Measuring a Mole of Photons: Optical Power Traceable to the Kilogram

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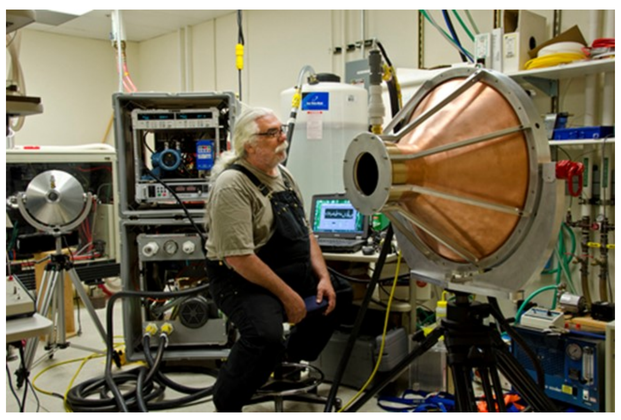
Goal: High-power CW primary standards

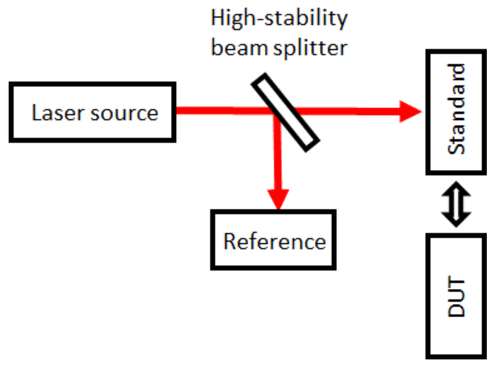
Traditional high-power/high-accuracy techniques measure laser power thermally by absorbing the light.

- Big (volume scales w/laser power)
- Slow (response time scales w/heat capacity)
- Not easily portable (supporting infrastructure)
- Exclusive (all the laser light is absorbed)



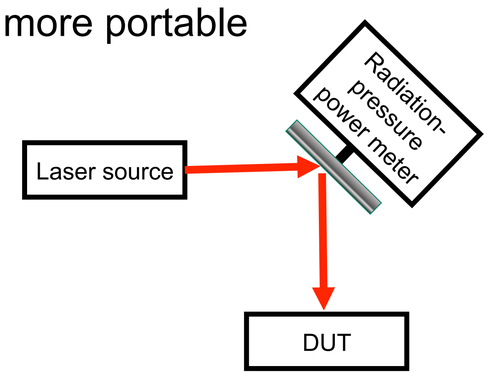
State-of-the-art thermal (traditional) 100 kW power meter

Simplified calibrations



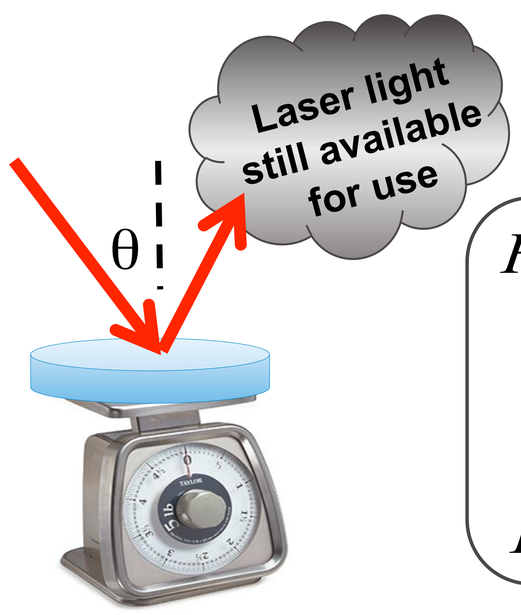
Traditional approach: DUT and Standard measured separately

Radiation pressure: Simultaneous measurements makes calibration easier and more portable



Radiation pressure measures laser power

The momentum of photons push on a mirror when they reflect. We measure laser power from that force.



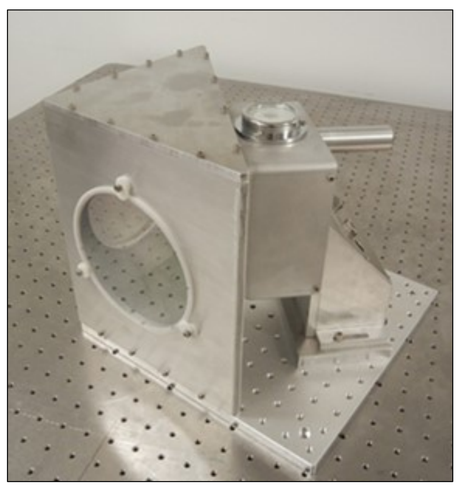
$$F = (2P/c)r\cos\theta$$

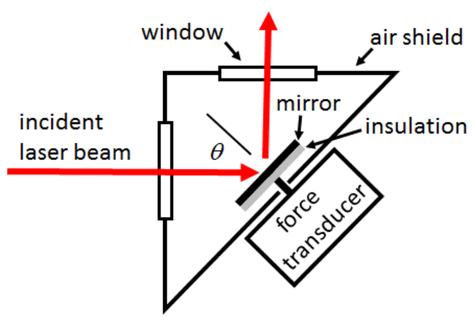
F = Force (Newtons)
P = optical power (Watts)
c = speed of light (m/s)
$r = R+(1-R)\alpha/2$ → reflectivity
θ = angle of incidence

