Photothermal deflection measurements in optical materials at 355 nm

OCLA 2021

Heidi Cattaneo

Institute for Microtechnology and Photonics / Optical Systems Manufacturing

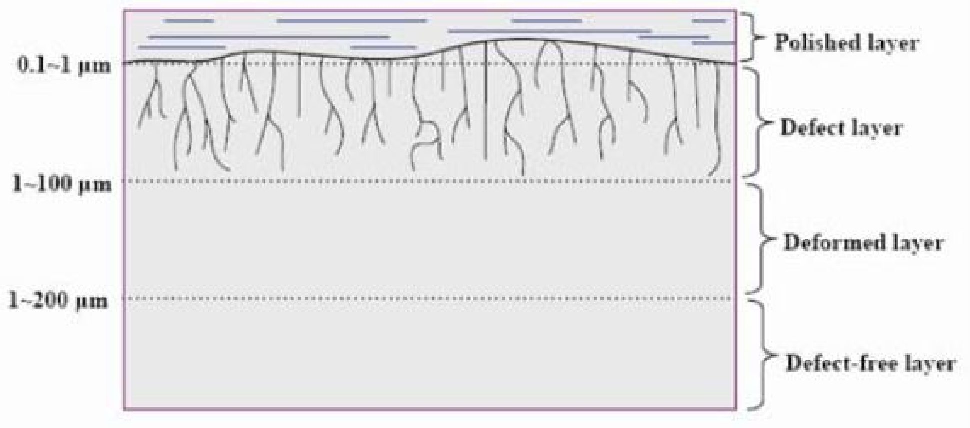
OST Ostschweizer Fachhochschule

Subsurface damage in optical materials

- Origin and forms of SSD:
  - Manufacturing steps, surface pretreatment, coating process, handling, material inhomogeneities, impurities,…
  - Cracks, contamination, sub-stoichiometry and other flaws in coatings

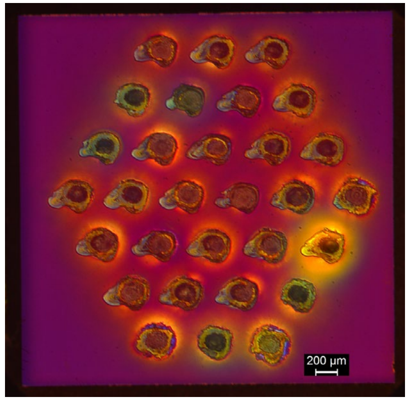
➡ Local variations in material properties

- Consequences of SSD
  - Local changes in absorption and scattering, electric field and light intensification
  - Premature degradation, reduced resistance for laser induced damage



