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APPLICATION OF OPTICAL COHERENCE TOMOGRAPHY TO MONITORING OF LASER ABLATION OF VARNISH

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Motivation

The protective varnish layer must be removed, if it has turned yellow or opaque, or it covers old, darkened retouching which are to be removed during the conservation process.

foto: Ludmiła Tymińska-Widmer

Varnish removal from wooden polychrome

Reaction of varnish (Winsor & Newton Matt Varnish) and underlying paint layer to different laser fluences

E = 1.1 J/cm^2

E = 1.45 J/cm^2

E = 1.65 J/cm^2

E = 1.7 J/cm^2

E = 1.85 J/cm^2

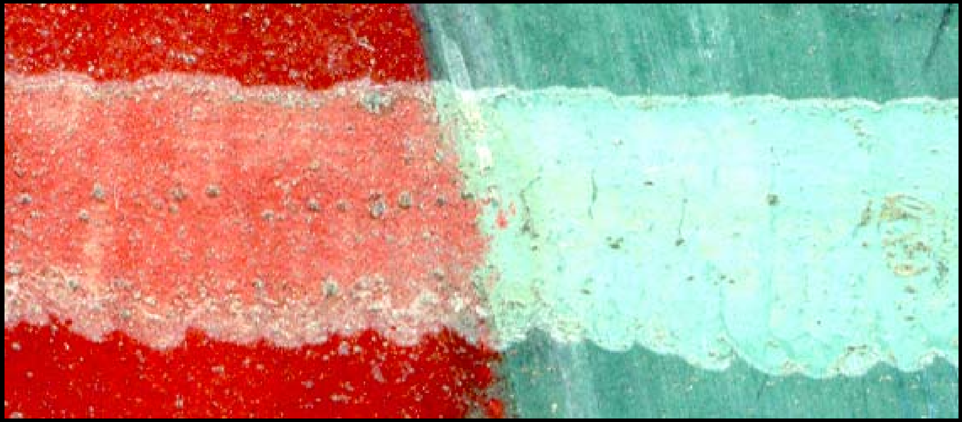
E = 2.1 J/cm^2

The magnitude of laser fluence (E) is crucial in laser ablation. It is determined by changing the pulse energy or irradiation spot size.

Er:YAG laser, λ=2.936 μm

Varnish removal from wooden polychrome

Reaction of varnish (Winsor & Newton Matt Varnish) with different underlying paint layers to the same fluence

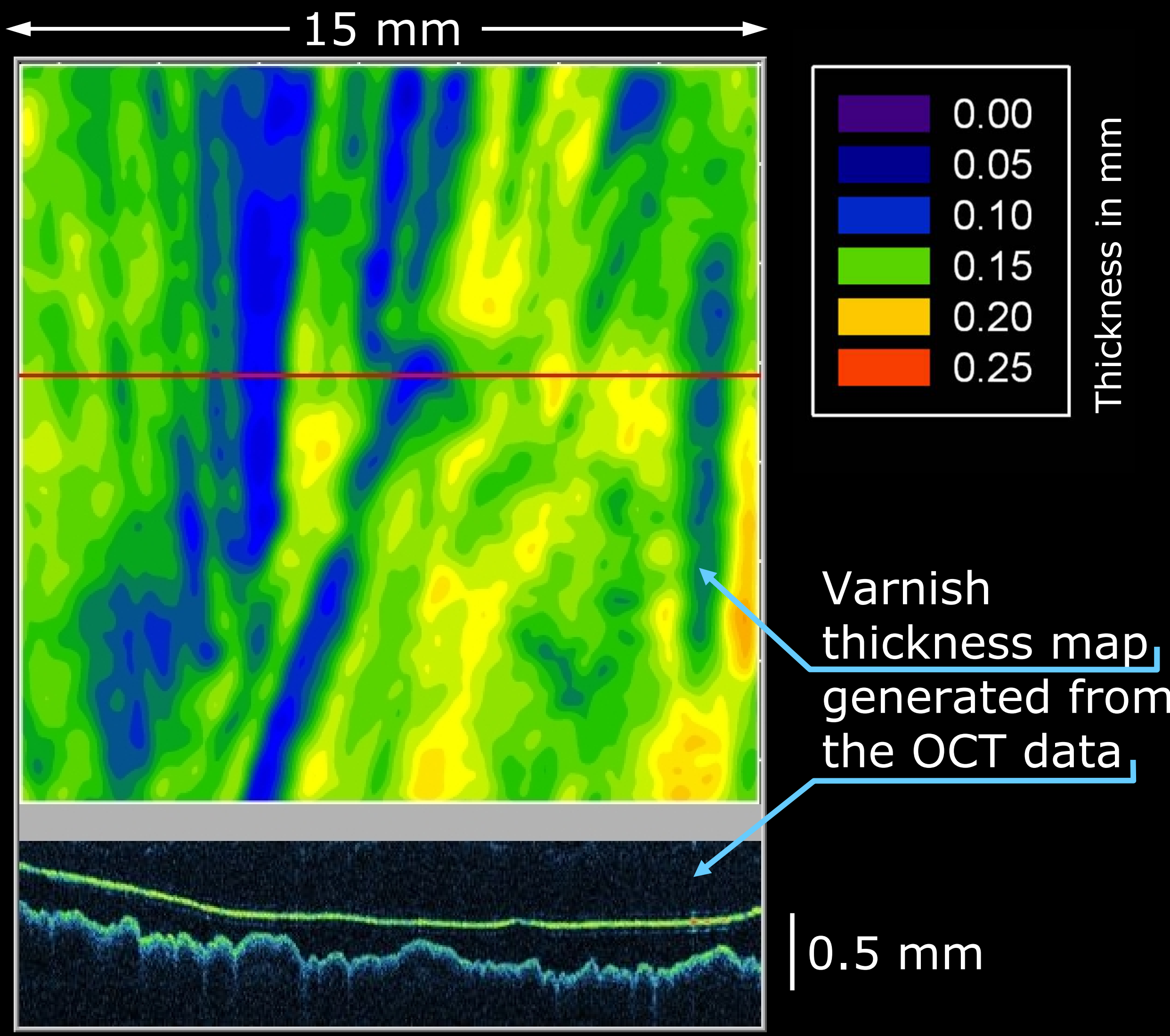


$E = 1.7\ J/cm^2$

Each part of the art work should be treated individually

Er:YAG laser, λ=2.936 μm

Imaging of the varnish layer with OCT



Varnish layer is very inhomogeneous

Why varnish ablation is a difficult task?

