Optical Absorption

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Symposium OCLA 2017

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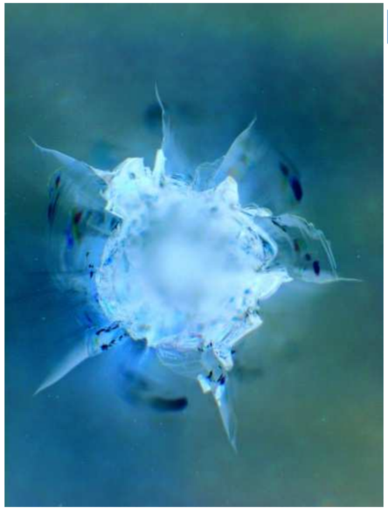
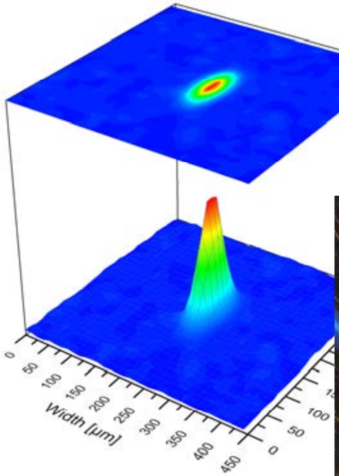
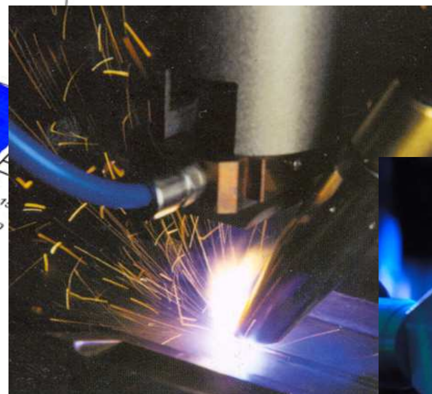
WHAT IS CRITICAL ABOUT ABSORPTION ?



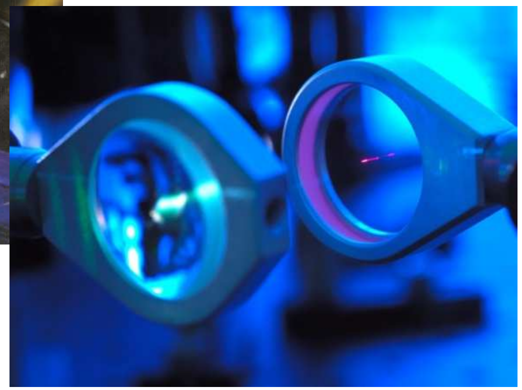
- Laser-induced Damage



- Thermal Lensing / Focal Shift



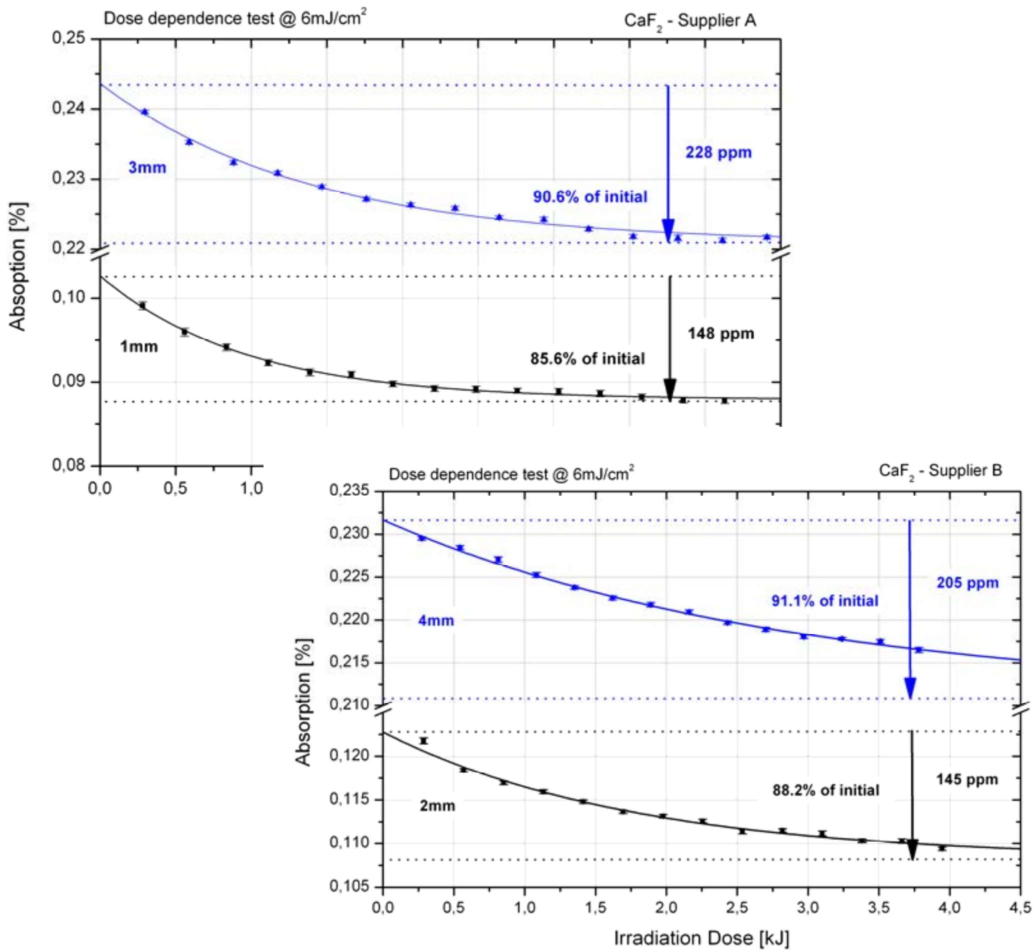
- Long Term Reliability



- Wavefront Deformation

Absorption is not only
ONE constant

193nm – DOSE DEPENDENCE



- exponential data fit (1st order decay)
- dose of 4kJ (20 kJ/cm^2) required for stationary absorption level (within 3% rel.)

