Tungsten and carbon based PFCs erosion and eroded material deposition under ITER-like ELM and disruption loads at the plasma gun facility QSPA-T

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F4E

Efremov Institute

RRC Kurchatov Institute

Outline

This activity is carried out under collaboration between European Union and the Russian Federation and is directed to obtain the data for the empirical estimation of the PFC lifetime and to validate the available numerical models used to predict the erosion under the expected conditions in ITER.

- Experimental conditions
- Tungsten erosion (melting, crack formation)
- Erosion products investigation
- Summary

This work was supported by EFDA (05-994 Task 4), the ROSATOM (H.4a.52.03.10.1003), the Impuls- und Vernetzungsfond der Hemholtz Gemeinschaft e.V. and RFBR grant Nr.11-02-91322

Experimental conditions

Quasistationary plasma accelerator

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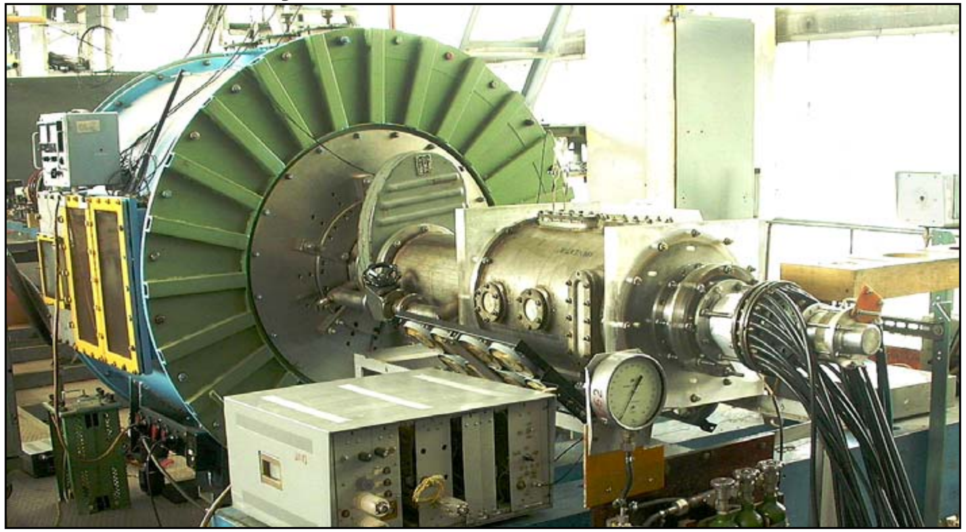
QSPA-T facility



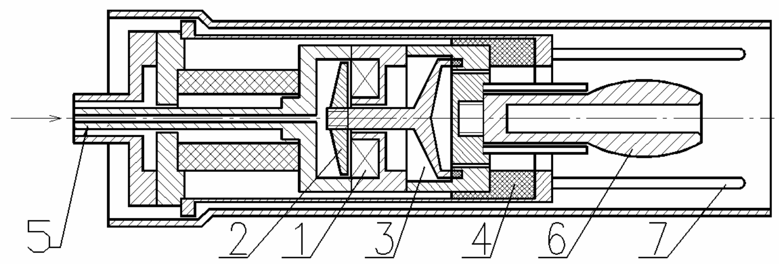
QSPA-Be facility

QSPA plasma parameters (ELMs):

- Heat load — 0.5 ÷ 5 MJ/m^2
- Pulse duration — 0.1 ÷ 0.6 ms
- Plasma stream diameter — 6 cm
- Ion impact energy — 0.1 ÷ 1.0 keV
- Electron temperature — < 10 eV
- Plasma density — $10^{22} \div 10^{23}$ m^{-3}

QSPA facility provides adequate pulse durations and energy densities. It is applied for erosion measurement in conditions relevant to ITER ELMs and disruptions

QSPA plasma gun



1 – coil of pulse electromagnetic gas valve;
2 – valve disk; 3 – volume of pulse valve;
4 – isolator; 5 – gas supply tube;
6 – cathode; 7 – anode.

Experimental conditions

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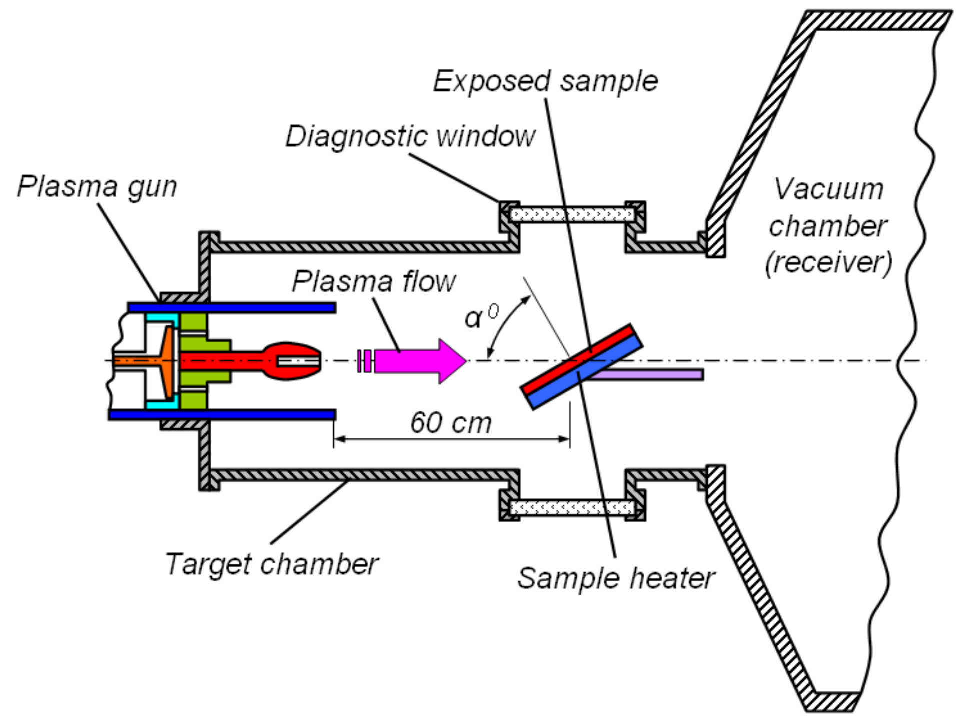
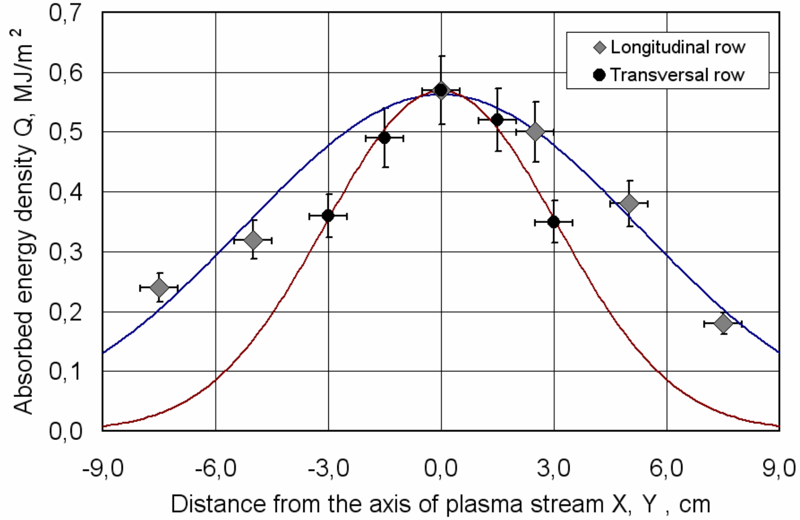
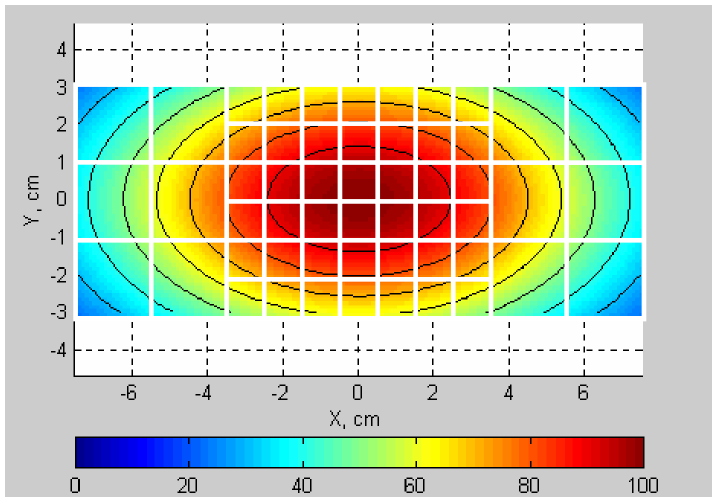
Scheme of PFCs testing under ELM-like heat load