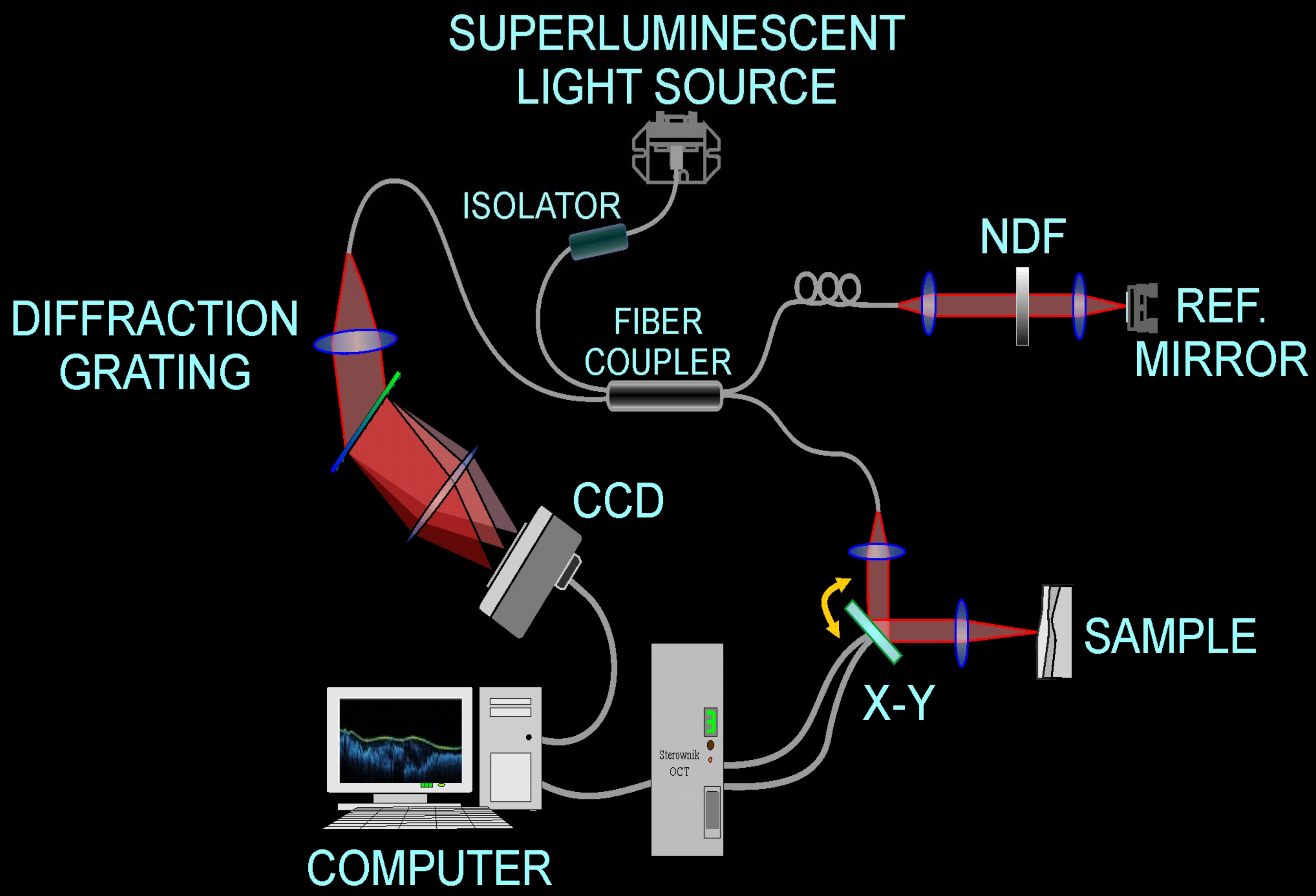
Expectations towards the ideal monitoring tool:

Fast and simple fluence determination

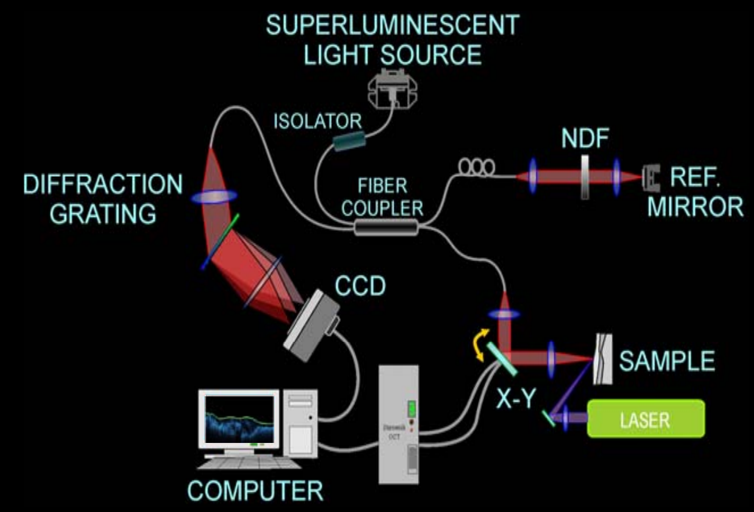
Ability to control the ablation process *on-site*, in real time