[1]I.Balasa, L.Jensen, H.Blaschke, D.Ristau, „Impact of SiO2 and CaF2 surface composition on the absolute absorption at 193nm “, Proc. Of SPIE 8190, 2011

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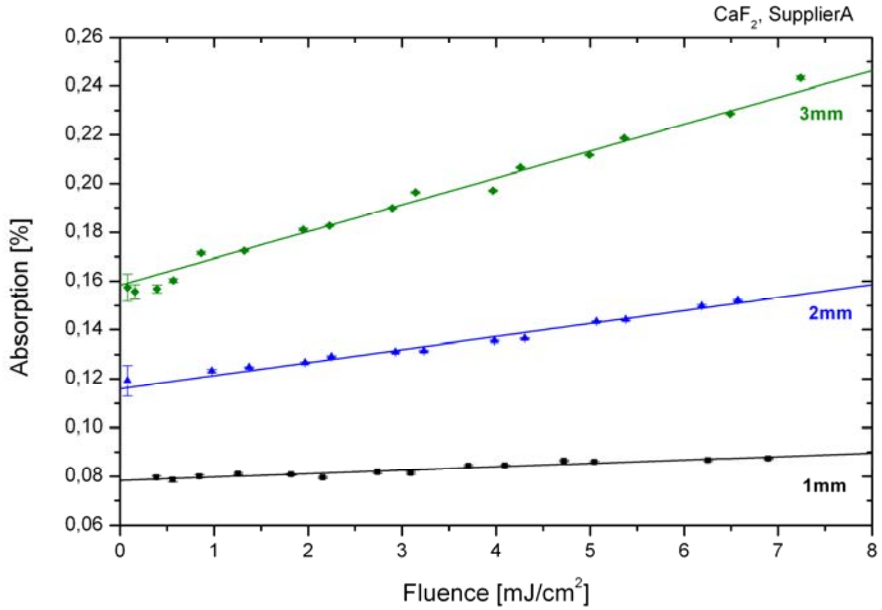
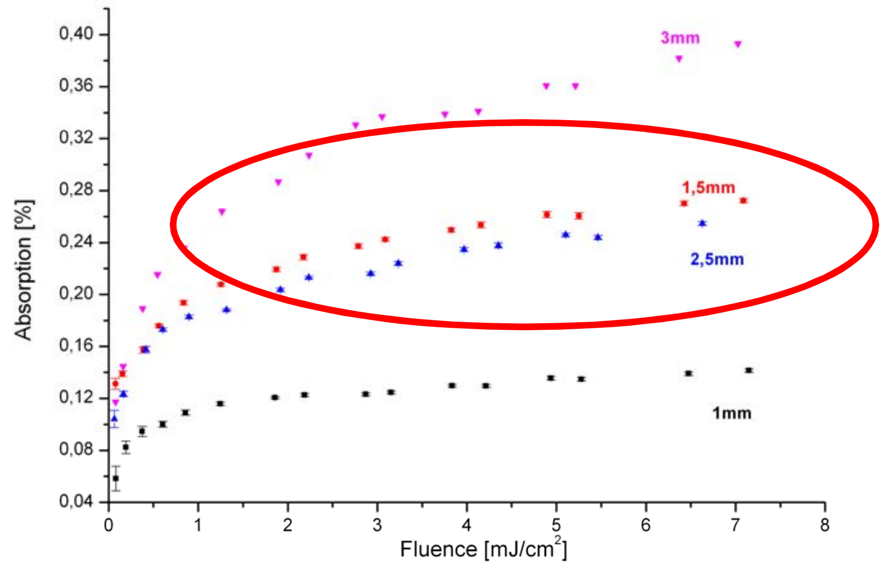
193nm – FLUENCE DEPENDENCE TEST – CaF_2 & FS





- slope of fluence dependence scales linear with sample thickness
- absorption offset scales with sample thickness
- separation of bulk and surface absorption

- nonlinear dependence of absorption in FS at 193nm[1]

[1] C. Mühlig, W. Triebel, S.Kufert, „Coefficients of stationary ArF laser pulse absorption in fused silica (type III)", Journal of non-crystalline solids 353 (2007), p.542-545

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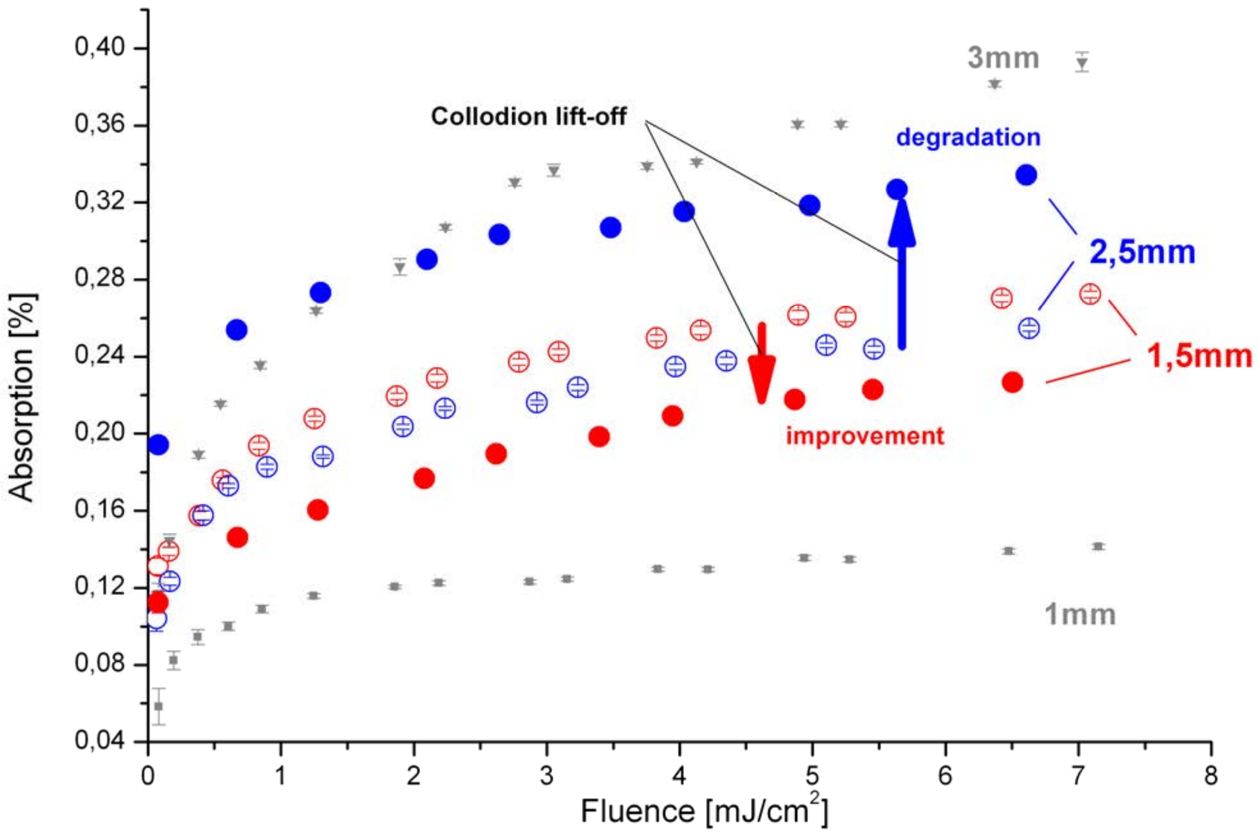
193nm – SUBSTRATE CLEANING



