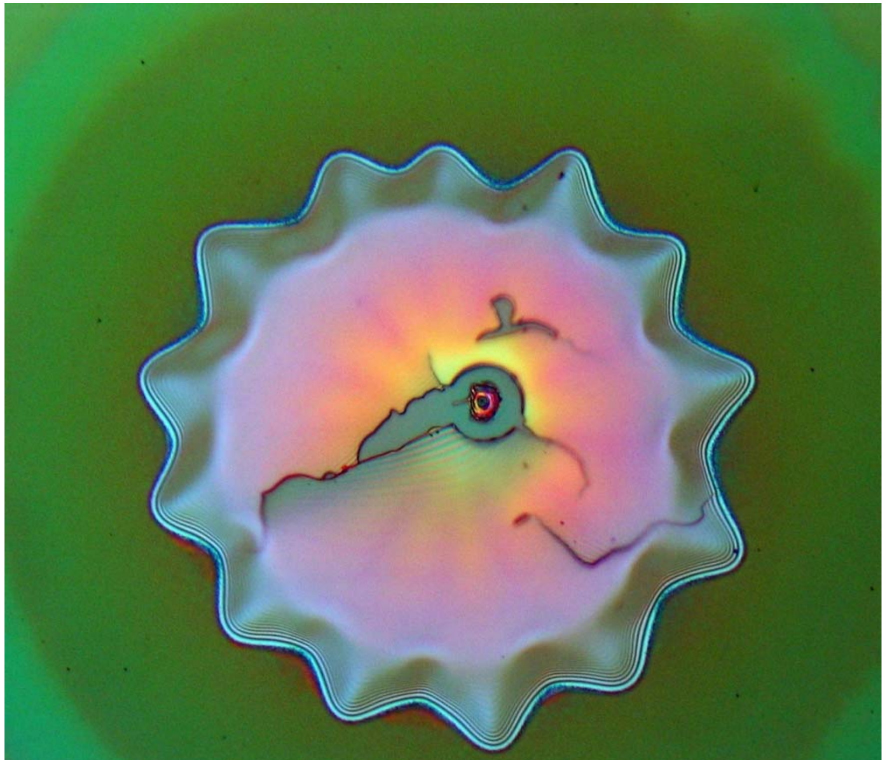
NTB
Interstaatliche Hochschule
für Technik Buchs

Workshop

Optical Coatings for Laser Applications 2015



Laser damage stress induced
@ 143 J/cm^2, 200µm, 14 ns, Nd:YAG-laser 1.064 µm

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SWISS PHOTONICS

Standardisation in Optics Characterisation

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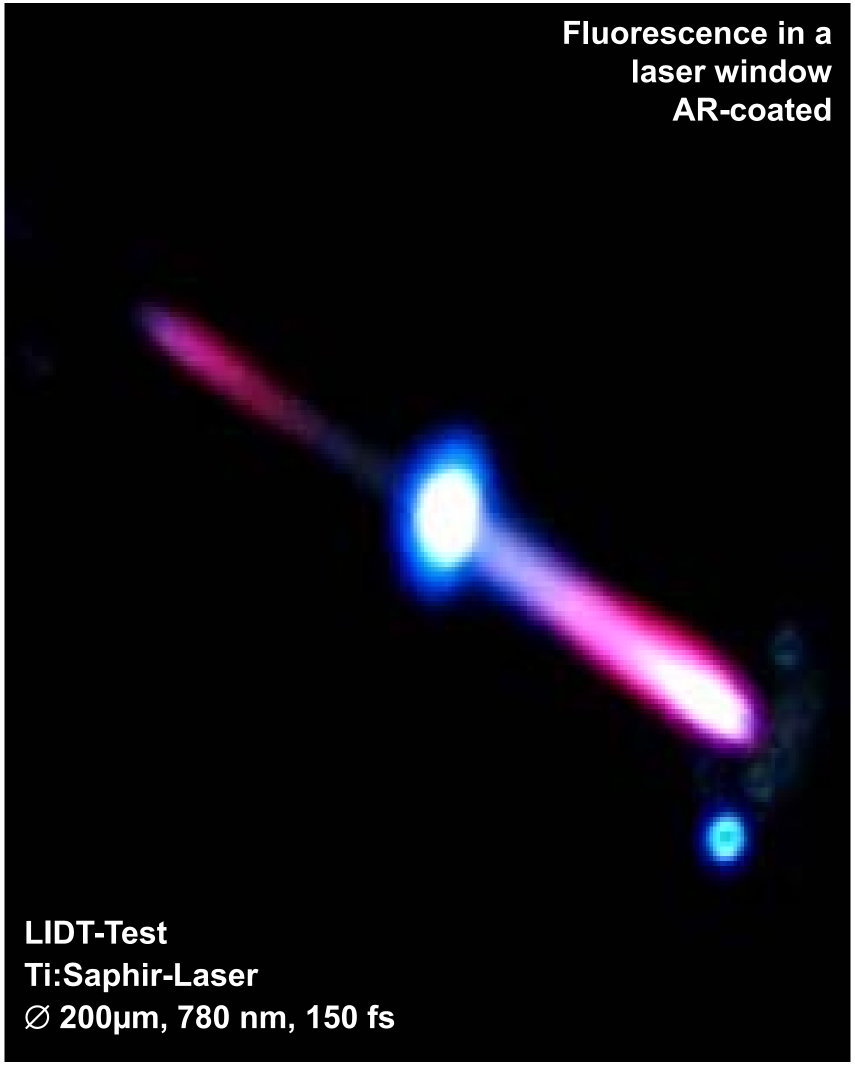


Standardisation in Optics Characterisation

Structure

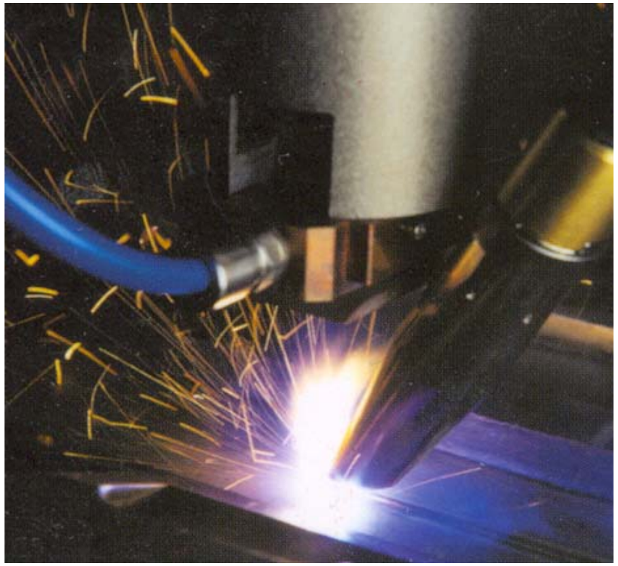
- Motivation and Survey
- Laser Induced Damage
- Absorption
- Scattering
- Total Losses
- Defects and Cleanliness
- Conclusions and Outlook

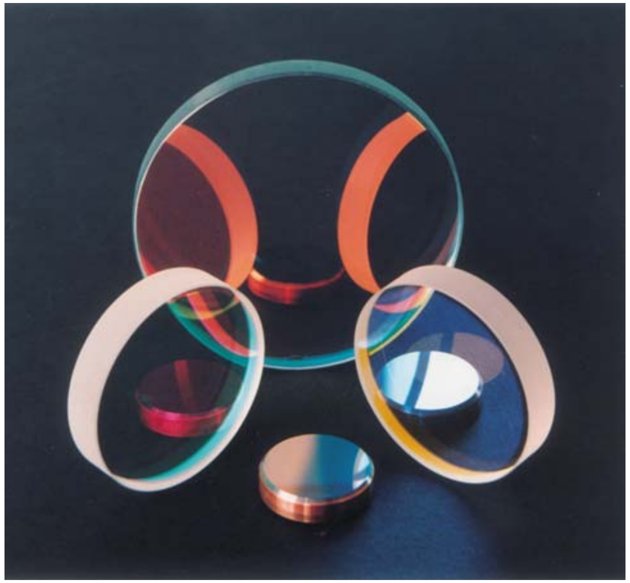
Motivation

Optical Coatings:

enabling technology for future fields:

- laser technology
- communication, display technology
- micro lithography
- life sciences
- fundamental research





