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Laser induced deflection (LID) – absolute photo-thermal absorption measurement in optical coatings and materials

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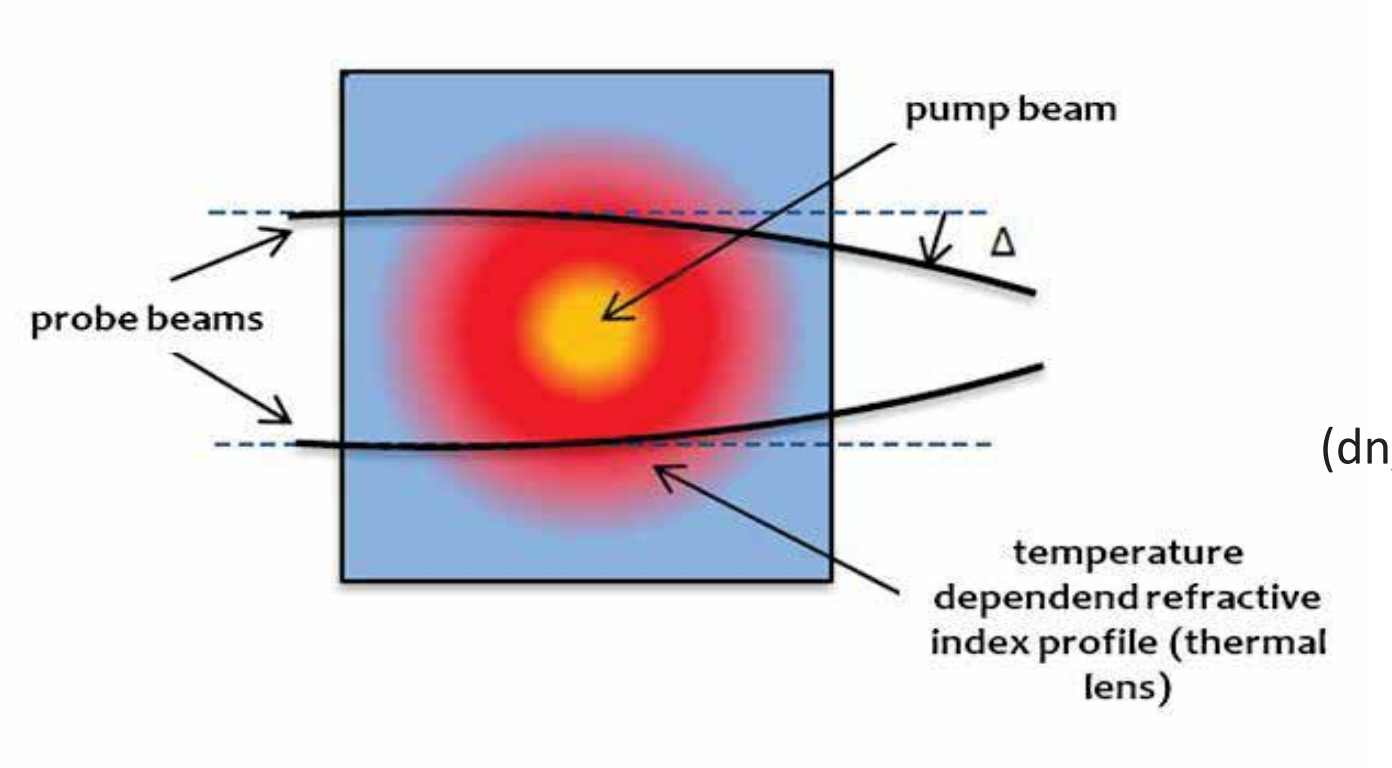
Outline

- Principle of **L**aser **I**nduced **D**eflection (LID) technique
- Calibration procedure
- Setup
- Measurement concepts
- Experimental results
- Summary

Laser induced deflection (LID)

Photo-thermal technique with ***transversal*** probe beam guiding



Absorption

↓

Temperature profile

↓

Refractive index profile
(dn/dT; thermal expansion → stress)

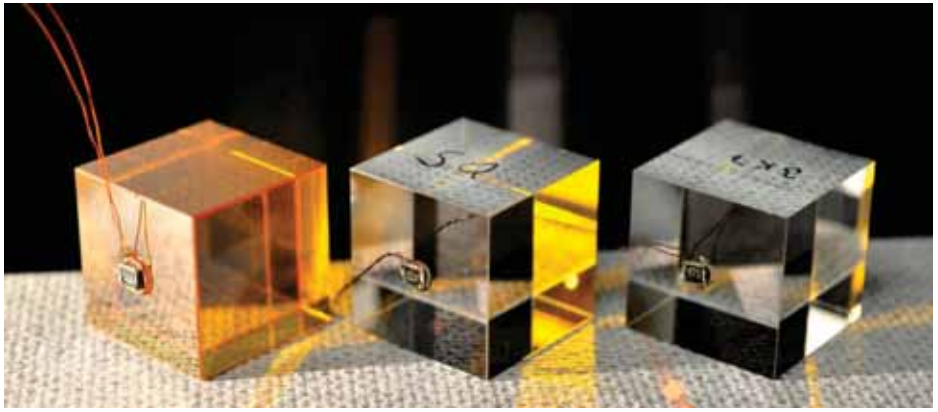
↓

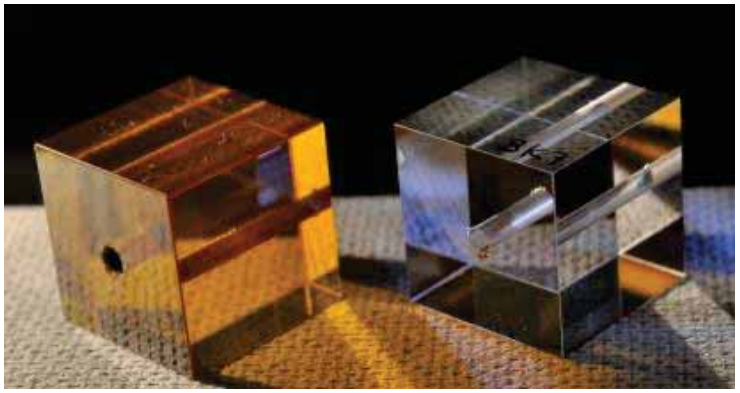
Probe beam deflection
(steady-state)

