Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Nationales Metrologieinstitut

Laser Power Meter Calibrations at PTB

Stefan Kück, Friedhelm Brandt, Helmuth Hofer,
Holger Lecher, Marco López

Outline

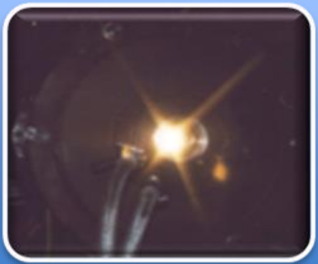
- Introduction
  - What is laser radiometry?
  - Why laser radiometry?
- Calibration chain, standards, corrections
- Services
- Recent developments

PTB

The Physikalisch-Technische Bundesanstalt (PTB)

- is the German national metrology institute
- founded in 1887

Laser Radiometry



Radiometry

- Measurement of the energy or power of electromagnetic radiation in the optical spectral range.

Laser Radiometry

- Measurement of the energy or power of laser radiation.

Photometry

- Measurement of electromagnetic radiation in the visible spectral range (light), evaluated with the sensitivity of the human eye.

Why Laser Radiometry?

Use of lasers

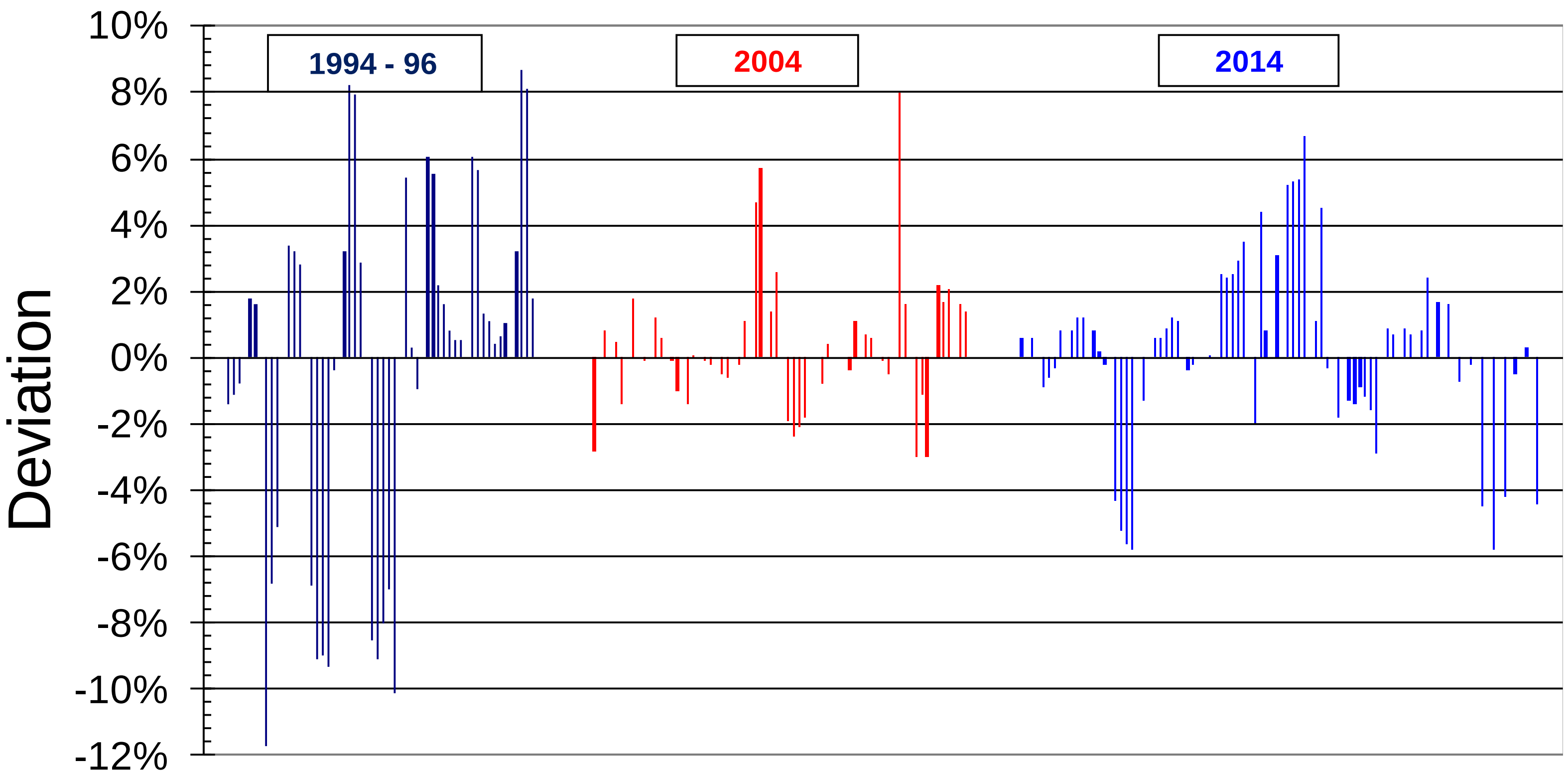
- with different powers
- at different wavelengths
- in material processing, medicine, communications engineering, metrology and research

requires calibrated laser power measuring instruments for

- quality assurance
- production control
- trade
- safety (e.g. eye protection)

Metrological motivation

Deviations between commercial laser power meters and PTB readings



Calibration

The **spectral responsivity** s of a detector is calibrated:

$$s = (V - V_0) / \Phi$$

or the **correction factor** f_K of a laser power meter:

$$f_K = \Phi / (A - A_0)$$

Φ: Laser power

V: Output signal of a detector during irradiation

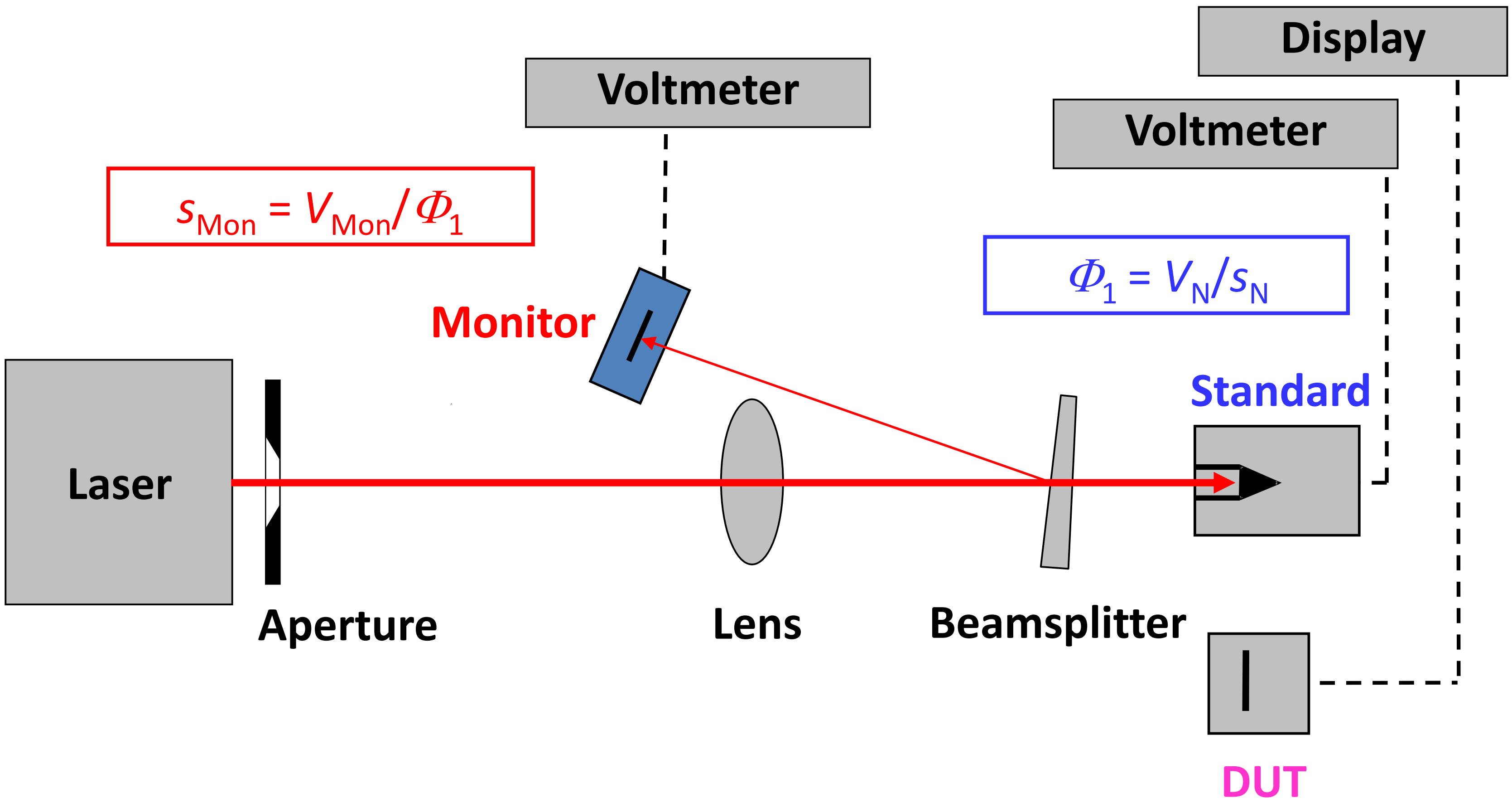
V_0: Zero point signal of a detector without irradiation

A: Display of a laser power meter during irradiation

A_0: Zero point of a laser power meter without irradiation

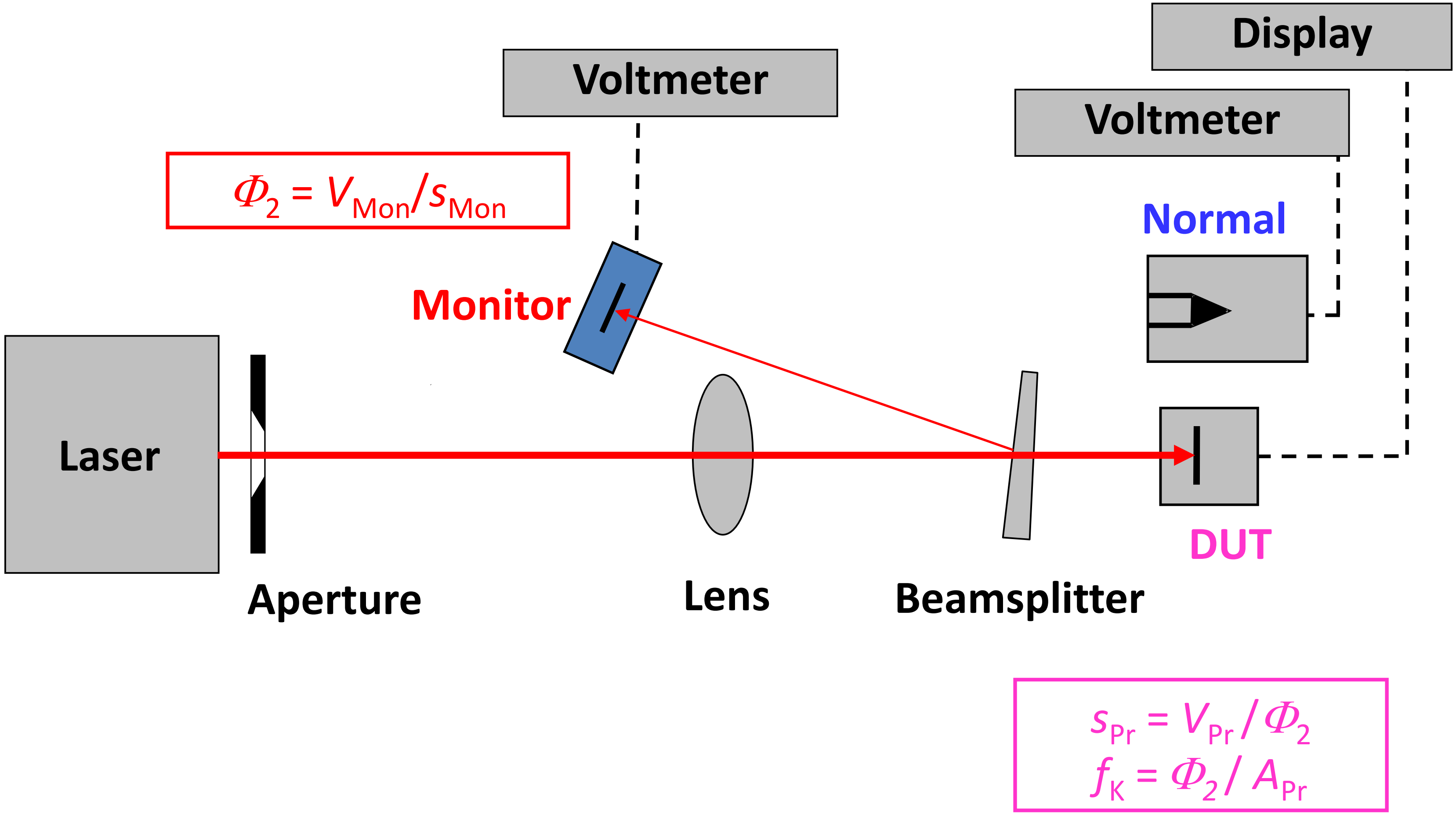
Calibration procedure

Step 1: Power measurement by a standard detector and calibration of a monitor detector.

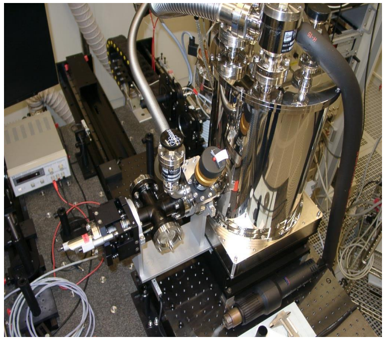


Calibration procedure

Step 2: Power measurement by a monitor detector and calibration of a device under test (DUT).