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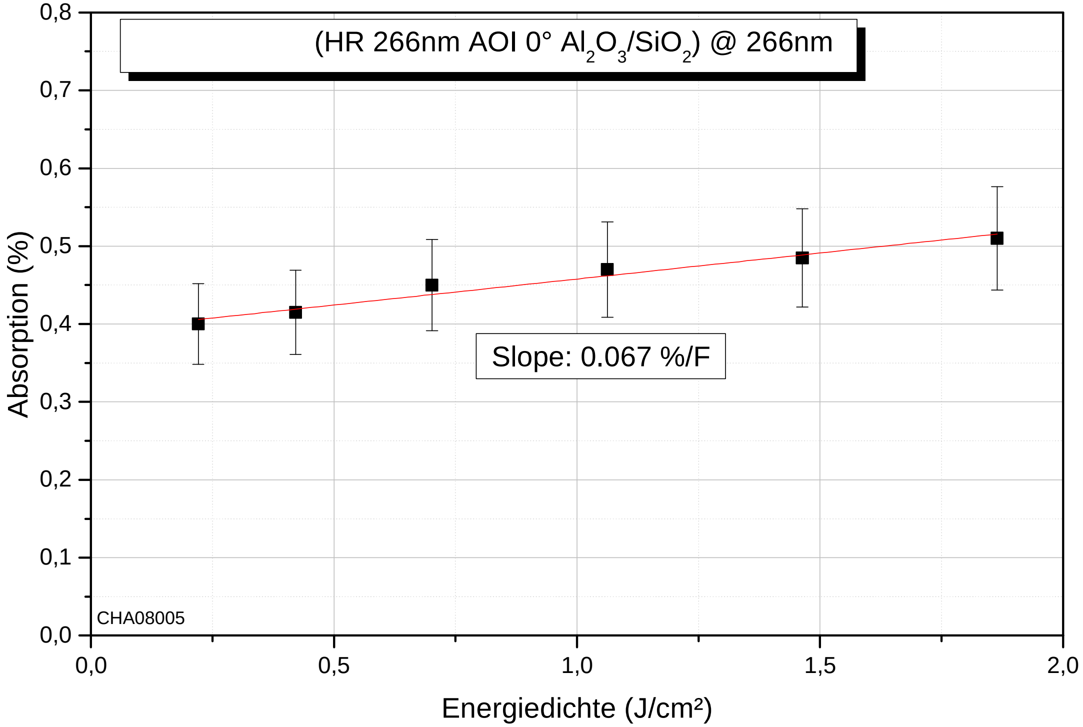
UV - TWO-PHOTON-ABSORPTION IN SiO_2/Al_2O_3

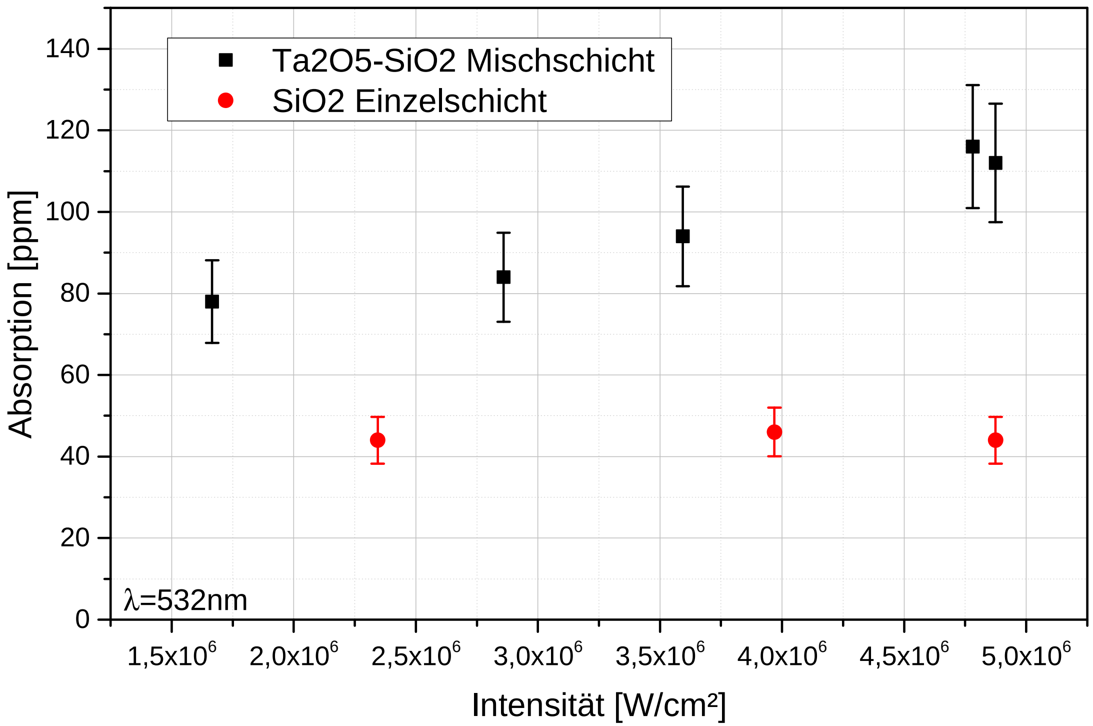
Nonlinear absorption at 266nm?

