Target material tests with the electron beam at the microtron in Mainz

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HELMHOLTZ GEMEINSCHAFT

DESY

Overview

- Introduction / Motivation
- Mainz Microtron (MAMI)
- Material for the tests
- Simulations results
- Material after the tests
- Summary

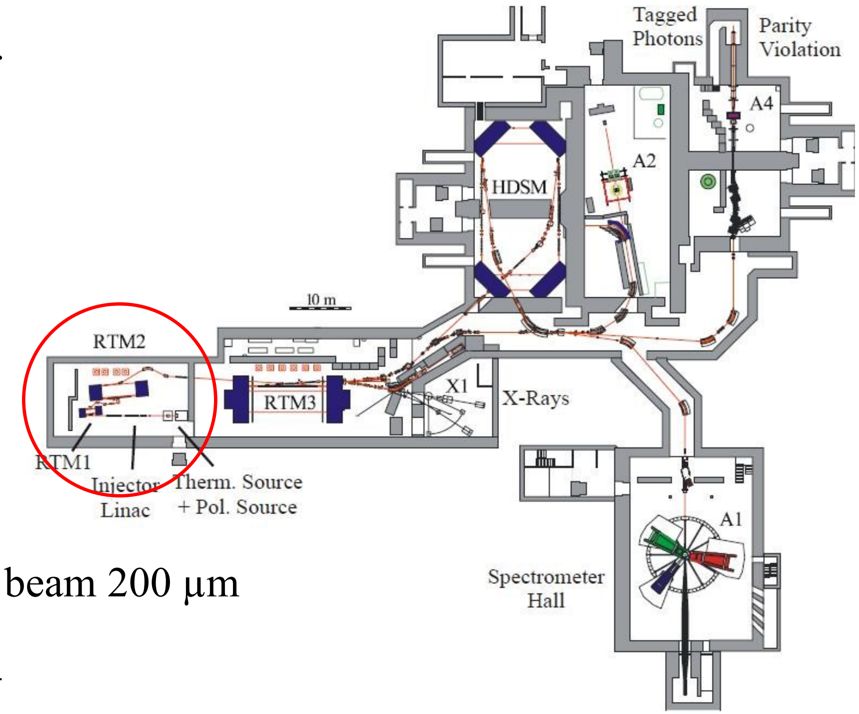
Introduction / Motivation

- Encouraging results for Ti and Ti alloys for KEKB. No tests to long-term cyclic load
- Idea to expose to high cyclic load the material for the ILC components
- Tests using injector of MAMI
- Ti alloy for the positron conversion target – high cyclic load
- What target thickness is better?

Mainz Microtron

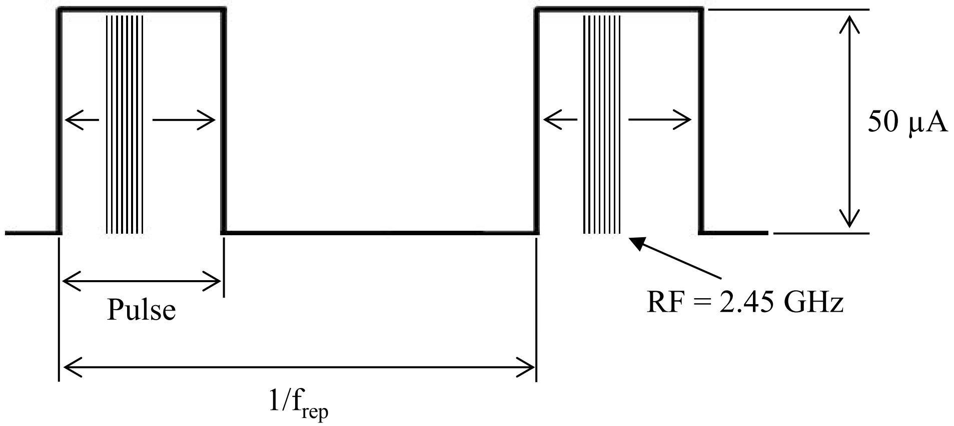
Mainz Microtron

The Mainz Microtron (MAMI) is an accelerator for electron beams run by the Institute for Nuclear Physics of the University of Mainz used for hadron physics experiments



cw e^- beams > 20 µA (polarized) or up to 100 µA (unpolarized)

In our tests:
14 MeV e^-, 10 µA average beam current, Gaussian beam 200 µm rms radius



Collaborators in Mainz

Kurt Aulenbacher

Philipp Heil

Valery Tioukine

+ Marco Dehn et al. (operators of MAMI)

Material for the tests

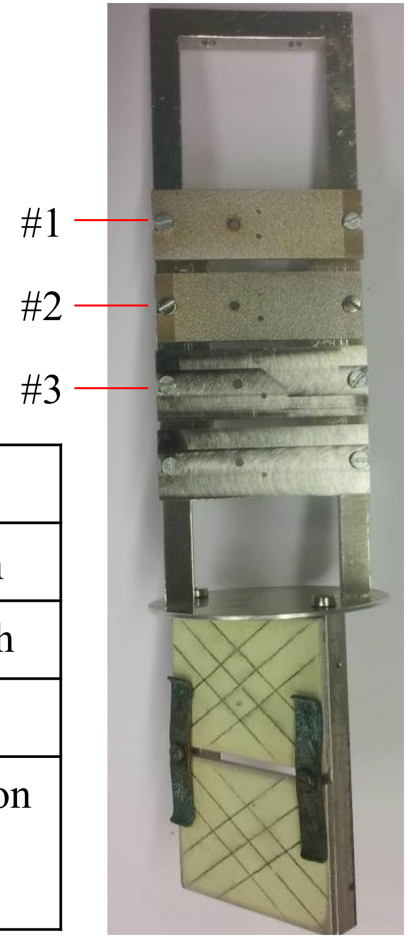
Assembly with the targets

Material of targets:

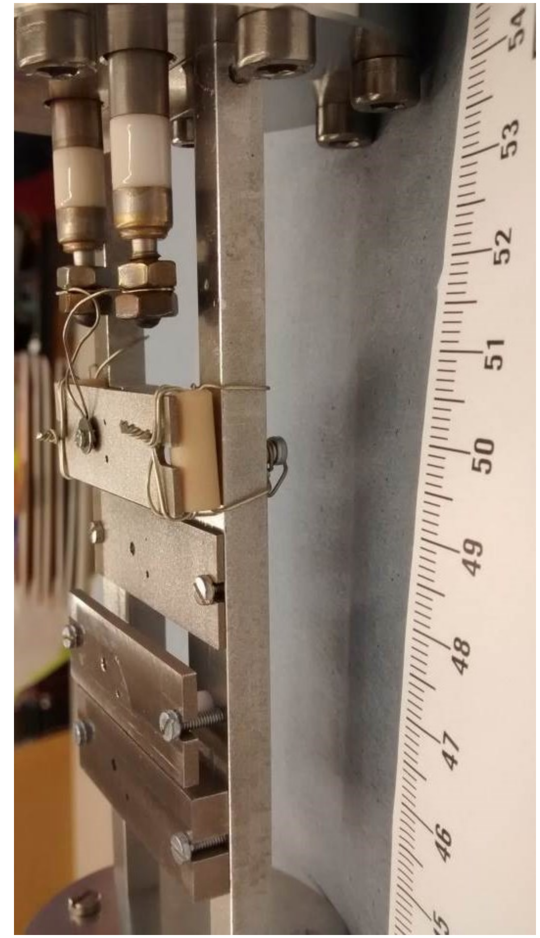
Grade 5 Ti – Ti6Al4V

Target	#1	#2	#3
Thickness	1 mm	1 mm	2 mm
Surface	Rough	Rough	Smooth
Fixation	Not fixed	Fixed	Fixed
Cooling	Radiation	Radiation + contact to the holder	Radiation

