developed (a) and view inside the vacuum chamber (b).

## DESIGN OF THE RADIOMETER

PARRoT is based on 20 mm diameter vertically aligned carbon nanotube (VACNT) absorber [6] grown on a microfabricated silicon bolometer chip. PARRoT is operated by closed-loop electrical power substitution method implemented using a field-programmable gate array (FPGA) board with custom electronics. PARRoT’s bolometer chip geometry has been optimized by thermal modeling so that its electro-optical inequivalence is less than 0.01% when a laser beam is centered on the absorber [7].

Figure 1 shows photographs of PARRoT. The copper base plate is temperature-stabilized to 295 K with thermoelectric coolers. Two bolometer chips are mounted to aluminum frames that are connected to the base plate via stainless steel cylinders. The bolometers are operated in a vacuum chamber to avoid convective cooling. Laser beam access is provided by an uncoated fused silica window with a wedge angle of 0.5° and diameter of 76.2 mm so that PARRoT can measure across broad spectral range from ultraviolet to near-infrared. Since the laser beam is aligned nearly perpendicular to the VACNT absorber and the vacuum window, PARRoT’s response is independent of light polarization.

PARRoT has two identical bolometer chips to compensate radiative coupling to changing ambient environment that reduces drifts in its response. The reference bolometer chip is heated to 325 K by constant electrical power of 290 mW and the measuring bolometer chip's heater is operated in closed loop. When a laser beam hits the measuring bolometer's absorber, the electrical power is reduced to maintain the temperature. Absolute optical power is obtained from the electrical power difference by correcting VACNT absorptance and transmittance of the wedge window that depend on the laser wavelength, correcting the electro-optical inequivalence obtained by thermal modeling, and correcting the parasitic resistance of the wirebonds that electrically connect the heater spirals to the flexible circuit board in Fig. 1.

## COMPARISONS AGAINST EXISTING DETECTOR STANDARDS

We compared PARRoT's response against a transfer standard silicon trap detector traceable to NIST's Laser-Optimized Cryogenic Radiometer (LOCR) at a laser wavelength of 633 nm and the C-series calorimeter at laser wavelengths of 405 nm, 532 nm, and 1064 nm. Figure 2 shows that on average PARRoT's laser power measurements agree with the transfer standard trap detector better than 0.008% and with the C-series calorimeter better than 0.05% [5]. These discrepancies are well within PARRoT's expanded measurement uncertainty. At laser powers of a few 100 µW, PARRoT's expanded uncertainty is limited by the measurement repeatability. At laser powers >2 mW PARRoT's expanded uncertainty ($k = 2$) reaches 0.13% and is limited by an uncertainty of the window transmittance correction (±0.1% rectangular distribution).

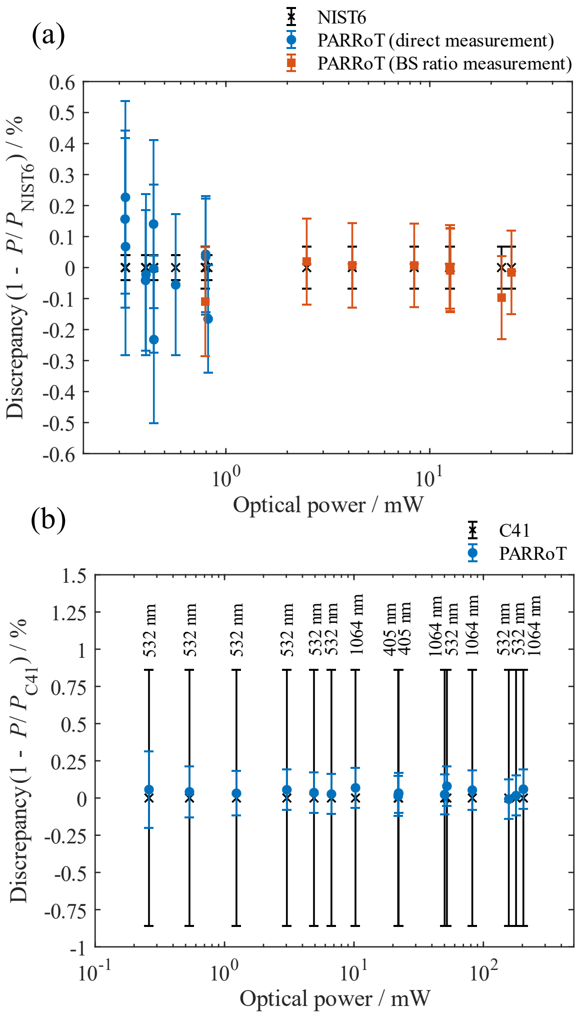

**Figure 2.** (a) Discrepancies in the optical power measured with PARRoT and the transfer standard silicon trap detector (NIST6). Beamsplitter (BS) ratio measurement was used at laser powers >1 mW. (b) Discrepancies in the optical power measured with PARRoT and the C-series calorimeter (C41). Uncertainty bars depict an expanded uncertainty ($k = 2$).

## ACKNOWLEDGMENTS

Jenny and Antti Wihuri Foundation, Finland is acknowledged for financially supporting Dr. Vaskuri's postdoctoral research at NIST.

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