Absorbed energy density profiles



Absorbed energy density distribution,%



- Target was preheated up to 300^{O} C
- Plasma pulse duration was t = 0.5 ms
- Plasma-surface angle α= 60^{0}
- Total number of pulses was up to 1000 for ELMs experiments
- Absorbed energy density was 0.5MJ/m^2

Experimental conditions

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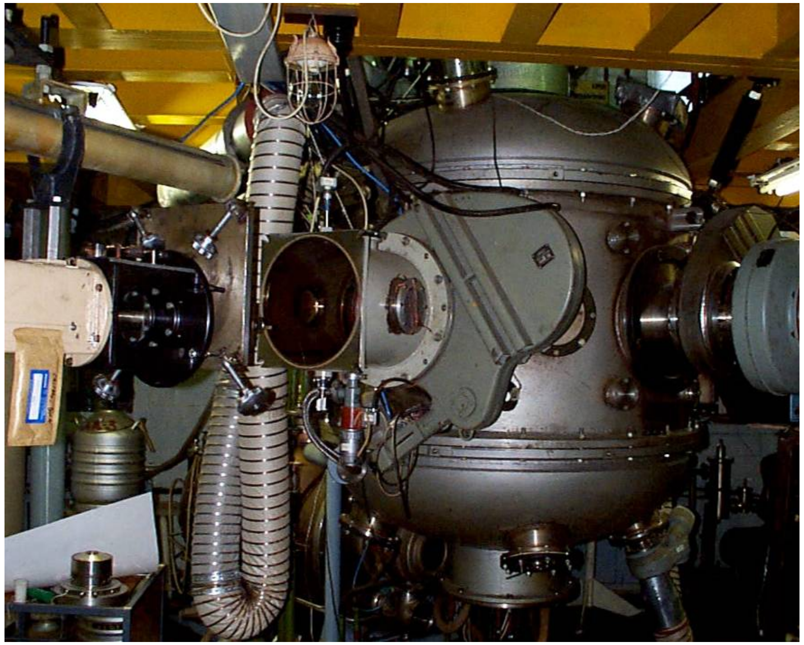
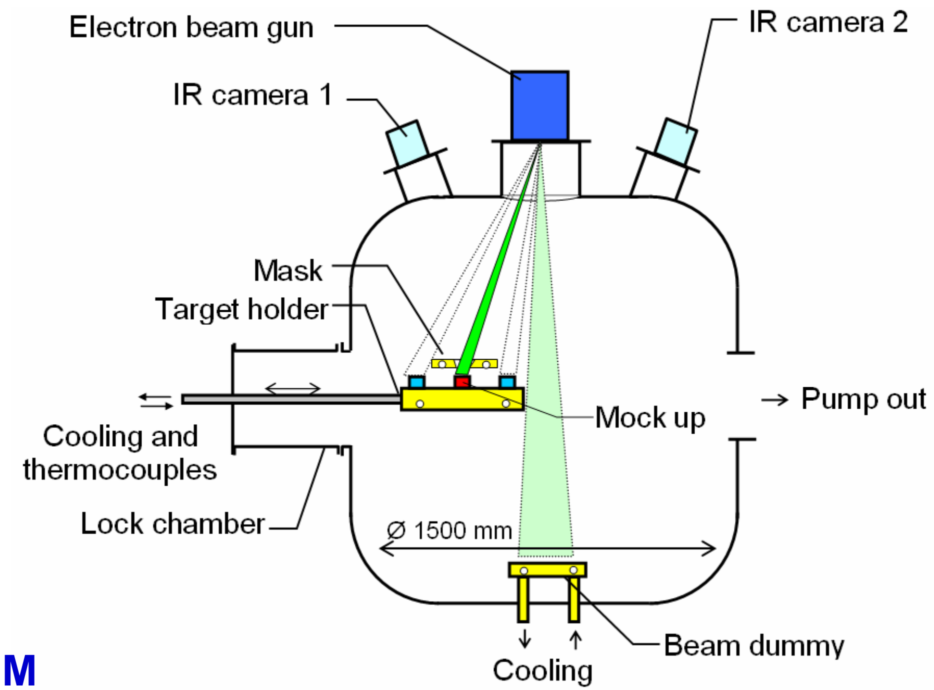
High heat flux test facility TSEFEY-M (Efremov Institute)





Technical characteristics of the TSEFEY- M

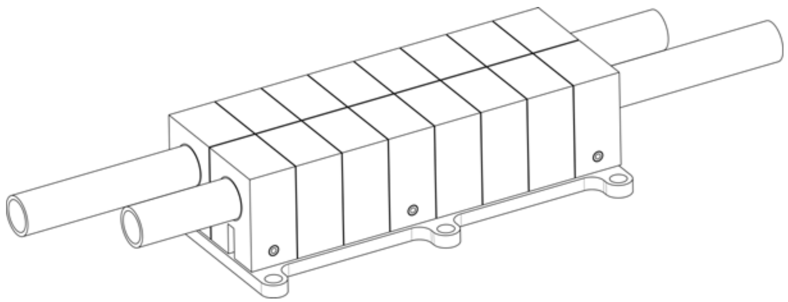
• Controlled beam power	1÷200 kW
• Maximal beam current	5A
• Maximum power density in beam	1000 MW/m^2
• Controlled accelerating voltage	0÷40kV
• Total deflection angle	±40°
• Minimal beam diameter at 40kV accelerating voltage, 5A current, 1m distance to target	15 mm
• Maximal density of the absorbed heat flux	30 MW/m^2
• Distance from deflecting system to sample	0.6÷1.2 m

TSEFEY-M facility allow to study of damages in various materials caused by abnormal high surface heat loads (including short-pulse loads), thermal strength and thermocyclic life time of multilayer structures at high temperature gradients, the heat exchange intensification processes, when structures with one-sided surface heating are cooled by water or gas.