Diagnostics: temperature and current measurement for target #1



Front view to the target assembly

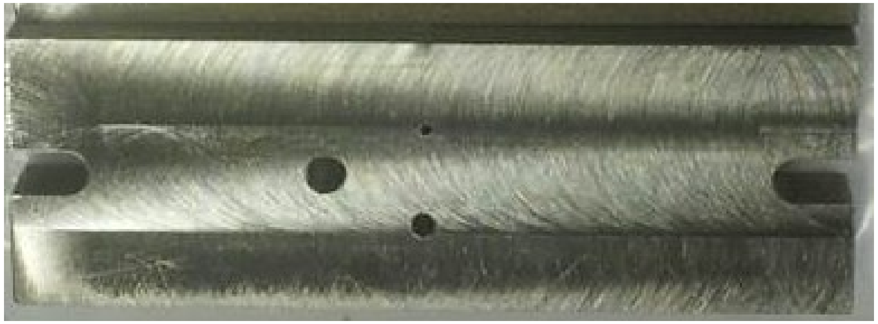


Side view to the target assembly

Targets

Targets #1 & #2

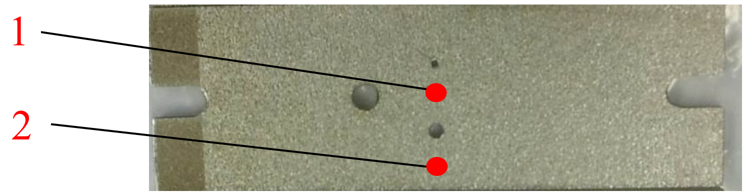
Rough surface, produced by erosion process from a thicker bar



Target #3

“Smooth” surface, milled

Program

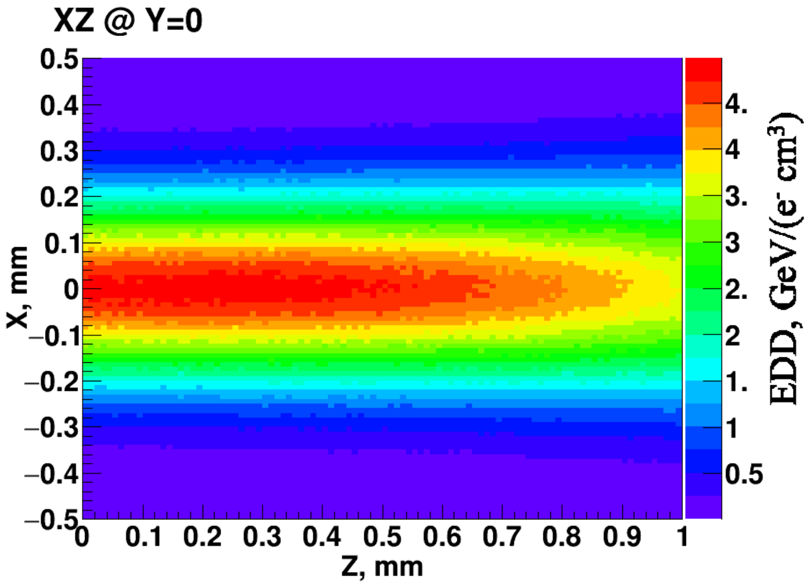


Target	Hit point	Regime	Beam time	Load cycles	Years of ILC operation*
#1	1	100 Hz, 2 ms, 10 µA average	18 h 28 min	$6.82 \cdot 10^6$	2.46
#1	2	67 Hz, 3 ms, 10 µA average	5h 4 min	$1.24 \cdot 10^6$	0.45
#2	1	67 Hz, 3 ms, 10 µA average	5h 4 min	$1.24 \cdot 10^6$	0.45
#3	1	100 Hz, 2 ms, 10 µA average	14 h 22 min	$5.17 \cdot 10^6$	1.87

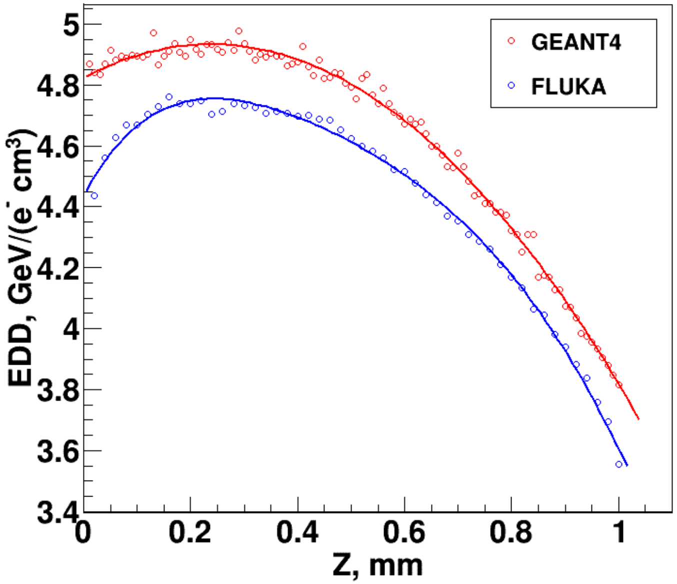
*1 year of ILC operation: 5000 h, 5 Hz, each point is irradiated every 6.5 s

Simulations results

GEANT4 and FLUKA simulations, targets #1 & #2



EDD (G4*) for 1 mm target



EDD vs depth along the beam axis for 1 mm target: G4* and FLUKA (A. Ushakov)

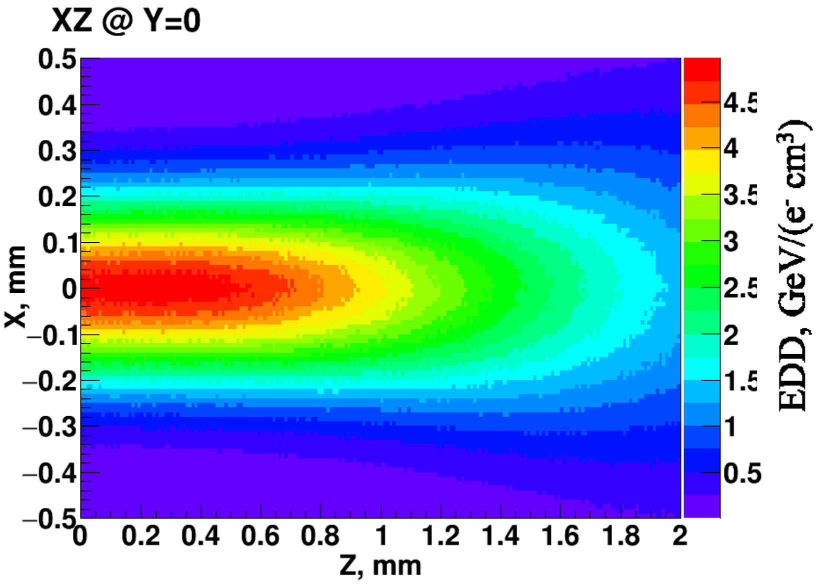
PEDD = 4.74 GeV/(e^- cm^3) = 4.37 $\cdot 10^{-5}$ J/(g·bunch) (FLUKA)

Number e^- per bunch = $2.55 \cdot 10^5$

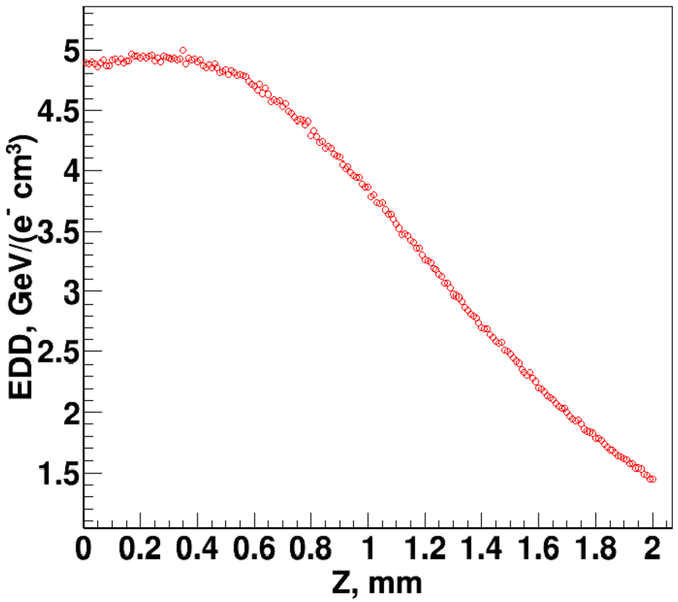
Number of bunches per pulse = $4.9 \cdot 10^6$ (2 ms) or $7.35 \cdot 10^6$ (3 ms)