Residual cracks in optical materials

J. Wang et al., J. Eur. Opt. Soc. – Rapid Pub., Vol. 6, 11001, 2011.



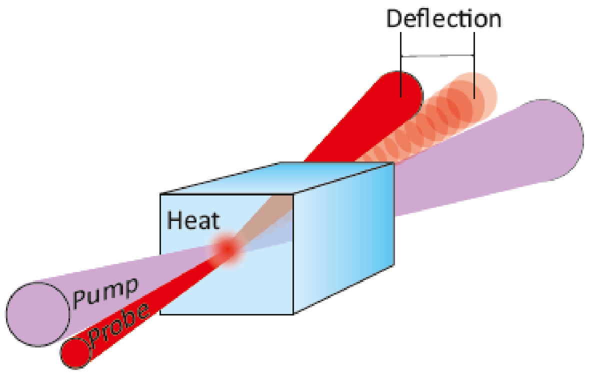
Microscope image of a sample after LIDT

Photothermal deflection

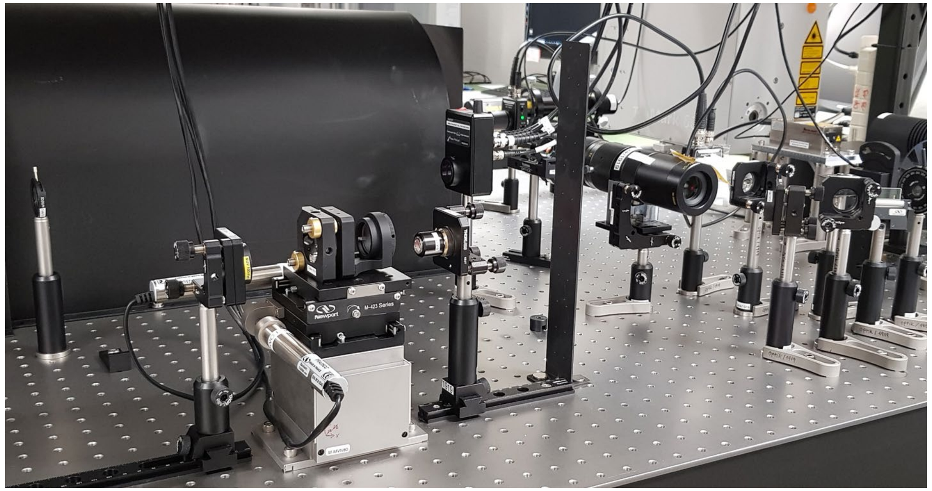
- Measurement principle:
  - Nonlinear pump-probe experiment
  - Based on absorption related changes in the material

    Absorption ➡ local heating ➡ T gradient ➡

    local refractive index gradient & surface displacement
  - Measurement signal: Probe beam deflection (defocusing, interference and polarization effects)
  - Detection scheme: transmission
- Parameters that effect PTD signal:
  - Laser parameters (P_{pump}, P_{probe}, d_{pump}, d_{probe}, f_{pump}, λ_{pump})
  - Thermal and optical properties of the sample (κ, ρ, α_{abs}, α_T, $V_{particle}$, dn/dT)

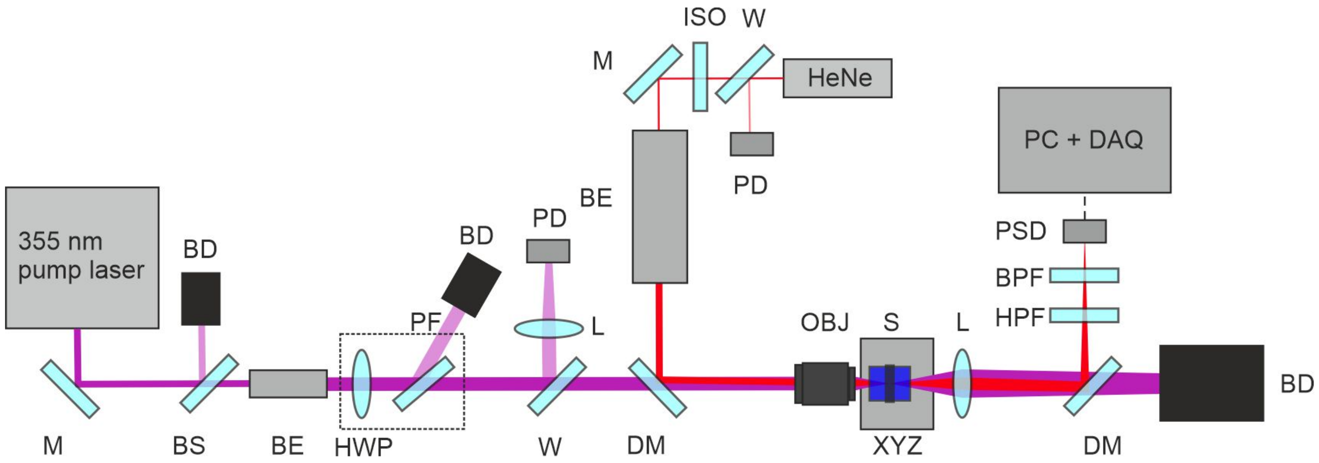


Photothermal deflection



Setup

- Pump lasers at 355 nm (P_{ave} max 5 W; f 20 kHz; τ_p 10 ns) & 375 nm (DL 70 mW; cw; analog modulation)
- Probe laser: stabilized HeNe-laser (1 mW; cw)
- Focusing through same achromatic objective (d ~ 10 - 20 µm)
- Scanning of the sample: XYZ translation stages (sub-µm resolutions)
- Detection with quadrant photodetector, Outputs: SUM (transmission), X and Y (DC and AC deflection)
- Resolutions: Transmission: d_{spot}/ Z_R; PTD: < 2.5 µm/ 25 µm