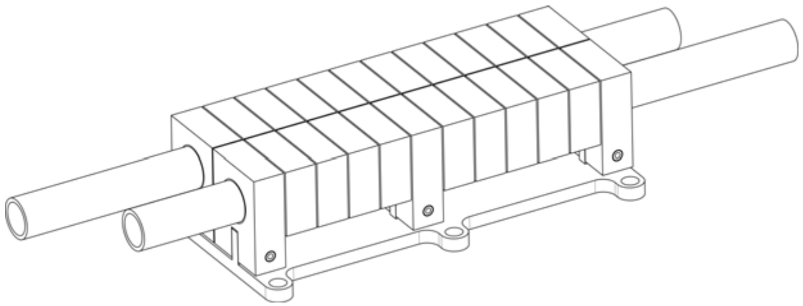
Experimental conditions

Target design (cooled mockup)

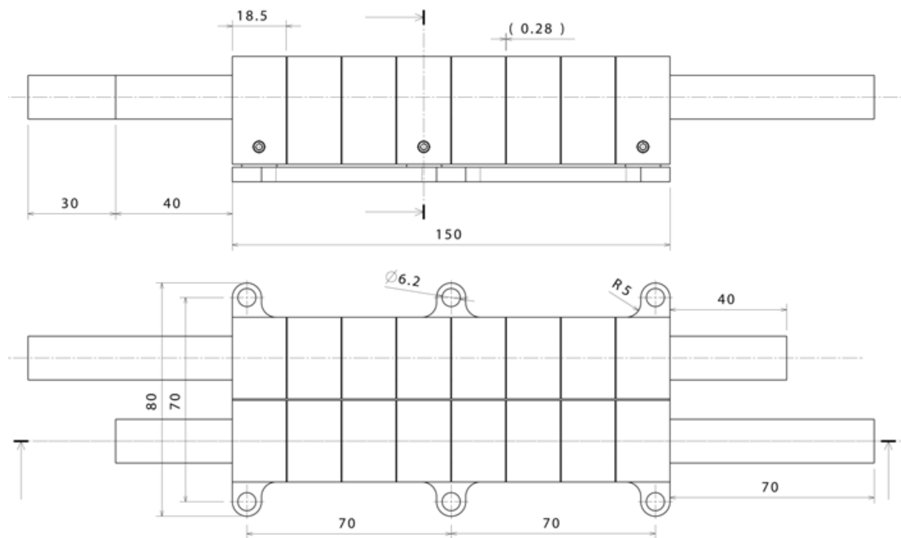
CFC cooled target

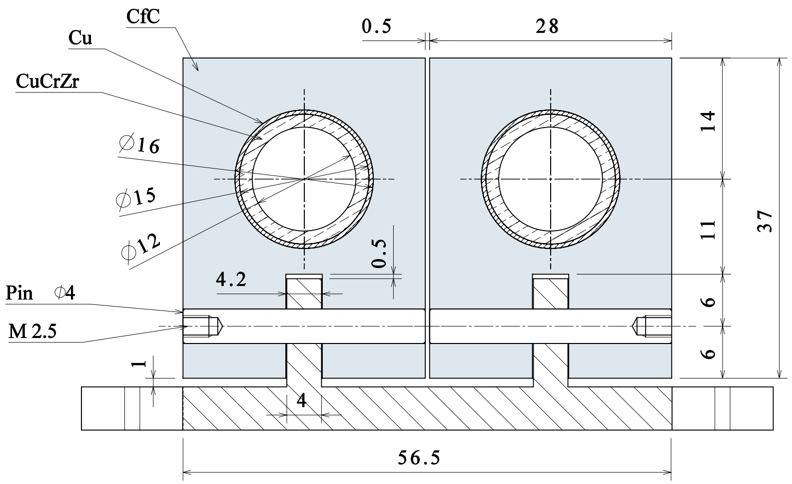


Tungsten cooled target



4 cooled targets: 2 W, and 2 CFC

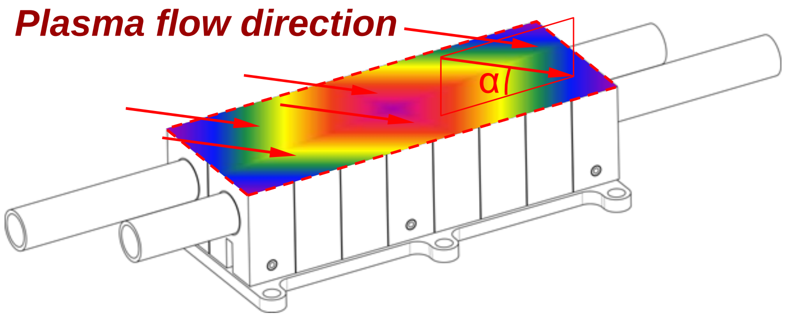




Experimental conditions

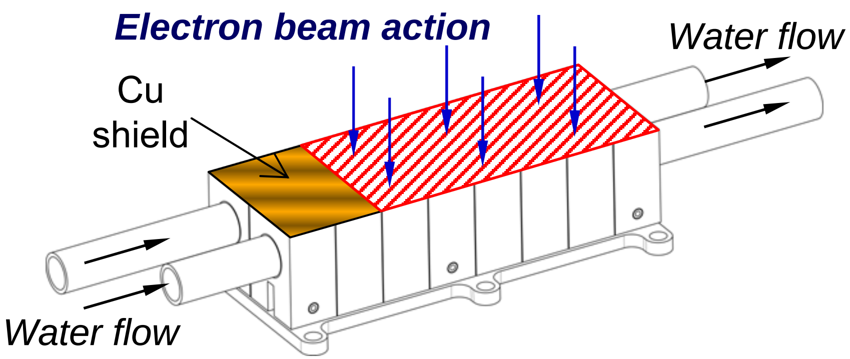
Plasma exposure + high heat flux testing

Step 1: N=500 plasma pulses, Q_0=0.5 MJ/m^2



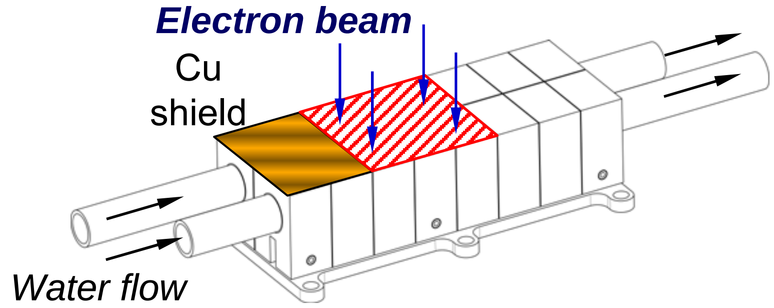
t_{pulse}=0.5 ms (W=1 GW//m^2), T_{surf}=300^{0}C, α=30^0