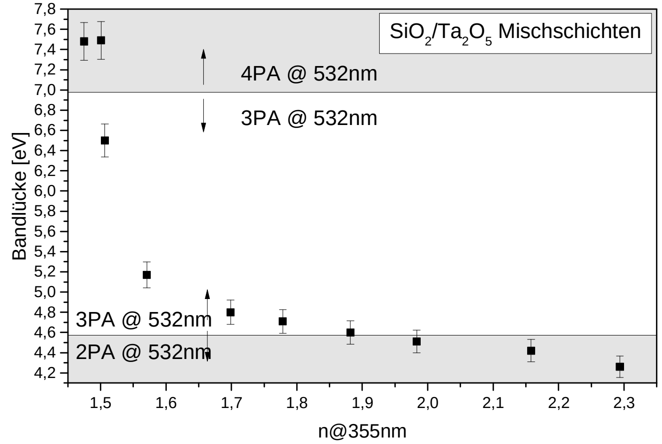
- HR SiO_2/Al_2O_3



L.Jensen, M.Jupé, D.Ristau, “UV Damage Mechanism in Oxide High Reflectors”, Proc. of SPIE 7132, 2008

VIS - TWO-PHOTON-ABSORPTION IN SiO_2/Ta_2O_5





- Nonlinear absorption observed for SiO_2/Ta_2O_5 compound
- Band gap close to two-photon absorption
- ...ance
- ...ers of magnitude
- ...damage initiation

L.Jensen, M.Mende, S.Sc... photon absorption in Ta2... damage", Opt.Lett. Vol. 3...

Short pulse regime:
O. Razskazovskaya, T. T. Luu, M. K. Trubetskov, E. Goulielmakis, V. Pervak, „Nonlinear behavior and damage of dispersive multilayer optical coatings induced by two-photon absorption", Proc. SPIE 9237, Laser-Induced Damage in Optical Materials: 2014, 92370L

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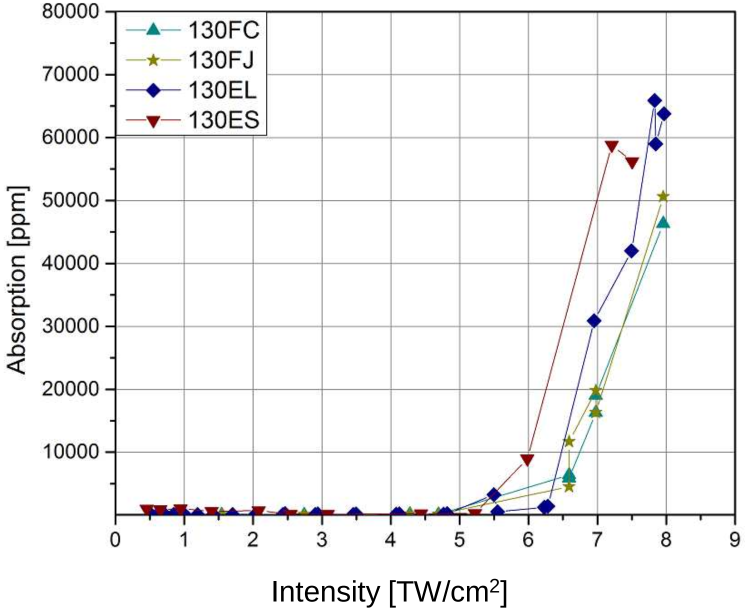
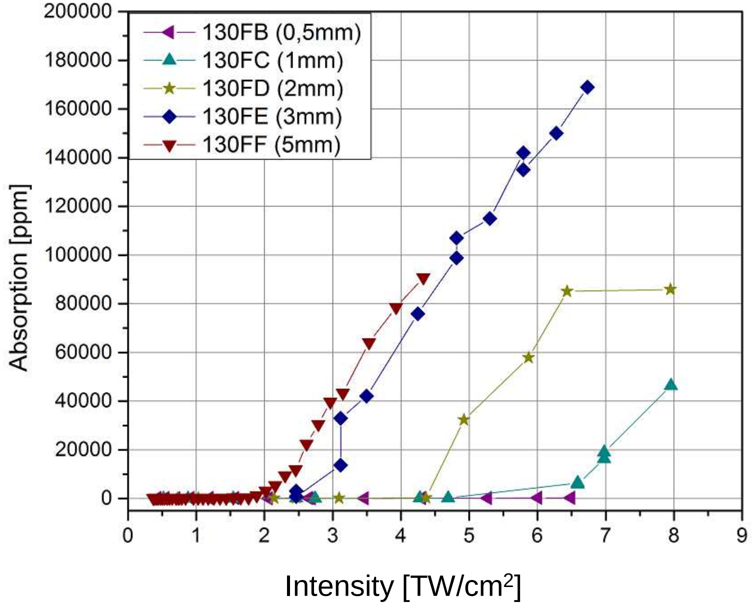
SHORT PULSE DURATION – SUBSTRATE THICKNESS





- band gap energies of different FS materials have minor influence (left)
- strong dependence on substrate thickness
- nonlinear test beam propagation effects (optical Kerr-effect)

$$P_{cr,G} = \frac{3.77}{8\pi n_0} \cdot \frac{\lambda^2}{n_2} \Rightarrow \approx 2\,MW$$ for λ= 800nm in fused silica