Calibration chain



Primary standard for optical power
Cryogenic radiometer
$350\ \text{nm} \le \lambda_i \le 1015\ \text{nm};\ \Phi \le 1\ \text{mW};\ U(\Phi) \le 0.002\ \%$

$406\ \text{nm} \le \lambda_i \le 995\ \text{nm}$
$\Phi = 0.4\ \text{mW}$

Transfer standard (Si-Trap Detector)
$406\ \text{nm} \le \lambda_i \le 994\ \text{nm};\ \Phi \le 10\ \text{mW};\ U(\Phi) \le 0.02\ \%$ ← $s(\Phi)$

Diode #3

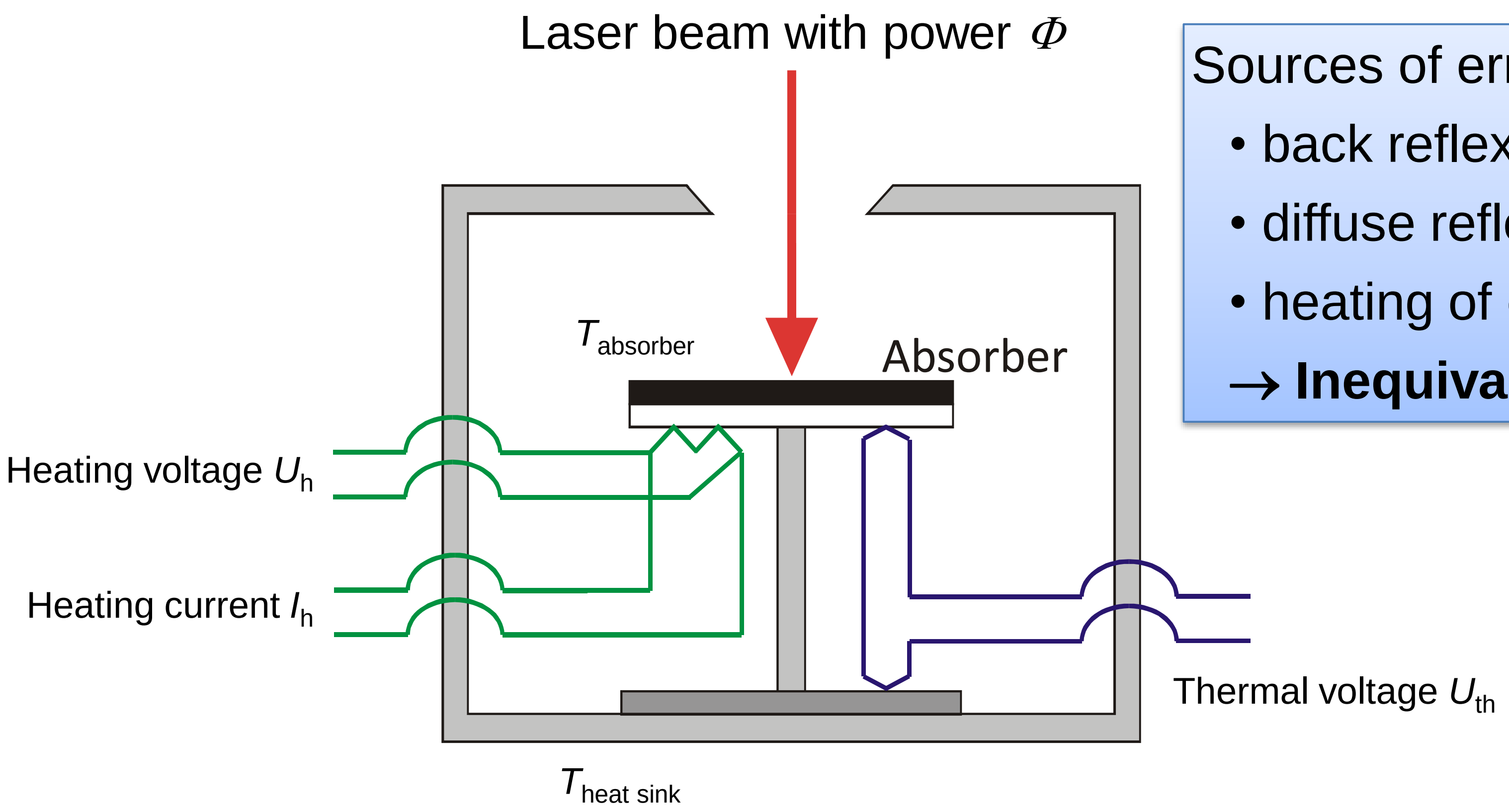
$406\ \text{nm} \le \lambda_i \le 800\ \text{nm}$
$\Phi = 5\ \text{mW}$

$s(\Phi)$ →
$s(\alpha)$ →

Standard for CW-Laser power ≤ 10 W (LM7)
HeNe-, Kr^+-, DPSS-, Nd:YAG-, CO_2-Laser

$337\ \text{nm} \le \lambda_i \le 1064\ \text{nm}$	$\lambda = 10.6\ \mu\text{m}$
$5\ \text{mW} \le \Phi \le 10\ \text{W};\ U(\Phi) = 0.1\ \%$	$U(\Phi) = 0.2\ \%$

PTB Detection principle



Sources of error:

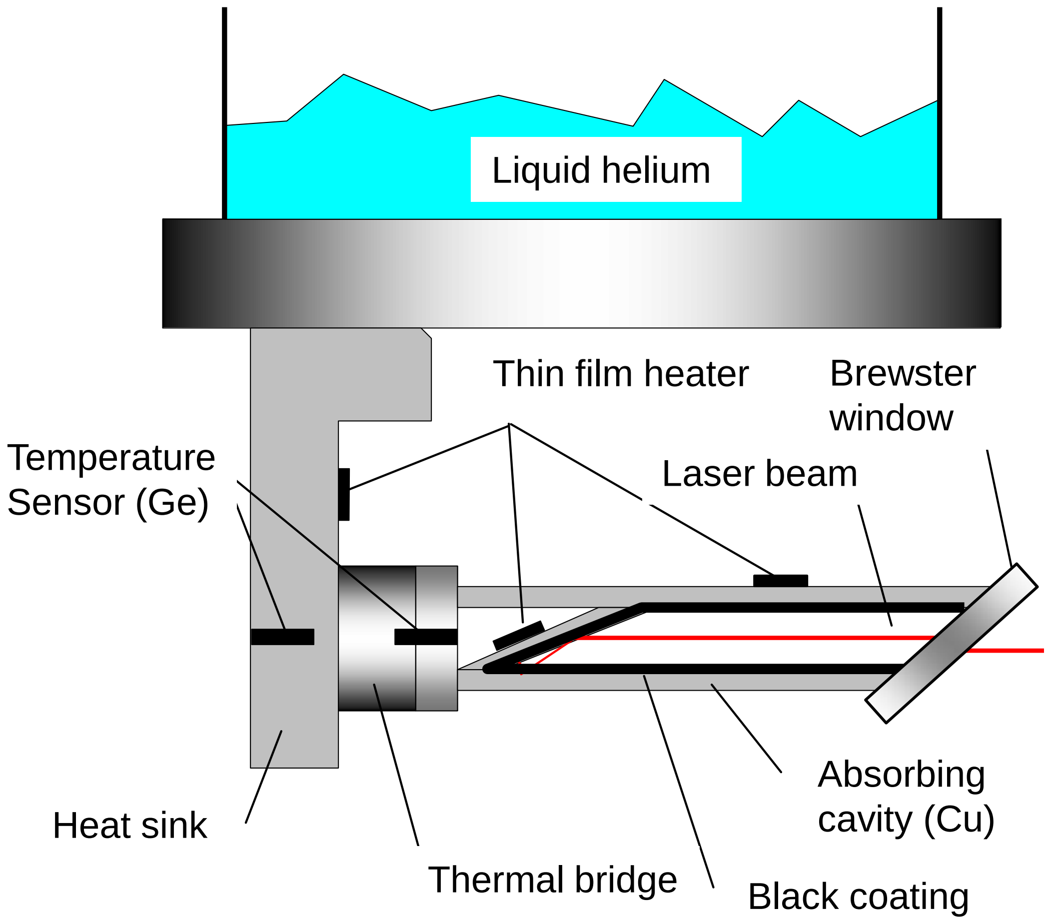
- back reflexion (specular)
- diffuse reflexion
- heating of environment