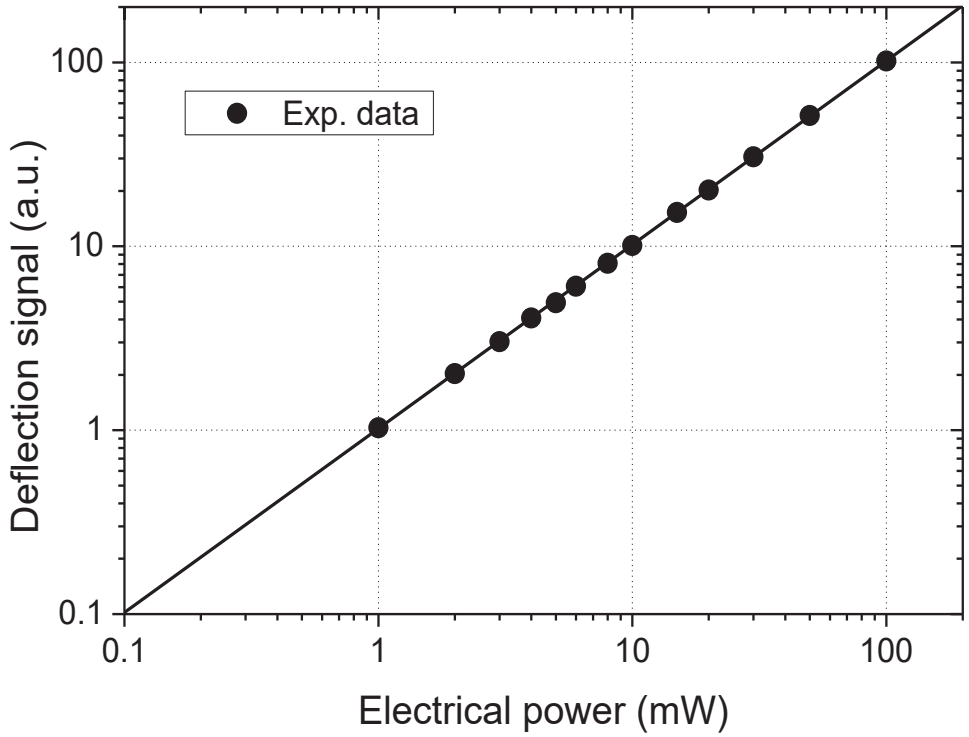
- Probe beam deflection is a *direct measure* for the absorbed mean laser power
- **Main challenge**: How to calibrate for ***reliable*** absolute absorption data?

Calibration (electrical)

- Absorption induced heat is simulated by electrical heating (adaption of calorimetry's calibration to a photo-thermal technique)
- Absolute data without simulations and knowledge of material's photo-thermal parameters
- Unique feature for photo-thermal techniques







- Linear behavior over multiple orders of magnitude of absorbed power
- Energy balance measurements (T+R+A+S=1) approve that no systematic error exists

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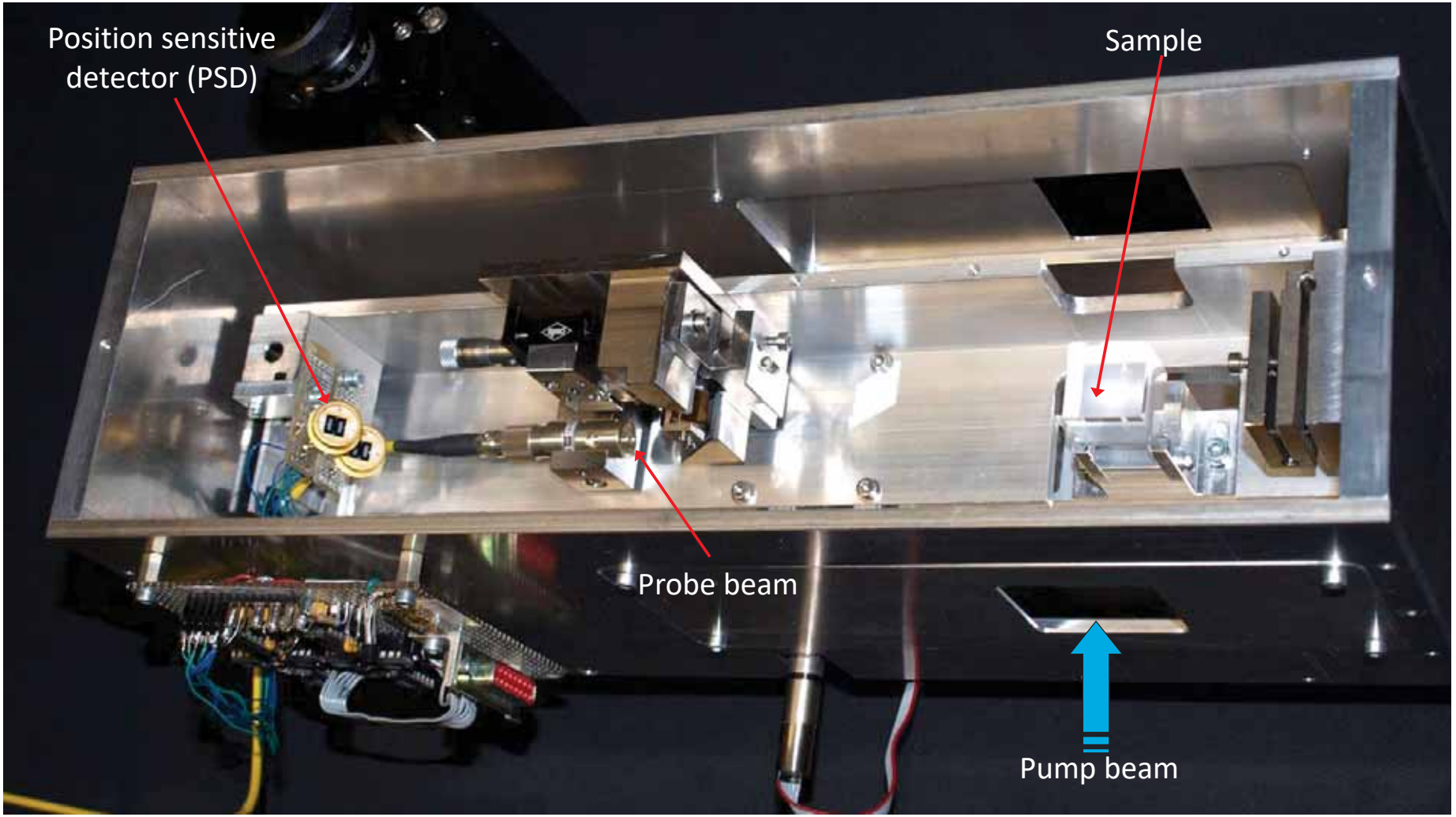
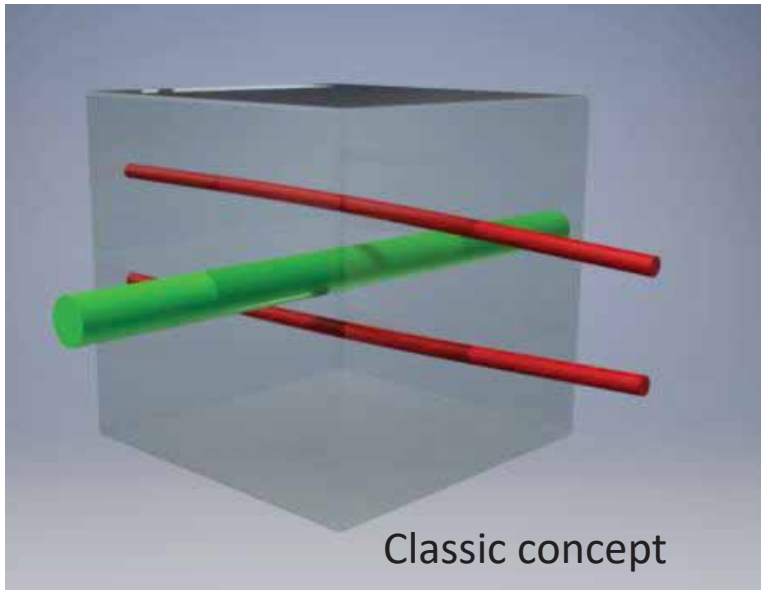
Setup