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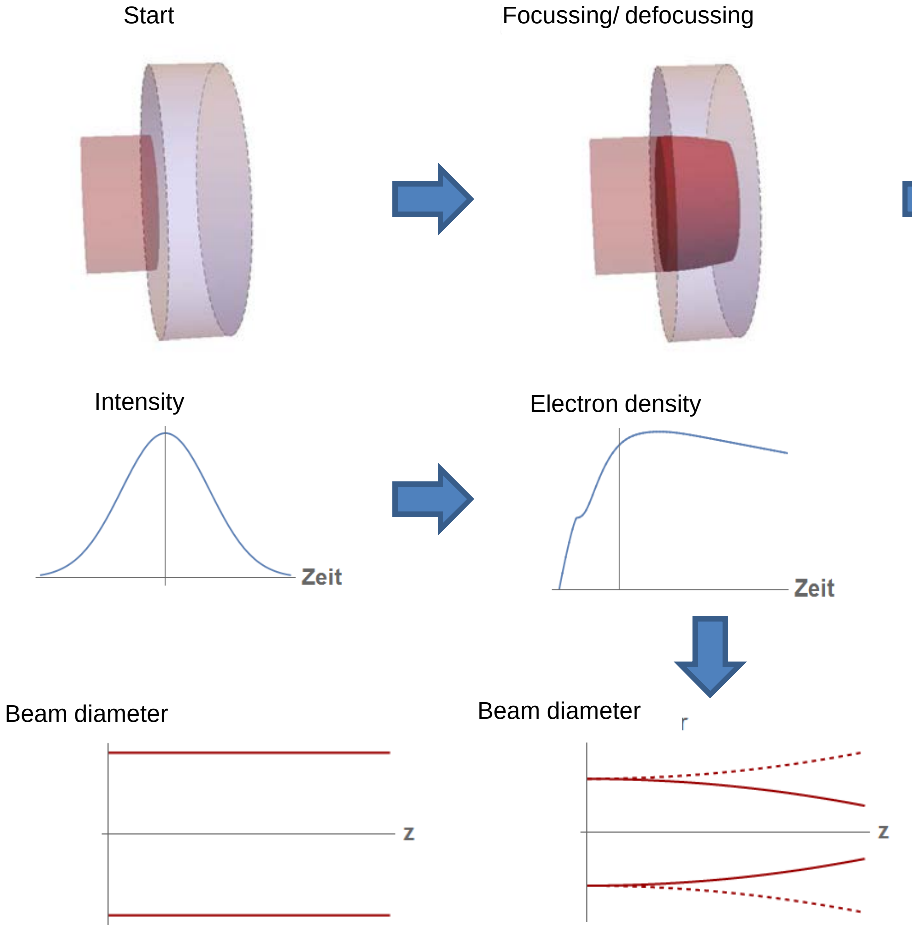
CALCULATION ALGORITHM



$$n_0 \Delta n = n_2 I - \frac{\omega_p^2 \tau_c^2}{2 n_0 (1 + \omega_0^2 \tau_c^2)}$$

- calculation of absorption inside slice

- change of field amplitude

- temporal and spatial intensity profile

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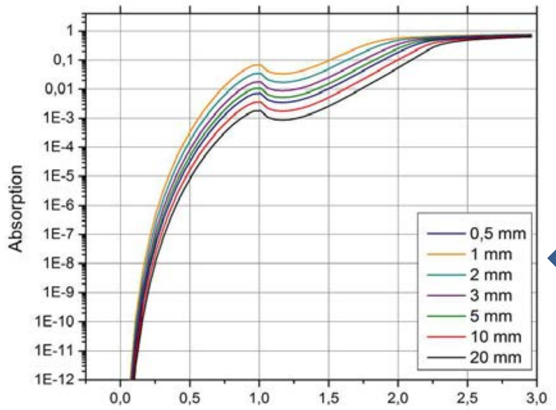
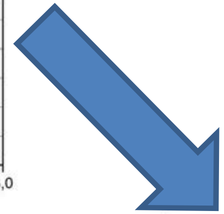
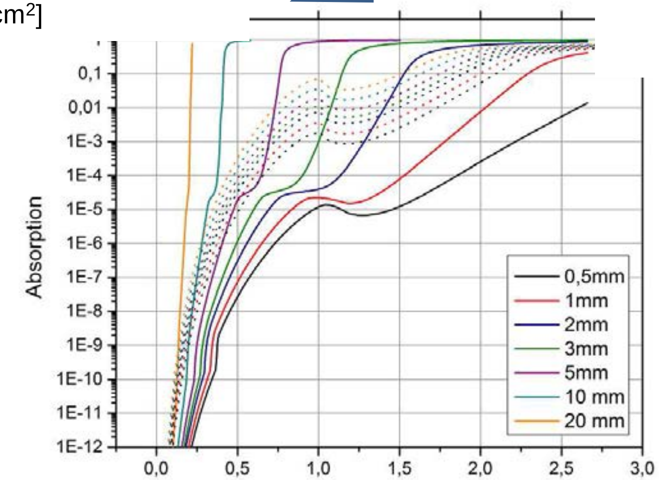
SELF-FOCUSING



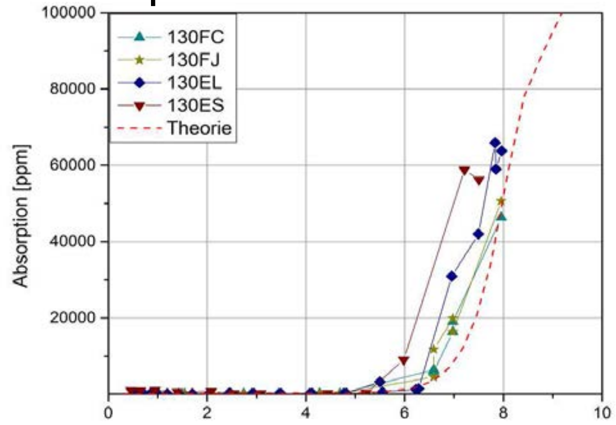
Energy density [J/cm^2]





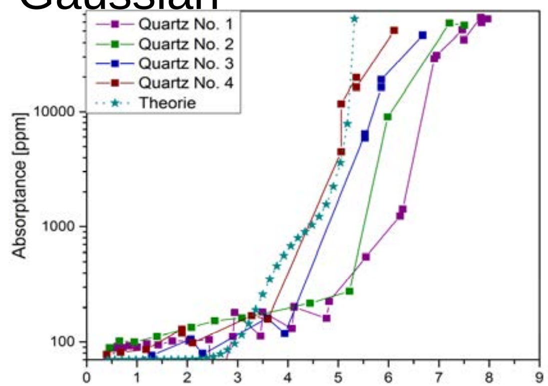
Energy density [J/cm^2]

Flattop



Intensity [J/cm^2]

Gaussian



Intensity [J/cm^2]