→ **Inequivalency!**

$\Delta T = T_{absorber} - T_{heat\ sink} \propto \Phi$

Laser power $\Phi \approx$ Heating power $U_h \cdot I_h$ $\Rightarrow s = \frac{U_{th}}{U_h \cdot I_h}$

Cryogenic radiometer



$$\Phi = \frac{\Delta P_{el}}{\tau \cdot a}$$

$\tau = 0.99934$

$\alpha = 0.99990$

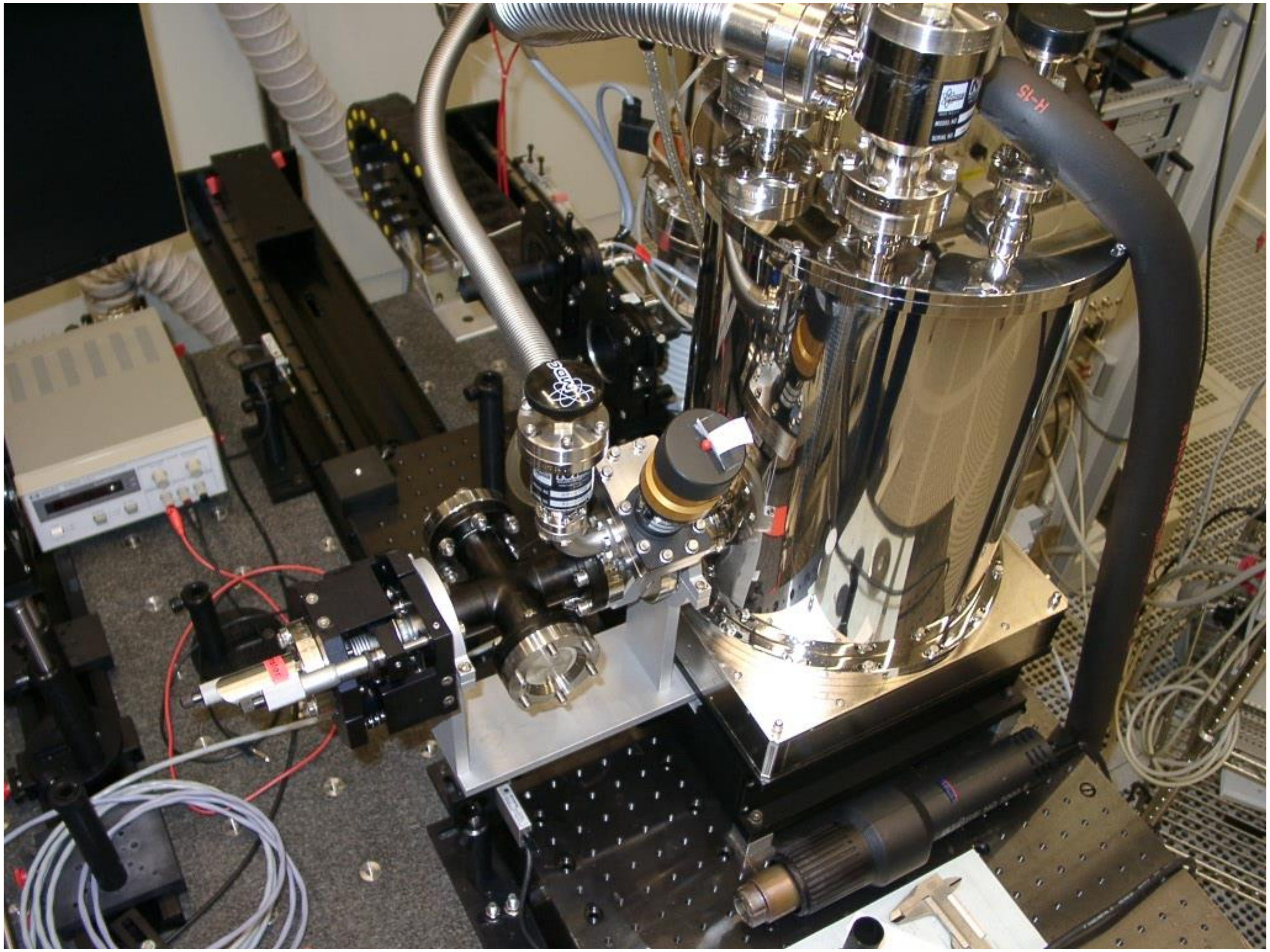
τ : Transmission of Brewster window

α: Absorptance of absorber

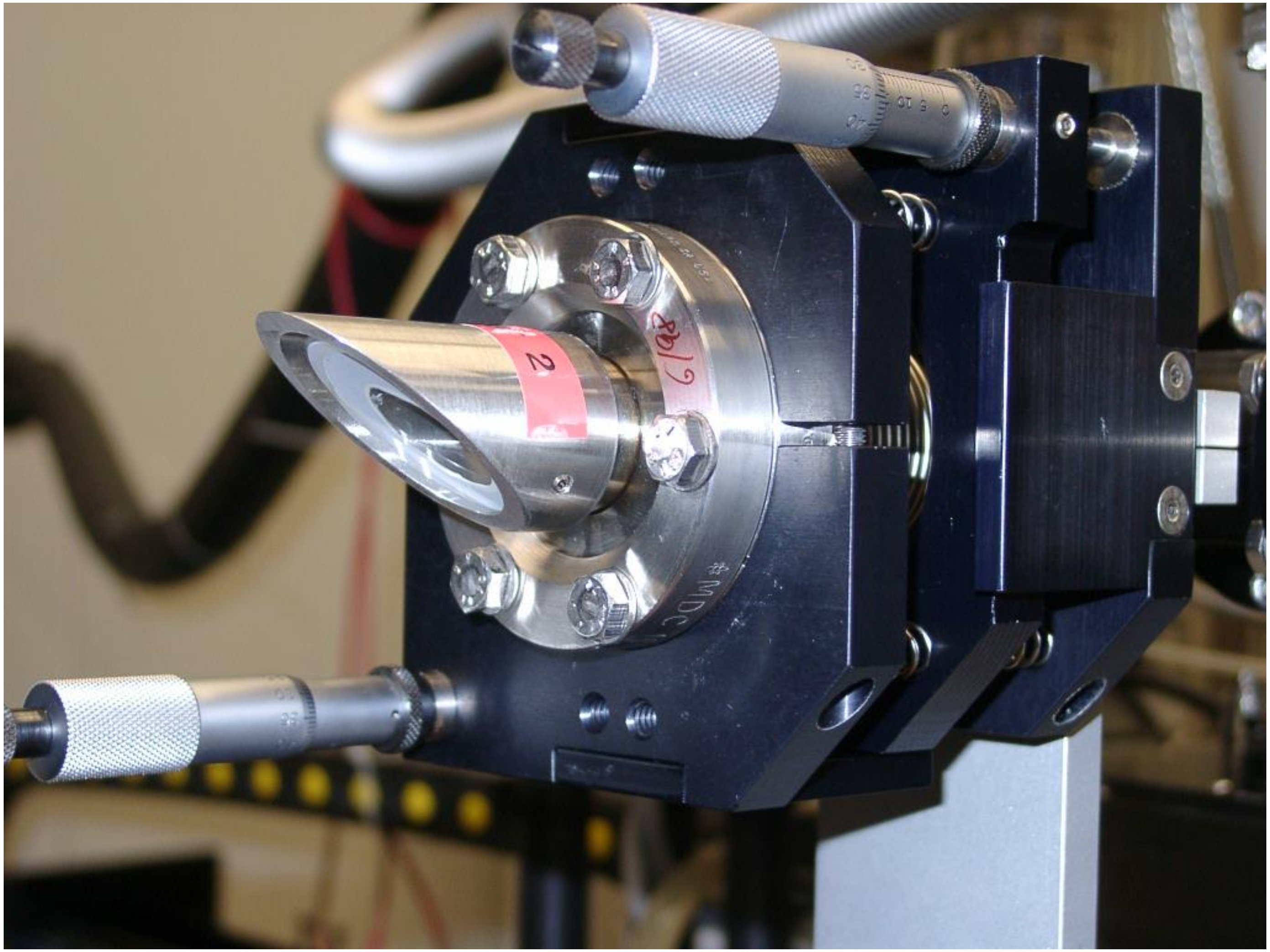
ΔP_{el}: substituted electrical power