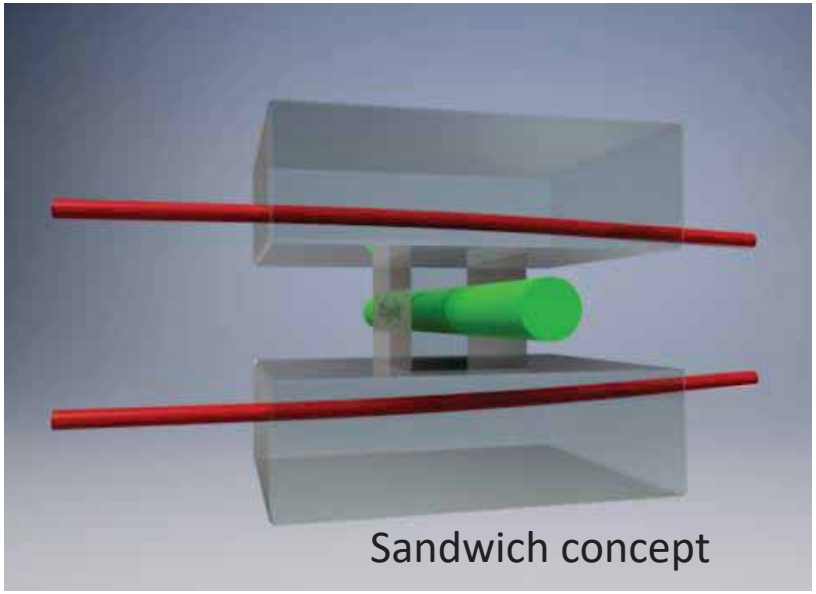


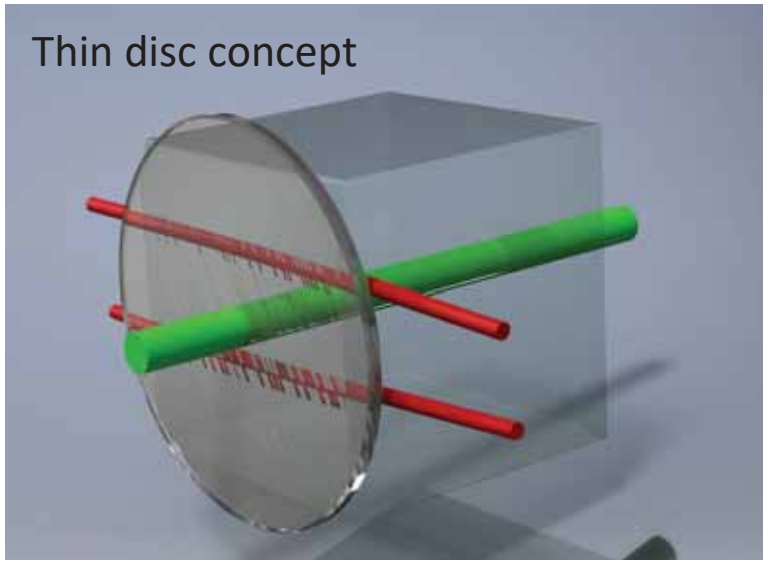
Example for sensitivity (fused silica): 10µW absorbed power

Measurement concepts

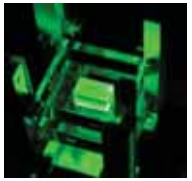
Different concepts for different requirements



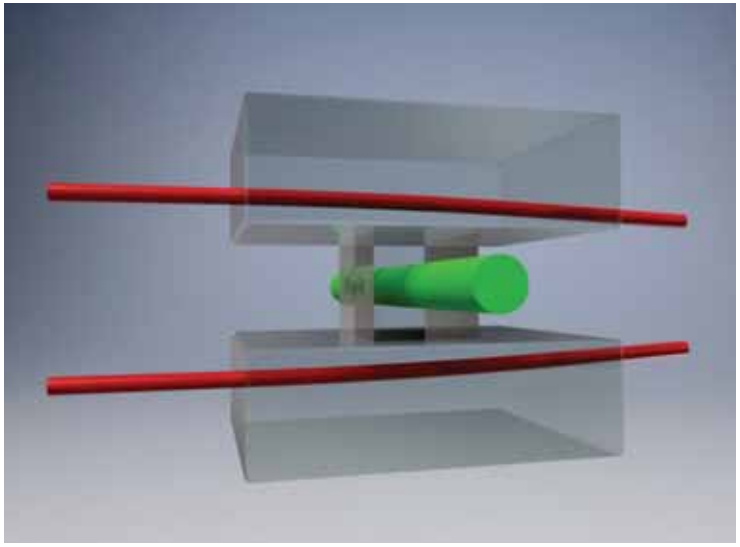




Measurement concepts

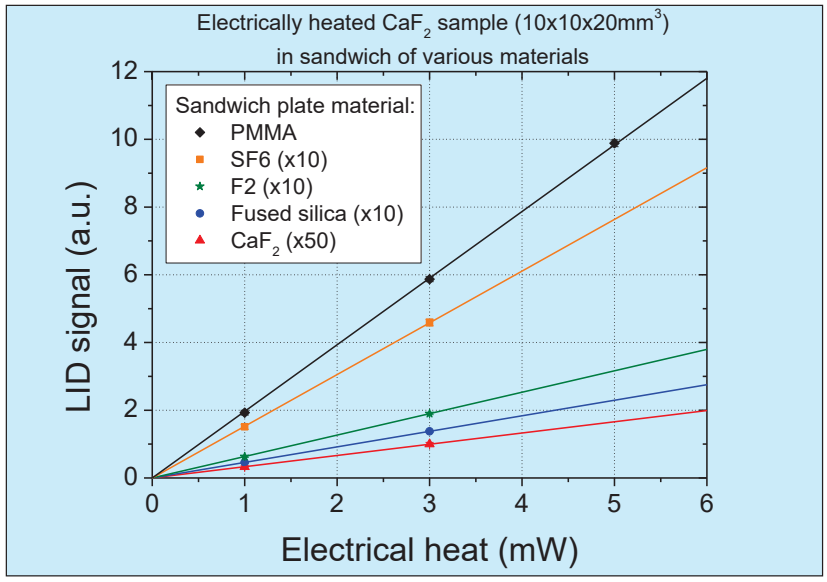


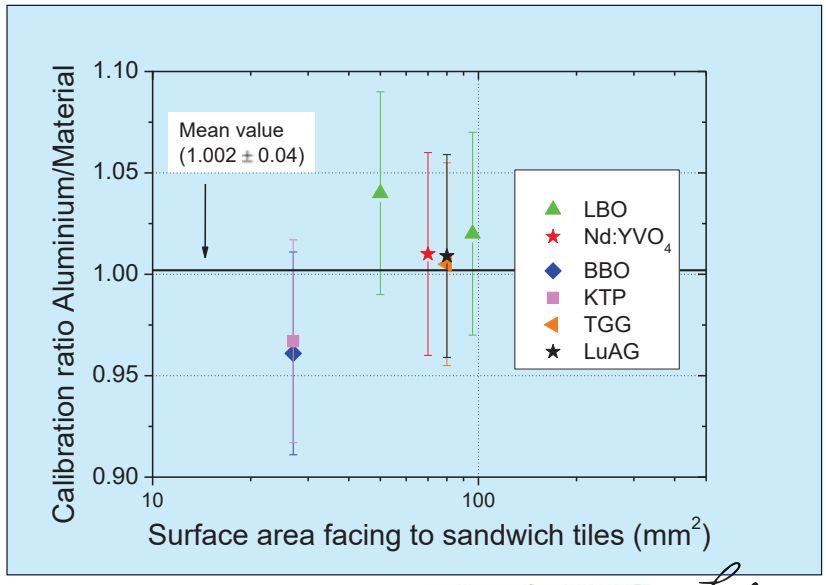
„Sandwich“ concept



Separating materials for pump and probe beam guiding allows for:

- ✓Measuring small samples like NLO and laser crystals
- ✓Measuring samples without side-face polishing
- ✓Strong sensitivity increase for materials with low photo-thermal response by choosing appropriate sandwich tile materials
- ✓Measuring samples which are not transparent for VIS probe beam wavelengths
- ✓Simplified electrical calibration for bulk absorption





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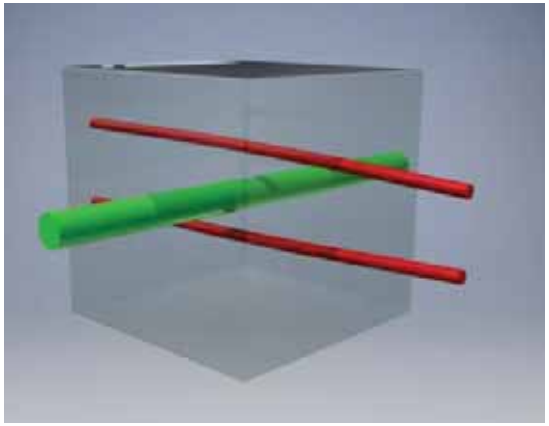
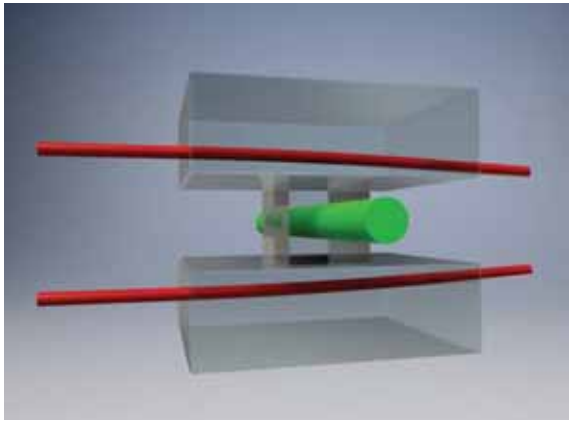
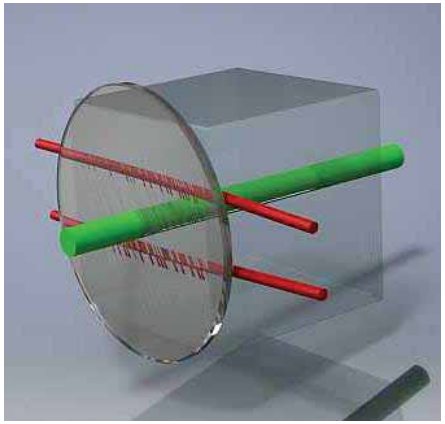
Measurement concepts

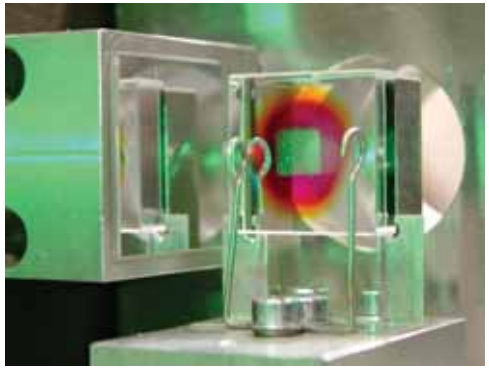
Concepts for particular „coating“ substrates





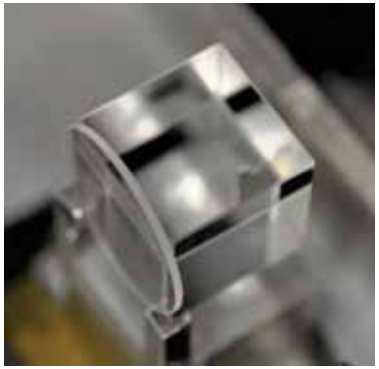


- (Large) rectangular samples (e.g. 20x20x6mm^3)

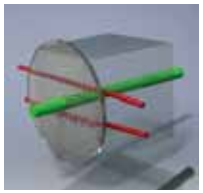


- ∅=1/2”, d=1/4”
- (Small) rectangular samples

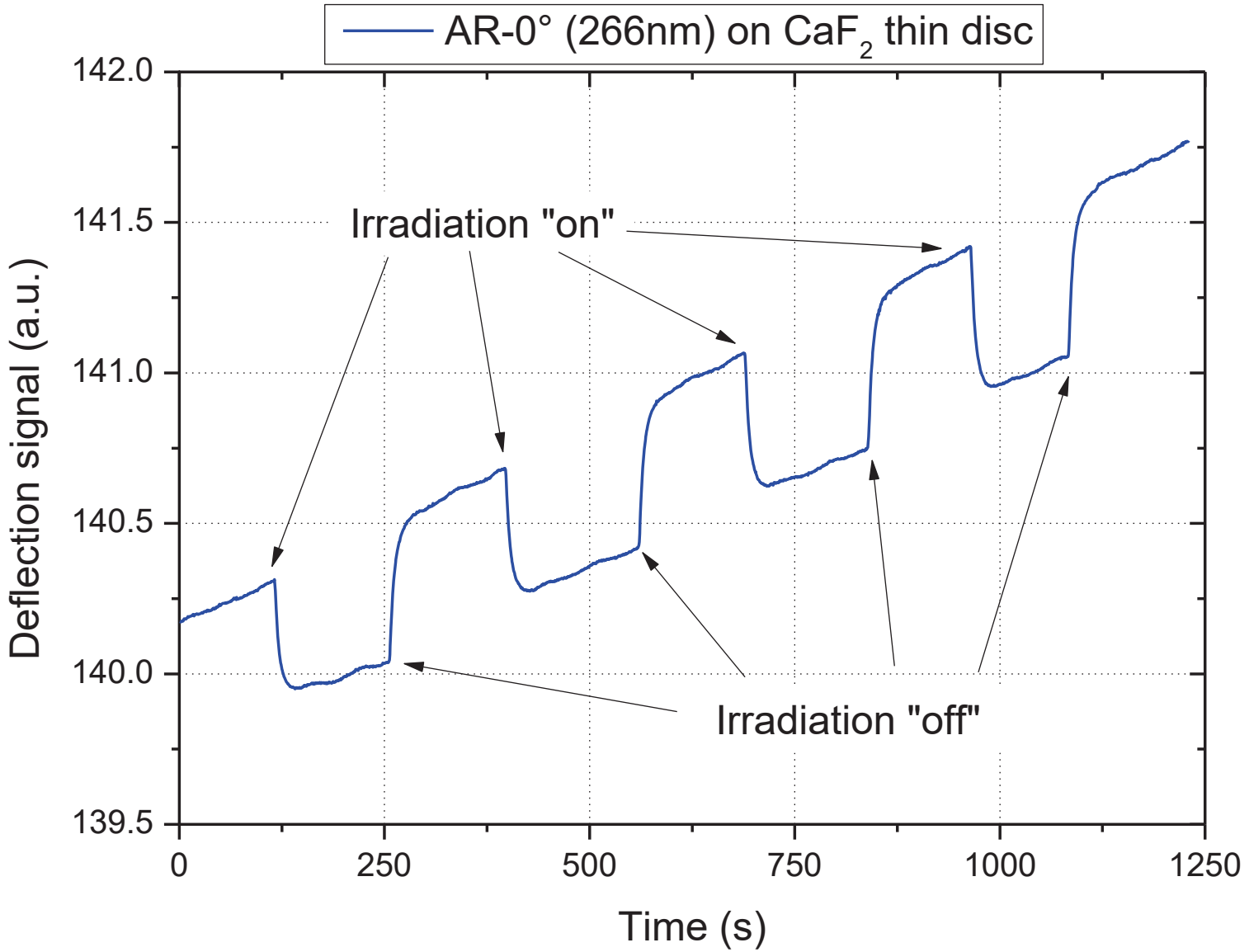
- ∅=1…2”, d=1mm



Experimental results



Measurement example



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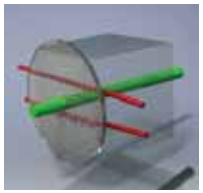