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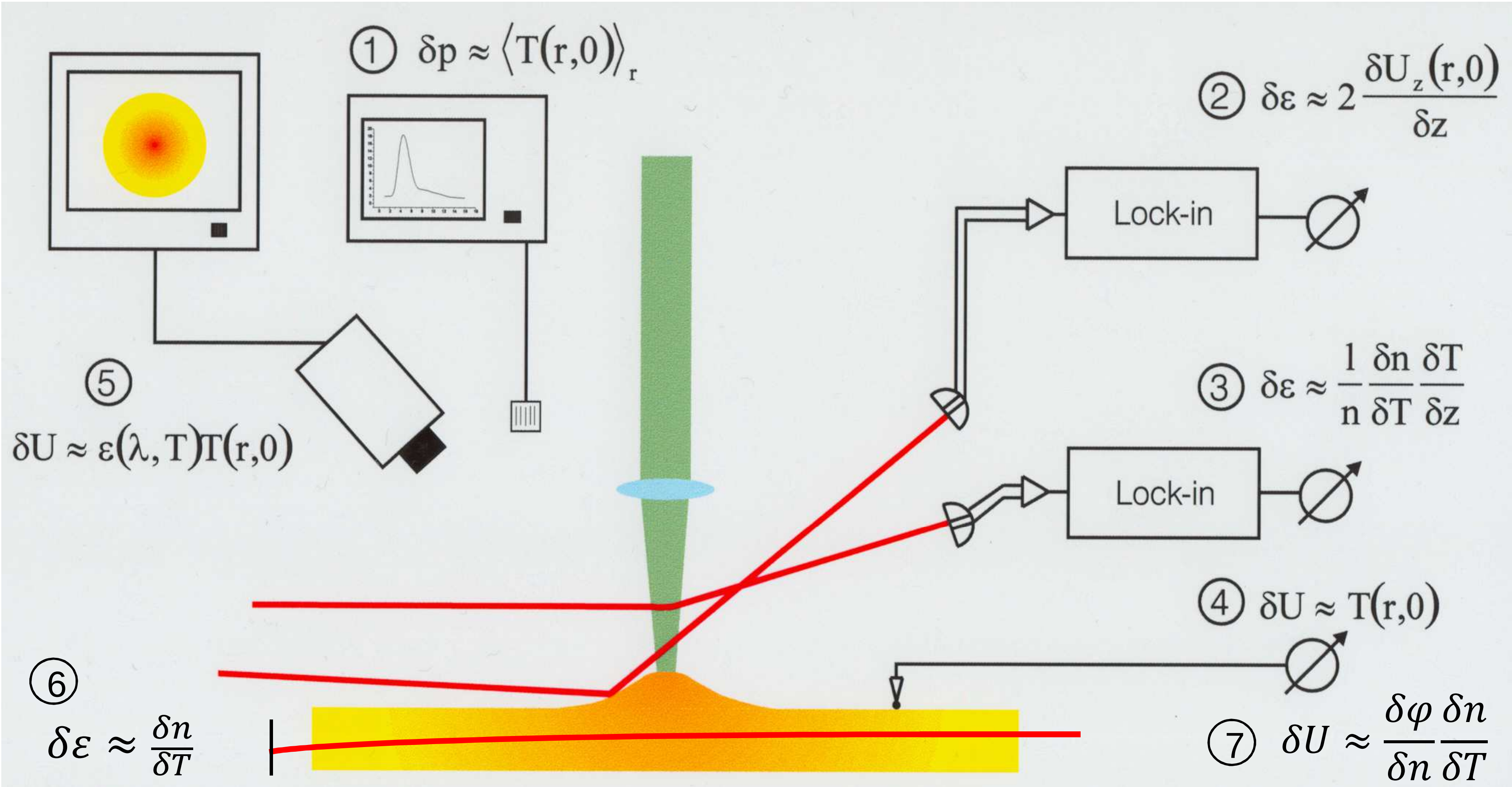
PHYSICAL CHARACTERISTICS IN ABSORBING MATERIALS