Step 2: N=2000 cycles, W=10 MW/m^2, Δt=30 s

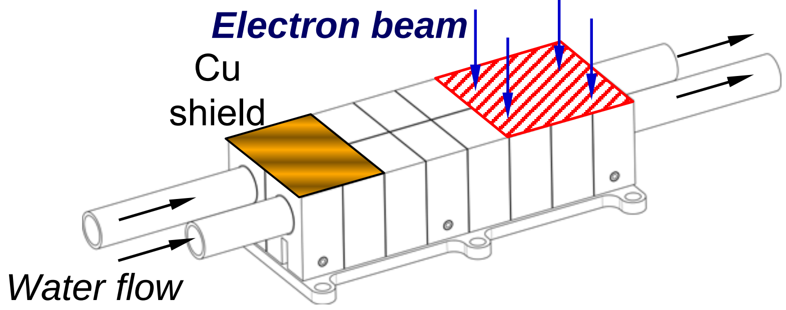


(15 seconds – shot and 15 seconds – pause),
T_{water}=40^{0}C, V_{water}=10 m/s, P_{water}=35 bar.
Screening test at 5 MW/m^2 before and after

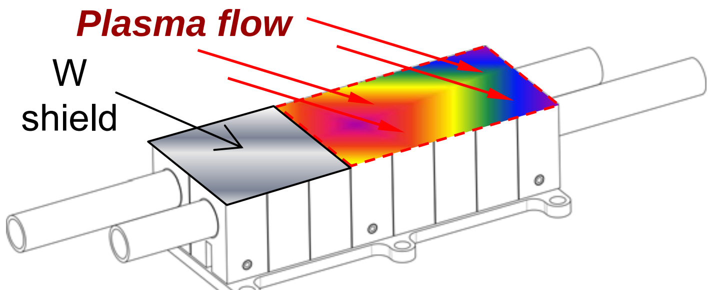
Step 3: N=300 cycles, W=20 MW/m^2, Δt=30 s



Step 4: N=300 cycles, W=20 MW/m^2, Δt=30 s



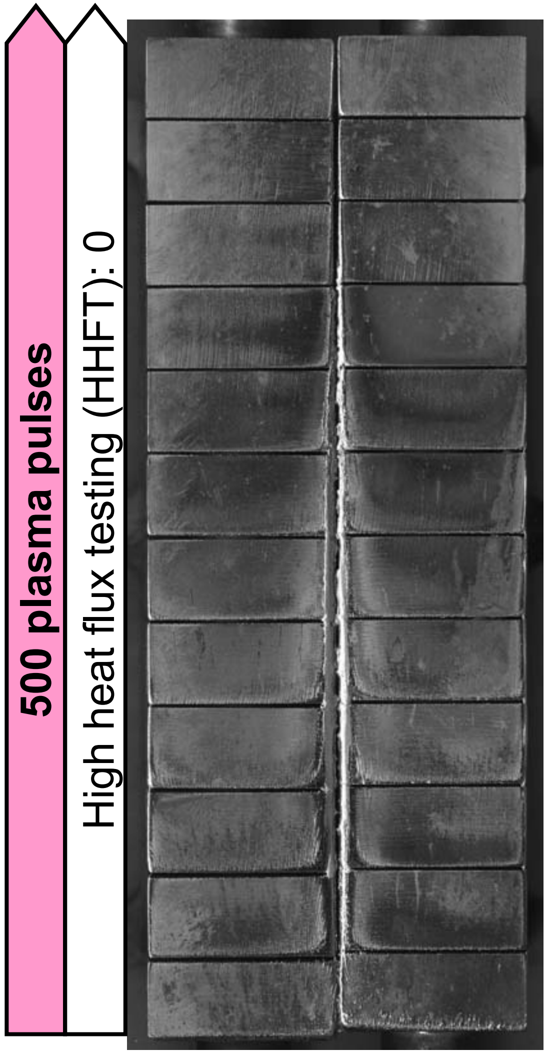
Step 5: N=500 plasma pulses, Q_0=0.5 MJ/m^2