precise and demanding specifications

need for international standards

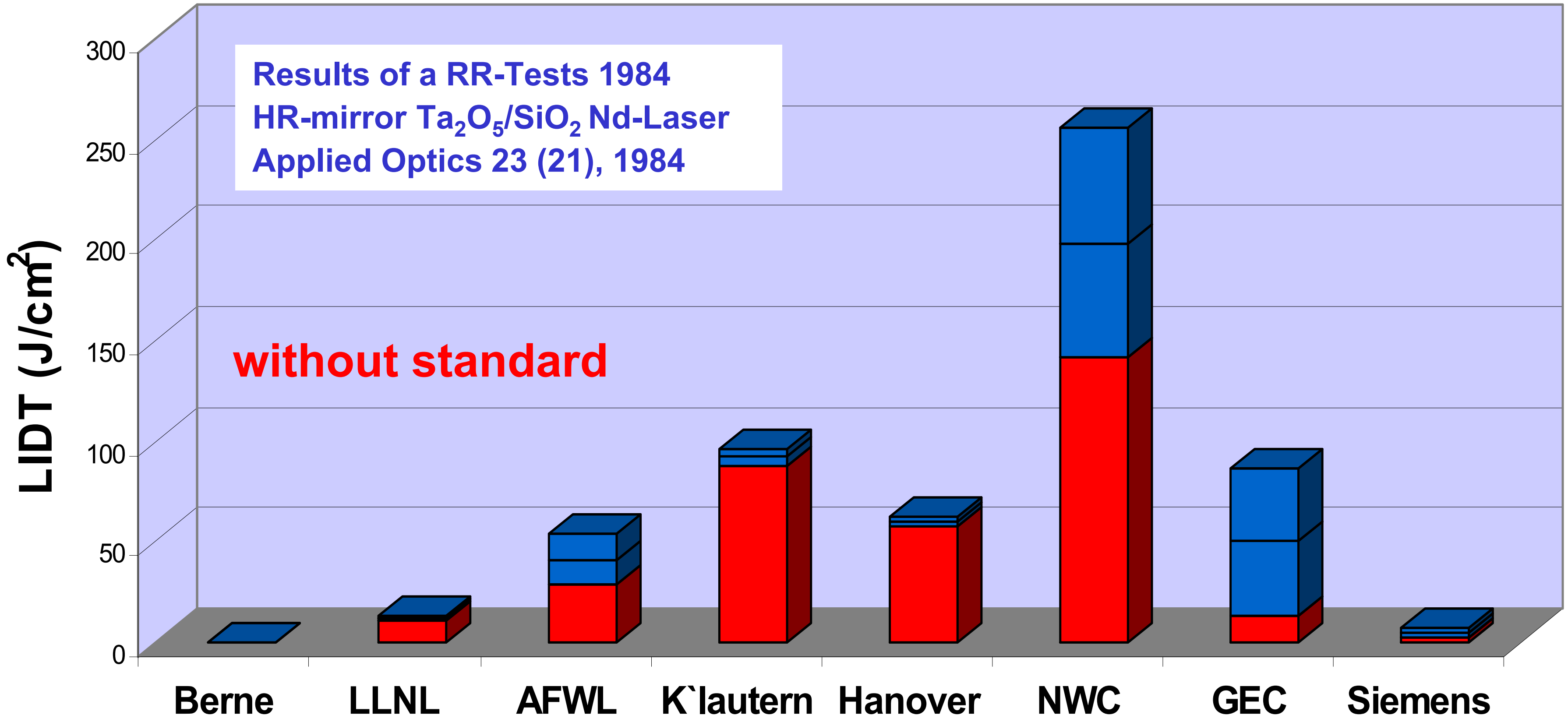
- basis for development and optimisation
- comparison of product specifications
- marketing of optical components

➔ **development of international standards in coatings characterisation extremely enhanced during the last two decades**

Survey: Specifications of Laser Components

Specification	Parameter / Unit		Standard / Measurement Principle	
Laser Induced Damage Threshold	cw-LIDT 1 on 1-LIDT S on 1-LIDT Certification	W/cm J/cm^2 J/cm^2 J/cm^2	**ISO 21254-1**: **ISO 21254-2**: **ISO 21254-3**: **ISO/TR 21254**:	definition and principles damage threshold measurement certification power handling damage detection
Optical Losses	Absorptance Scattering Total Losses	ppm ppm ppm	**ISO 11551**: **ISO 13696**: **ISO/DIS 13142**:	laser calorimetry total scattered radiation cavity ring down
Transfer Function	Reflectance Transmittance	% %	**ISO 15368**: **ISO 13697**:	spectrophotometry precise ratiometric method
Surface Quality	Form-Toler. Scratch/ Digs Roughness	λ/N 5/NxA nm_{rms}	**ISO 10110**: **ISO 10110**:	part 5, interferometry 13 parts containing different types of imperfections
Stability	Abrasion Environmental Stability		**ISO 9211**: **ISO 9022**:	different test methods 24 parts containing a variety of conditioning methods

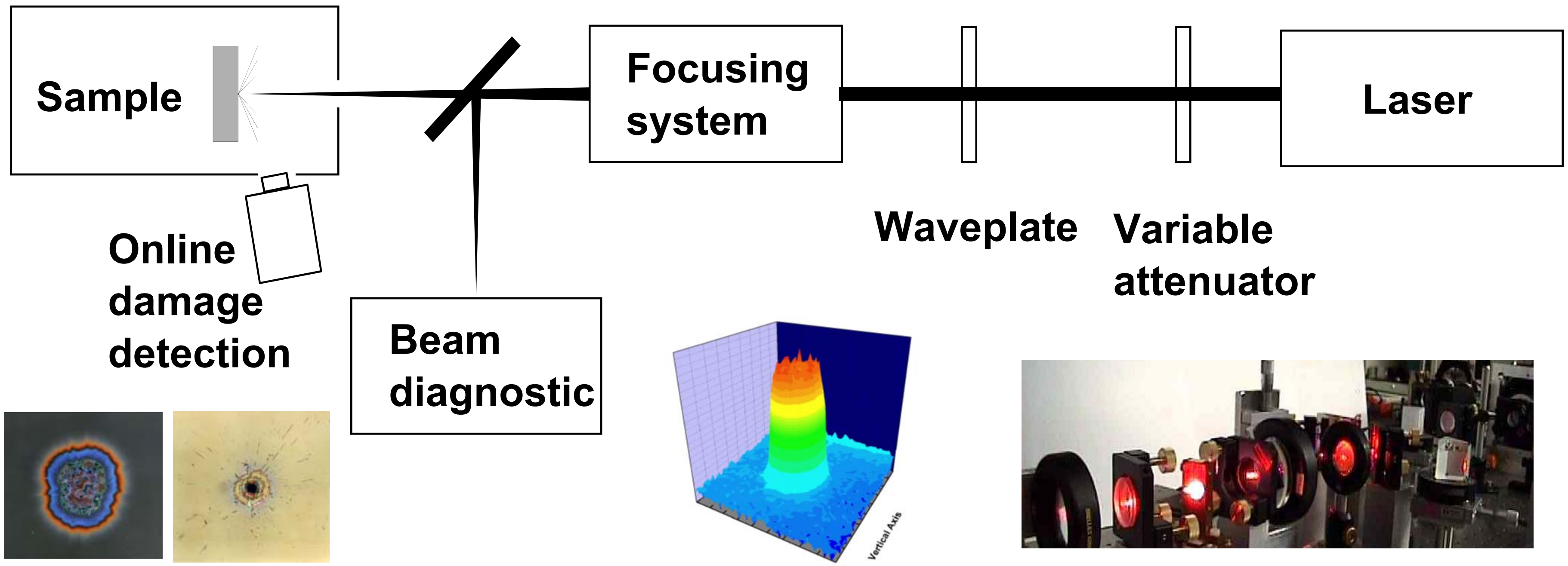
Laser Induced Damage Thresholds



LIDT: complex, statistical measurement value, dependent on:

- beam parameters (pulse duration, beam diameter, wavelength),
- set-up (calibration, accuracy, stability),
- operation conditions, data reduction techniques, evaluation.

ISO 21254: Laser Induced Damage Thresholds

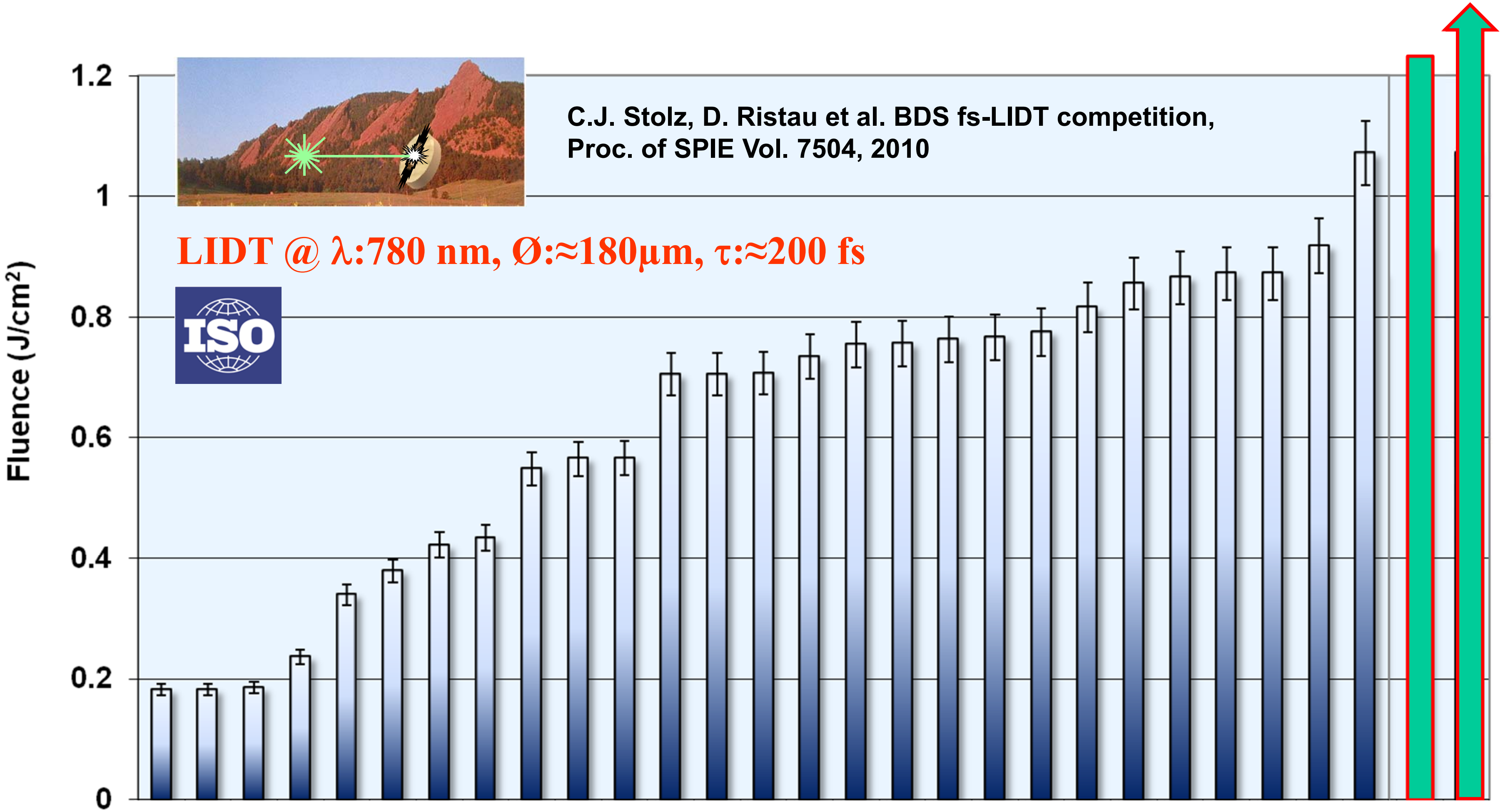


ISO 21254 (former 11254) series defines parameters and procedures for:

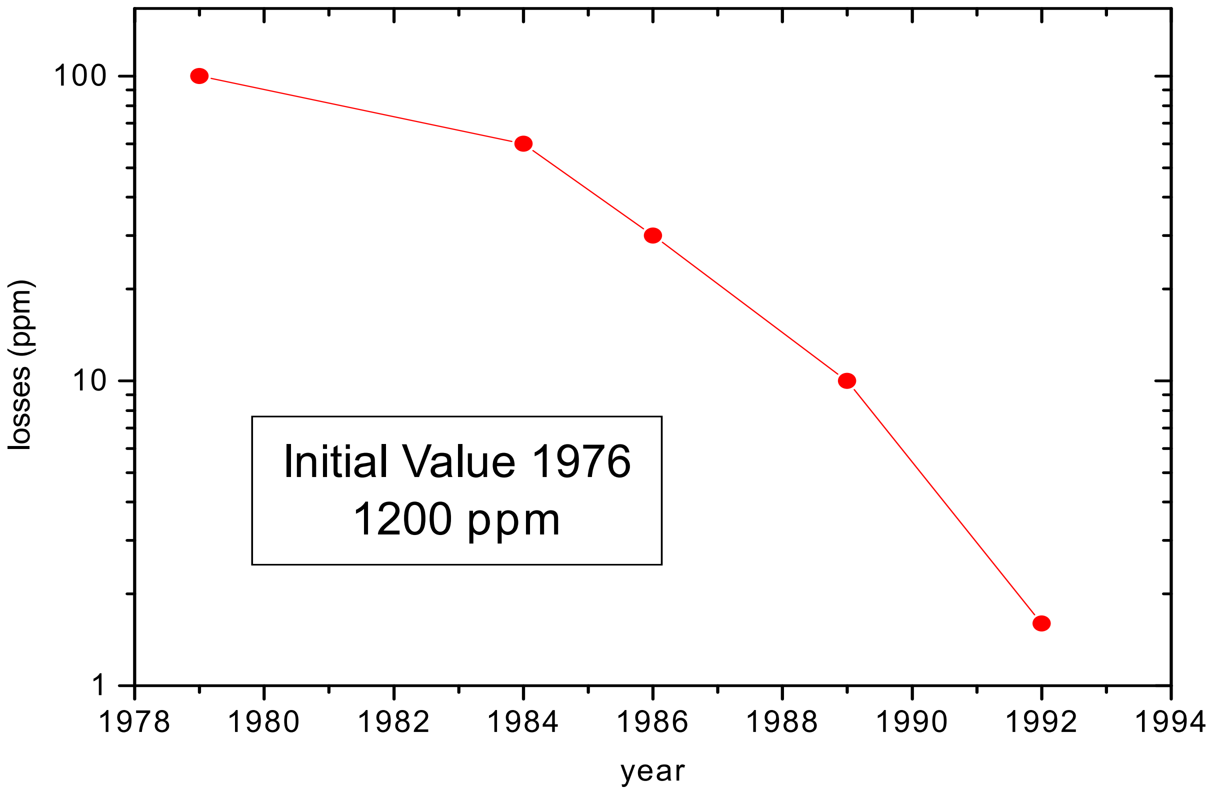
1 on 1- LIDT: one pulse or one cw-irradiation per surface site
S on 1- LIDT: train of S identical pulses per surface site
Certification: assurance of defined power handling capability

ISO TC 172/SC9/WG6

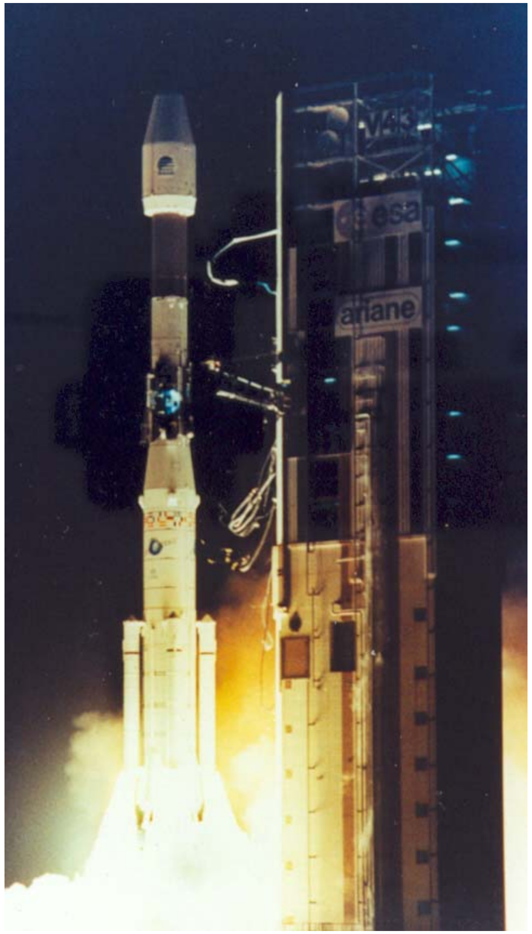
ISO 21254: LIDT Damage Competition



Optical Losses in Laser Coatings

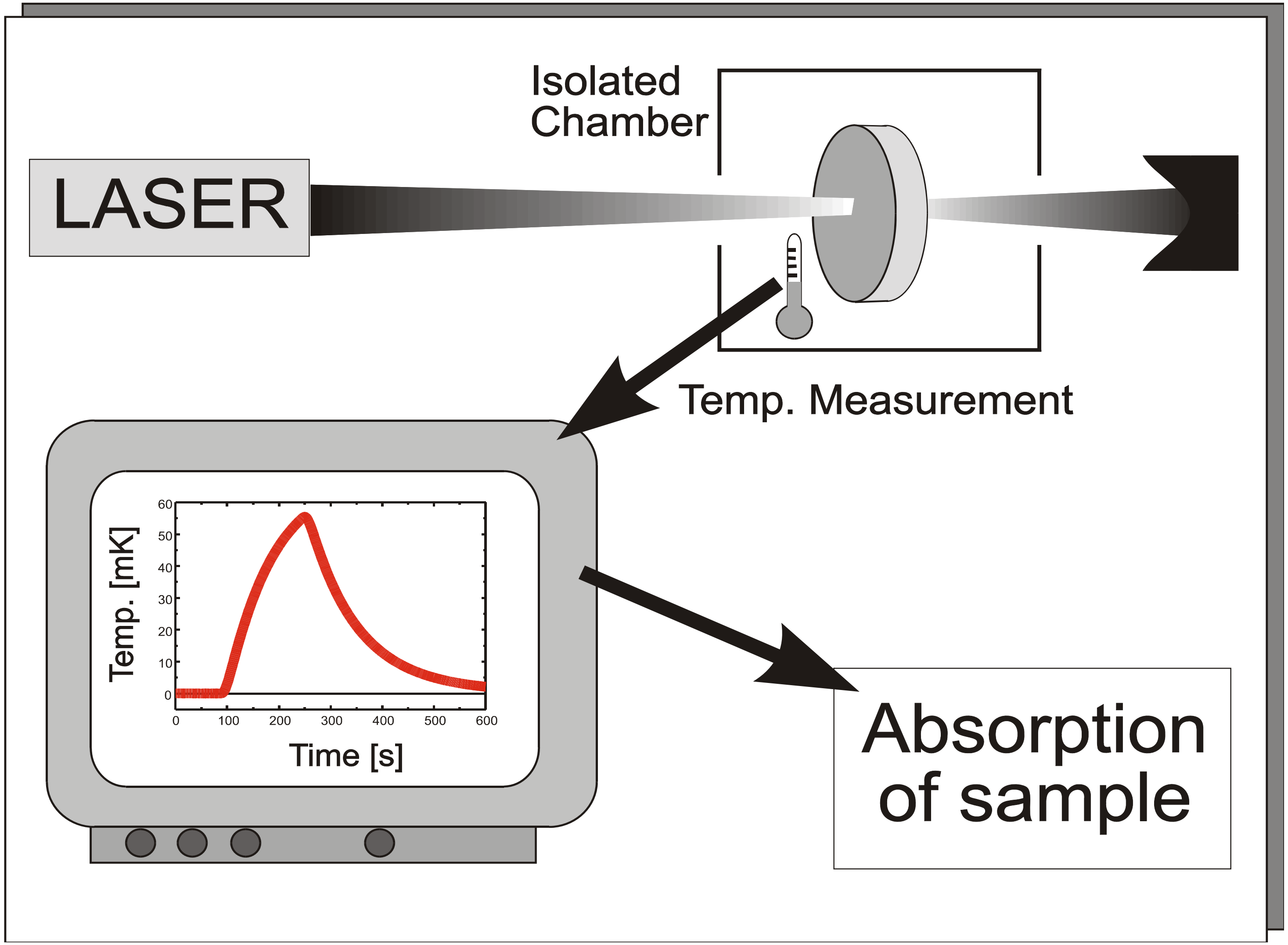


„Learning Curve" for the total losses of HR-mirrors for the Nd:YAG-Laser (λ=1.064nm). Nowadays absorption losses well below 1ppm are reported.