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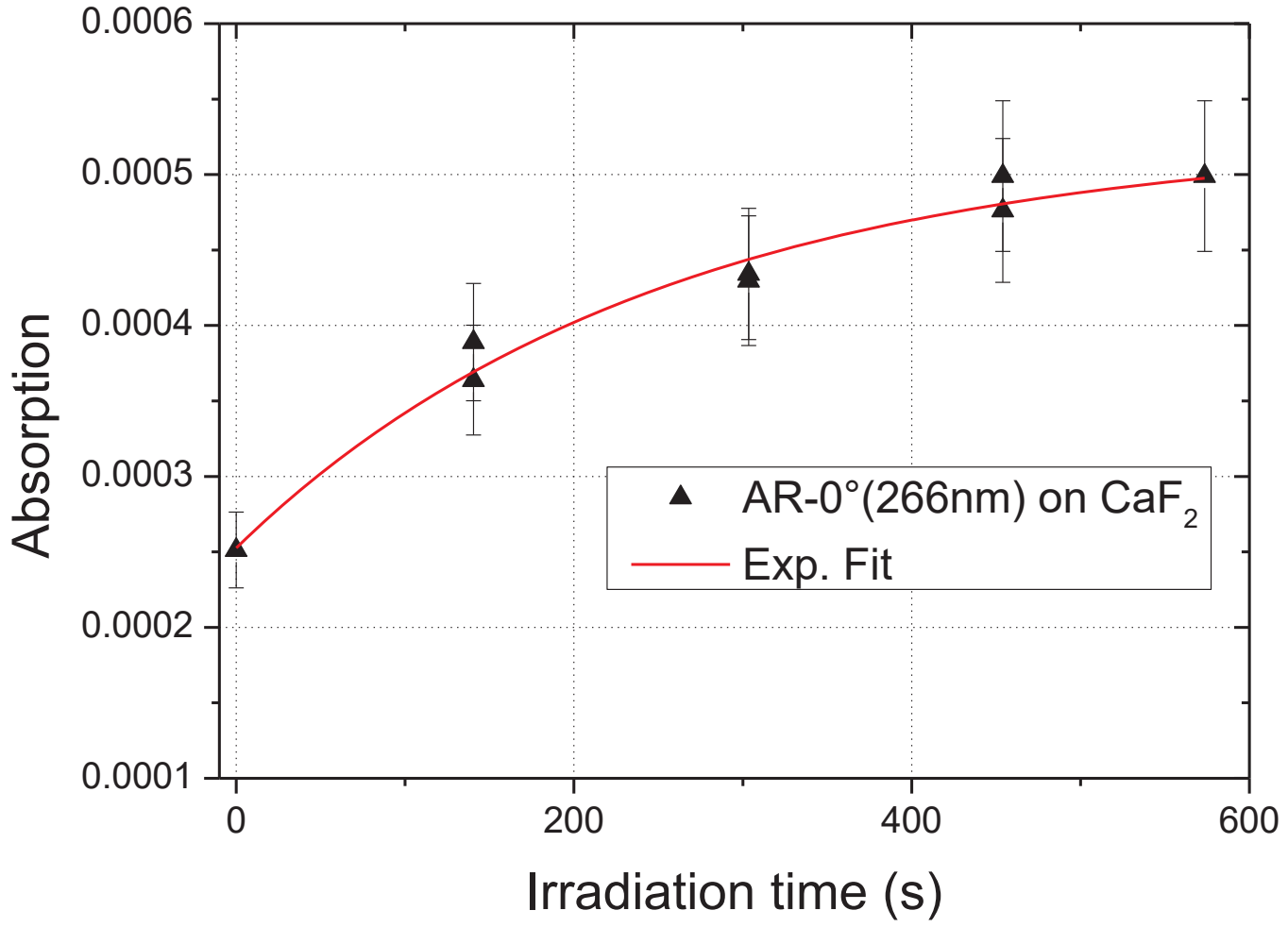
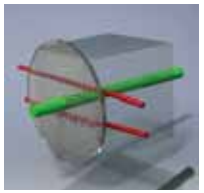
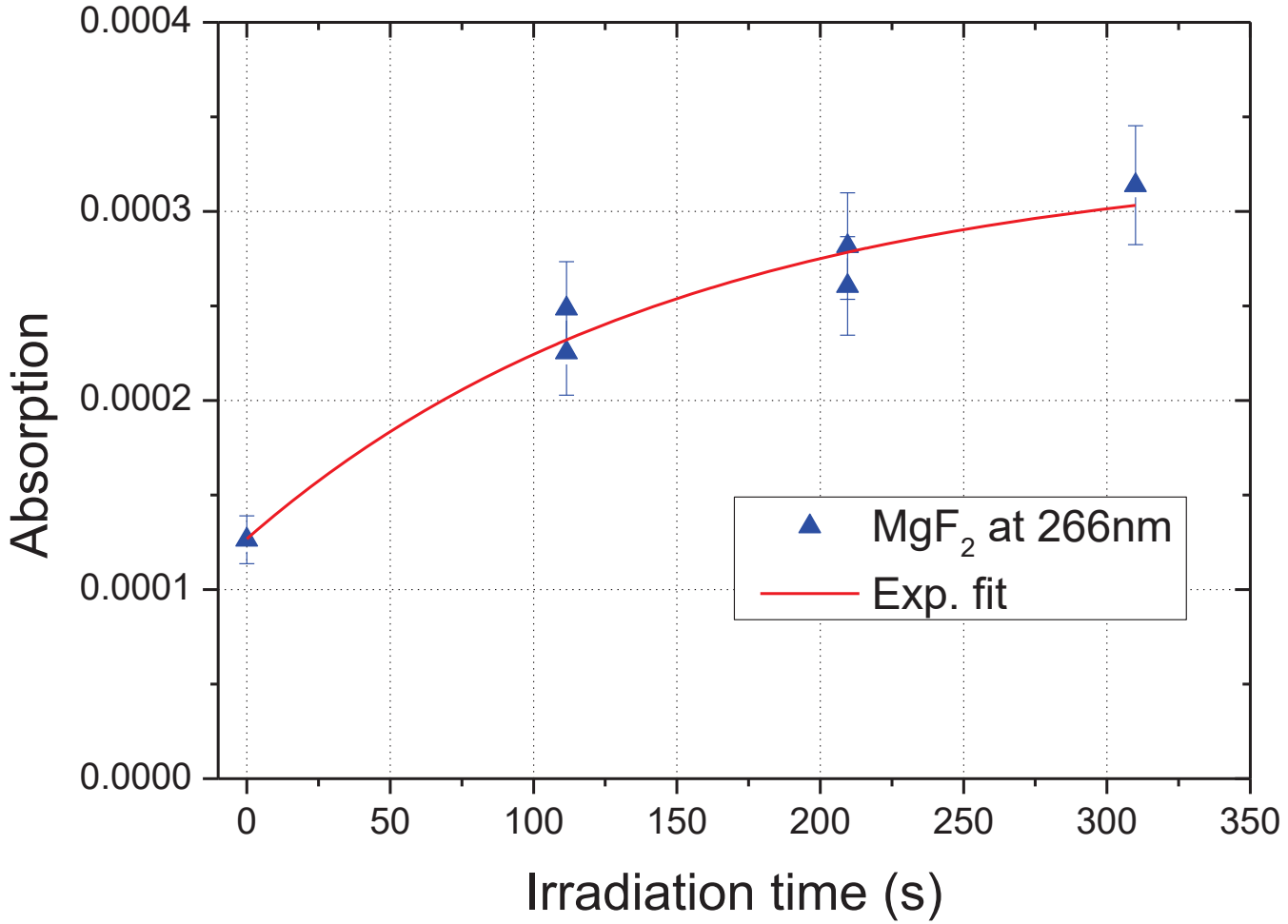