Measurement uncertainty in the range of 10^{-5}!

Cryogenic radiometer

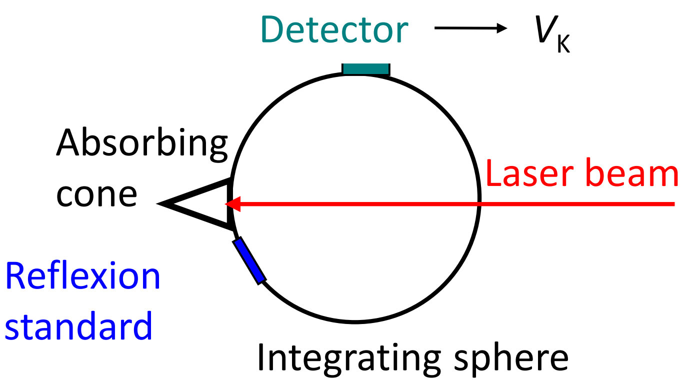


Cryogenic radiometer



Wavelength expansion: Reflexion measurements

1. Laser beam impinges on absorbing cone

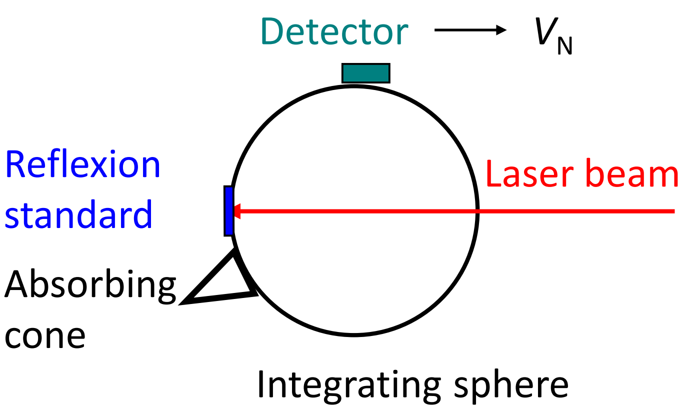


Standard for CW-Laser power ≤ 10 W (LM7)

HeNe-, Kr^+-, DPSS-, Nd:YAG-, CO_2-Laser

337 nm ≤ λ_i ≤ 1064 nm	λ = 10.6µm
5 mW ≤ Φ ≤ 10 W; $U(\Phi)$ = 0.1 %	$U(\Phi)$ = 0.2 %

2. Laser beam impinges on reflexion standard



Reflexion of absorbing cone:

$\rho_K = \rho_N \cdot (V_K - V_0) / (V_N - V_0)$

ρ_N: Reflexion of reflexion standard

V_K: Detector signal with absorbing cone

V_N: Detector signal with reflexion standard

V_0: Dark signal of detector

Absorption of absorbing cone: $\alpha_K = 1 - \rho_K$

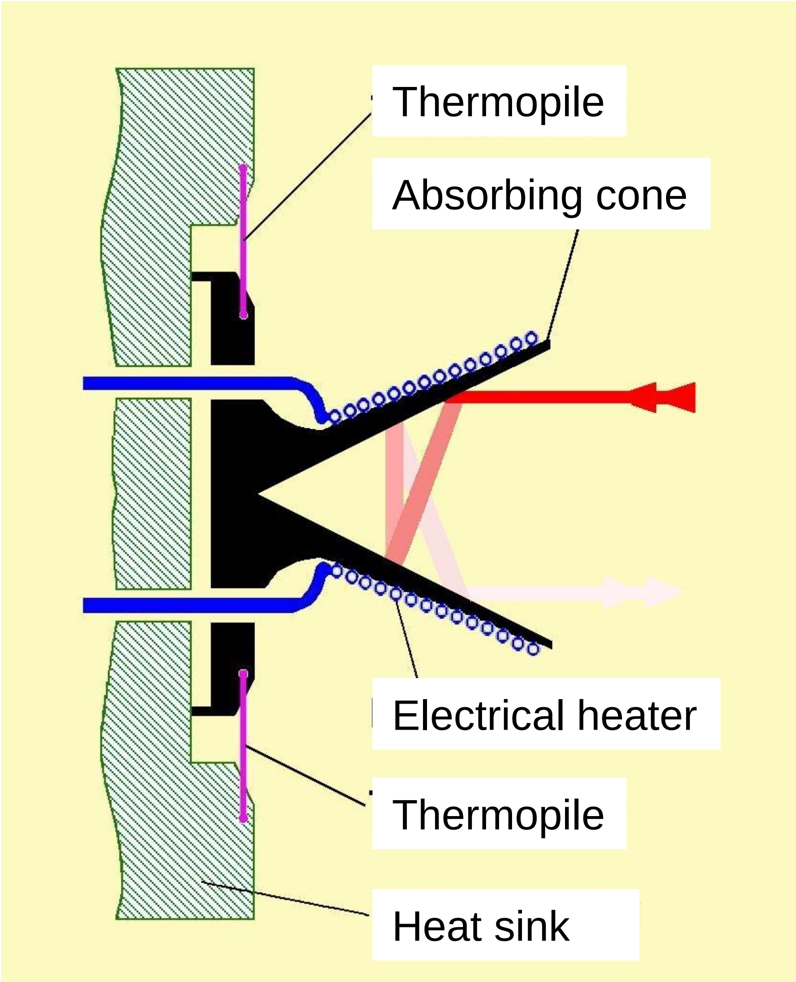
Power expansion: Linearity measurements

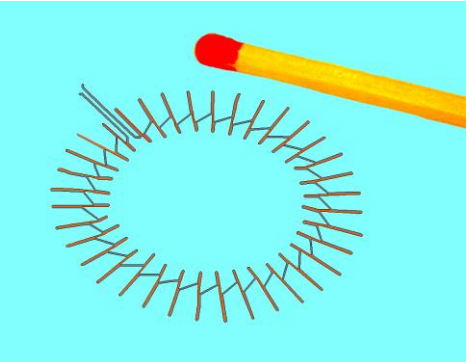
Standard for CW-Laser power ≤ 10 W (LM7)

HeNe-, Kr^{+}-, DPSS-, Nd:YAG-, CO_2-Laser

$337\ \text{nm} \le \lambda_i \le 1064\ \text{nm}$; $5\ \text{mW} \le \Phi \le 10\ \text{W}$; $U(\Phi) = 0.1\ \%$

$\lambda = 10.6\ \mu\text{m}$; $U(\Phi) = 0.2\ \%$





Measurement of electrical responsivity:

$s_{el}(P_{el}) = U_{th}/P_{el}$

$s(\Phi) \propto s_{el}(P_{el})$

$\Rightarrow$ power-dependent correction factor for responsivity *s*

Corrections to the standard LM7

The responsivity of thermal detectors depends on temperature T, power Φ (or signal) and wavelength λ:

$$s(T,\Phi,\lambda) = s_0(\lambda)\cdot(1 + \beta_\phi\cdot(\Phi - \Phi_0)\cdot(1 + \beta_T\cdot(T - T_0))$$

$$s(T,\Phi,\lambda) = s_0(\lambda)\cdot(1 + \beta_V\cdot(V - V_0)\cdot(1 + \beta_T\cdot(T - T_0))$$