PTD results: Variations in T and UV absorption mappings

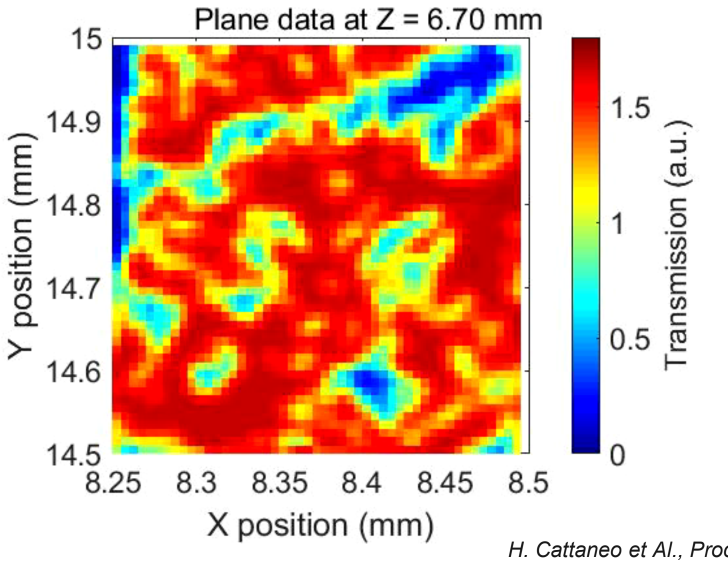
SSD as cracks in optical substrates

- Transmission (SUM): Cracks already visible as reduced transmission
- PTD (X/Y AC): «0»-signal inside a crack, beam deflection on crack wall

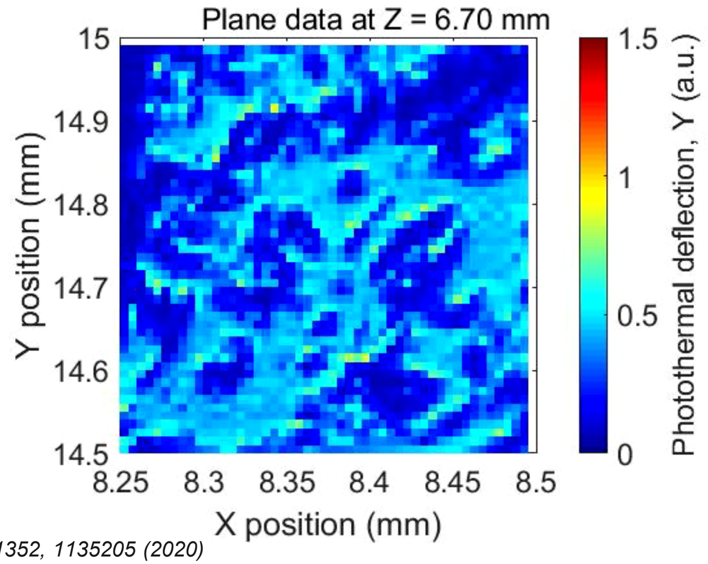
Example:

Nbk-7 substrate, (500 µm)^2 area, 25 µm scanning step in z, 5 µm lateral, P_{UV} ~ 60 mW

PTD signal: SUM (Transmission)



PTD signal: Y deflection (normalized)