- Irradiation induced absorption increase to steady state value
- MgF_2 part of the AR seems to be responsible

Experimental results



Measurement example



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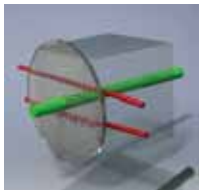
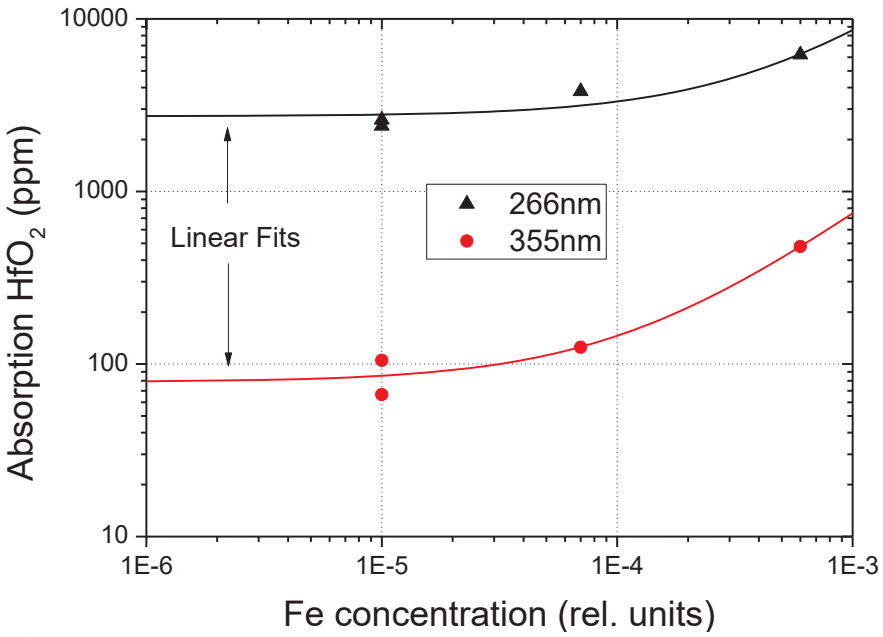
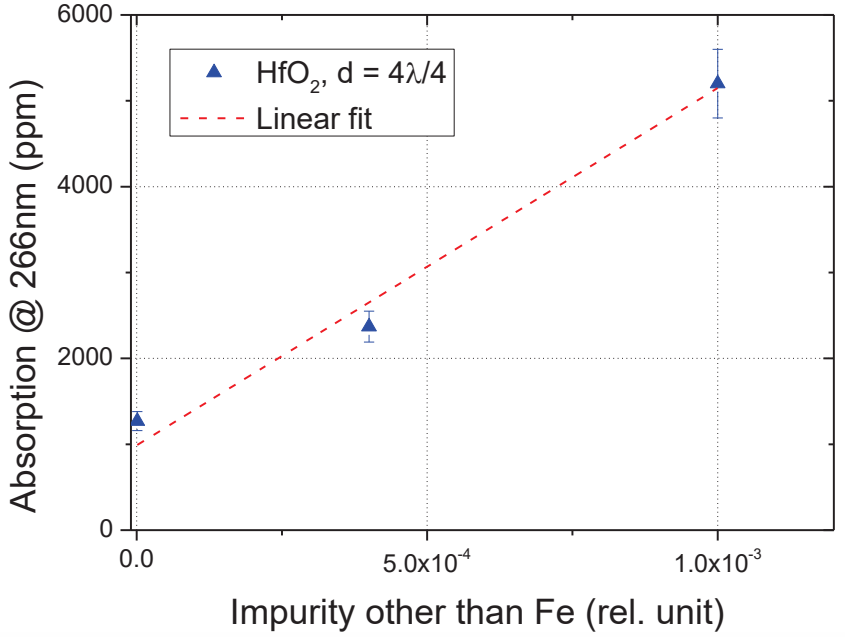
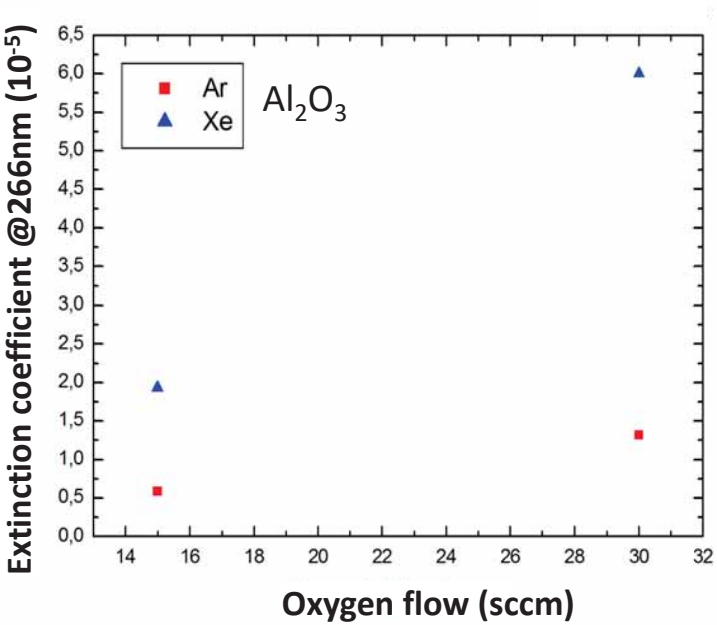
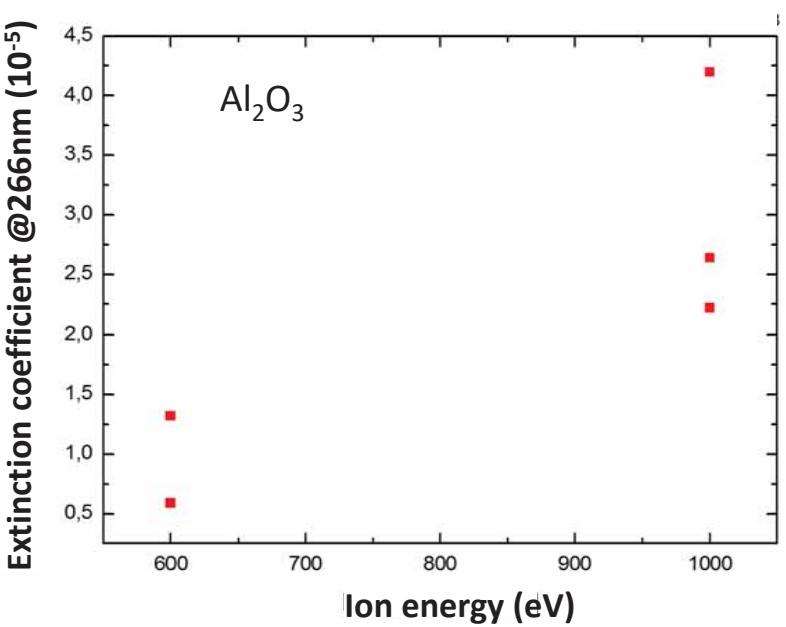