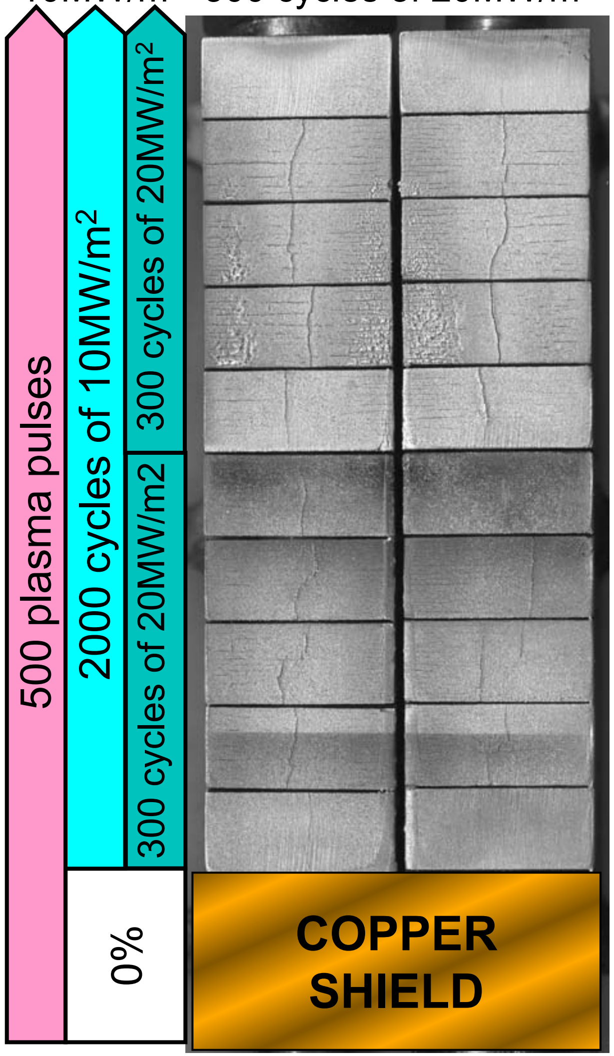
Experimental results

Plasma exposures + High heat flux testing

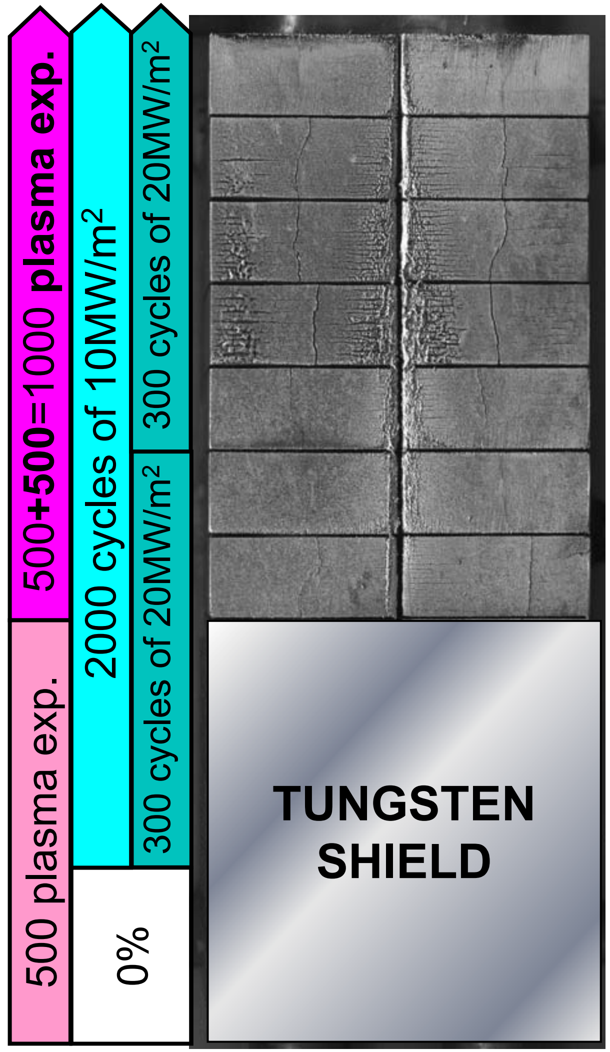
Step 1: 500 plasma pulses



Step 2: +2000 cycles of 10MW/m²+300 cycles of 20MW/m²



Step 3: +500 plasma pulses



Tungsten erosion

Plasma exposure + High heat flux test

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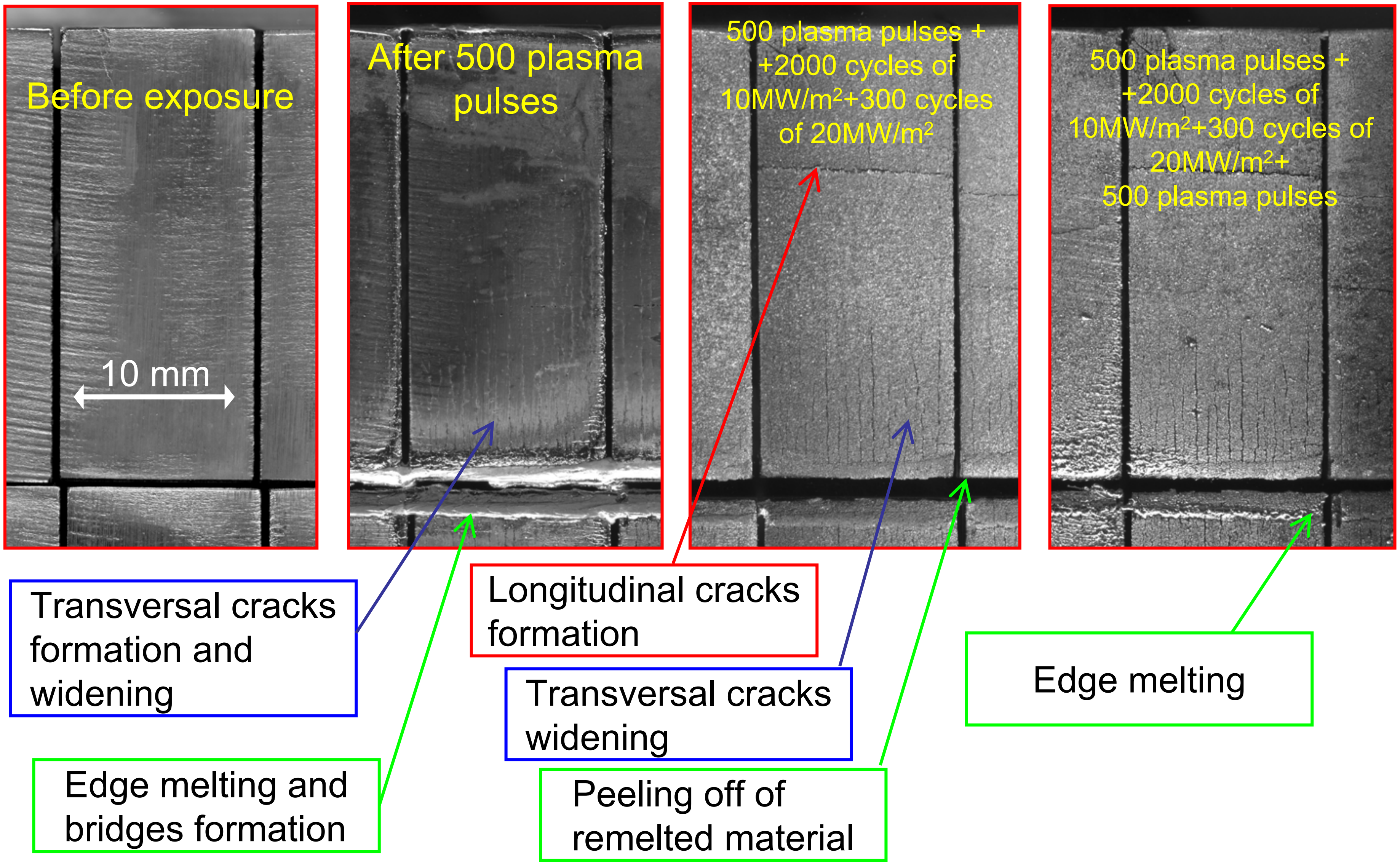

Tungsten erosion

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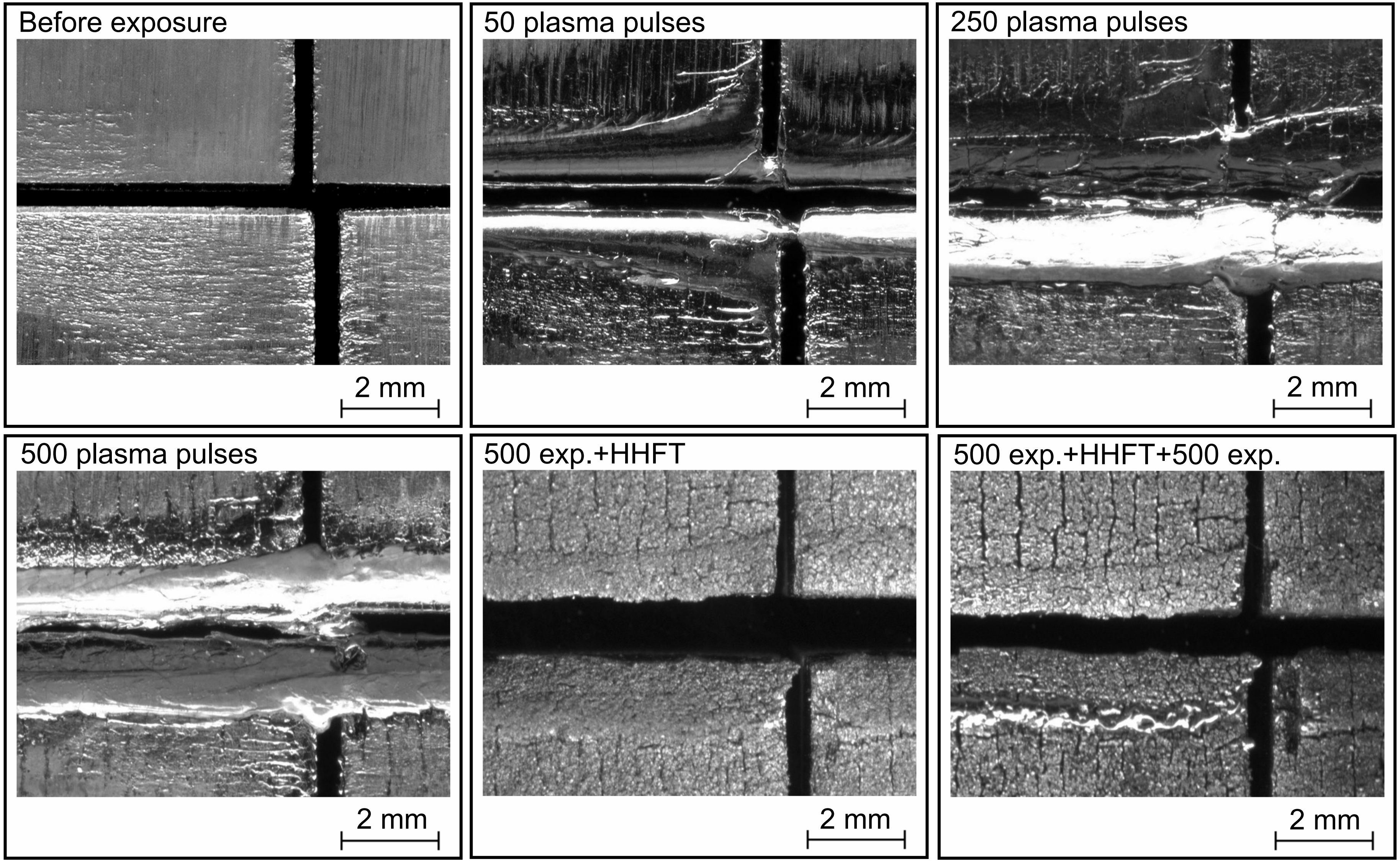
Arising and remelted material peeling off