Ariane IV starting: not possible without low-loss coatings

Optical Absorption: Laser Calorimetry



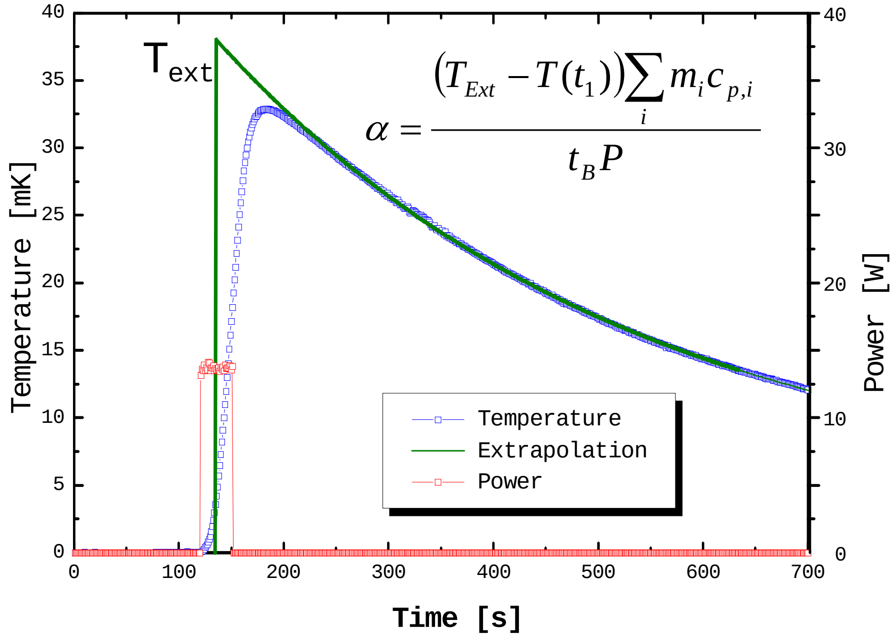
ISO 11551

ISO11551: Laser Calorimetry Evaluation

solution of heat equation

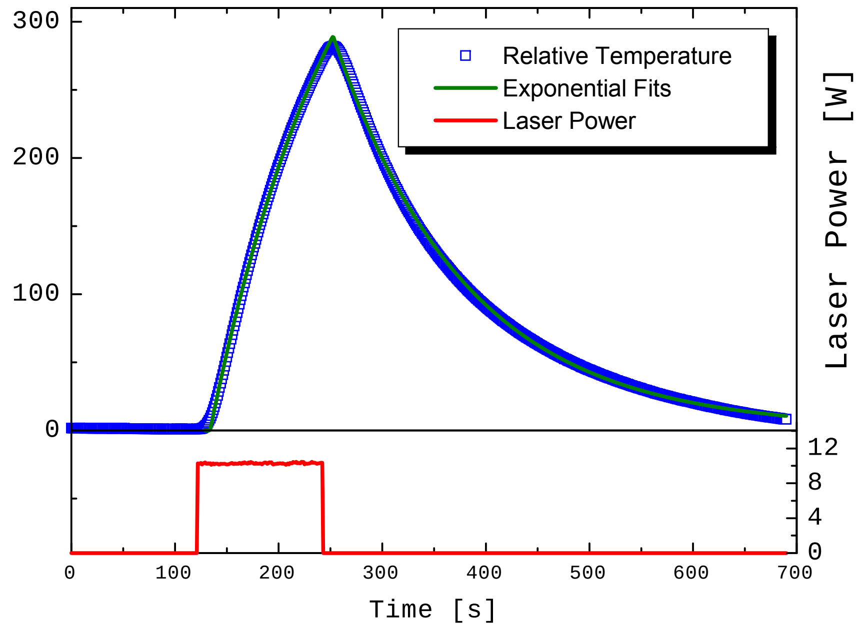
$$\frac{dT}{dt} = \frac{\alpha P}{C_{eff}} - \gamma T$$

$$\begin{cases} T(t) = T(t_1) + \dfrac{\alpha P}{\gamma C_{eff}}\left(1 - \exp(-\gamma(t - t_1))\right) & \text{heating} \\ T(t) = T(t_1) + \dfrac{\alpha P}{\gamma C_{eff}}\left(\exp(-\gamma(t - t_2)) - \exp(-\gamma(t - t_1))\right) & \text{cooling} \end{cases}$$



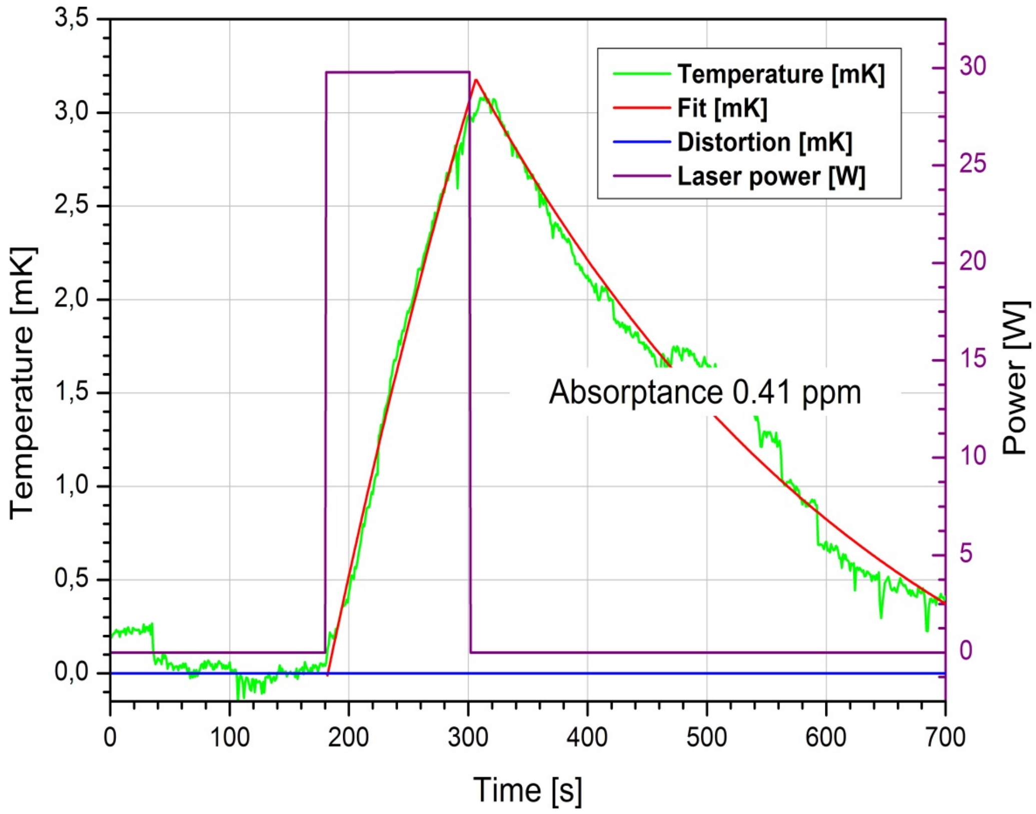
$$\alpha = \frac{(T_{Ext} - T(t_1))\sum_i m_i c_{p,i}}{t_B P}$$

pulse method



exponential method

ISO11551: Laser Calorimetry Sensitivity



sample: SiO_2-substrate, Ø=25mm d=1mm
laser: Nd:YVO_4, 1064nm, 10ps, 160MHz, 30W
errors: cal: 1%, T(t): 2%, P_L:10%

*U. Willamowski, D. Ristau, E. Welsch, Appl. Opt. 37 (36), 1998;
D. Ristau, ICCG, 2006; K. Starke, D. Ristau et al., OSA TD, 2007

Sensitivity limit

Example: Quartz-Substrate 1.064nm

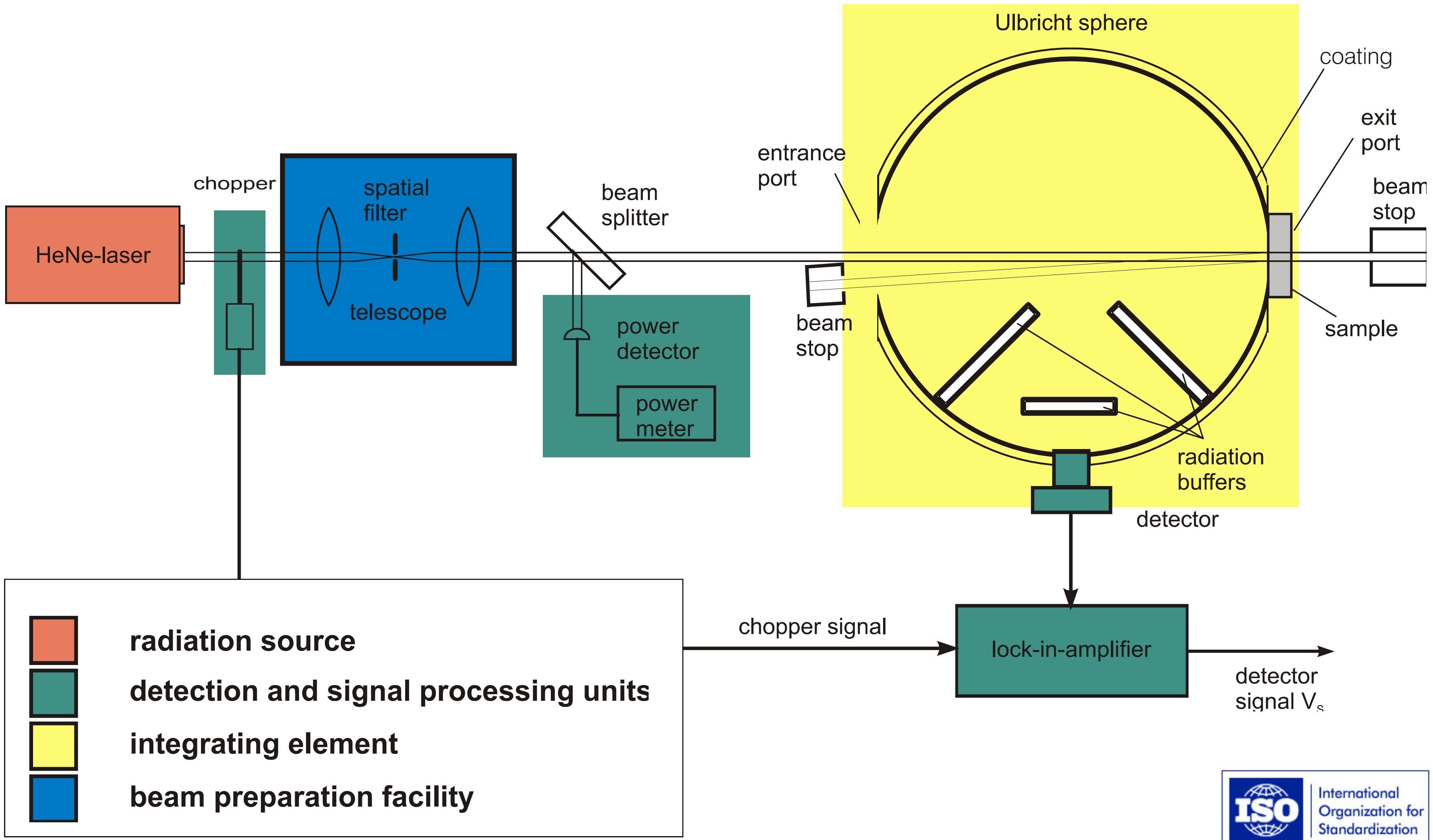
- absorption: **0,4ppm**
- T-fluctuations < 200µK
- sensitivity **0,02ppm**
- further scaling possible: 5 W < P_L < 100 W