H. Cattaneo et Al., Proc. SPIE, Vol. 11352, 1135205 (2020)

PTD results: #2

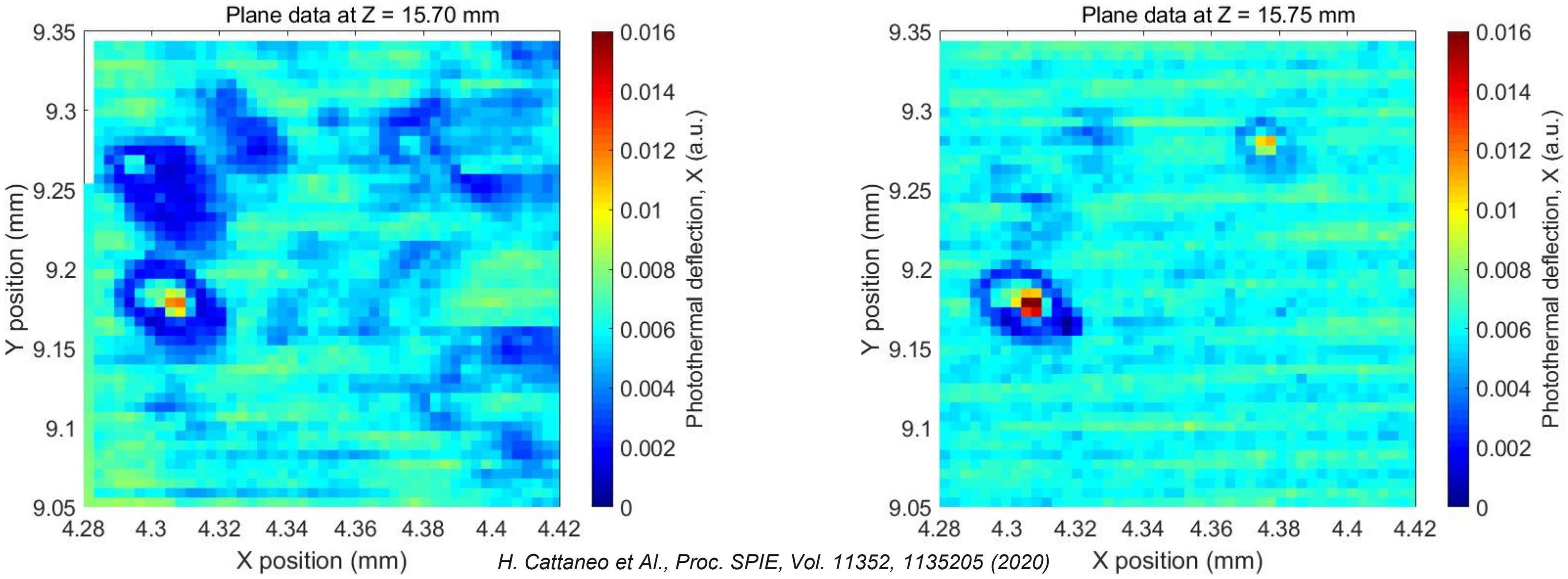
SSD as inhomogeneities and contamination

- Transmission (SUM): changes in optical properties (scattering sites, dust particles,…)
- PTD (X/Y AC): Material inhomogeneities, contamination visible as peaks

Example:

Uncoated LBO crystal, (150 μm)^2 area, 5 μm step, P_{UV} ~ 200 mW

PTD signal 50 μm below surface *PTD signal at surface*



H. Cattaneo et Al., Proc. SPIE, Vol. 11352, 1135205 (2020)

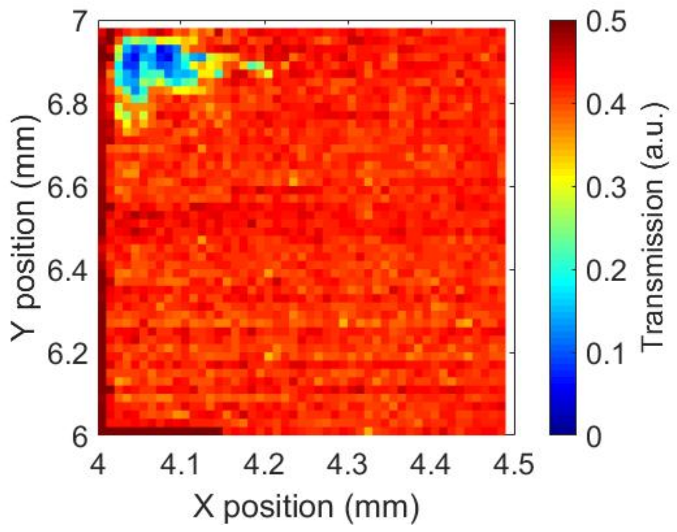
PTD results: #3

SSD as coating failure

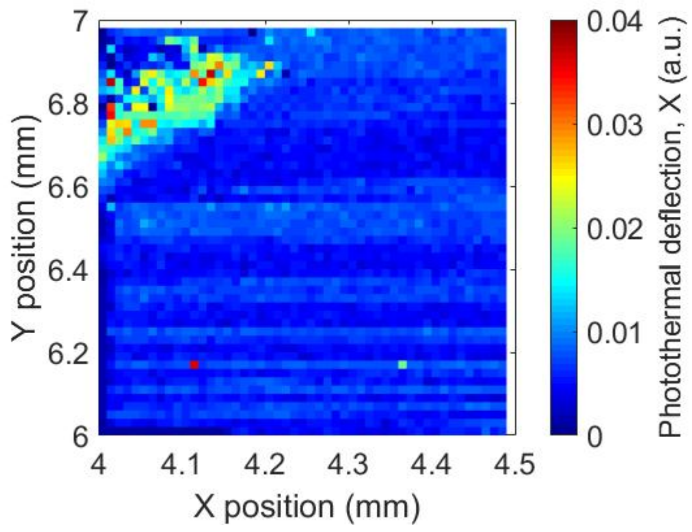
- Transmission (SUM): coating failure as reduced transmission
- PTD (X/Y AC): «Damage front»

Example: Coated LBO crystal, $(500\ \mu m)^2$ measurement area, 10 µm step size, $P_{UV} \sim 20$ mW

PTD signal: SUM (transmission)



PTD signal: X deflection



H. Cattaneo et Al., Proc. SPIE, Vol. 11352, 1135205 (2020)

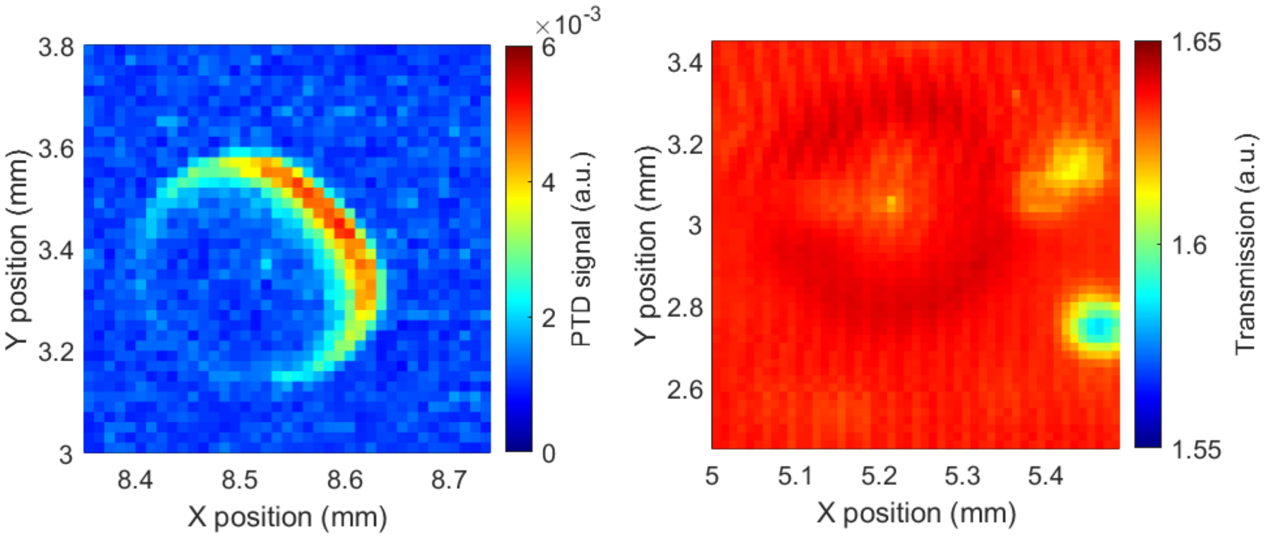
PTD results: #4

SSD as material changes under LIDT sites

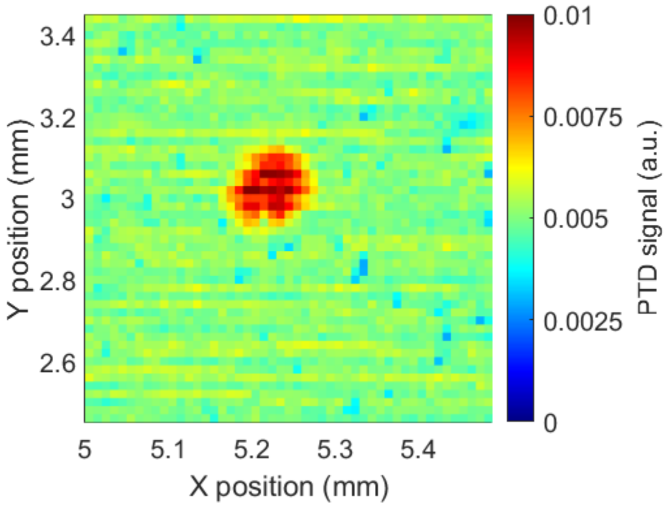
- Transmission (SUM): LIDT as reduced transmission, coating changes / delamination as increased transmission
- PTD (X/Y AC): material changes (e.g. density)