Tungsten erosion

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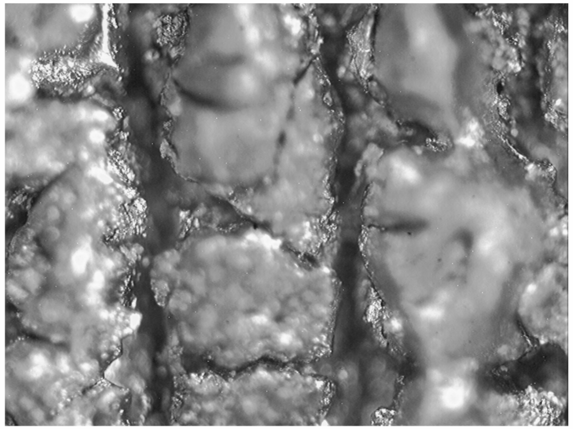
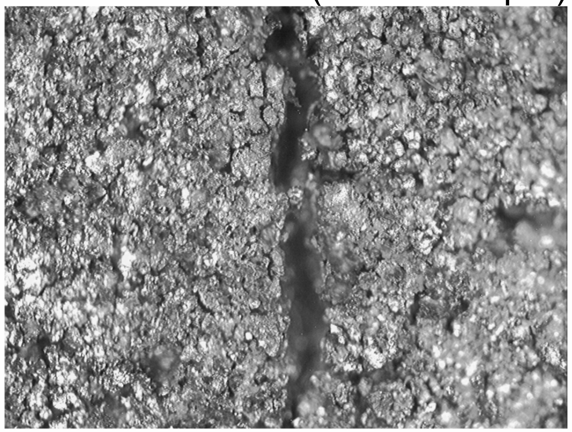
Types of cracks

Transversal cracks



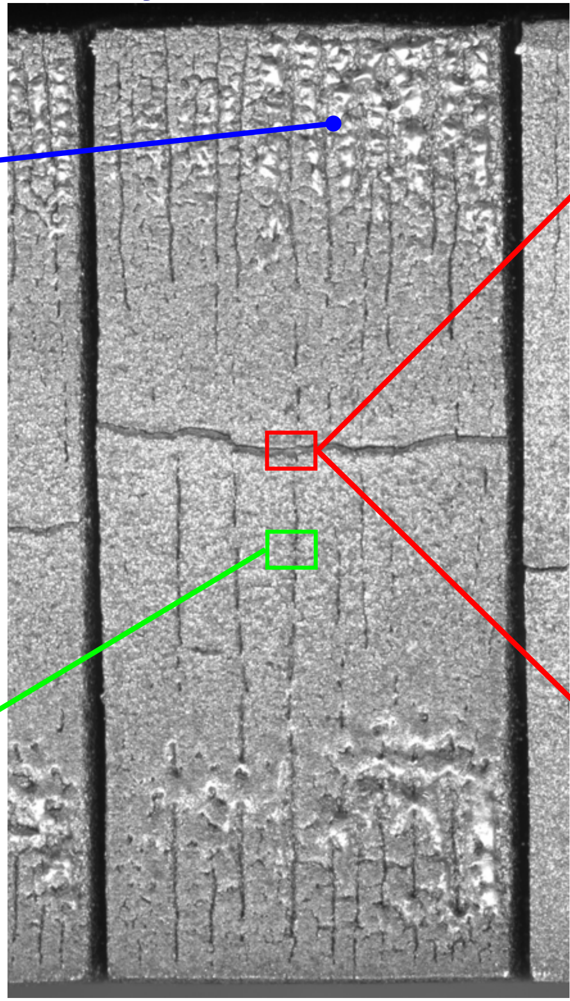
400 µm

Transversal crack (width ~100µm)

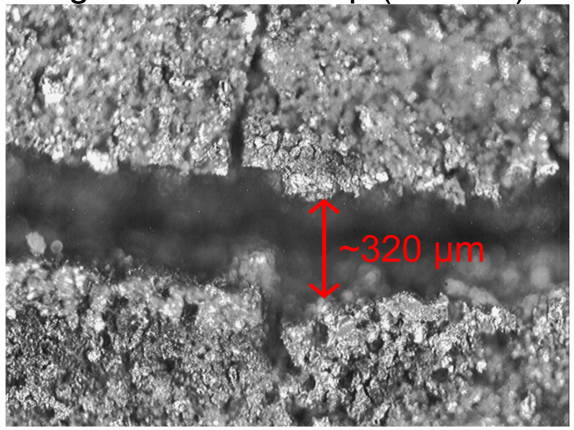


400 µm

500 plasma pulses+ +2000 cycles of 10MW/m^2+300 cycles of 20MW/m^2

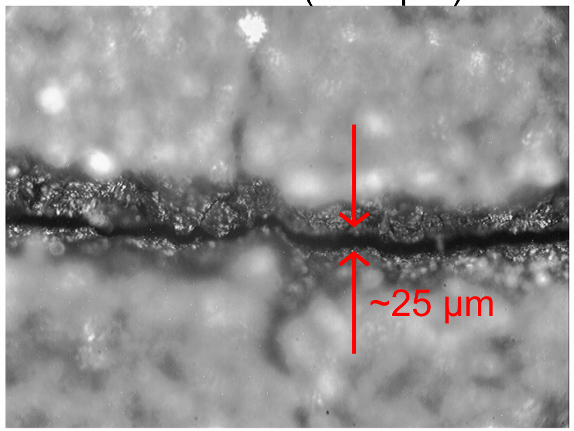


Longitudinal crack top (surface)