* GEANT4.10.02, physics list FTFP_BERT

Simulation, target #3



EDD (G4) for 2 mm target



EDD vs depth along the beam axis for 1 mm target, G4

PEDD = 4.74 GeV/(e^- cm^3) = 4.37 $\cdot 10^{-5}$ J/(g·bunch) (FLUKA)

Number e^- per bunch = $2.55 \cdot 10^5$

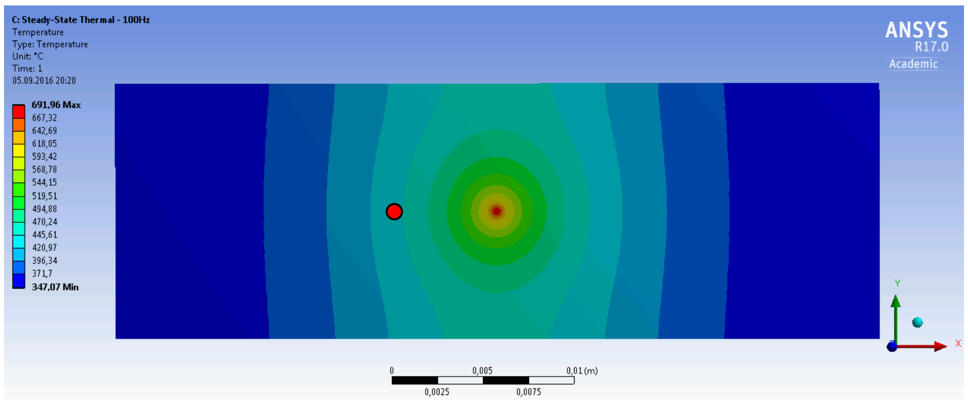
Number of bunches per pulse = $4.9 \cdot 10^6$ (2 ms) or $7.35 \cdot 10^6$ (3 ms)

ANSYS simulation, target #1

Target	#1
Thickness	1 mm
Surface	Rough
Fixation	Not fixed
Cooling	Radiation

Neglect low thermal conductivity to the holder via ceramics etc

Consider cooling by radiation from the surface only

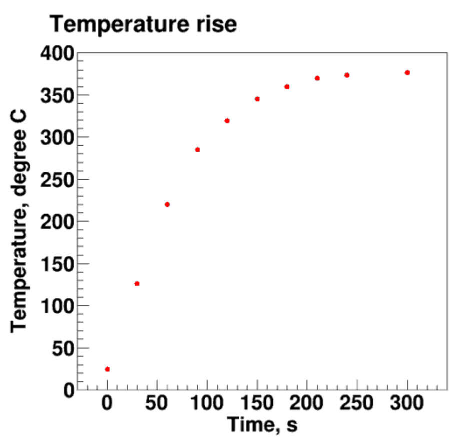


Max. average T = 691 °C

Max. T rise / pulse (@ 700 °C) = 82 °C

Max. T in target #**1**: **691 + 82 °C**

Distribution of the average temperature (ε=0.5)*



→ $\varepsilon \gtrsim 0.5$

* Here and later:

- Ambient T = 22 °C
- Ti6Al4V properties according to

K.C. Mills, 2002, Recommended Values of Thermophysical Properties For Selected Commercial Alloys, p. 217, as referenced by J. Yang

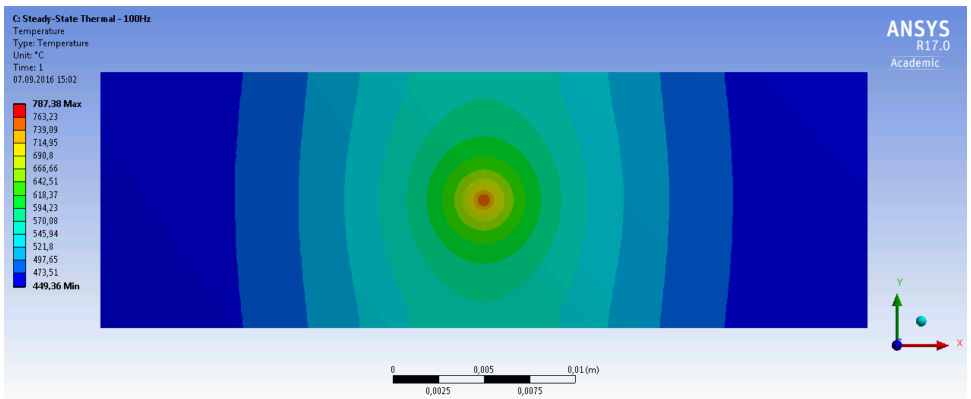
Real temperature measurement in ●

ANSYS simulation, target #3

Target	#3
Thickness	2 mm
Surface	Smooth
Fixation	Fixed
Cooling	Radiation

Neglect thermal conductivity to the holder via ceramics and fixation screws

Consider cooling by radiation from the surface only

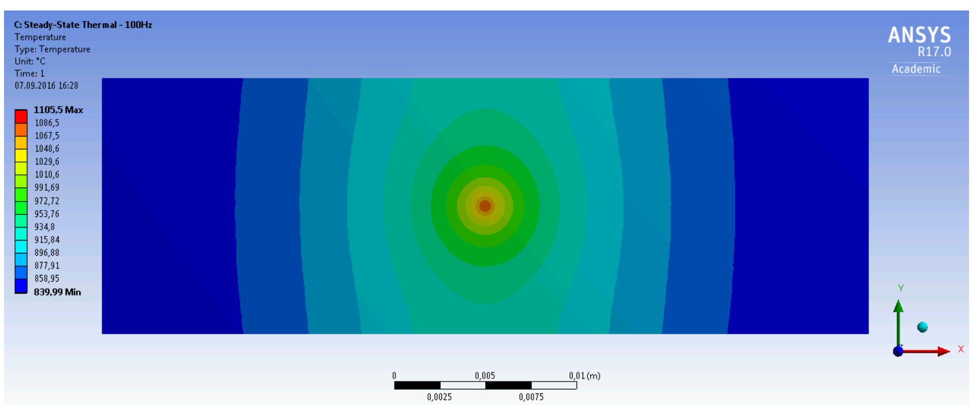


$\varepsilon = 0.5$

Max. average T = 787 °C

Max. T rise / pulse (@ 760 °C) = 88 °C

Max. T in target #**3**: **787 + 88 °C**

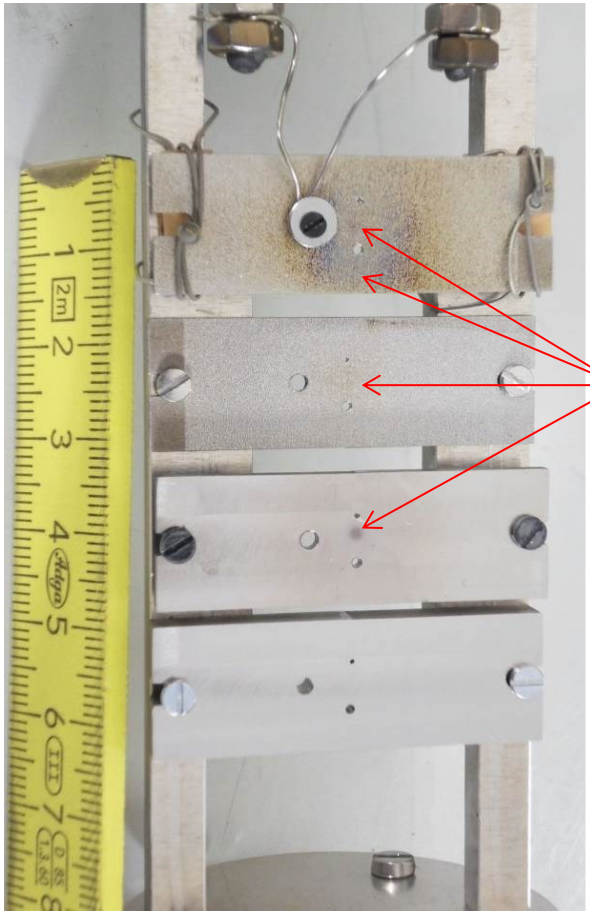


Although, if $\varepsilon = 0.1$:

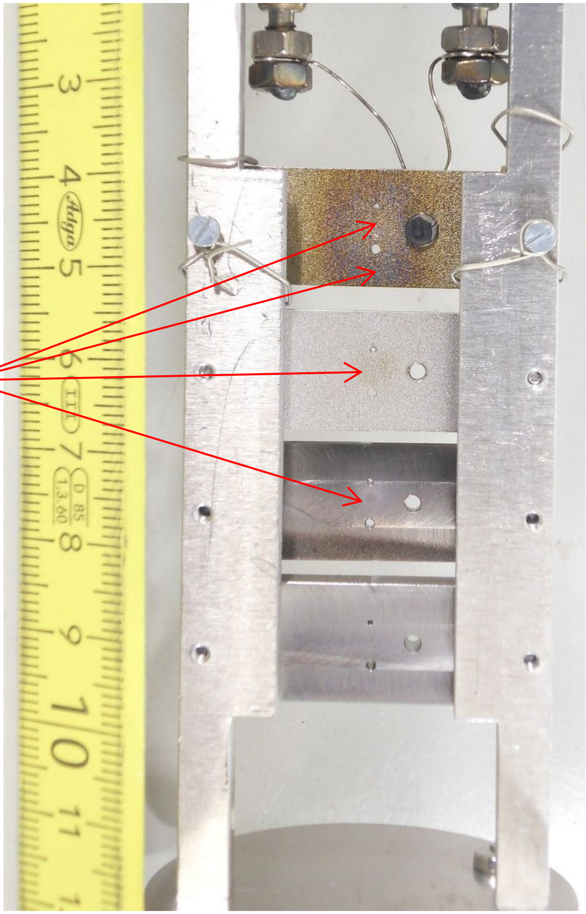
Max. average T = 1105 °C

Material after the tests

Targets after testbeam



Irradiation spots

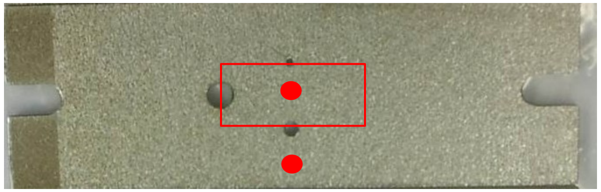


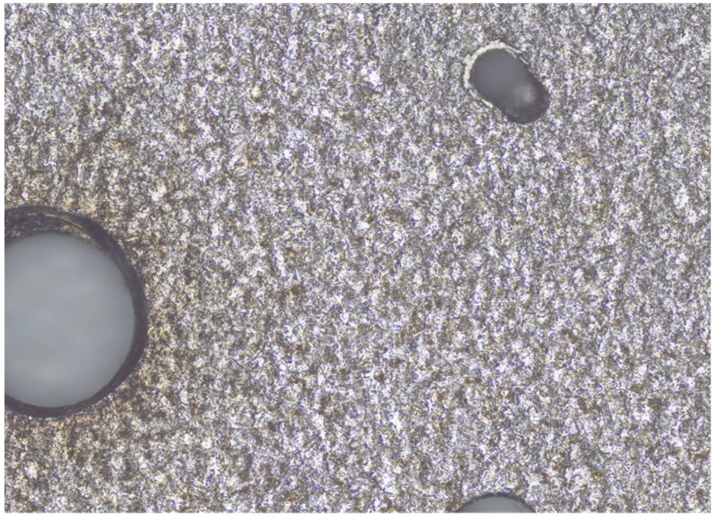
Holder with targets, entrance side

Holder with targets, exit side

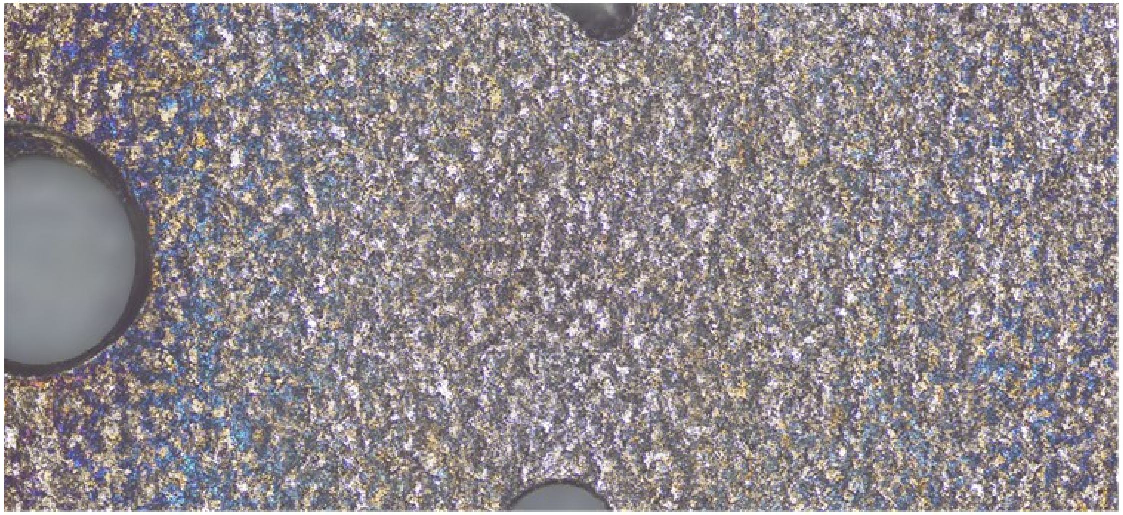
Target #1, entrance side, surface investigation