Example: Coated FS substrate, (400 - 500 µm)^2 measurement area, 10 µm step size, P_{UV} ~ 400 mW

PTD signal: Y deflection / transmission, 200 µm below the surface



PTD signal: Y deflection, 100 µm below the surface



OST

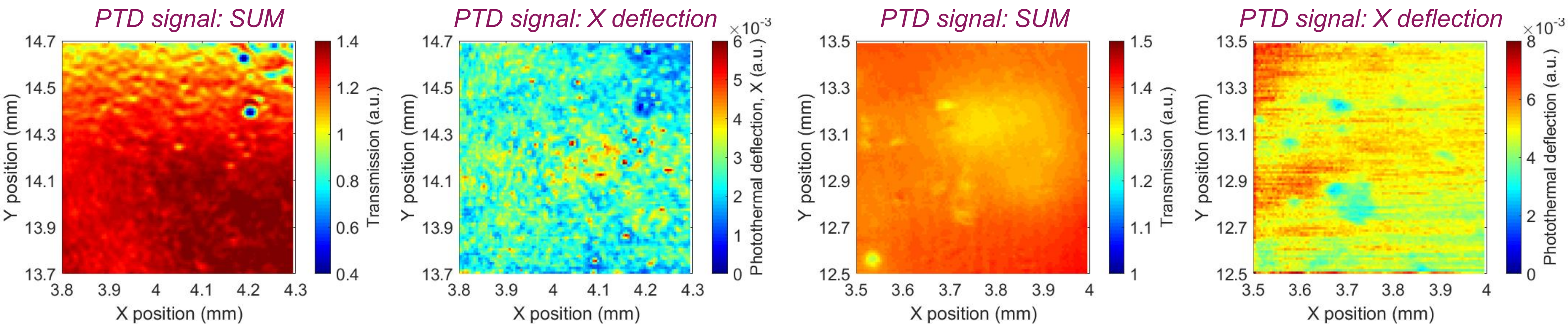
PTD results: #5

SSD as material inhomogeneities / effect of surface pretreatment

- Transmission (SUM): variations in transmission due to surface roughness
- PTD (X/Y AC): granular structure visible as local variations in absorption

Example: uncoated ion-beam milled LBO crystal, $(500\ \mu m)^2$ measurement area, 5 µm step size, $P_{UV} \sim 200$ mW

Ion-beam milling of 20 µm: Ion-beam milling of 1.5 µm:



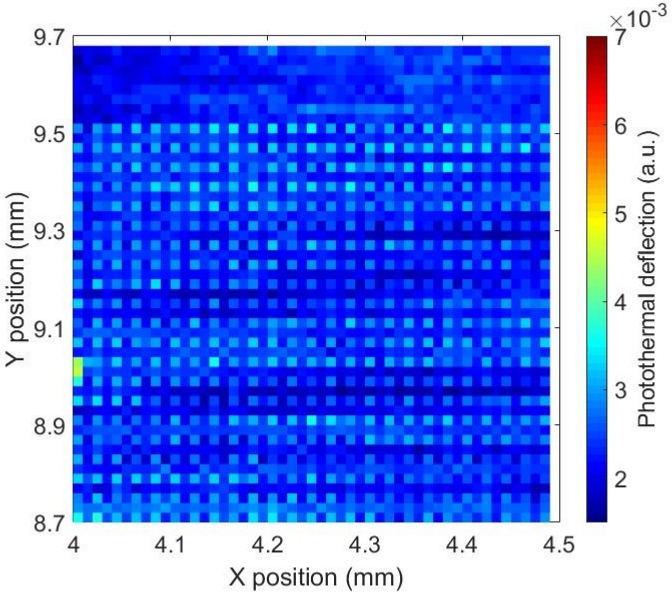
H. Cattaneo et Al., Proc. SPIE, Vol. 11352, 1135205 (2020)