Ability to monitor partial removal of varnish layer

The SOCT instrument

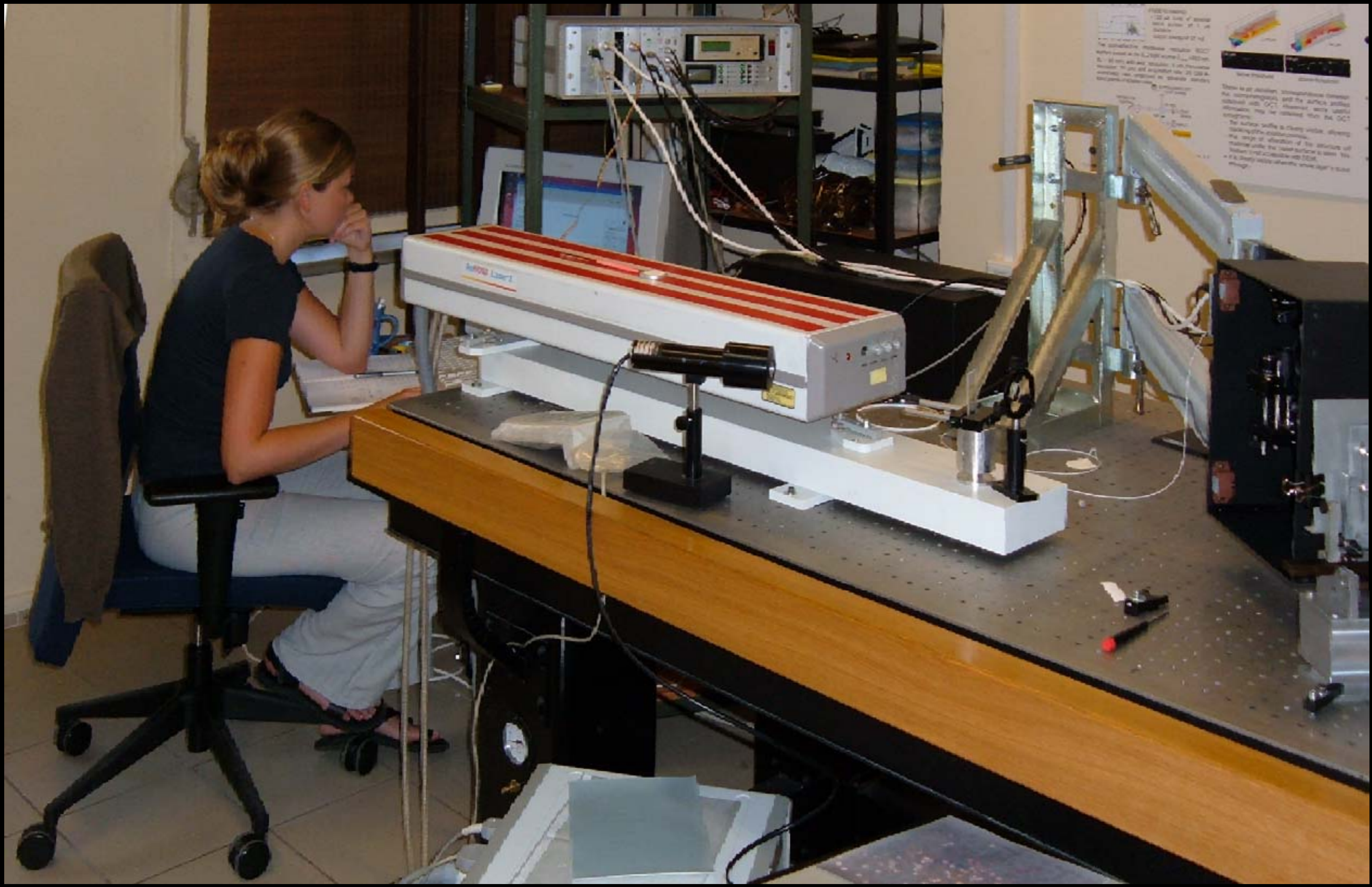


The SOCT instrument



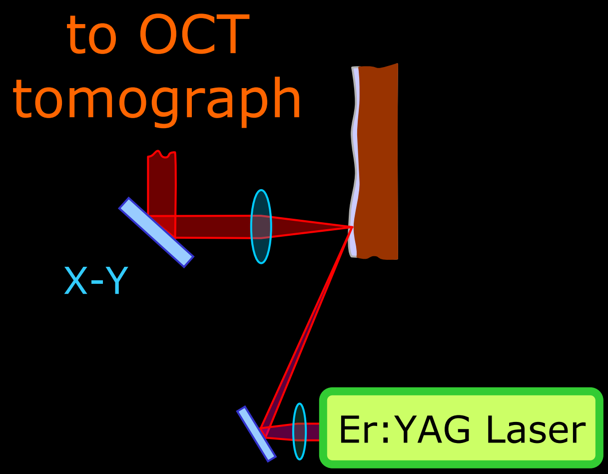
- Central wavelength: 840 nm
- Bandwidth (FWHM): 50 nm
- Very low irradiation: 200 – 800 μW
- Axial (in-depth) resolution
  Δz = 9 μm in media
- Transverse resolution Δx ~15 μm
- Sensitivity: 108 dB
- A/D conversion: 12 bits
- Acquisition rate:
  - 40 μs/A-scan
  - 0.2 s / 2D image (cross section, 5000 A-scans)
  - OCT movie: 16 frames/s x 1200 A-scans
  - real time monitoring: 2 frames/s x 200 A-scans

The SOCT instrument



Lasers used in this study

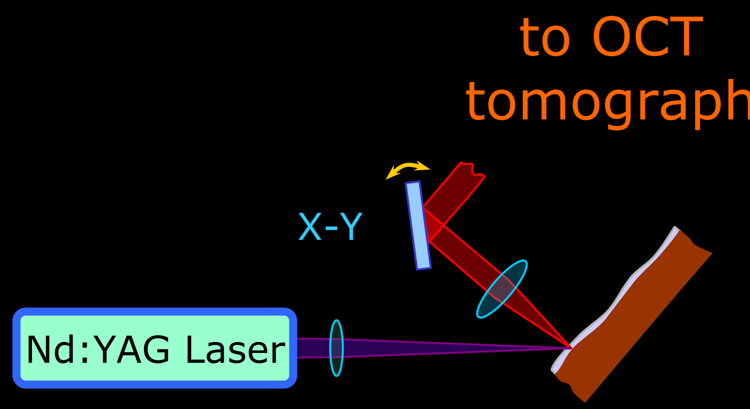
Er:YAG laser
$\lambda = 2.936\ \mu m$



Short free running mode:

- several impulses (about 1 μs each) of free generation
- total time of the burst ≤ 80 μs
- output energy ≤ 80 mJ
- 2 pulses/sec

Nd:YAG laser, 4th harmonics
$\lambda = 0.266\ \mu m$



Q-switched :

- model: ReNOVALaser 5
- pulse duration = 10 ns
- output energy ≤ 120 mJ
- energy used = 10 ÷ 70 mJ
- 2 ÷ 8 pulses/sec

How OCT may be used for this task?

Step 1: Intodoctory – post-process analysis of the ablation crater:

- treshold fluence
- ablation rate

Step 2: Treatment planning - post-process analysis of varnish removal

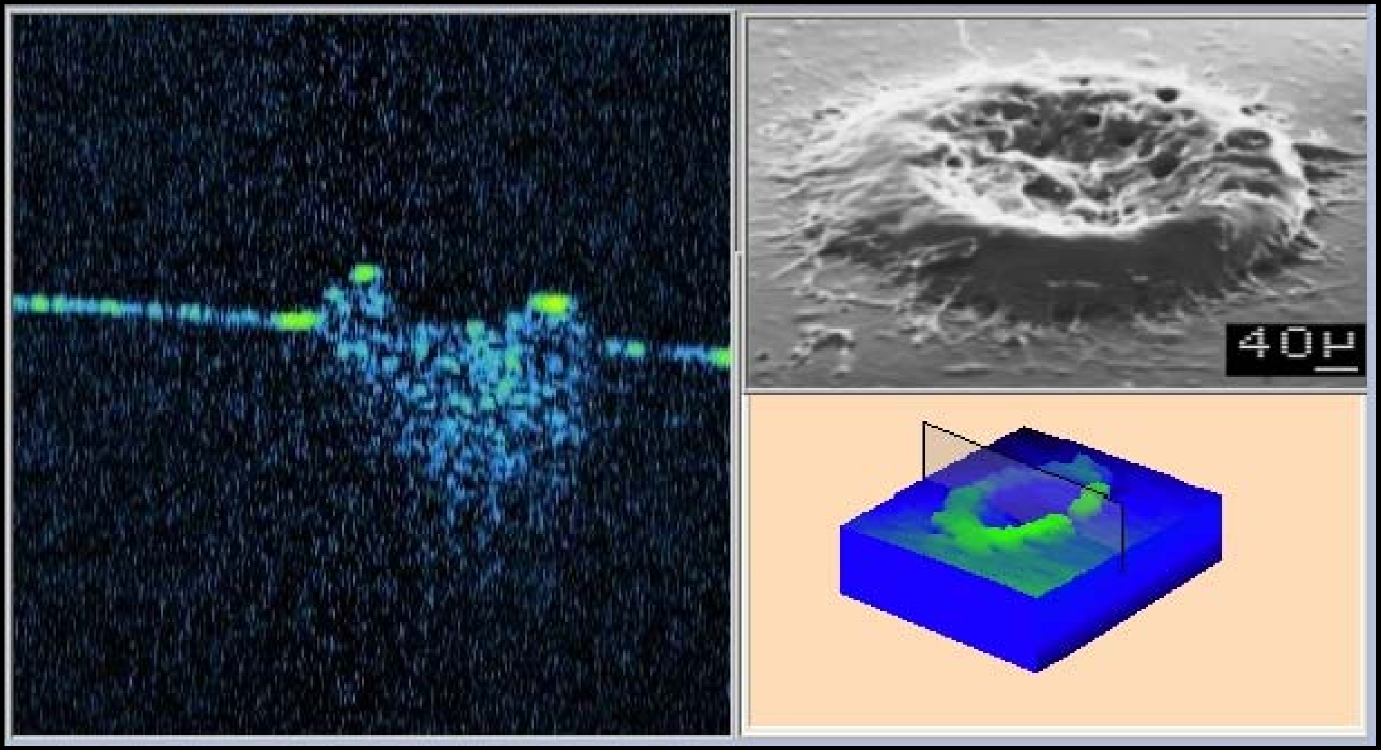
- ablation mechanism
- risk analysis

Step 3: *In-situ* monitoring of ablation

- monitoring of continous varnish removal

Step 1 – post-process analysis

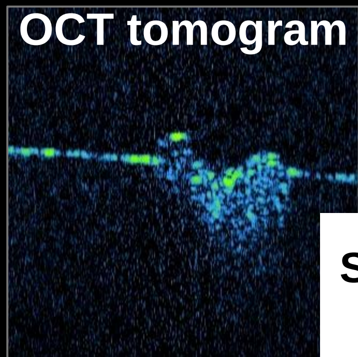
Qualitative analysis

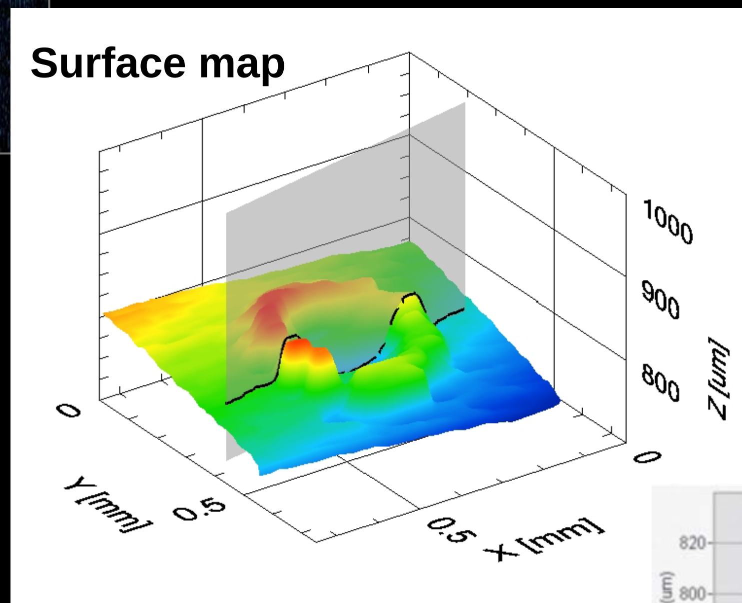


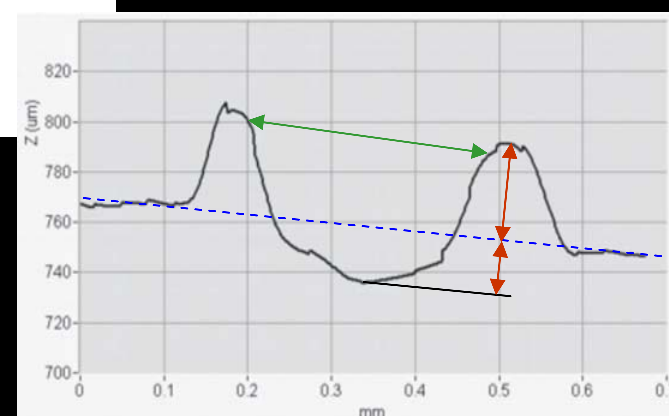
OCT acts as a precise profilometer

Step 1 – post-process analysis

Quantitative analysis

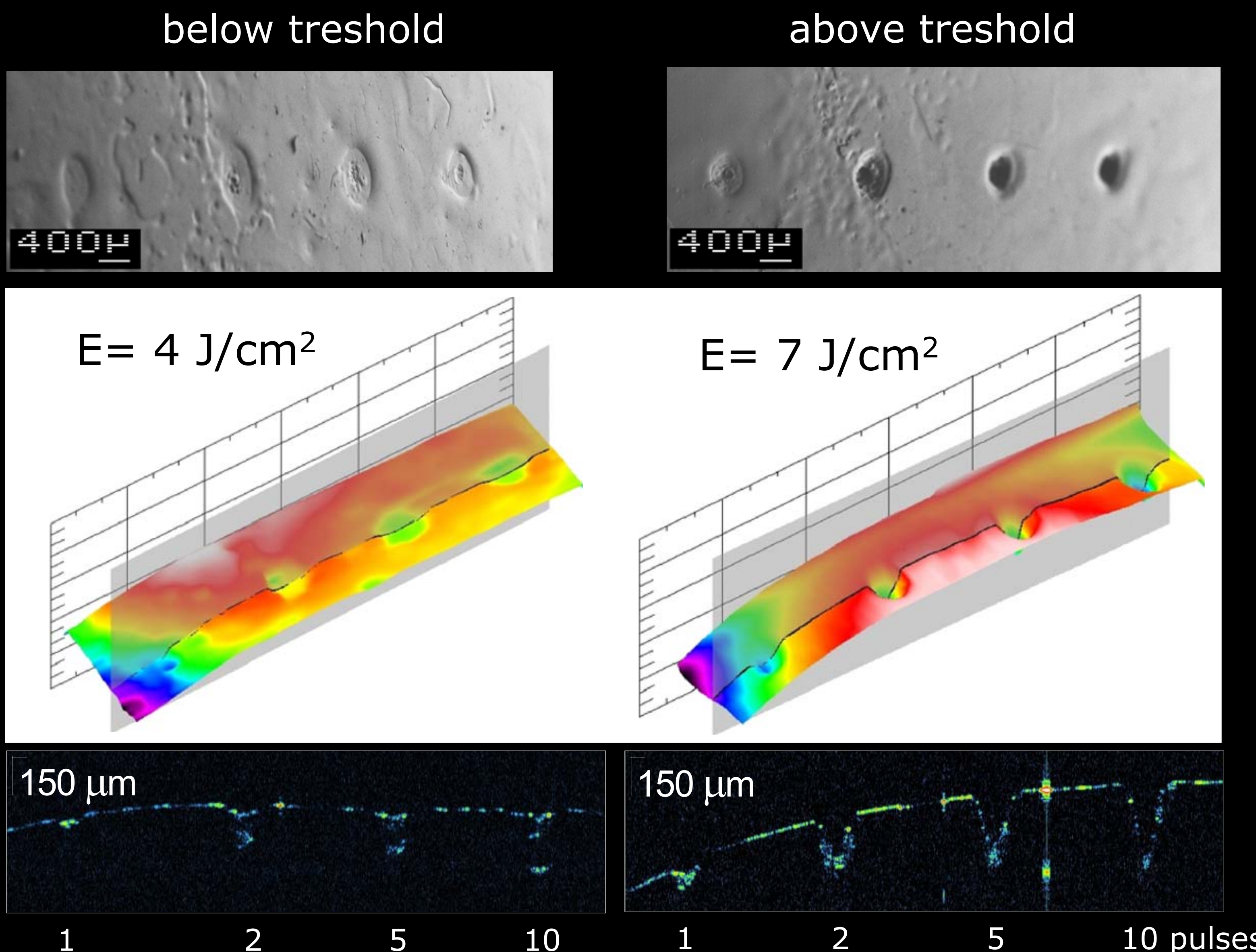




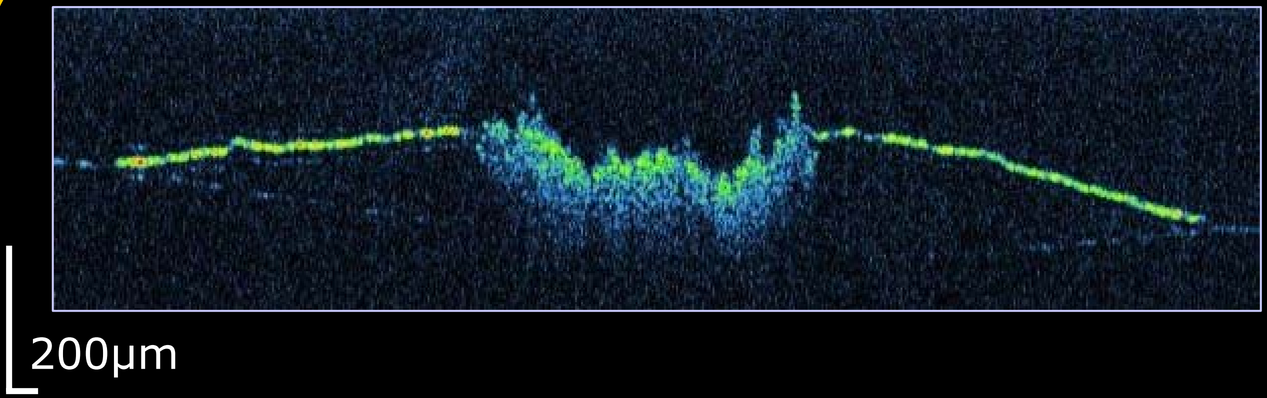


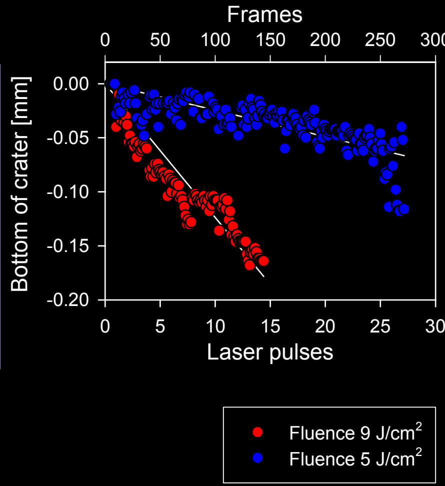