TEST METHODS FOR DIFFERENT APPLICATIONS

Phase sensitive methods

- focal shift in lenses
- influence of absorption on imaging quality

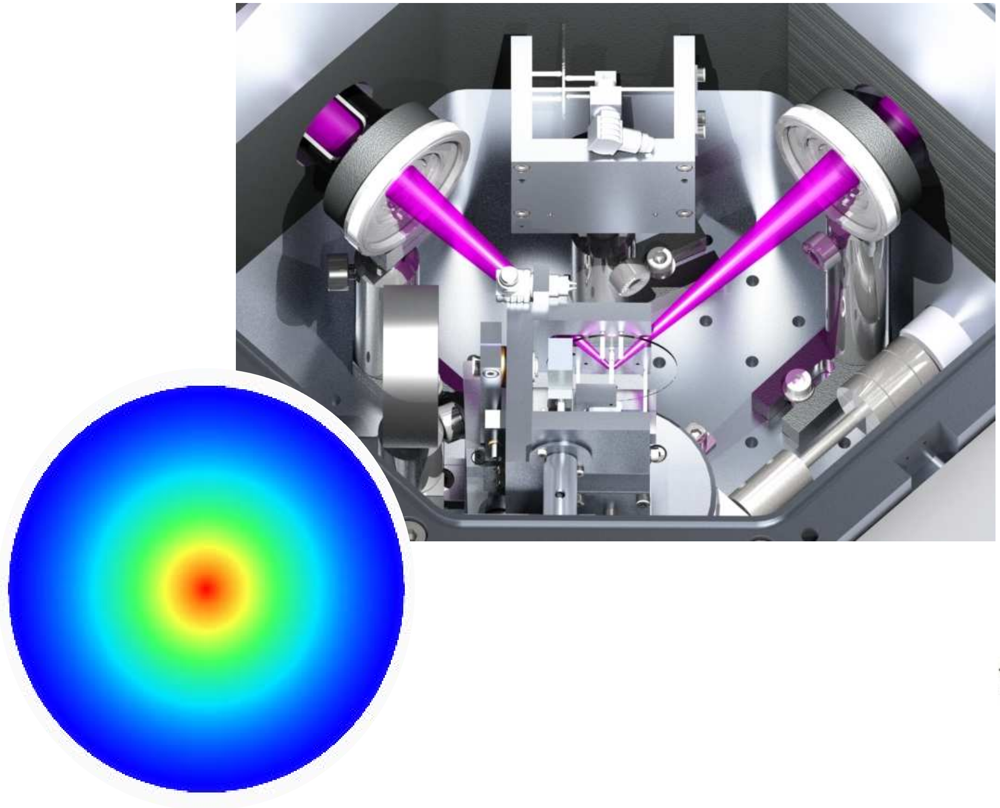
Spatial resolution – deflection methods

- separation of surface and bulk materials
- fast measurements

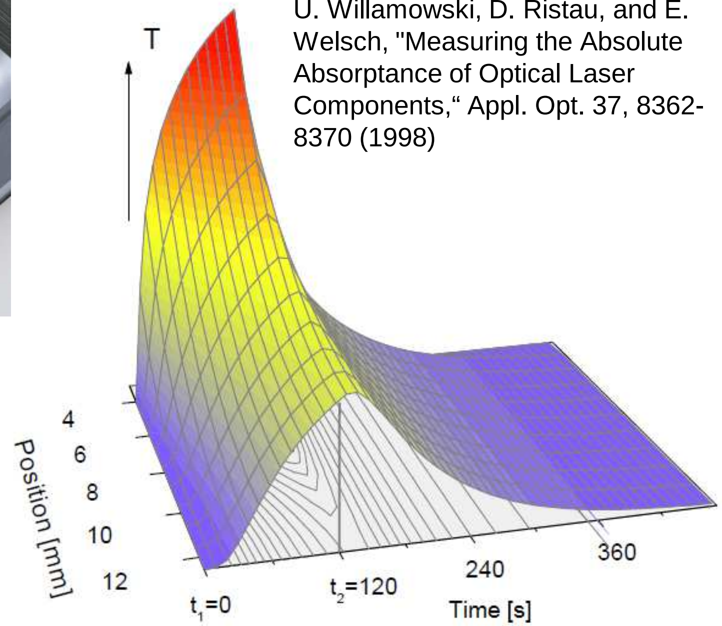
Absolute calibration

- direct measurement of the physical characteristic of interest
- quality assurance
- thin films
- standardized measurement procedure

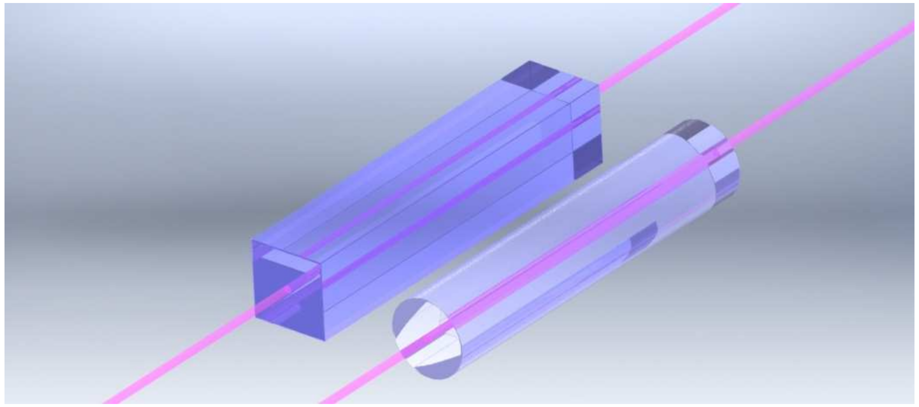
LASER CALORIMETRY – FINITE HEAT CONDUCTIVITY



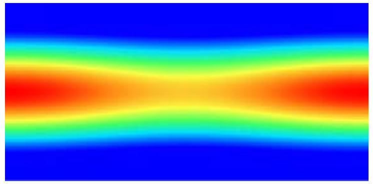
U. Willamowski, D. Ristau, and E. Welsch, "Measuring the Absolute Absorptance of Optical Laser Components," Appl. Opt. 37, 8362-8370 (1998)

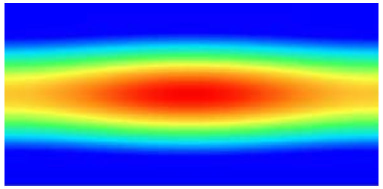


FINITE HEAT CONDUCTION –
COLLINEAR TEMPERATURE DISTRIBUTION

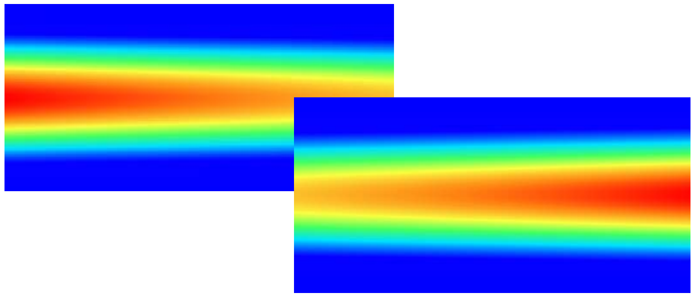


AR





substrates
NLO crystals
„calibration“



SHG, THG, …
TFP
HR
PR

ISO 11551

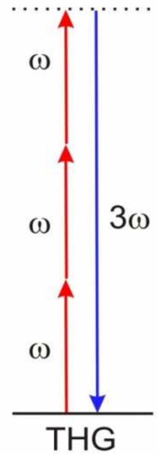
- Standard is currently under revision in working group **ISO TC 172/SC 9/WG 1**
  - Calibration procedures
  - recommendations for UV applications
  - vacuum applications
  - measurement of bulk materials with low cross section-to-thickness-ratio
  - Advanced data evaluation method for arbitrary sample geometries
  - absorption mapping by laser calorimetry

THIRD HARMONIC IN THIN FILMS

Direct Third Harmonic Generation (THG):