Absorption as function of particular impurities or deposition parameters









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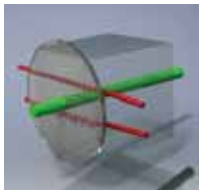
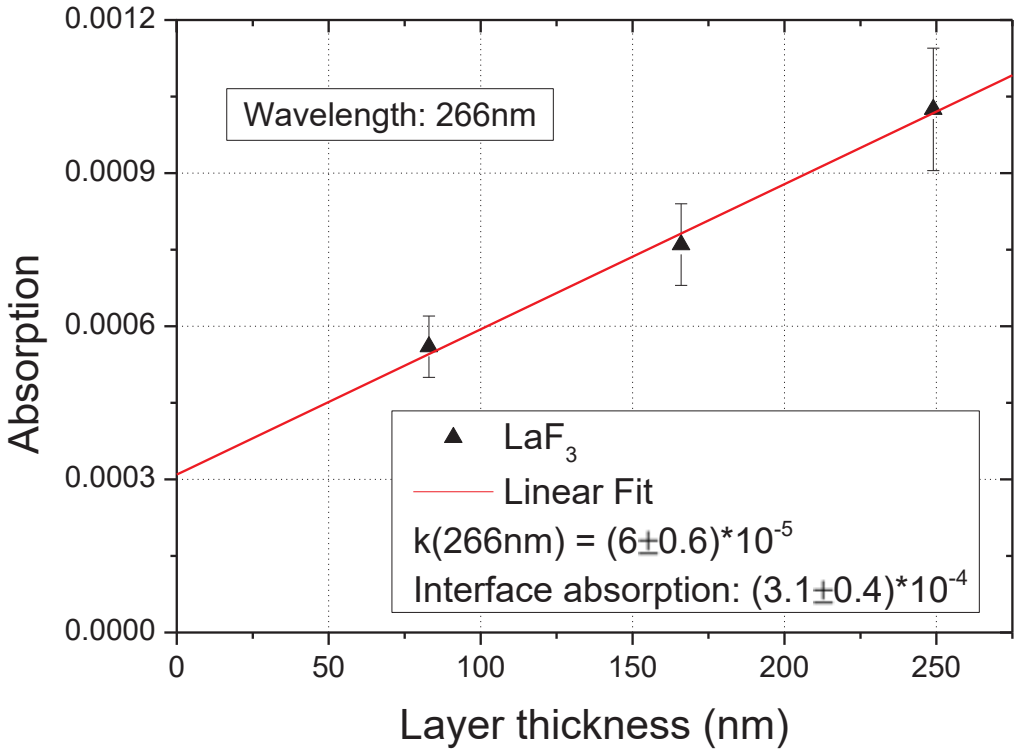
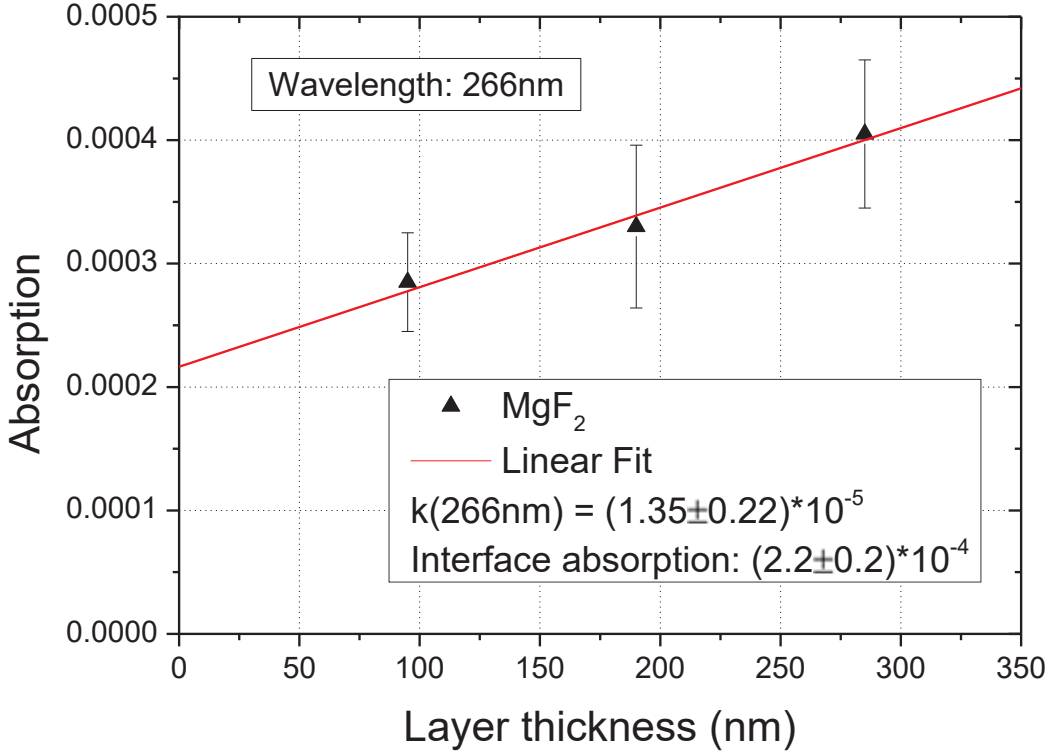


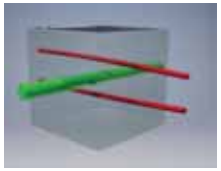
Thin film thickness series to separate coating and interface absorption

- Fluoridic single layers (optical thickness: multiple of $\lambda/4$) on thin CaF_2 disc, attached to fused silica cube for sensitivity enhancement
- Total absorption vs. film thickness allows to separate between interface and layer absorption
- Requirements: identical CaF_2 discs, interface and layer properties





Experimental results



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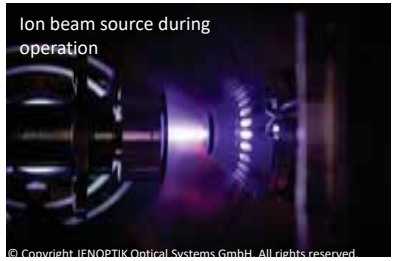
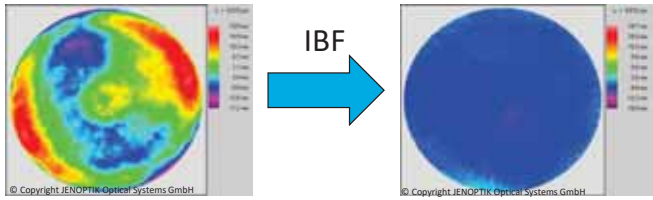
Effect of IBF treatment on CaF_2 surface absorption at 193nm

Sample	Treatment	**Absorption** (% per surface @193nm)
# 1	*Pitch polishing (standard)*	***0.08** ± 0.008*
# 2	*Pitch polishing (standard)*	*0.083 ± 0.01*
# 5	IBF (standard parameters)	0.3 ± 0.035
# 6	IBF (double neutralization)	0.39 ± 0.03
# 7	IBF (double treatment time)	**0.445** ± 0.035
# 8	IBF (step-like treatment)	0.355 ± 0.03
# 9	IBF (optimized removal)	0.365 ± 0.035
# 10	IBF (preserve treatment)	0.355 ± 0.03