1995-2007: improvement by 2 orders of magnitude*

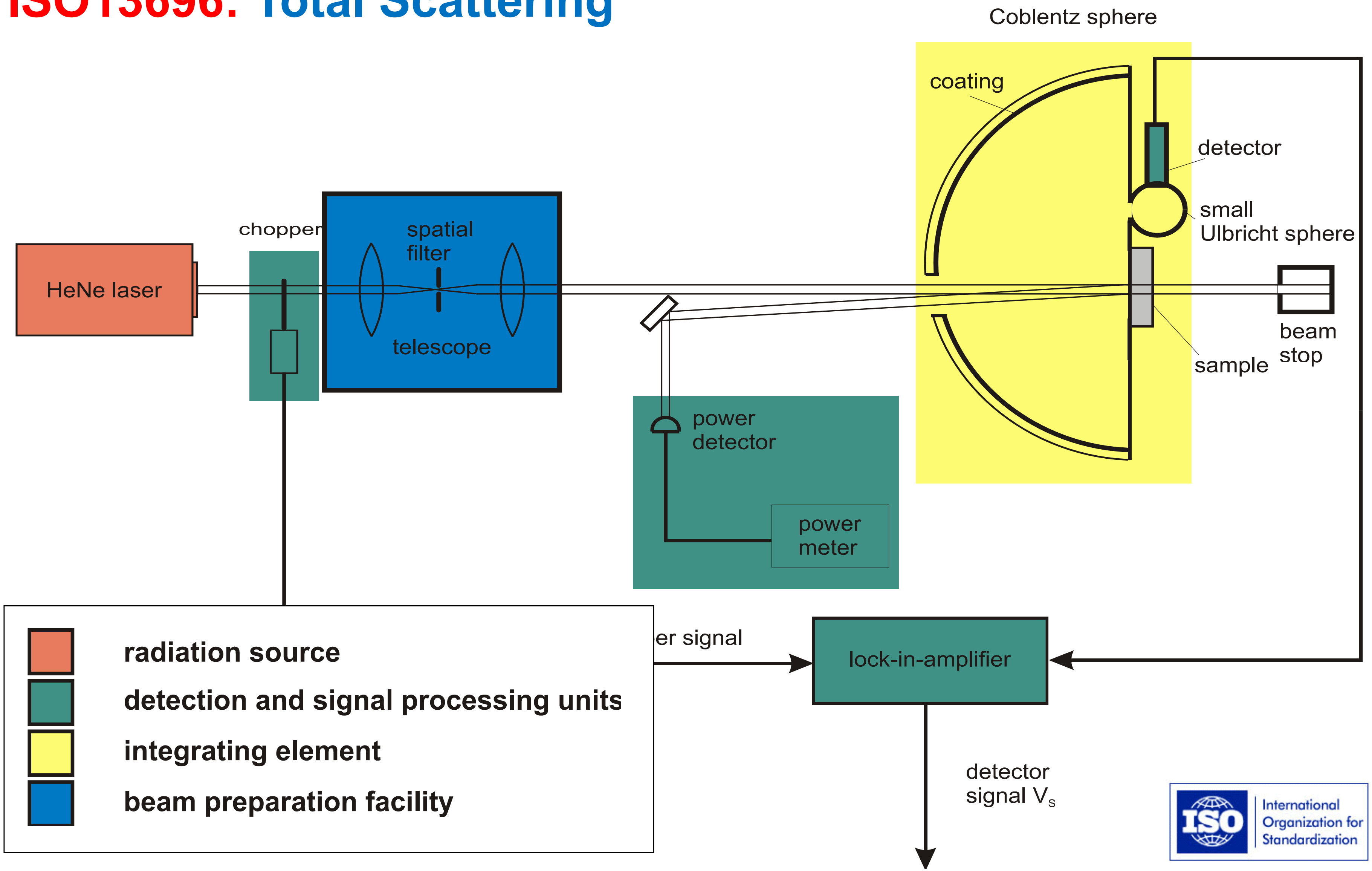
Recent approaches:

- combination LC with PTD
- multi-wavelength
- wavelength tuning
- ps- and fs-regime
- complex geometries