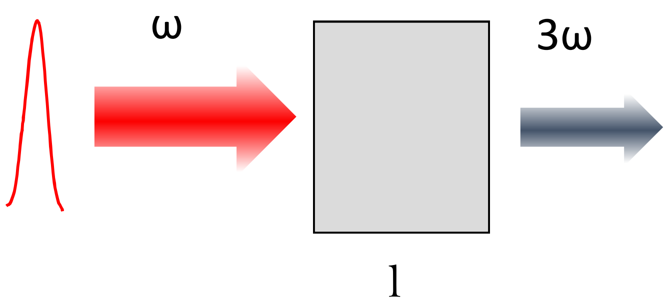
third order nonlinear optical effect

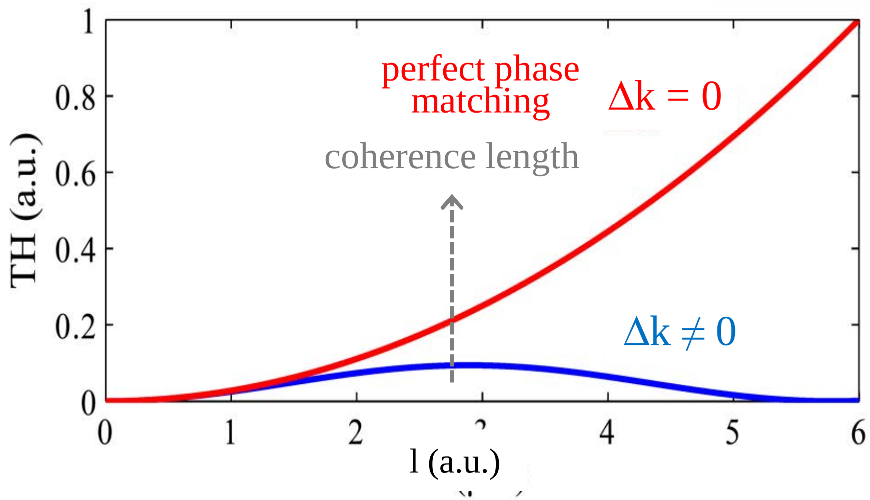
- **THG-efficiency dependent on $\chi^{(3)}$**
- **input intensity I(ω) at fundamental**
- **phase matching Δk**



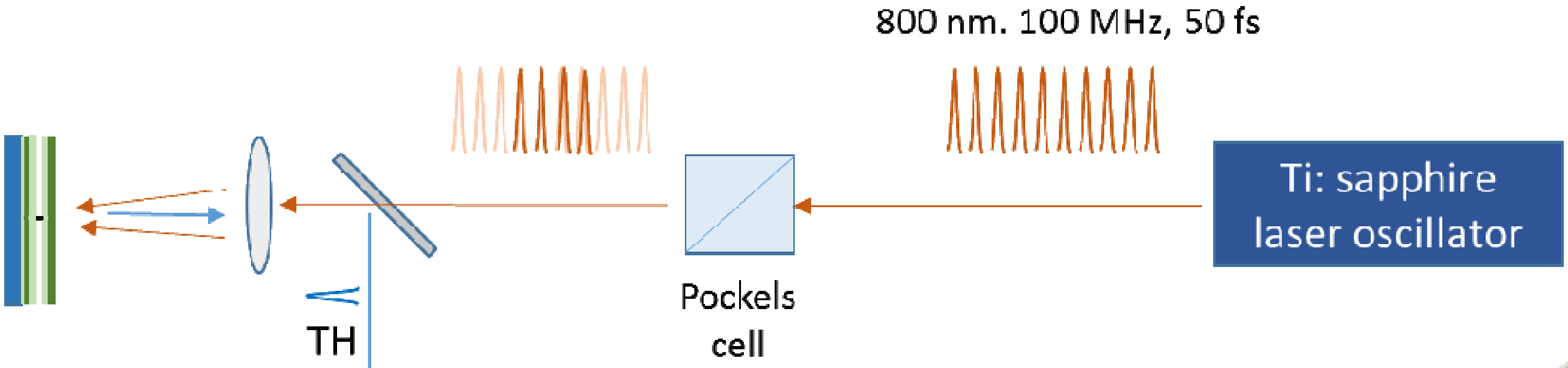
$$\Delta k = k(3\omega) - 3k(\omega) = \frac{3\omega}{c_0} n_{3\omega} - \frac{3\omega}{c_0} n_\omega$$

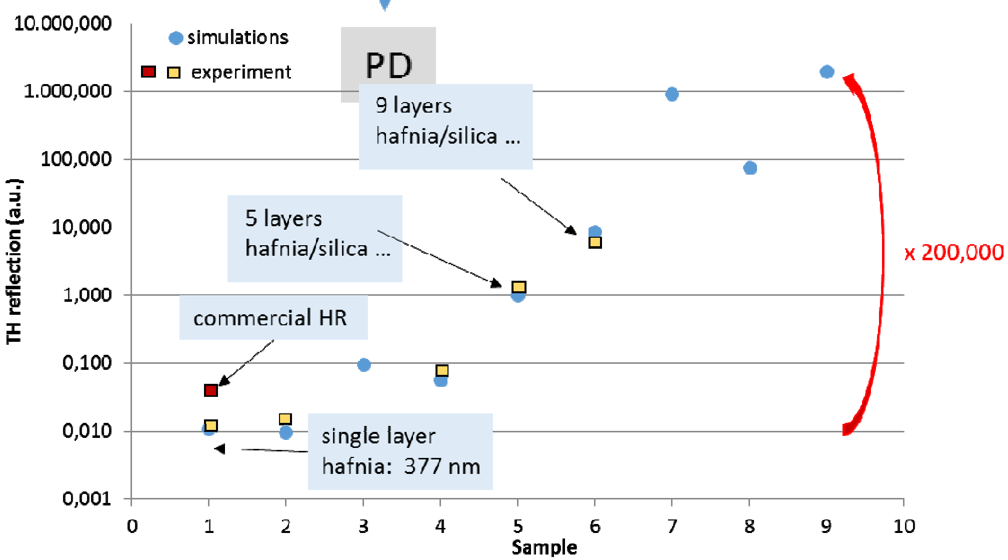
$$I(3\omega, l) = \left\{ \frac{3\omega \chi^{(3)}(3\omega)}{4 n_1 n_3 {c_0}^2 \varepsilon_0} \right\}^2 l^2 I^3(\omega)\, \mathrm{sinc}^2 \left\{ \frac{\Delta k l}{2} \right\}$$

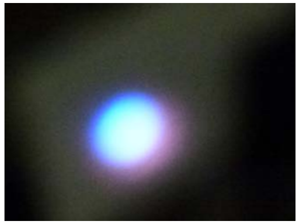


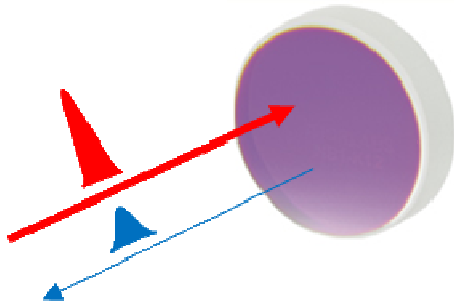


THG IN FILMS - RESULTS









Observed:

0.5% – 1% at 0.16 J/cm^2

(limited by Ti:sapphire oscillator)

Expected:

10% – 15%

THANK YOU FOR YOUR ATTENTION.

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