PTD results: #6

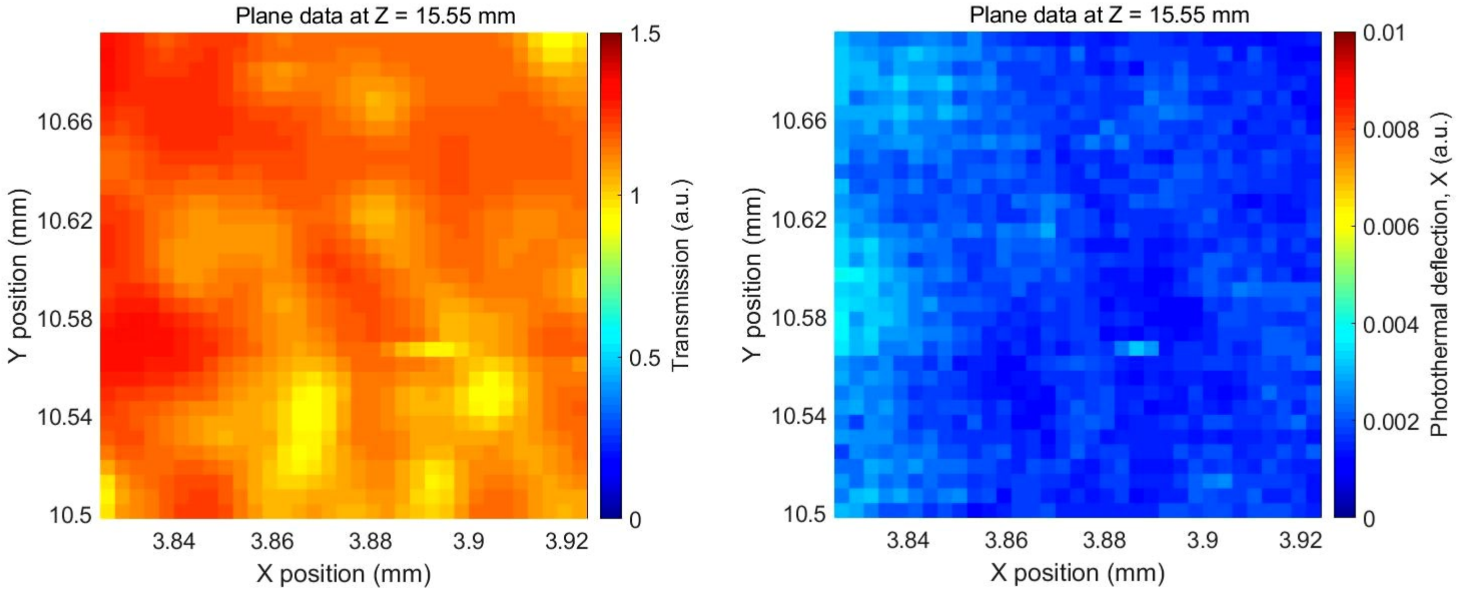
Other effects in materials due to UV absorption

- Enhanced absorption in non-linear materials:
  - Two-photon absorption in the UV region & creation of meta-stable states
- UV-enhanced stresses and surface cleaning

Locally increased absorption in LBO



Surface cleaning in LBO (transmission / photothermal deflection)



H. Cattaneo et Al., Proc. SPIE, Vol. 11352, 1135205 (2020)

Photothermal deflection measurements in optical materials at 355 nm

- SSD in optical materials
  - Origins from manufacturing and handling steps
  - Cracks, contamination, material inhomogeneities,…
  - Effects the life time and damage resistivity of the material
- Photothermal deflection in transmission configuration
  - Sensitive, capable for high resolution
  - Transmission and PTD scans can be measured simultaneously
- Assignment of different types of SSD
  - Variations in transmission mapping: cracks, other scattering sites, surface inhomogeneities
  - Variations in UV absorption mapping: thermo-optical inhomogeneities, contamination, damage front in coatings

Acknowledgements

Special thanks to:

- Innosuisse for financial support
- Project partners:
- Collegues at OST and RhySearch

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Innosuisse - Schweizerische Agentur
für Innovationsförderung

OPTICS BALZERS

evatec process systems

Thank you for your attention!

OST
Eastern Switzerland
University of Applied Sciences
IMP | Institute for Microtechnology
and Photonics