400 µm

The crack bottom (-330 µm)

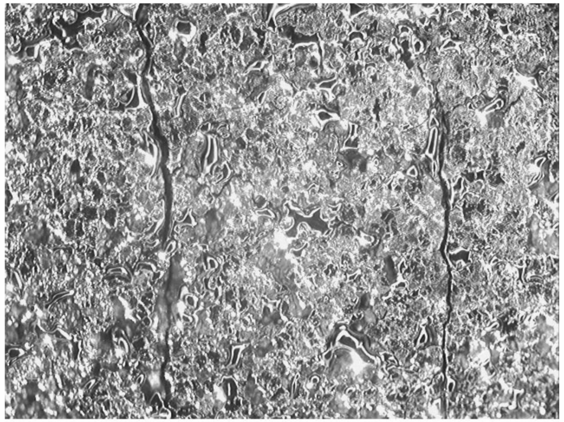


400 µm

Tungsten erosion

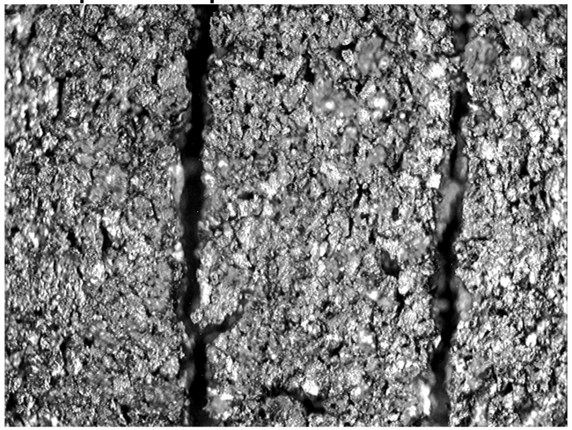
Cracks width dynamics

500 plasma pulses



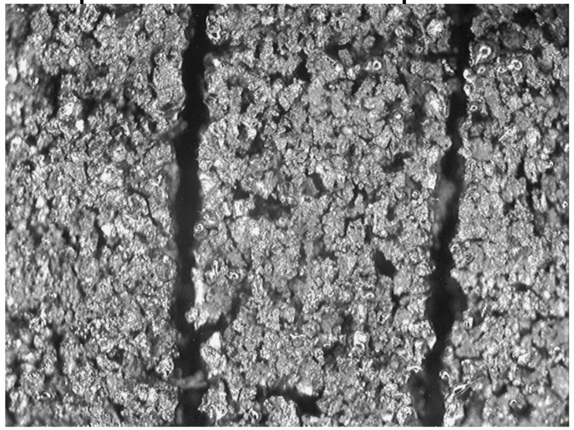
400 µm

500 plasma pulses+HHFT



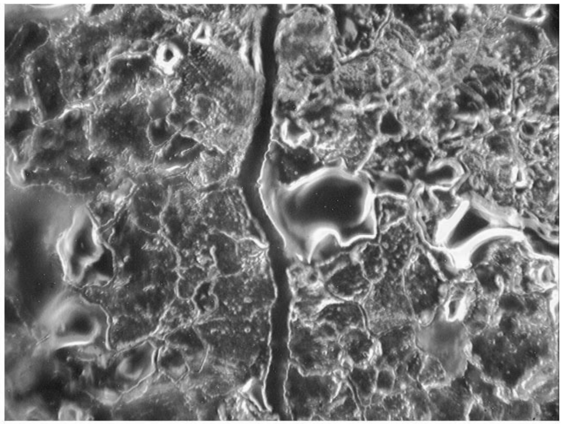
400 µm

500 pulses+HHFT+200 pulses



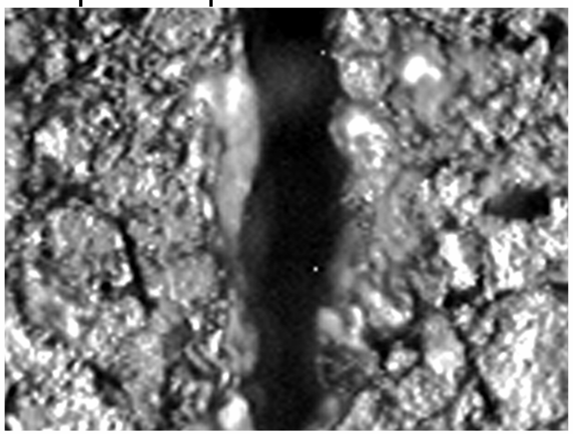
400 µm

500 plasma pulses



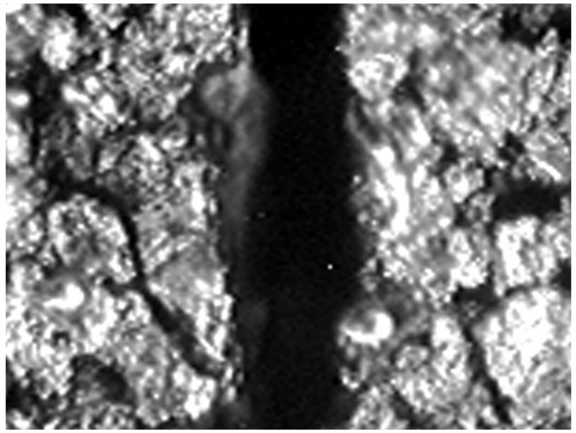
100 µm

500 plasma pulses+HHFT



100 µm

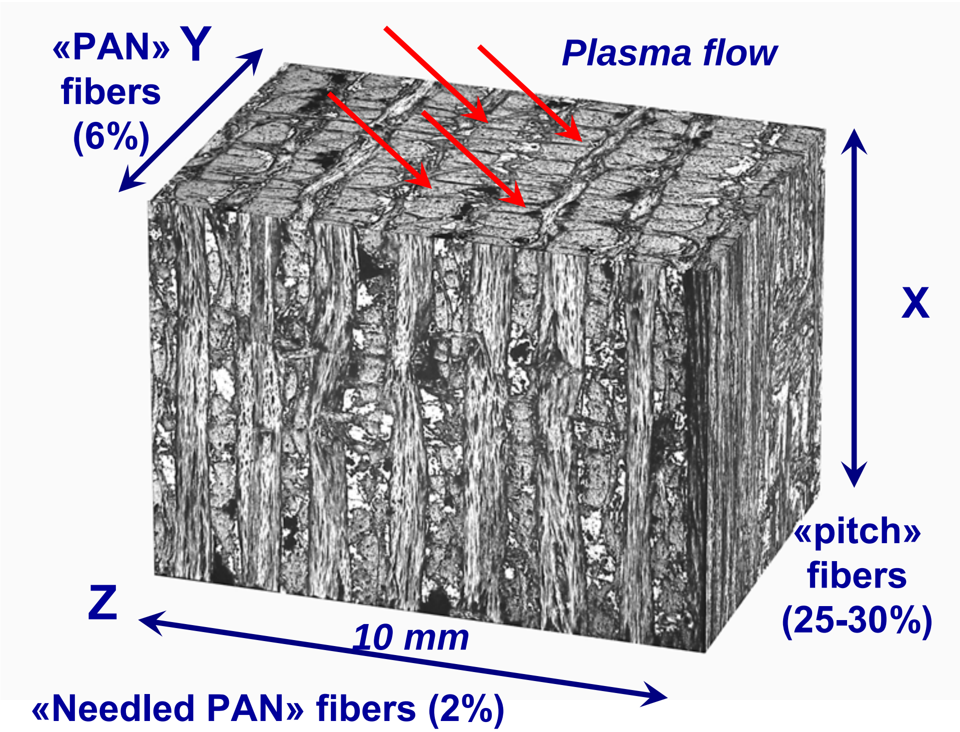
500 pulses+HHFT+200 pulses

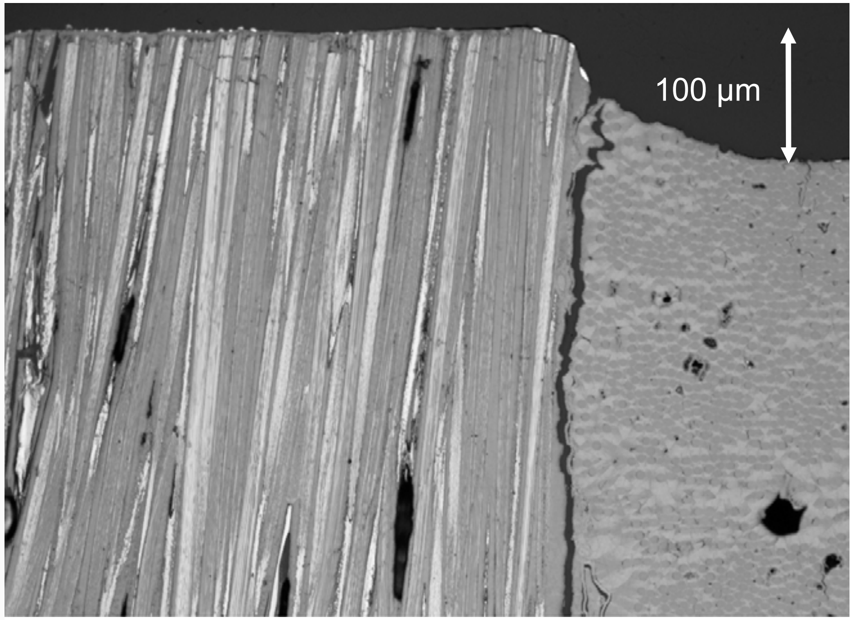


100 µm

Dust investigation

PAN-fibers erosion of CFC





Q = 1MJ/m^2, Δt=0.5 ms, N=100 pulses