OCT enables determination of the volume of removed material

Step 1 – estimation of the fluence

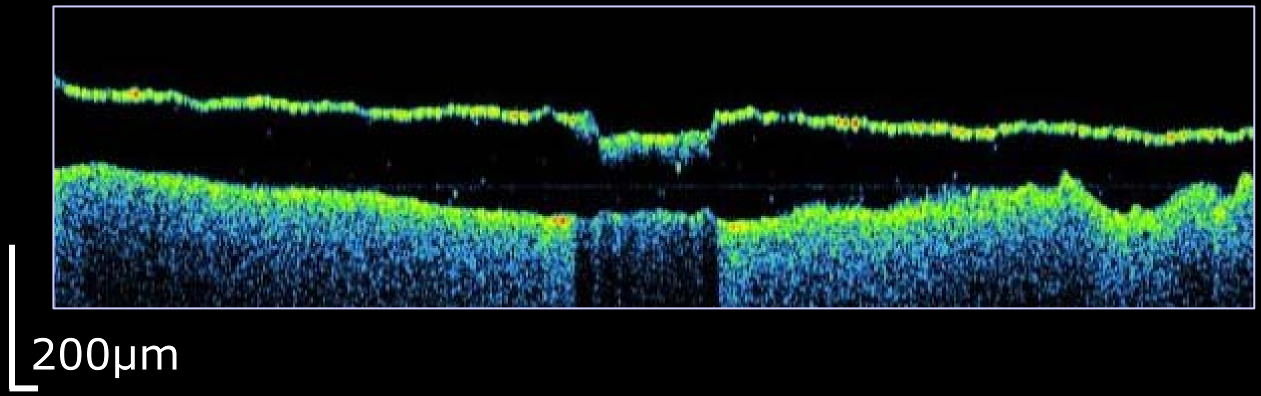


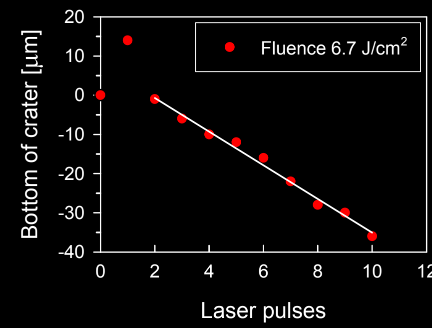
Step 1 – estimation of the fluence





Frame from the OCT movie of crater ablation for Rembrandt Talens Mat (ketone) varnish, 35 consecutive IR pulses

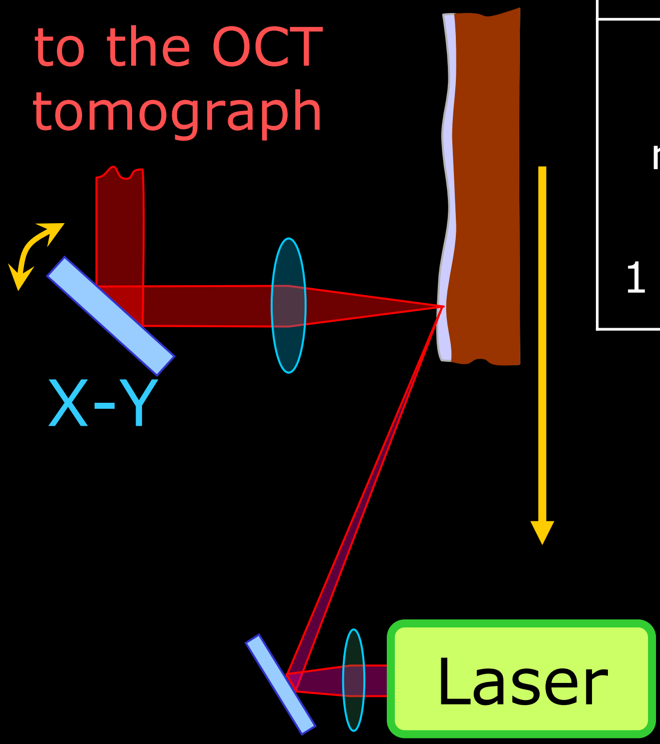




Talens Acrylic varnish (Mat), 10 consecutive UV pulses

Step 2/3 - Experimental set-up

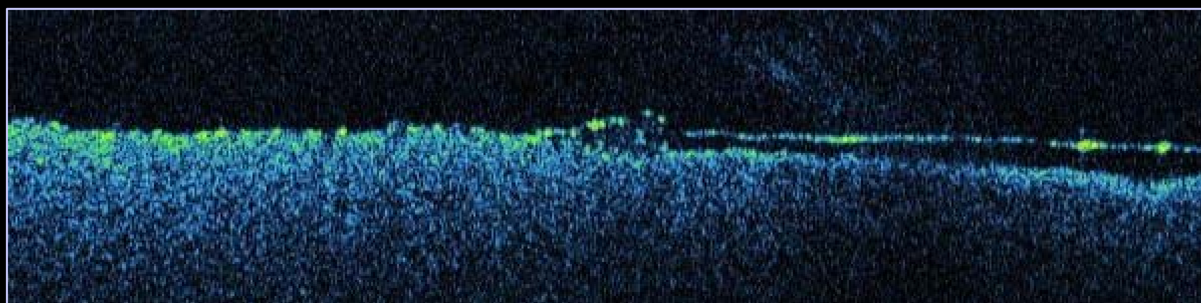
Step 2 Movie mode	**Step 3** RT monitor
16 frames/sec recording time: 20 s 1 frame: 1200 A-scans	2 frames/sec working time: ∞ 1 frame: 200 A-scans