Surface investigation with 3D laser scan microscope VK-X100/X200 series





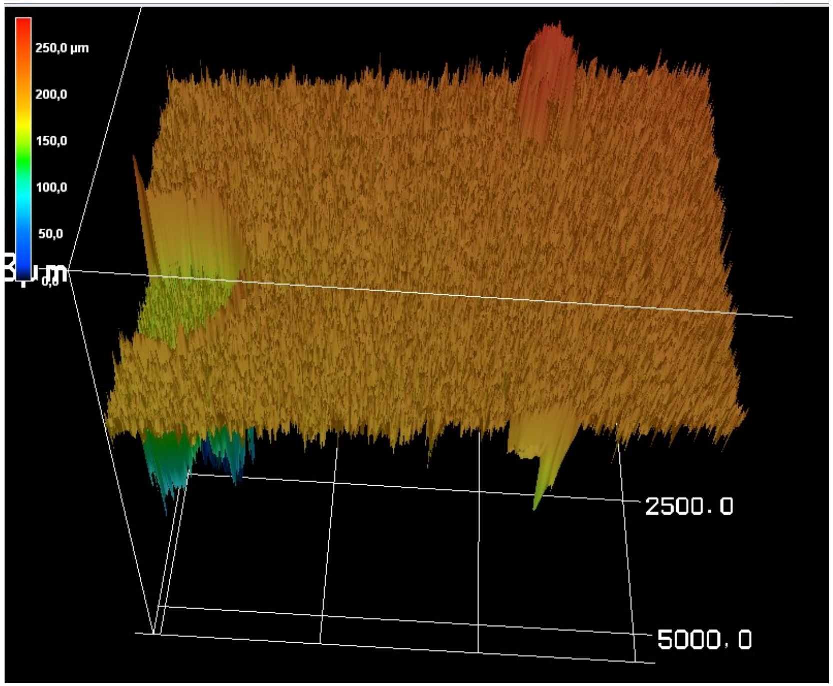
Before



After

Color change observed, no major changes to the surface

Target #1, entrance side, surface investigation



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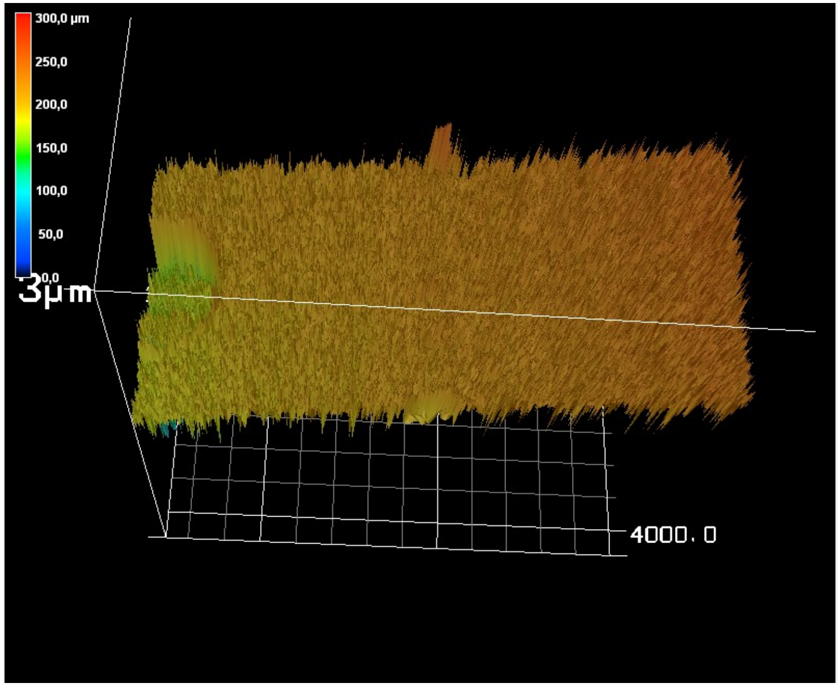
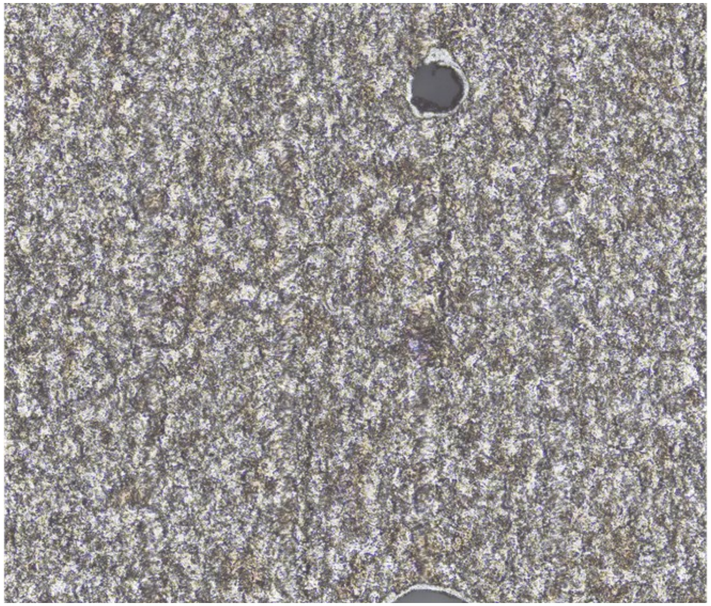