ISO13696: Total Scattering

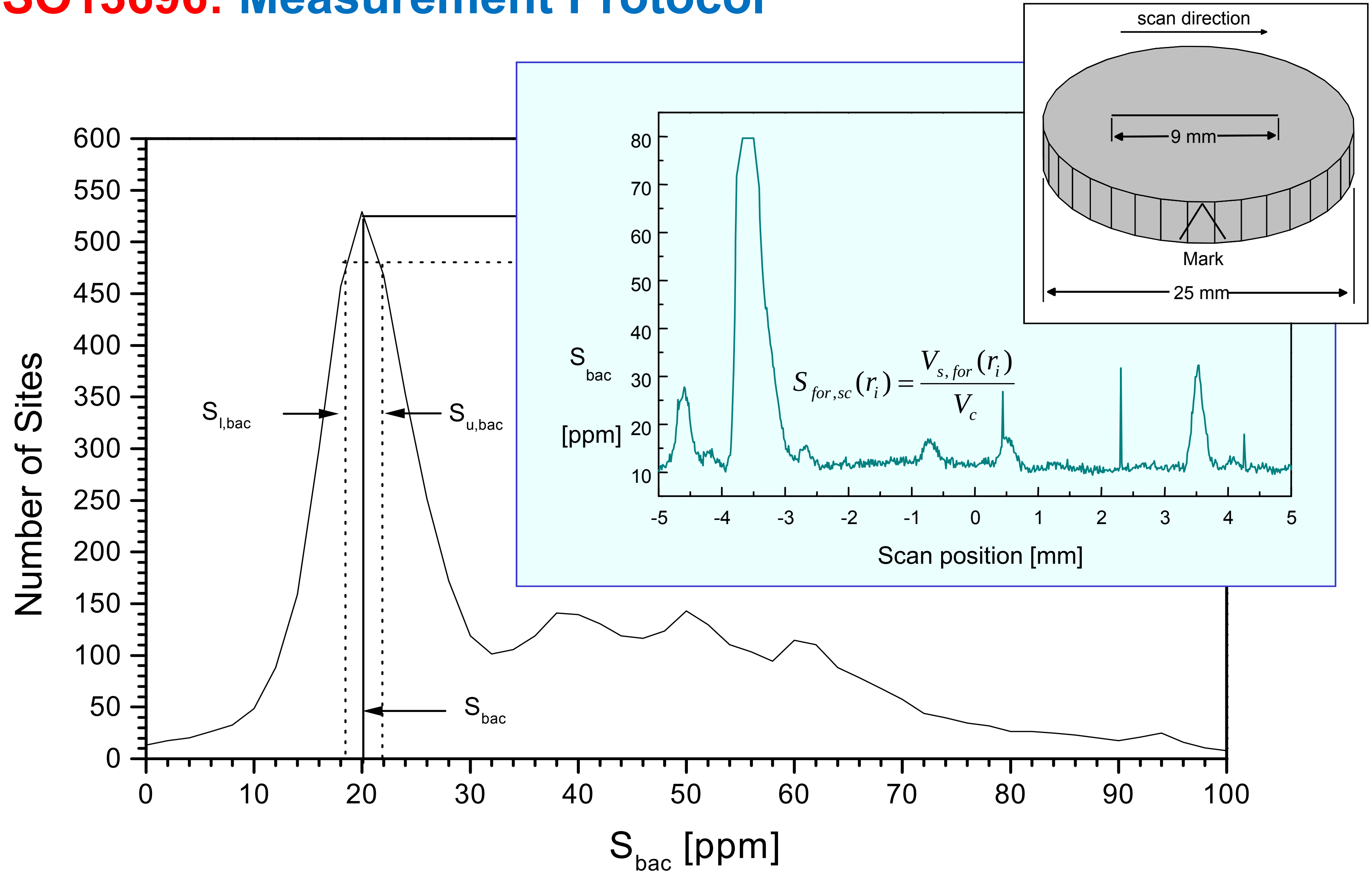


ISO13696: Total Scattering

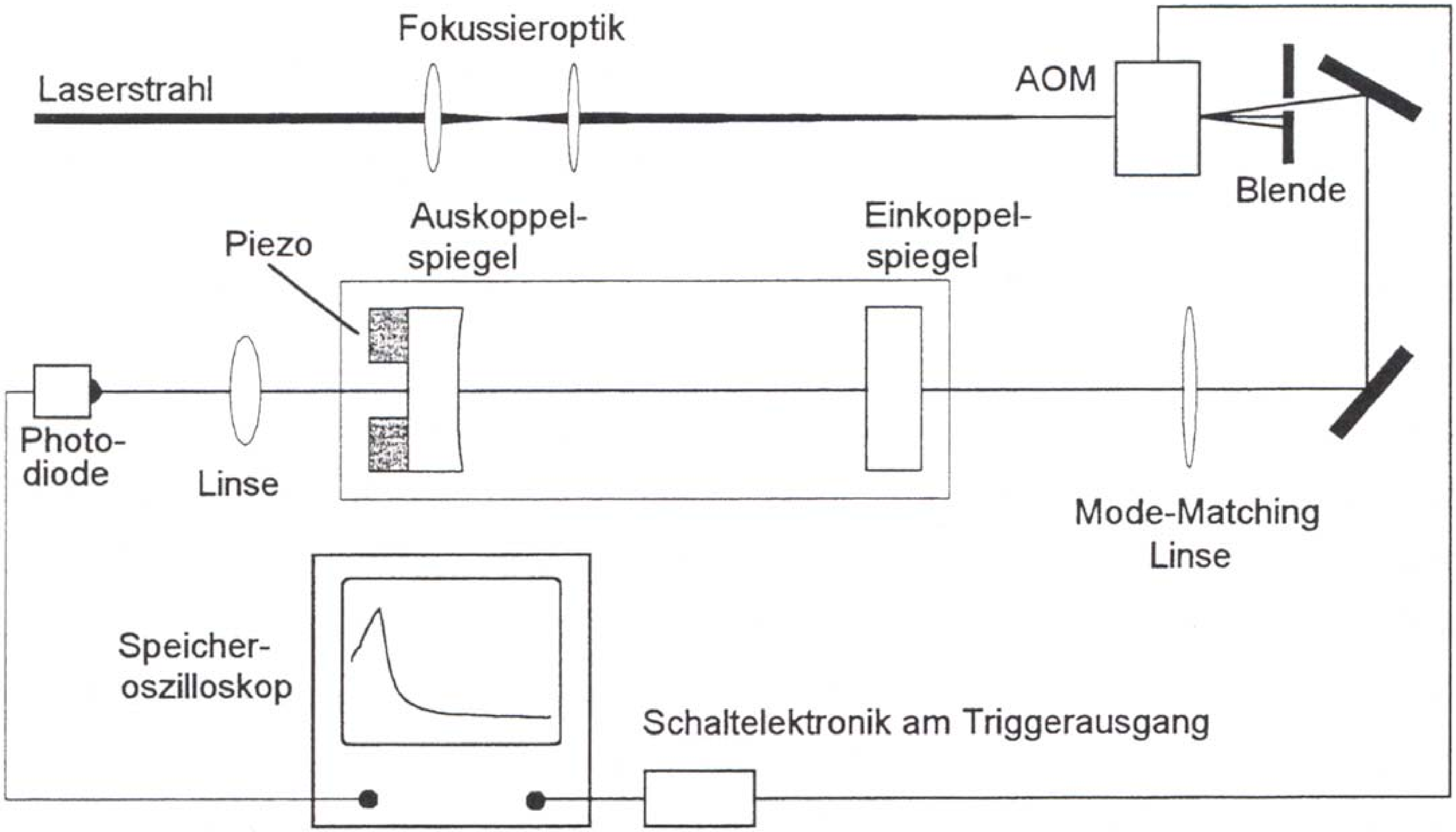


International Organization for Standardization

ISO13696: Measurement Protocol

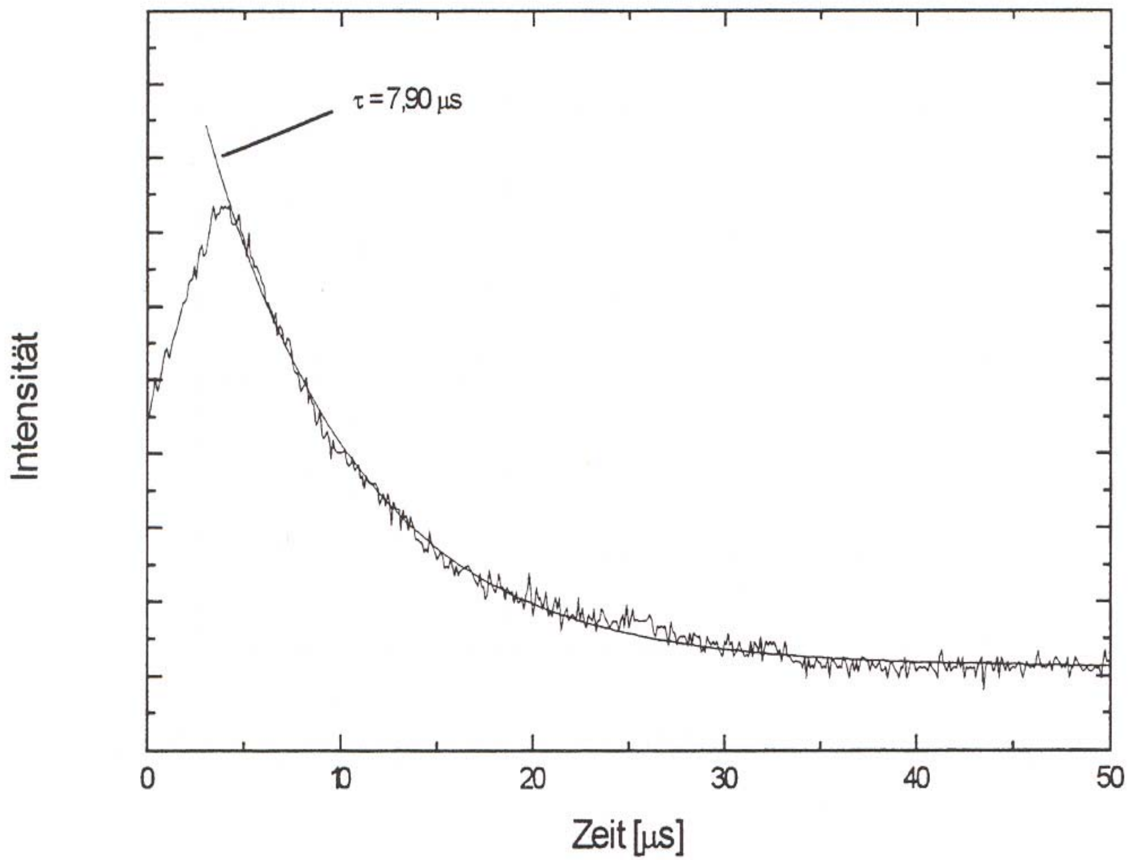


Cavity Ring Down Techniques



U. Schmidt, Charakterisierung von optischen Komponenten mit geringsten Verlusten, Diplomarbeit, Universität Hannover, 1994

Cavity Ring Down Techniques



CRD-signal: The decay time (t_C=7.9µs, HR 532nm, losses V=16ppm, resonator length L=244mm) can be derived from the measurement curve.

decay time:
average life-time of a photon in the cavity:

$$\tau_C = \frac{L}{cV}$$

decay time depenedent on total losses:

Transmission
Scattering
Absorption

of both mirrors.
Reference mirror of defined reflectance necessary.

U. Schmidt, Charakterisierung von optischen Komponenten mit geringsten Verlusten, Diplomarbeit, Universität Hannover, 1994

Cavity Ring Down Techniques

Precise measurement techniques: losses und transfer properties

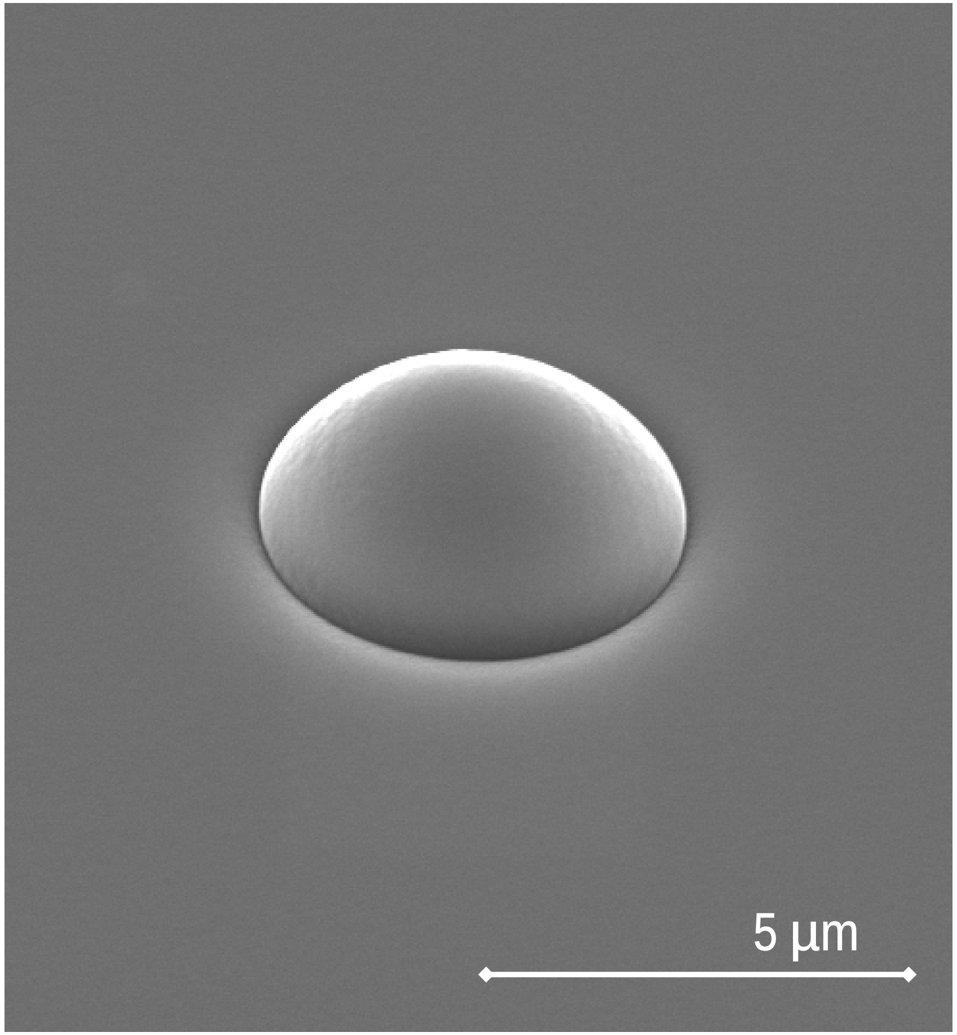
- **absorption: laser calorimetry ISO11551, PTD-methods, A_M< 0,1ppm**
- **scattering: Total Scattering ISO13696*, TS_M< 0,3ppm****
- **total losses: Cavity Ring Down**
- **R: laser ratiometry ISO13697, $\Delta R/R<10^{-5}$, $\Delta R<200$ppm [3*]**
- **T: different methods, residual transmission<10^{-9}**

losses [ppm]	**mirror 1**	**mirror 2**	**mirror 3**
absorption (A)	10 ± 2	< 2	4 ± 1
Total Scattering (S)	6 ± 2	4 ± 2	6 ± 2
transmission (T)	144 ± 5	11 ± 5	26 ± 4
sum of losses (A+S+T)	**160 ± 9**	**$< 18 \pm 7$**	**36 ± 7**
total losses CRD	**163 ± 8**	**18 ± 1**	**40 ± 2**

comparison[4*] of techniques for the measurement of losses: CRD ↔ T+S+A, wavelength 514nm
mirrors: Ta_2O_5/SiO_2, reactive IBS-process (results of 1994)