s_0: normalized responsivity

β_ϕ: power coefficient

β_V: signal coefficient

β_T: temperature coefficient

For LM7: β_V = 0,020 %/mV

β_T = 0,088 %/°C

International comparison EURAMET.PR-S2

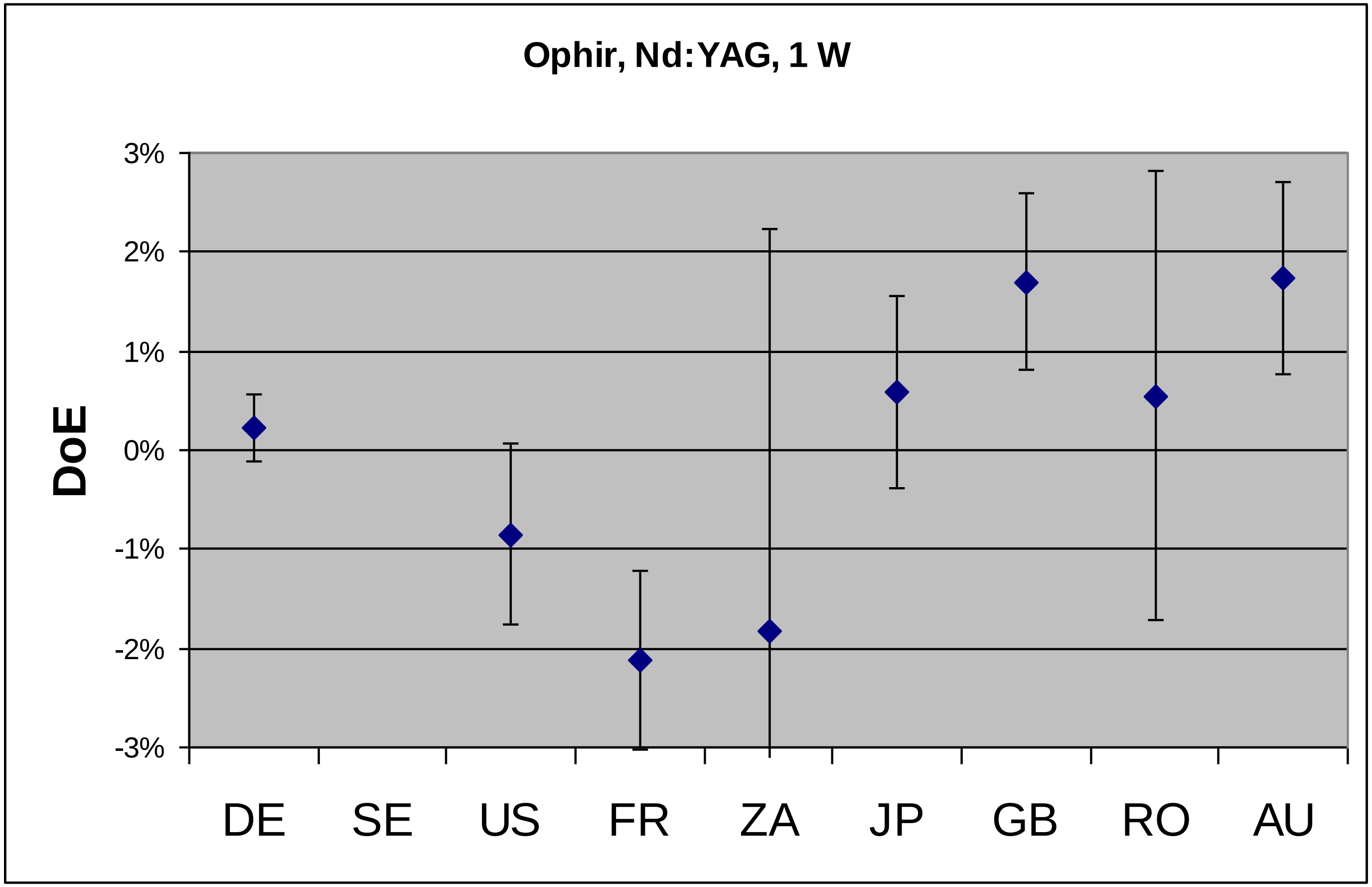
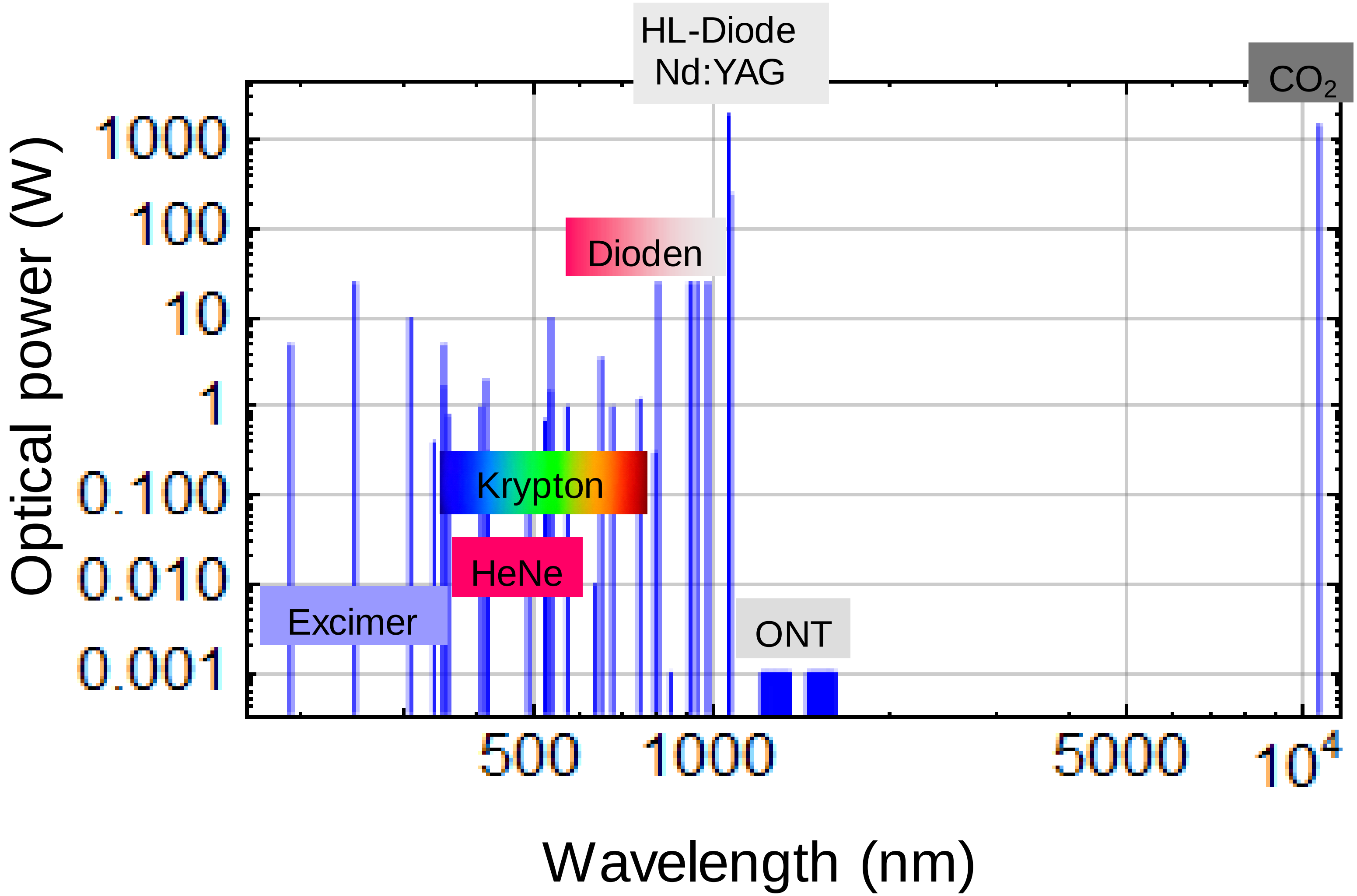


Figure 9: Unilateral Degree of Equivalence (DoE)

Metrologia, 2010, **47**, *Tech. Suppl.*, 02003, EUROMET.PR-S2 Final Report, 2010, 216 pages

Wavelengths and optical laser power levels



Recent activities

Calibrations:

- up to 2 kW @ 1065 nm (with own laser)

- Up to 4,5 kW @ 1065 nm (via electrical calibration)

Standard for cw laser power (SCT391)
1-µm-Laser, CO_2-Laser
$\lambda = 1.06$ µm, $\lambda = 10.6$ µm,
$100\ W \leq \Phi \leq 1400\ W$
$U(\Phi) = 0.6\ \%$

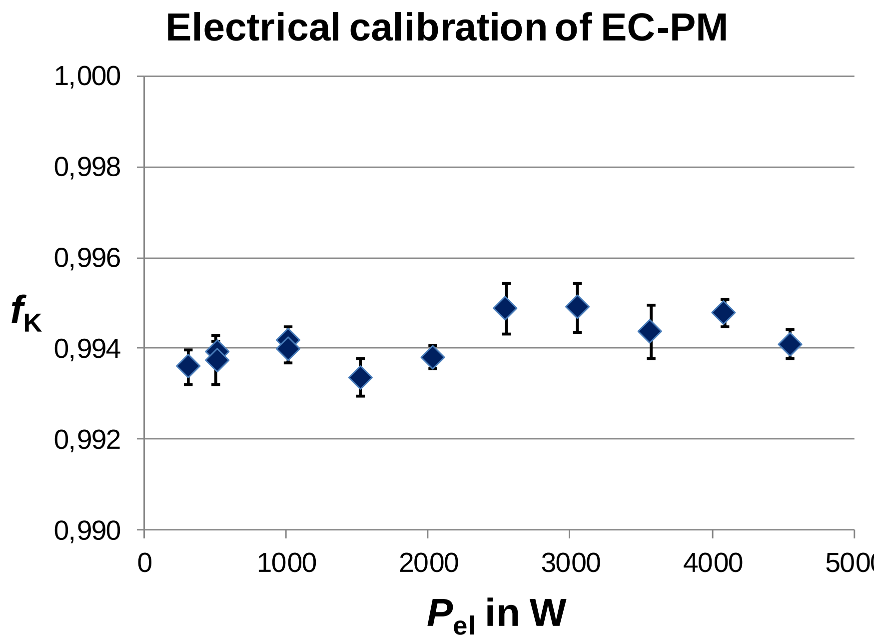
$\lambda = 1065$ nm
$\Phi = 1000$ W

Modified EC-PM
$\lambda = 1065$ nm;
$500\ W \leq \Phi \leq 4500\ W^*$
$U(\Phi) = 0.8\ \%$