IBF treatment

Enhanced surface absorption





Sample	**Absorption** (% per surface)	**Absorption after coating process** (%)		**Absorption decrease after coating, taking into account an AR absorption of ~0.0003** (%)	
		AR coated side	Uncoated rear side	AR coated side	Uncoated rear side
# 1	***0.08** ± 0.008*	***0.121** ± 0.016*			
# 2	*0.083 ± 0.01*	***0.125 ± 0.015***			
# 5	0.3 ± 0.035	**0.12 ± 0.012**	**0.23 ± 0.025**	**0.21**	**0.07**
# 7	**0.445** ± 0.035	**0.118 ± 0.01**	**0.225 ± 0.025**	**0.357**	**0.22**
# 9	0.365 ± 0.035	**0.125 ± 0.012**	**0.25 ± 0.025**	**0.27**	**0.115**
# 10	0.355 ± 0.03	**0.135 ± 0.02**	**0.27 ± 0.025**	**0.25**	**0.085**

After one-side AR coating (LaF_3/MgF_2):

- Total absorption of AR coated sides are virtually identical for IBF and pitch polished samples.
- Uncoated rear side shows higher absorption than AR coated side.
- Proposed annealing mechanisms:
  - High deposition temperature
  - Fluorine supply by coating materials

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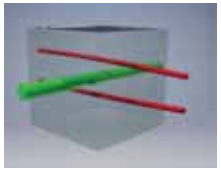
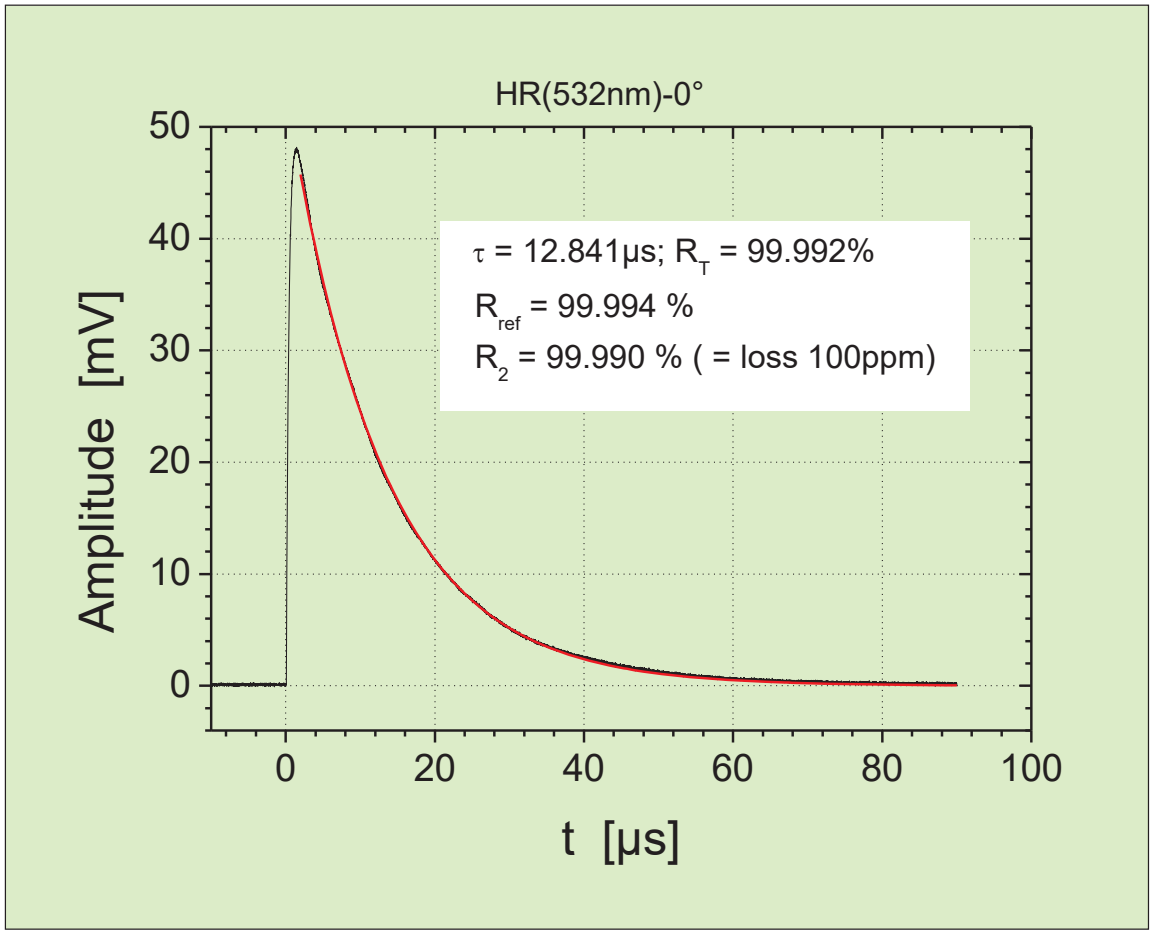
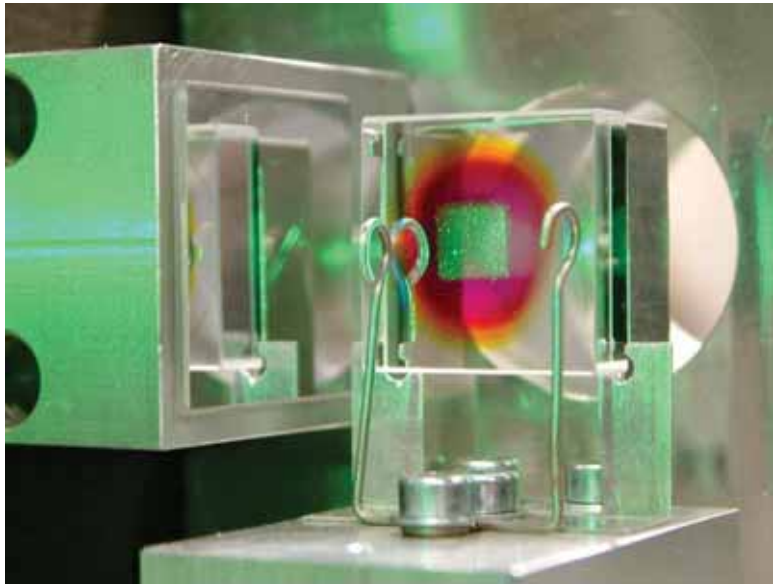
Experimental results



Combining absorption and CRD measurements





LID-measurement:
A (532nm) = 18.8 ppm

From multiple CRD-measurements:
(T+A+S) = 113 ppm

Summary

- **L**aser **I**nduced **D**eflection (LID) allows for highly sensitive direct absorption measurements by using the photo-thermal effect
- Unique electrical calibration procedure provides verified absolute absorption data without knowledge of material parameters/simulations
- Table-top setup with access to all wavelengths if required (laser) power is available (no restrictions to laser beam quality)
- Variety of measurement concepts for different requirements
- Combination with additional measurement techniques (CRD, fluorescence…)

Acknowledgement

- The Federal Ministry of Economics and Technology for financial support within the framework of the Confederation of Industrial Research Associations (projects: “LIDAG-OK” and “Kompakter, gepulster 266nm-Festkörperlaser hoher Leistung und Lebensdauer für die Materialbearbeitung“).

- Numerous partners for their trust in our measurement technique and ongoing new challenges.

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There is also a poster on the topic for more information
and time for discussion!