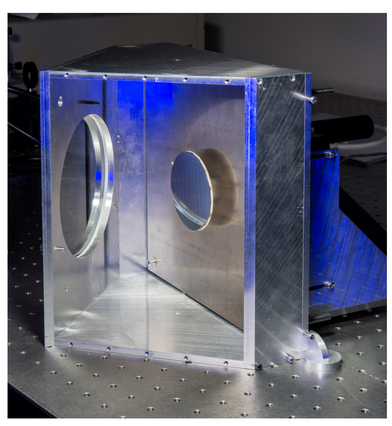
$$P = F \cdot (c / 2r\cos\theta)$$

One mole of photons at 1 eV is approximately 120 kW

Practical implementation



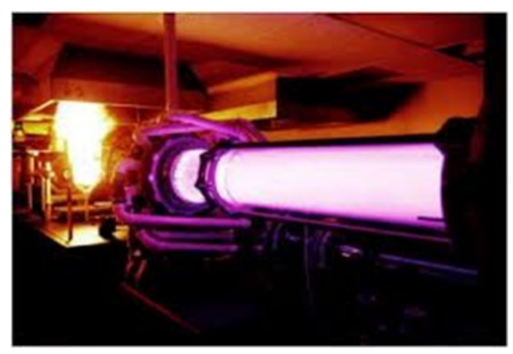




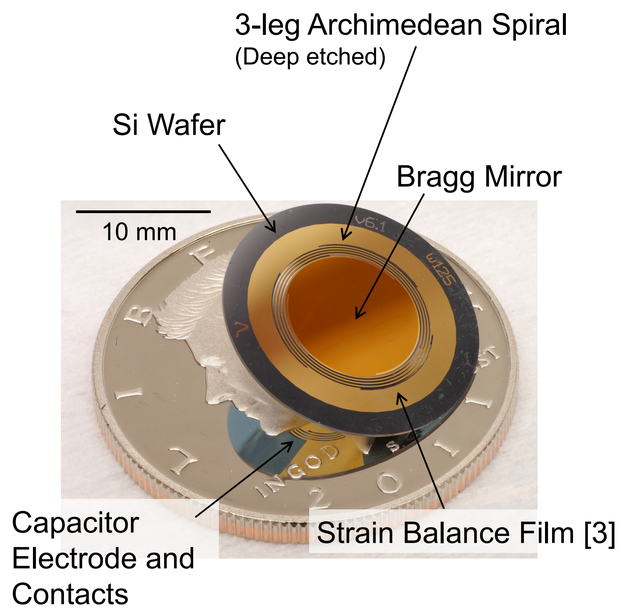
Dimensions: 30x30x30 cm3
Settling time: 5 s
Noise equivalent power: 100 W/√Hz
Validation: 1-10 kW (1.6 %, 2U)

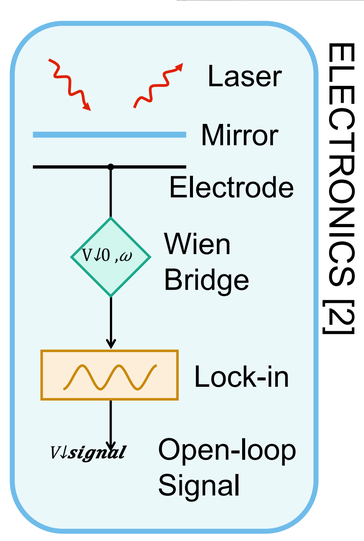
Applications

High power: so far 92 kW CW preliminary testing (CO_2 laser, 10 cm beam dia., 1.2 kW/cm^2)



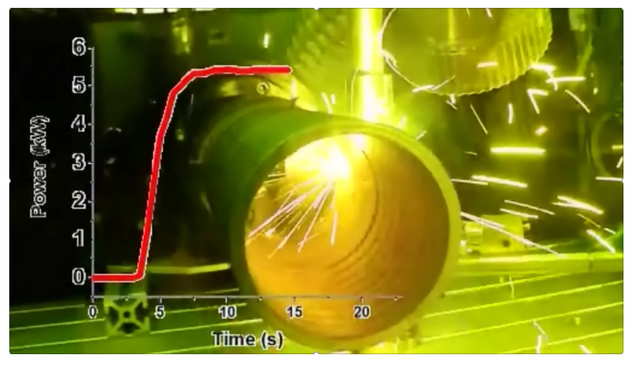
Silicon Flexure + Mirror + Top Electrode





Manufacturing: A miniaturized RPPM for use In a welding or powder bed system.

***In-situ*:** Radiation pressure power measurements do not absorb the laser power. The full power of a laser can be measured during laser welding or additive manufacturing. Miniaturization to fully realize this capability is underway.



Distribution

National Institute of Standards & Technology

Specifications

Standard Reference Instrument Series 6009

Radiation Pressure Power Meter

Description: The Radiation Pressure Power Meter is an instrument that measures the optical power output from a laser by measuring the force due to photon momentum imparted on a mirror by the reflected laser light. The description of the concept and the practical implementation as well as analysis of measurement uncertainty are detailed in the referenced publication [1].

Design, assembly and technical measurements leading to the production of this SRI were performed by members of the Sources and Detectors Group of the NIST Applied Physics Division.

Support aspects involved in the issuance of this SRI were coordinated through the NIST Office of Reference Materials.

Specifications: NIST provides the Radiation Pressure Power Meter as a Standard Reference Instrument (SRI) with performance that is equivalent to the published description of Reference

A radiation pressure power meter can be made according to the published description (below) or purchased as a NIST Standard Reference Material (SRI 6009).

www.nist.gov/programs-projects/photoforce-project

P. Williams, et al., "Portable, high-accuracy, non-absorbing laser power measurement at kilowatt levels by means of radiation pressure," Optics Express, 25, 4382-4392, 2017.