$\lambda = 1065$ nm,
$500\ W \leq \Phi \leq 2000\ W$

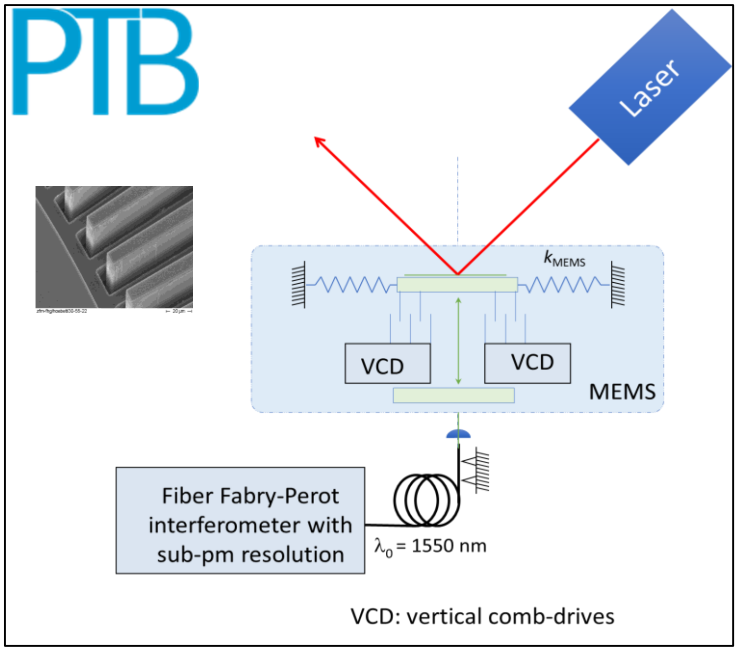
Customer Transfer Standard
$\lambda = 1065$ nm;
$500\ W \leq \Phi \leq 4500\ W^*$
$U(\Phi) \geq U(\text{EC-PM})$,
depending on device

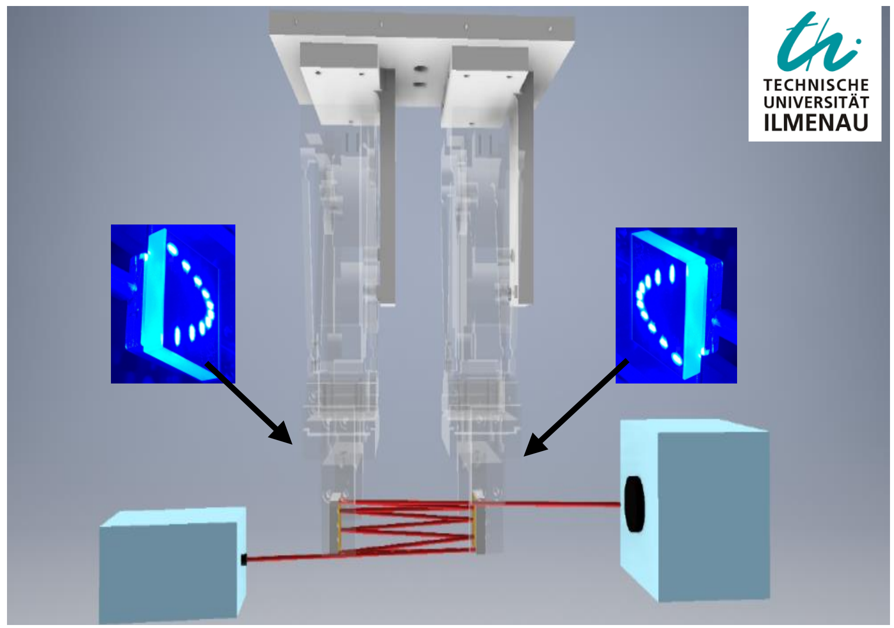
www.primes.de



Research and Development

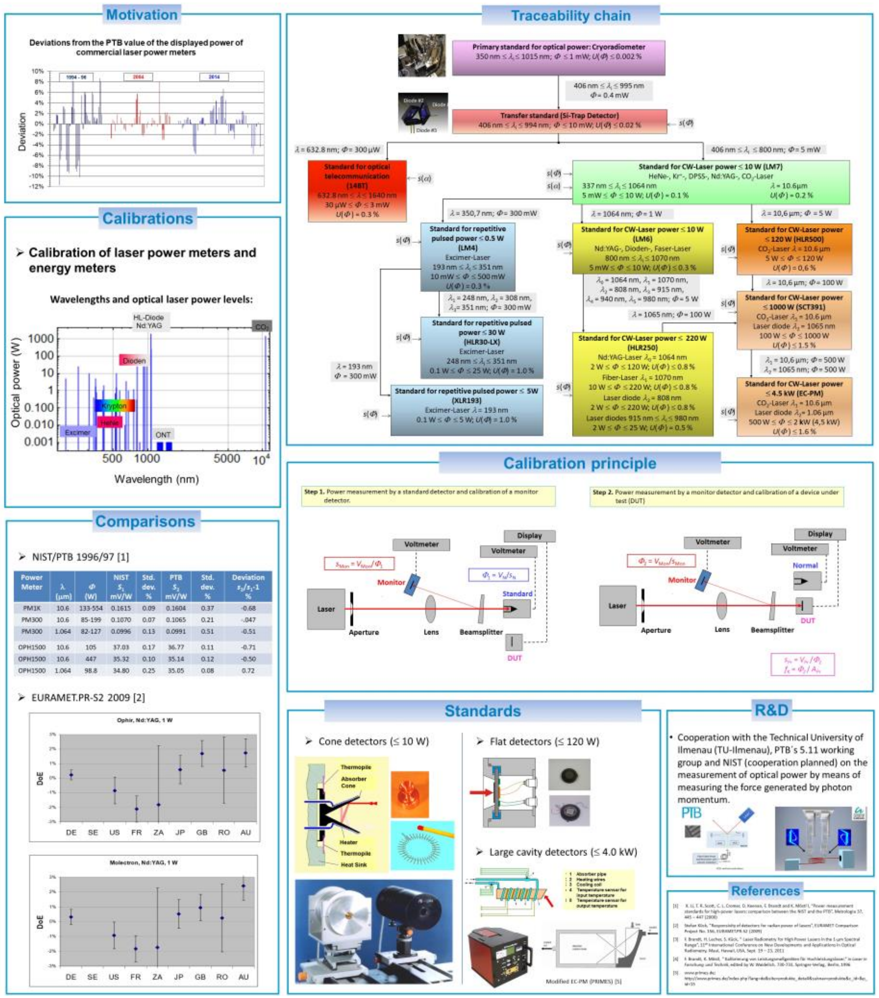
Cooperation with the Technical University of Ilmenau (TU-Ilmenau), PTB´s 5.11 working group and NIST (cooperation planned) on the measurement of optical power by means of measuring the force generated by photon momentum.





Laser Radiometry at PTB: See also Poster

Thanks for your attention



Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin
Bundesallee 100
38116 Braunschweig

Stefan Kück
Abteilung Optik / Optics Division

Telefon: #49 531 592 4010
E-Mail: stefan.kueck@ptb.de
www.ptb.de

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