Laser: 2÷8 pulses/s

Step 2 – Results

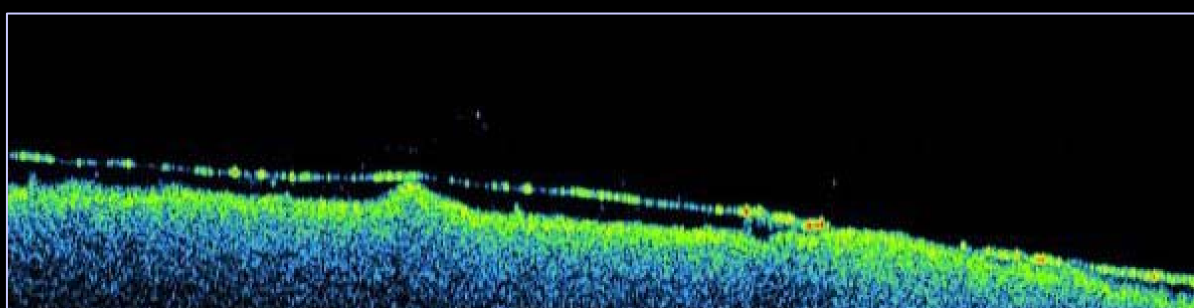
Talens Picture Varnish (ketone, glossy) 002.



(ablation)

200µm

Er:YAG laser, λ=2.936 µm, (2.2 J/cm^2, 2Hz)



(ablation)

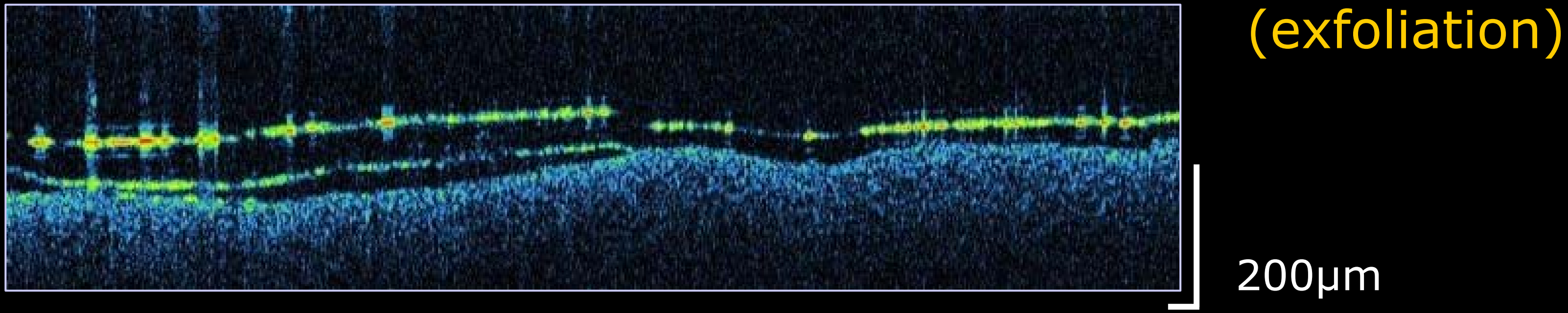
200µm

Nd:YAG laser, λ=0.266 µm, (4 J/cm^2, 2 Hz)

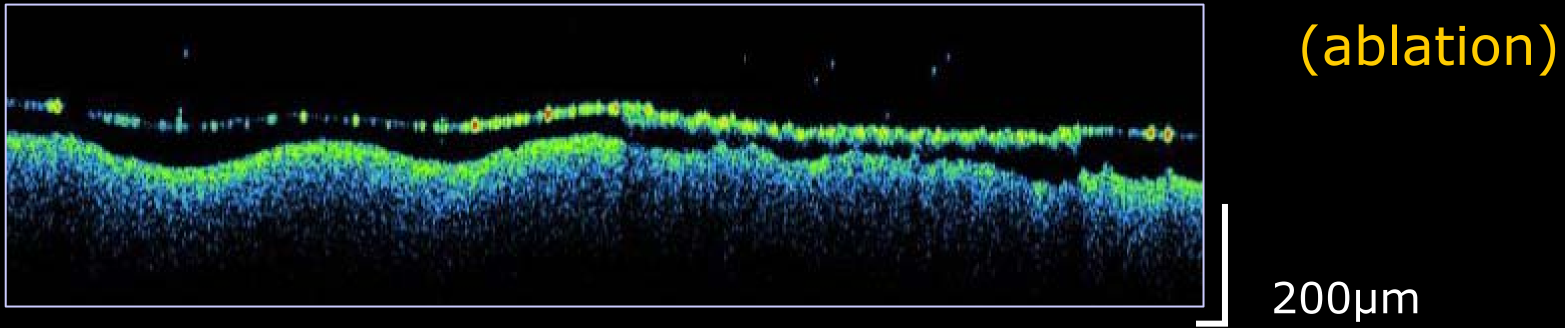
Appl. Phys. A 92, 1-9 (2008)

Step 2 - Results

Talens Acrylic Varnish (matt) 115.



Er:YAG laser, λ=2.936 µm, (1.2 J/cm^2, 2 Hz)



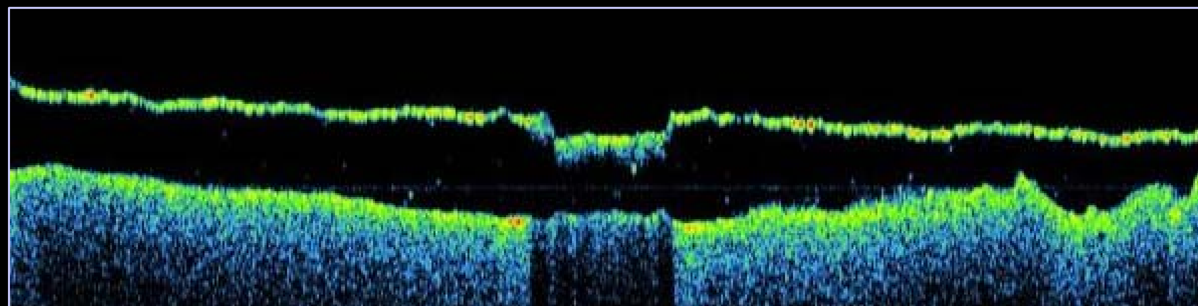
Nd:YAG laser, λ=0.266 µm, (2.7 J/cm^2, 2 Hz)

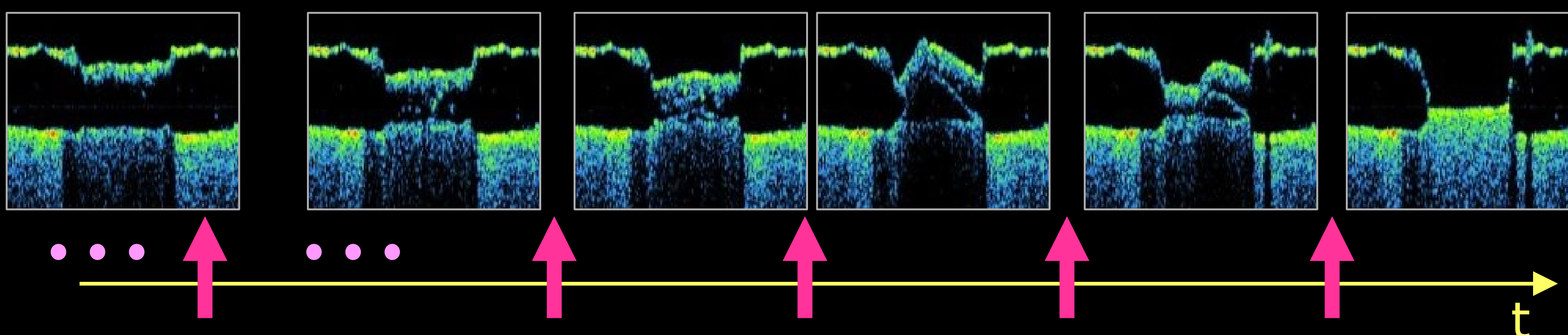
Appl. Phys. A 92, 1-9 (2008)

Step 2 - Results

Talens Acrylic Varnish (matt) 115.