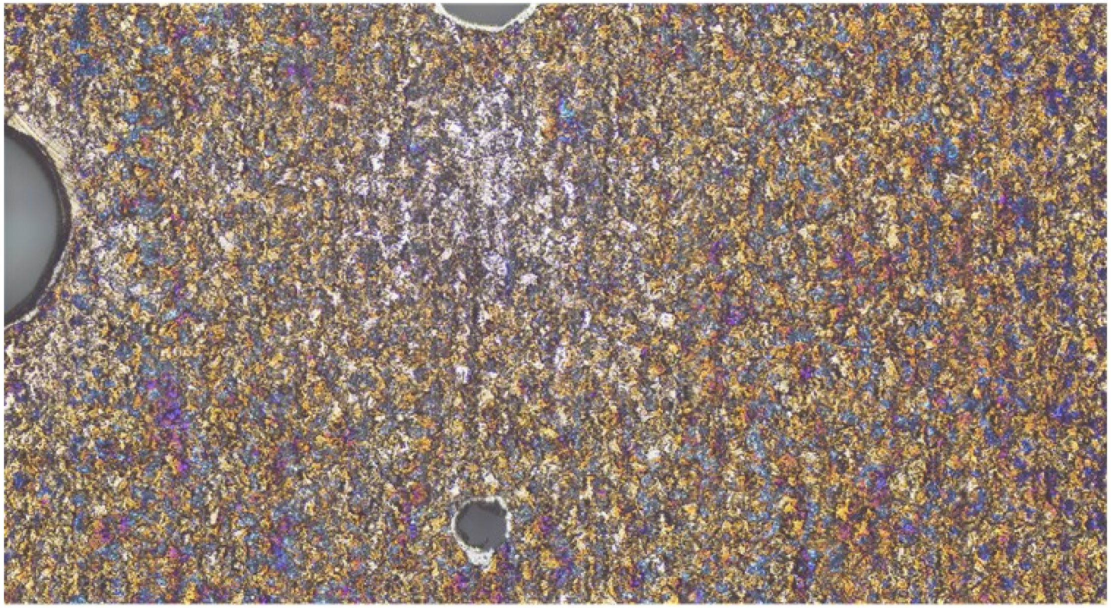
After

Flat surface observed before and after irradiation, no major changes

Target #1, exit side, surface investigation



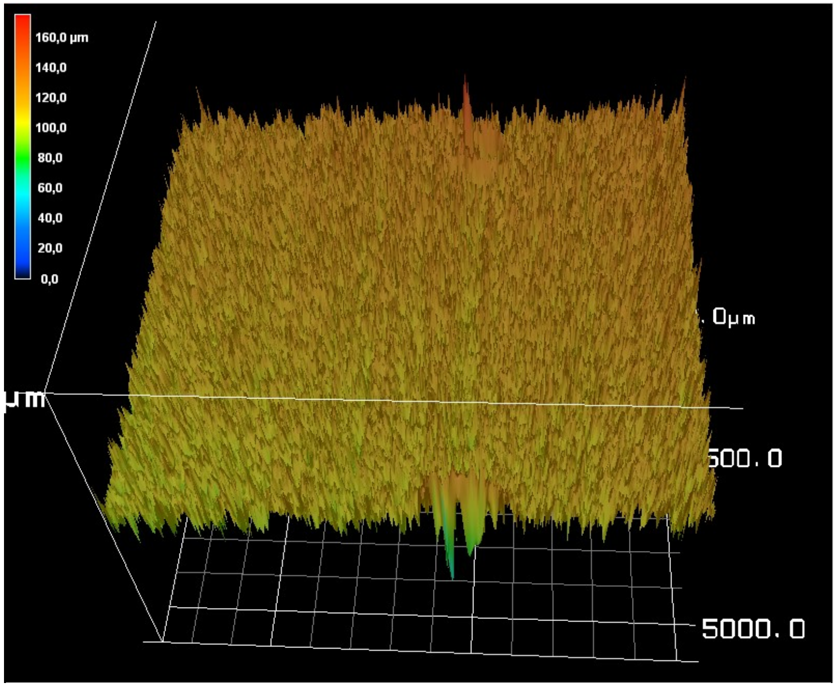
Before



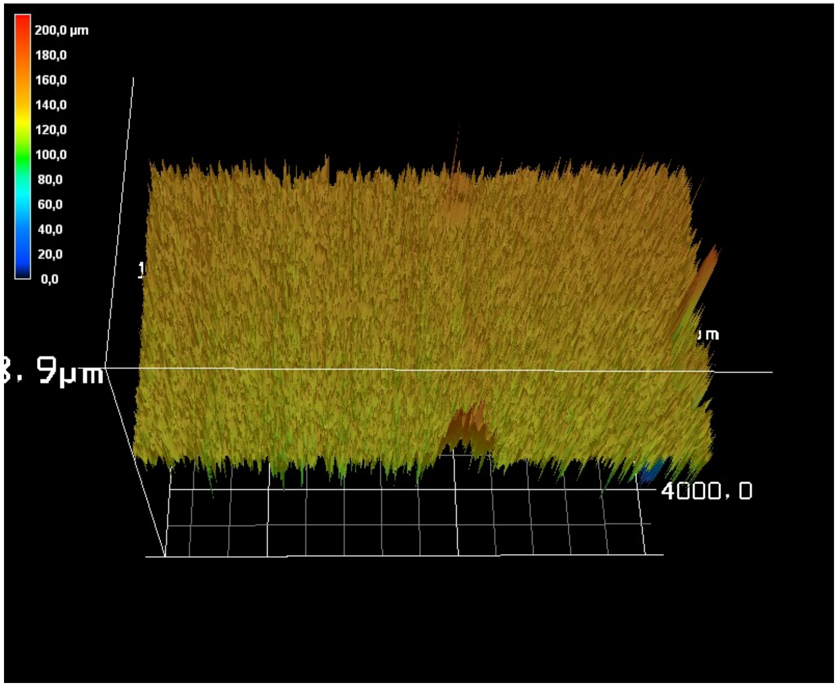
After

Color change observed, no major changes to the surface

Target #1, exit side, surface investigation



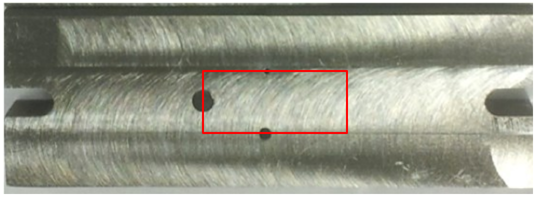
Before

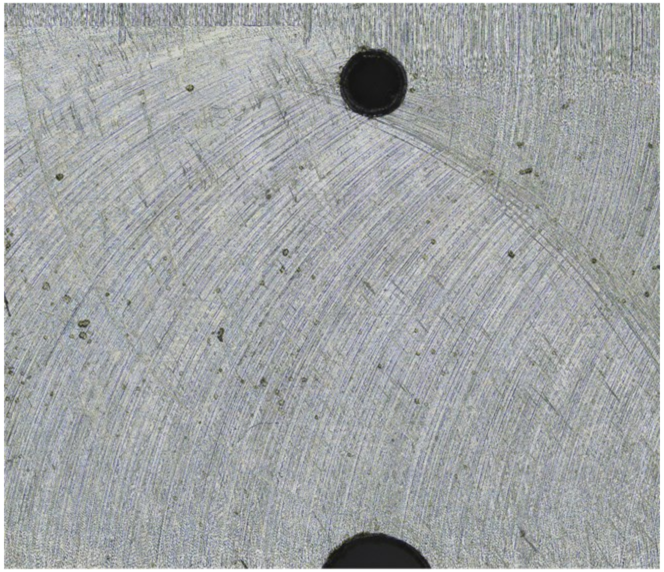


After

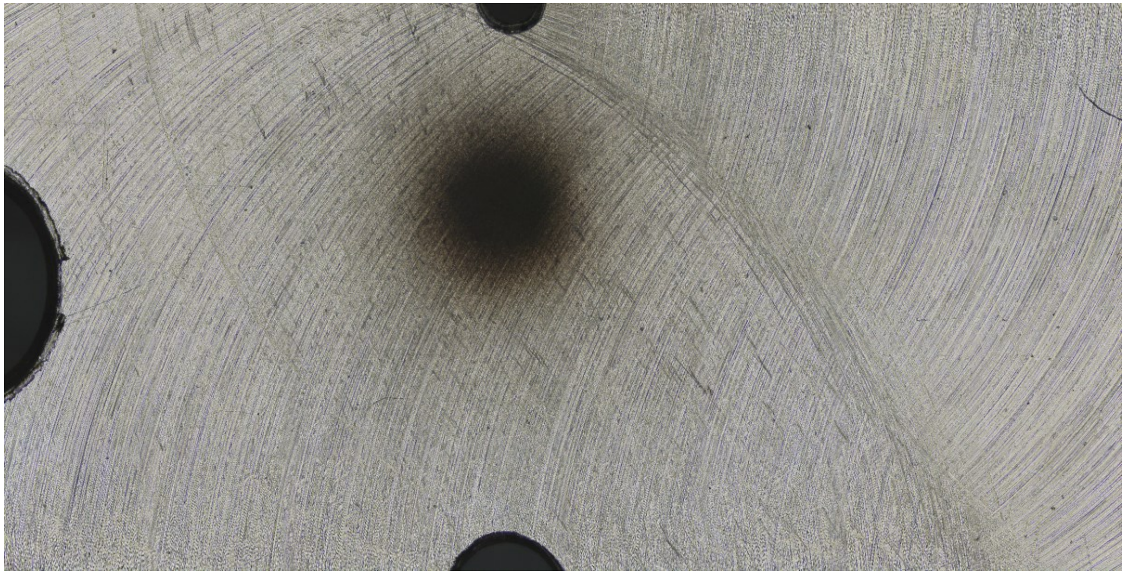
Flat surface observed before and after irradiation, no major changes