*ISO13696: 2002, int. project: D. Ristau 1992-2008; **P. Kadkhoda, A. Müller, D. Ristau et al., Appl. Opt. 39 (19), 2000;
[3*]M.Jupé, D. Ristau et al. SPIE 4932, 2003; [4*]R. Henking, D. Ristau, H. Welling, SPIE 2428, 1994

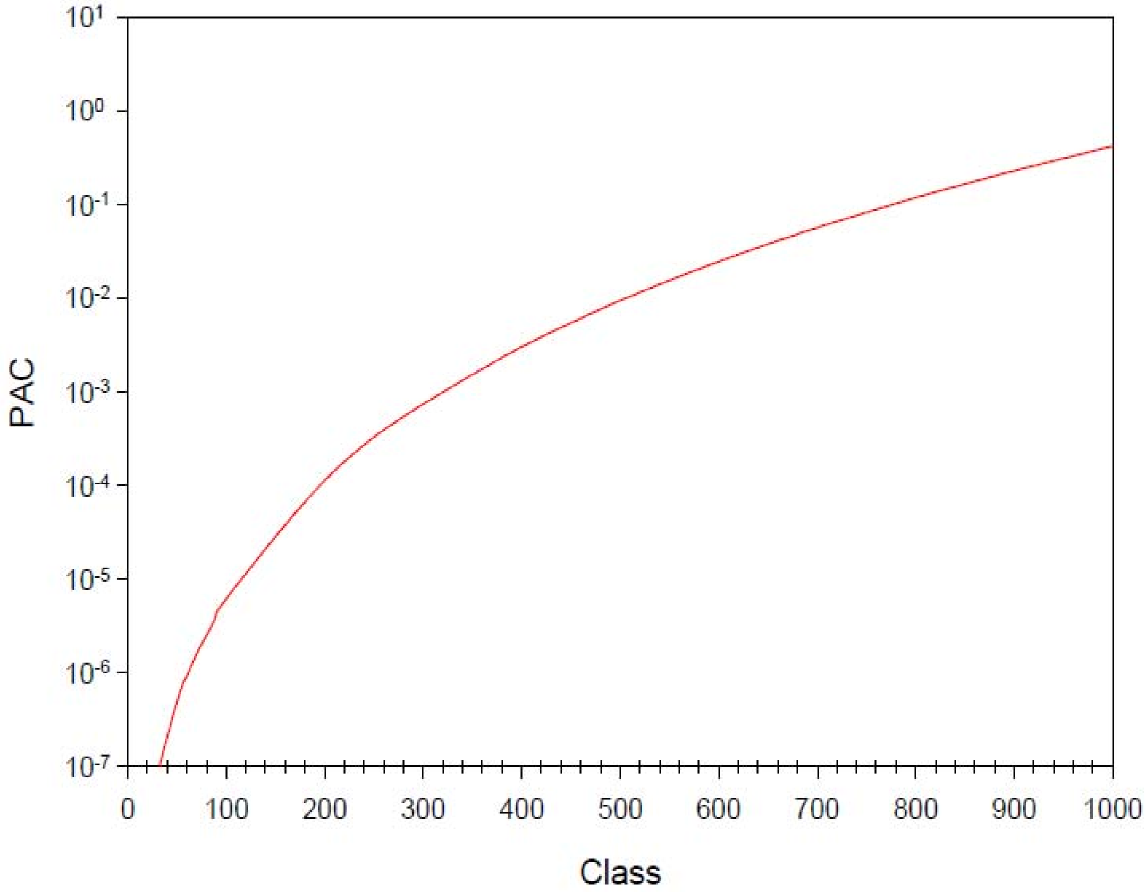
Cleanliness of Optical Surfaces: Defects



Defects: Major Problems

- **deteriorate spectral transfer properties**
- **increase scatter and absorption losses**
- **reduce LIDT for cw- pulsed laser applications**
- **enhance laser induced contamination effects**
- **no standardised definition and measurement technique**

ISO/WD 17935: Specification of Surface Cleanliness



Major Definitions

- **PAC:**
  Particle Percent Area Coverage
- **Class:**
  Cleanliness class, the largest particle expected to occur in a 0.1 m^2 area

Project Leader: Jon Arenberg, USA
Document ISO/TC 172/SC 9/WG 6 N 295, 2013

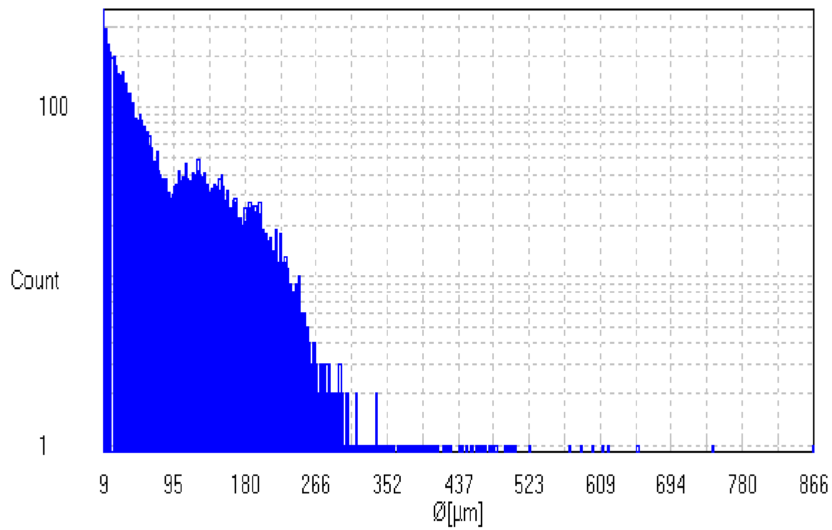
Ex-situ Measurement of Defects

Prominent methods:

- Visual inspection (f.e. ISO 9211-4 Annex C)
- Microscopic image comparator (ISO 14997)
- Dark field microscopy in conjunction with adapted image processing
- Electron microscopy

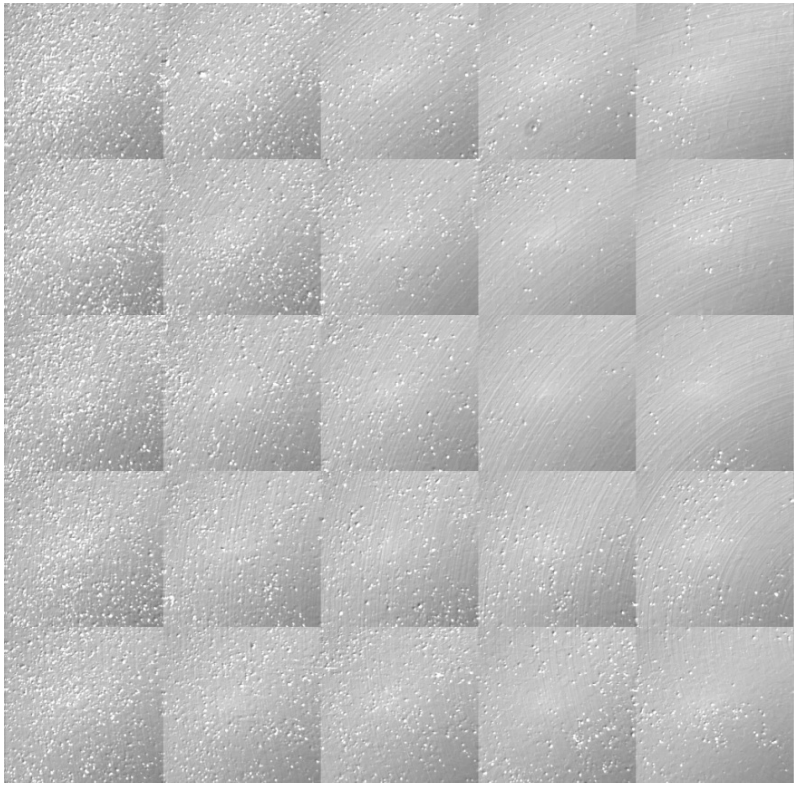
Alternative methods:

- Photothermal microscopy
- Third harmonic generation microscopy
- Evaluation of laser damage
- Fast TS: Total Scatter mapping



Specification of Surface Cleanliness: Microscopy

Copper (5x5 mm^2), 2µm/Pixel



Advantages:

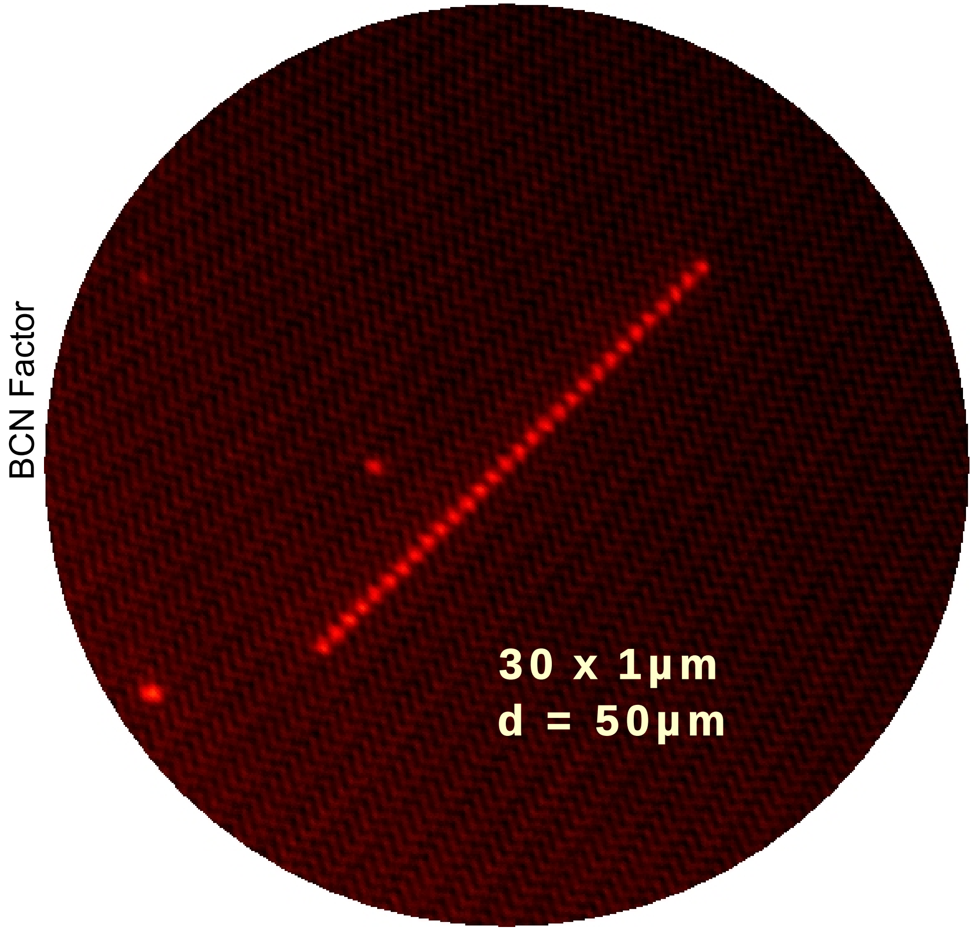
- Commercial systems
- Variable magnification up to 500x
- Automatic positioning , recording
- Advanced image processing
- Numerical correction (illumination)
- Flexibility to sample geometry

Disadvantages:

- Relatively slow mapping process
- Focusing at high magnification

Need for an inspection tool with high resolution and high throughput for quality management in routine production environment

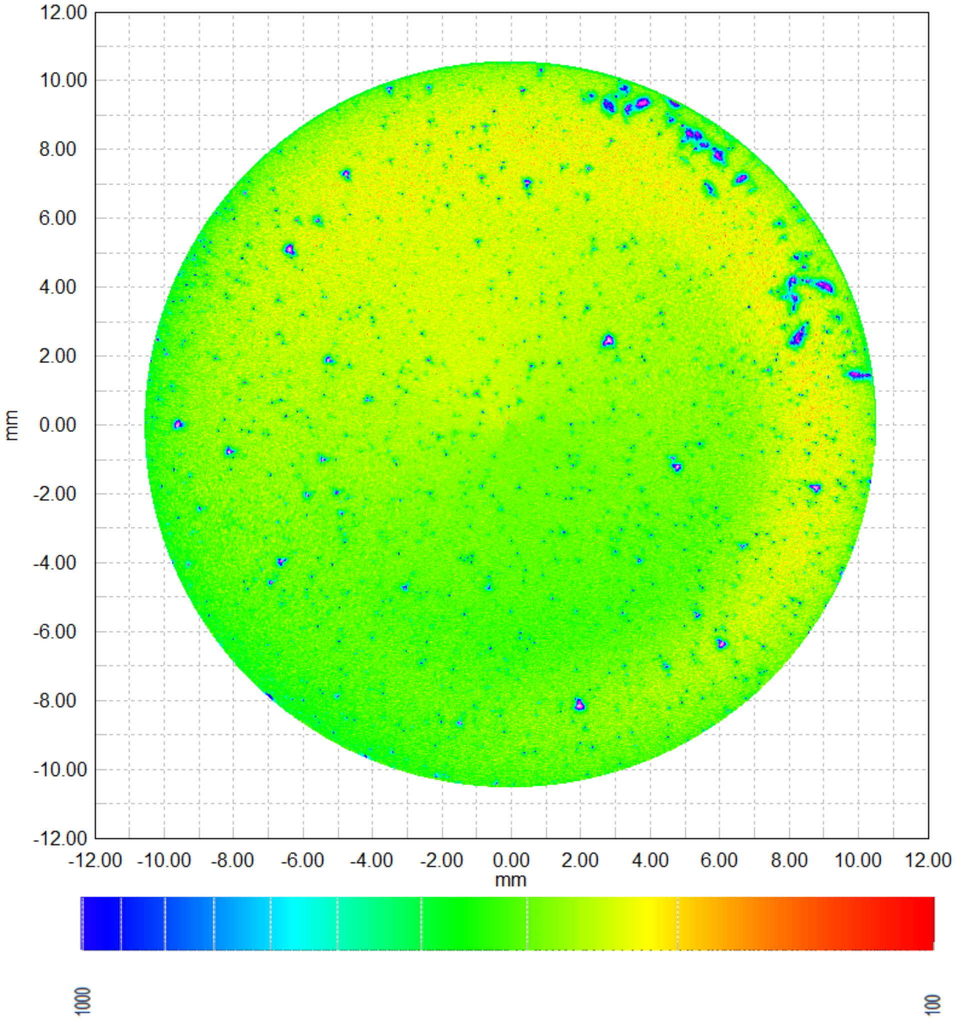
Fast TS Surface Inspection Technique

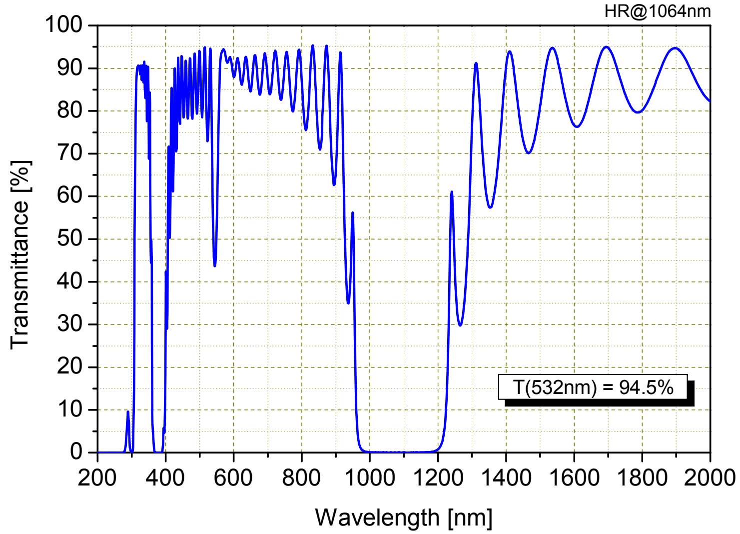


Major Properties of Fast TS

- According to ISO 13696
- Coblentz-sphere ROA [2° - 85°]
- Spiralic mapping, rate 500 kHz few minutes per sample
- Dynamic range $>10^8$ by adjustment PMT High Voltage
- Sensitivity $< 10^{-6}$ in center of sample holder
- Resolution for "particles" < 1 µm for distance 50 µm
- single defects < 100 nm
- Calculation of scatter map typ. 60 Mio. data, statistics
- Scatter value ≠ defect size

Fast TS Surface Inspection Technique





Specifications HR samples

- HR @1064nm on SQ2 substrates
- e-beam, Ta_2O_5 / SiO_2, 27 QWOT
- TS loss: 270ppm
- S on1 LIDT (P07) : 0%: 20 J/cm^2

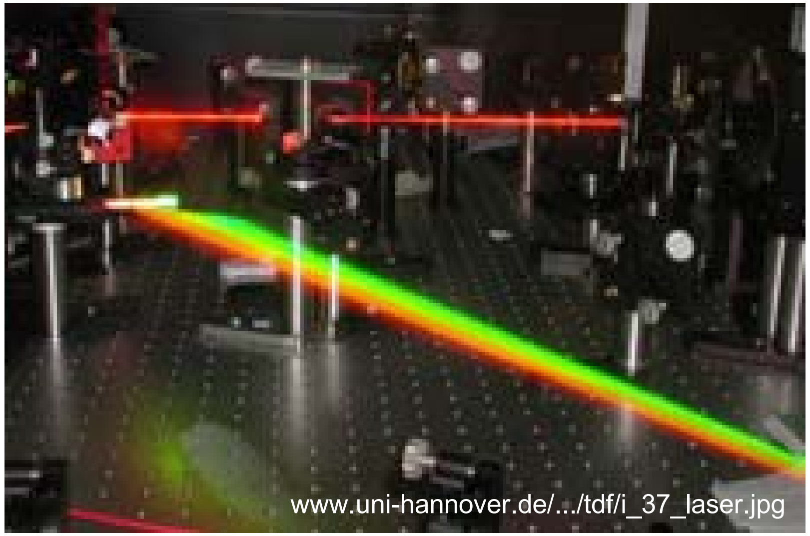
  50%: 60 J/cm^2

Conclusions and Outlook

Present Optics Characterisation Standards:

established in research, industry, and market
revisions under discussion for:

- ISO 21254 : data reduction techniques
- ISO 11551 : different geometries
- ISO 13696 : DUV/VUV-spectral range
- ISO 11151 : revision completed
  new version in print



New Standards and Future Trends:

concrete Standard projects

- ISO/WD 17935: cleanliness
- ISO/DIS 13142: cavity ring down
- ISO/NWIP: angle resolved scattering
- ultra-short pulse optics
- cleaning, storage, and transportation
- lifetime and degradation effects


Thank You
for your attention