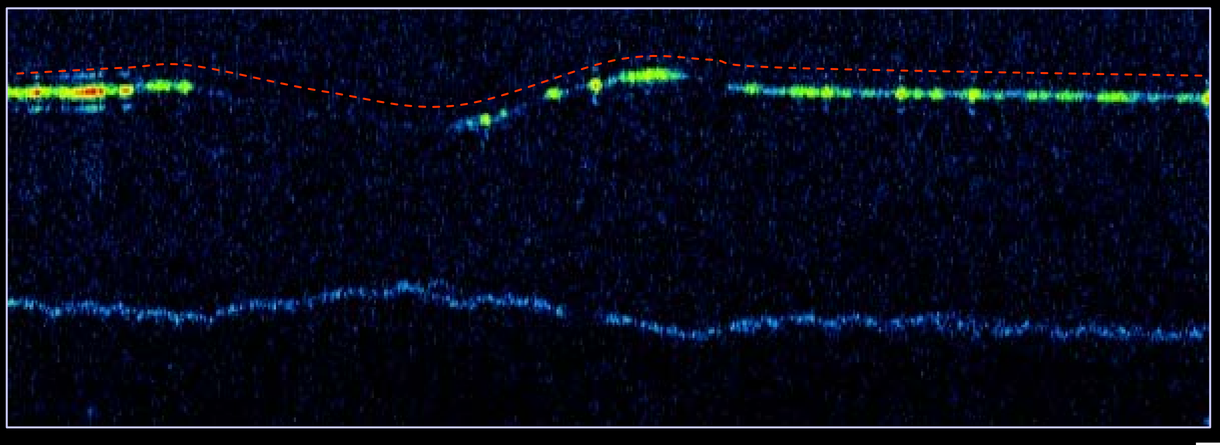
Do we have exfoliation with UV laser?





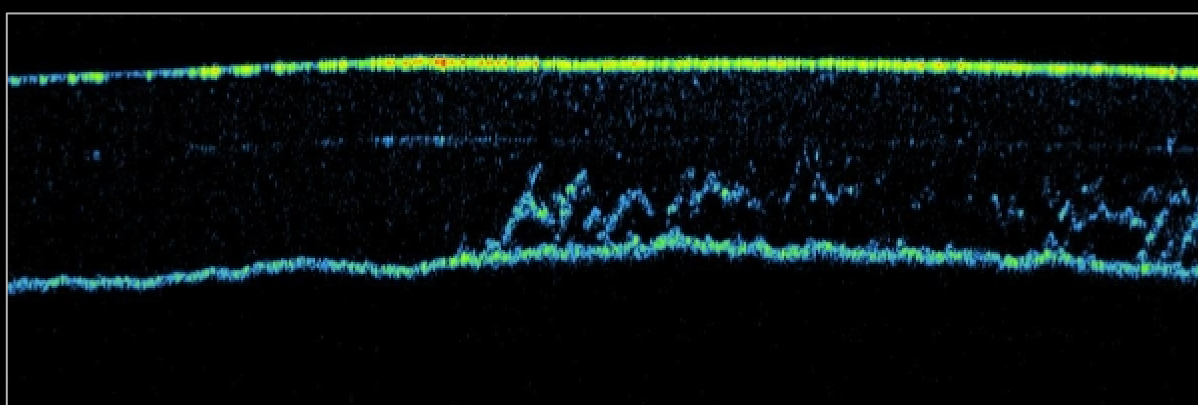
Step 2 - Results

Maimeri Dammar Matt Varnish.



(melting)

Er:YAG laser, λ=2.936 µm, (1.2 J/cm^2, 2 Hz)

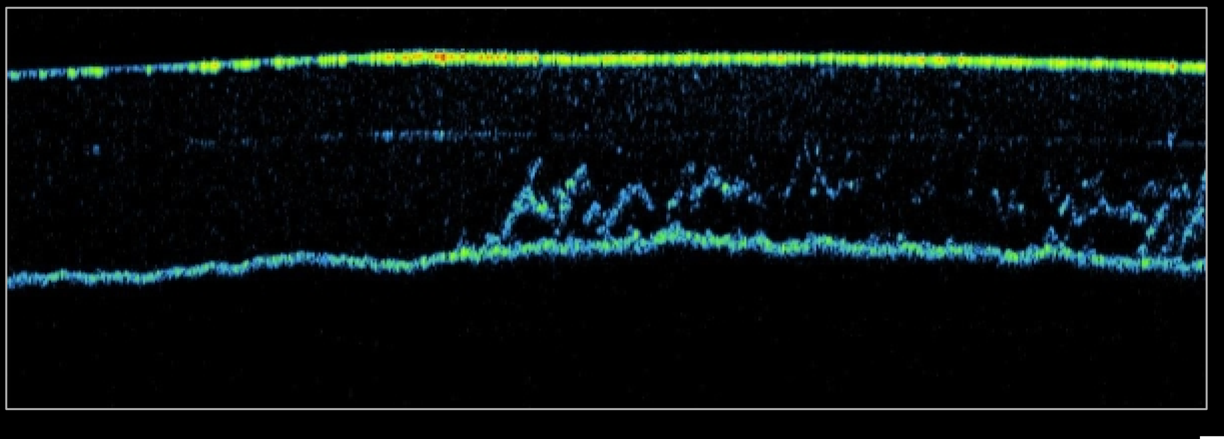


(ablation, very week)

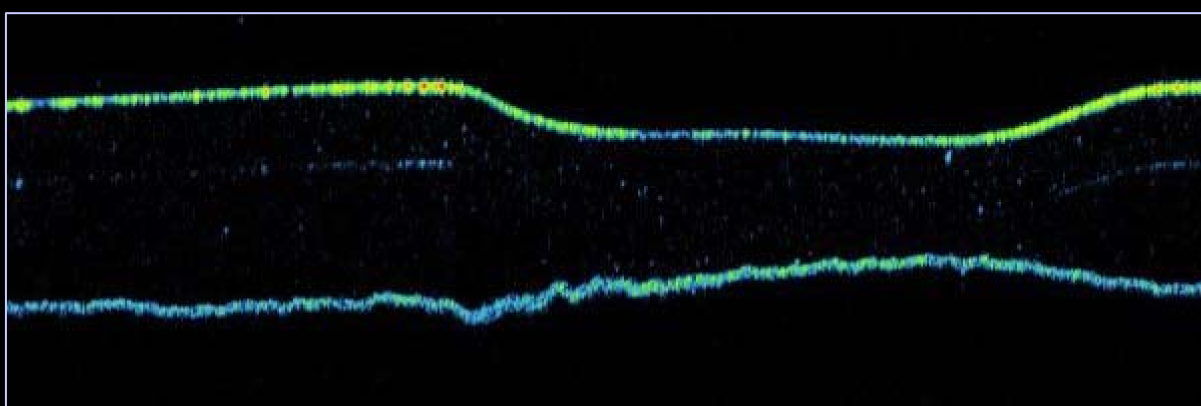
Nd:YAG laser, λ=0.266 µm, (4.3 J/cm^2, 2 Hz)

Step 2 - Results

Maimeri Dammar Matt Varnish.