Target #3, surface investigation, entrance side





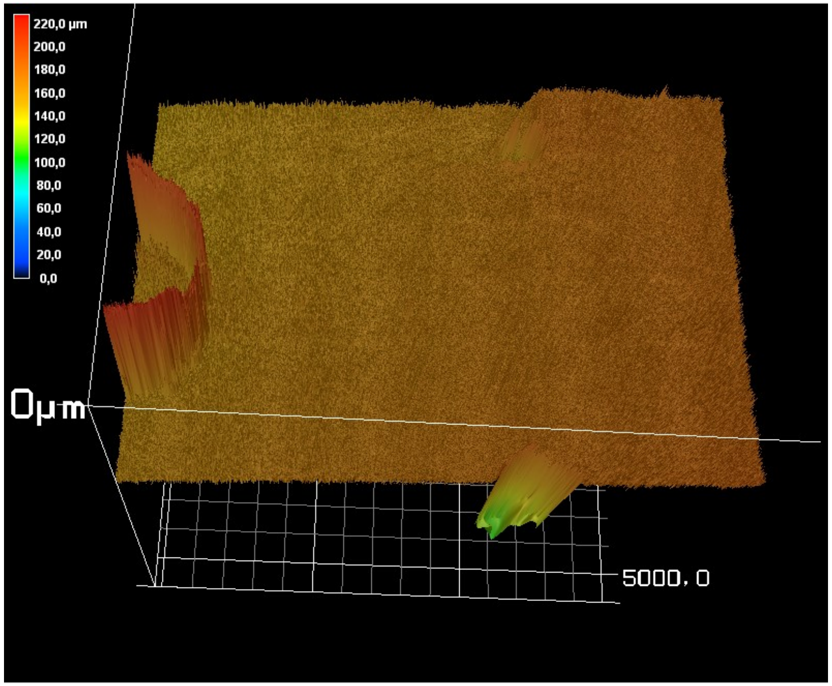
Before



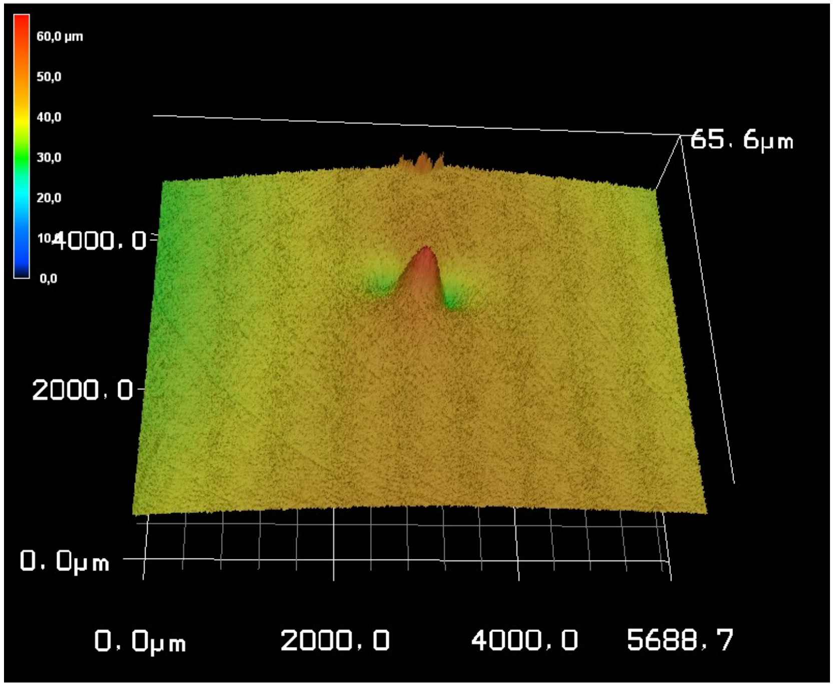
After

Beam spot clearly seen, major changes

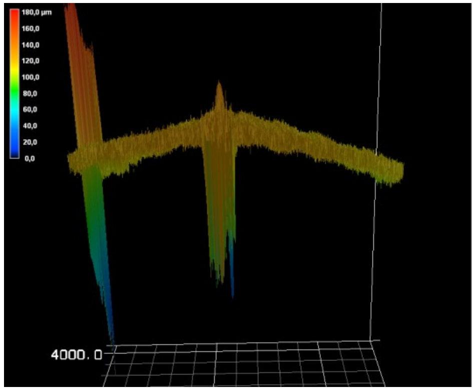
Target #3, surface investigation, entrance side



Before



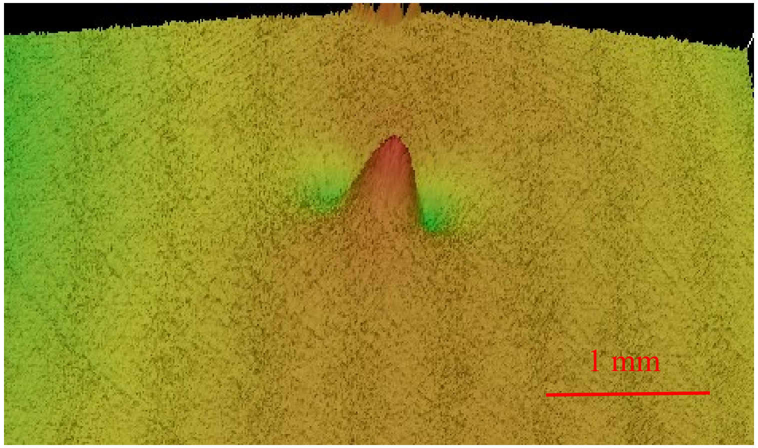
After



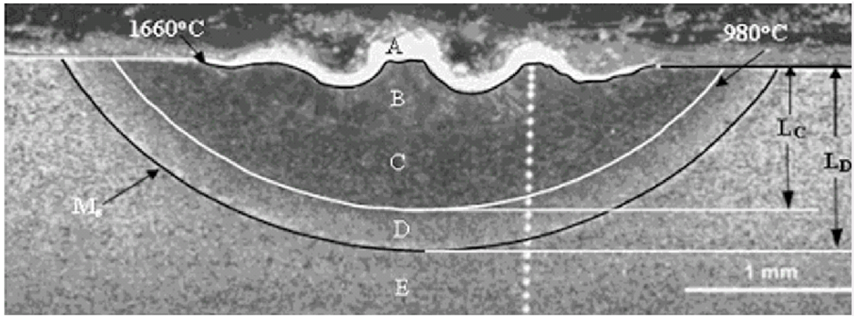
Flat surface observed before irradiation

Plastic deformation after irradiation, 1 peak and 2 deeps observed in the beam spot: ~ 35 µm from the bottom of the deep to the top of the peak

Target #3, entrance side



Surface of target #3

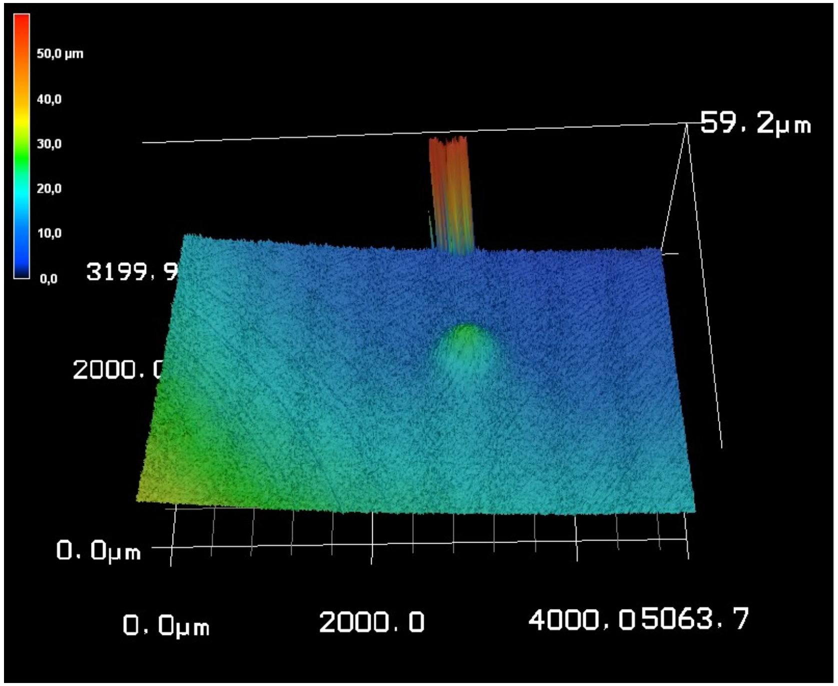


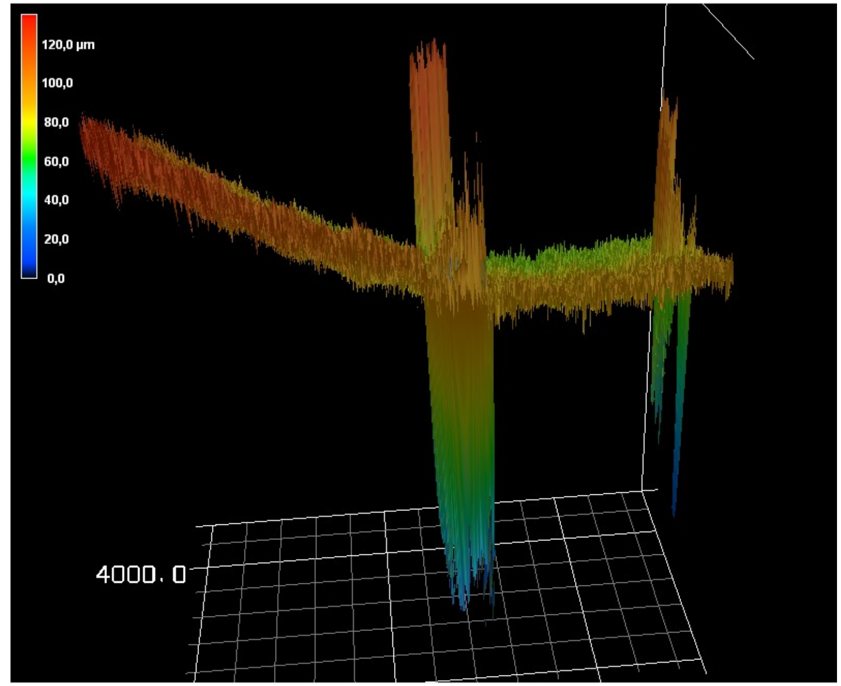
Surface of a Ti6Al4V plate heated by laser beam *

Heated up to 1660 °C ?

* J. Yang et al., Journal of Materials Processing Technology 210 (2010) 2215-2222

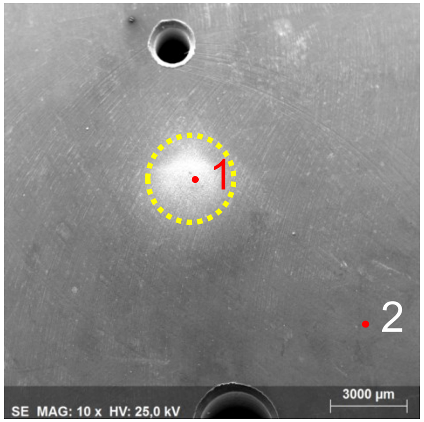
Target #3, surface investigation, exit side





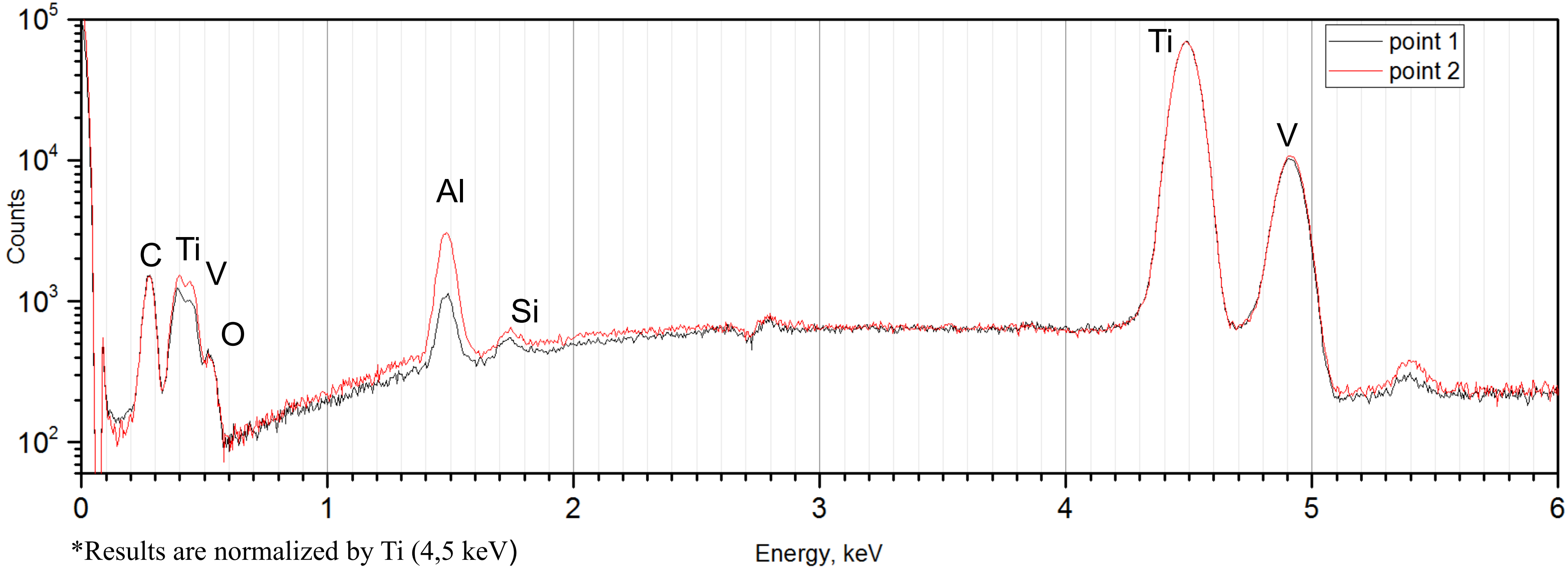
Plastic deformation after irradiation, 1 peak observed in the beam spot: ~ 25 µm from the surrounding to the top of the peak

Target #3, SEM image (Yegor Tamashevich)



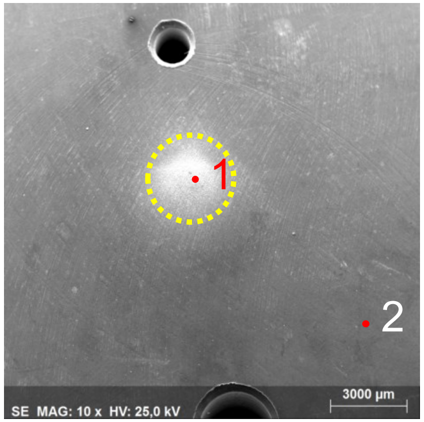
Point 1 – Beam spot area
Point 2 – Un-irradiated area

Aluminum concentration is lower in the beam spot area



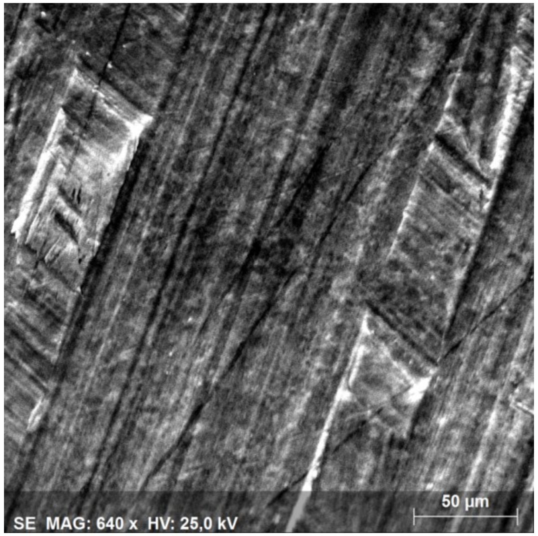
*Results are normalized by Ti (4,5 keV)

Target #3, SEM image (Yegor Tamashevich)

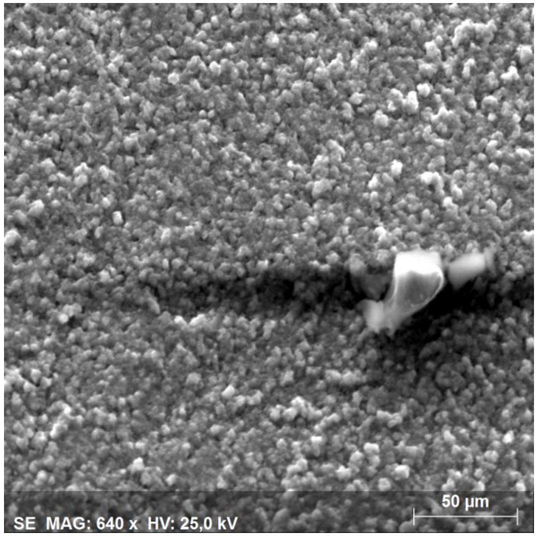


Point 1 – Beam spot area
Point 2 – Un-irradiated area

Surface outside beam spot



Beam spot area



Ablation and condensation process ?

Summary

- Ti6Al4V targets survived high cyclic load of up to $6.82 \cdot 10^6$ cycles heated to at least 690 °C

- No major damage to the material after the tests at the temperature of at least 690 °C

- Noticeable changes only for the material (plastic deformation, surface change) exposed to the temperatures >780 °C

- Next steps:
  - further tests at 14 MeV
  - tests at 3.5 MeV: material for target & for the dump vacuum window

Thank you for your attention!