2 Hz, 4.3 J/cm^2



8 Hz, 5 J/cm^2

Nd:YAG laser, λ=0.266 µm

STEP 2 - Experimental set-up

All presented films are recorded as raw data and processed as video files

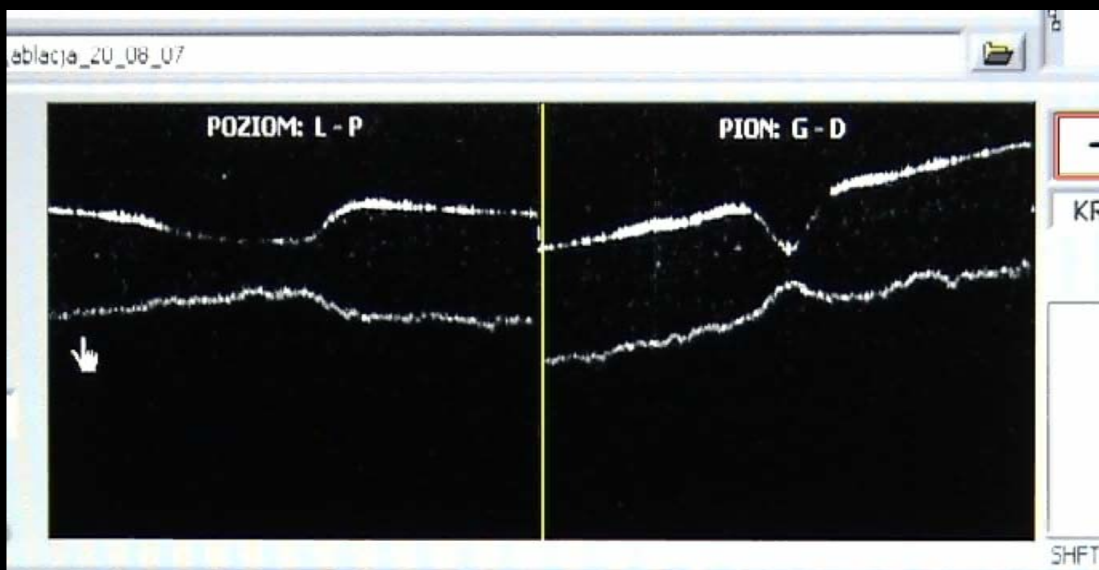
- Advantages:
  - high quality due to the high density and high frame rate
  - replay available
- Disadvantages:
  - no control of the process in real time
  - limited recording time

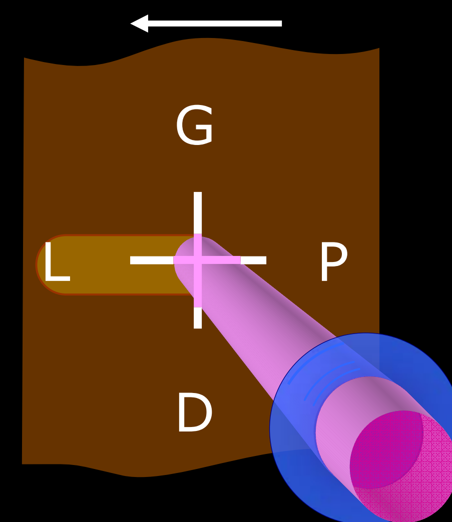
Step 3 - Where was the bottleneck?

CCD linear detectors used can collect and transmit
~ 30 000 A-scans / second

Major limitation came from
computation speed and displaying

Imaging in real time 2 double frames of 200 A-scans / second:



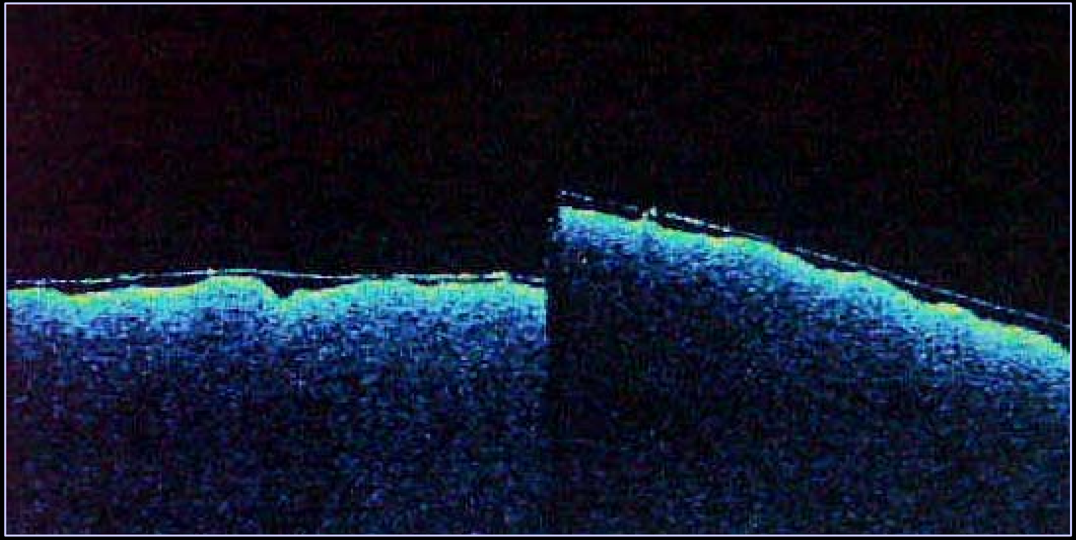


Step 3 – New systems capabilities

CCD linear detectors used can collect and transmit ~100 000 A-scans / second

~~Major limitation came from computation speed and displaying~~ ovecomed:

Imaging in real time 30 double frames of 256 A-scans / second:



Axial resolution 2μm in media

Conclusions

SOCT as a monitoring tool of varnish ablation:

- ✓ Enables estimation of the ablation conditions
- ✓ Permits registration of the ablation process
- ✓ Makes possible real-time monitoring of varnish ablation process

Reasonable in-depth resolution of 2 μm is already available, but a light source is still expensive

Higher framerate can be achived with the CMOS cameras

Collaboration

Nicolaus Copernicus University, Toruń, Poland

- T. Bajraszewski, I. Gorczyńska, **M. Góra**, A. Szkulmowska, M. Szkulmowski, M. Wojtkowski, P. Targowski, A. Kowalczyk
  – Institute of Physics

- B. Rouba, T. Łękawa-Wysłouch, L. Tymińska-Widmer, M. Iwanicka
  – Institute for the Study, Restoration and Conservation of Cultural Heritage

Military University of Technology, Warszawa, Poland

- J. Marczak, A. Rycyk

Thank you for your attention