• PAN fiber damage is a main mechanism of CFC erosion under ELM-like and disruption-like plasma load

• Eroded material is deposited on the vacuum chamber and diagnostics windows in a form of carbon films

Dust investigation

Dust collectors

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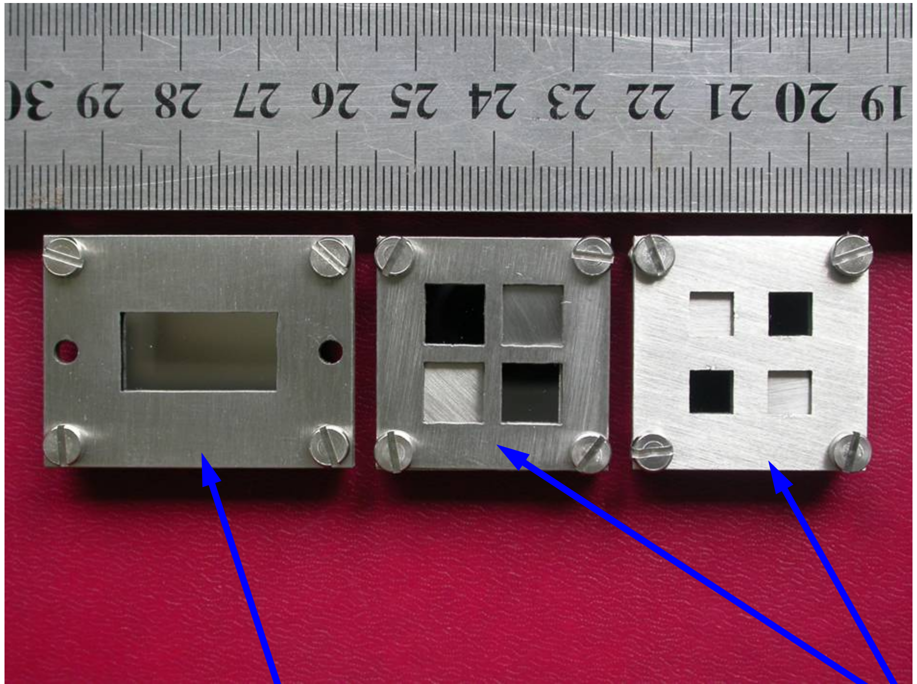
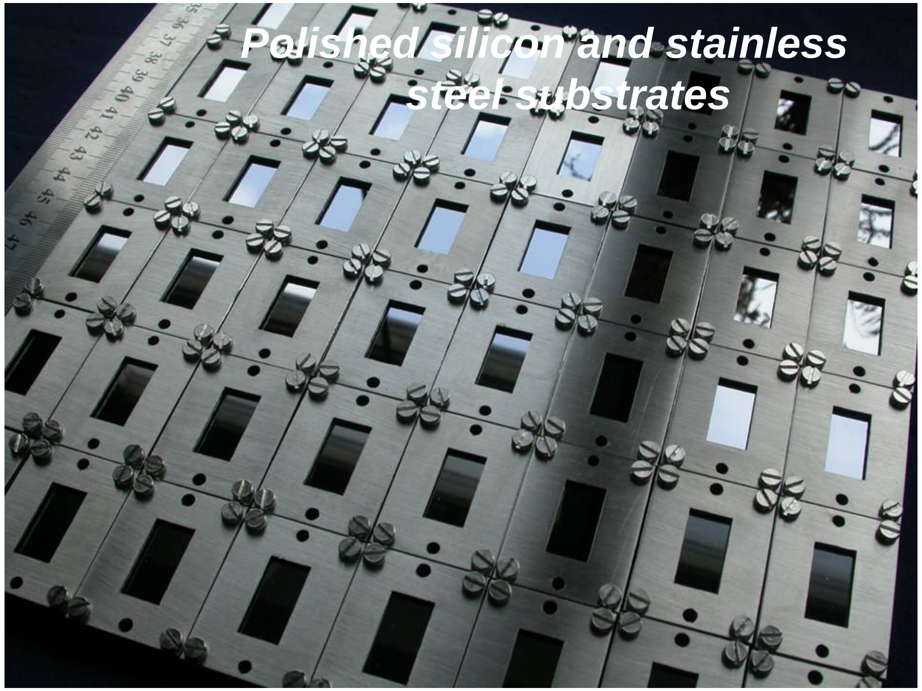
The modernized target vacuum chamber allow to place various dust collectors





Collectors of type I:
thickness, volume, and mass measurements,

Collectors of type II:
thermodesorption spectroscopy

Total number of collectors in the plasma pulse series (200 pulses) were 55 collectors of type I, 10 collectors of type II

Dust investigation

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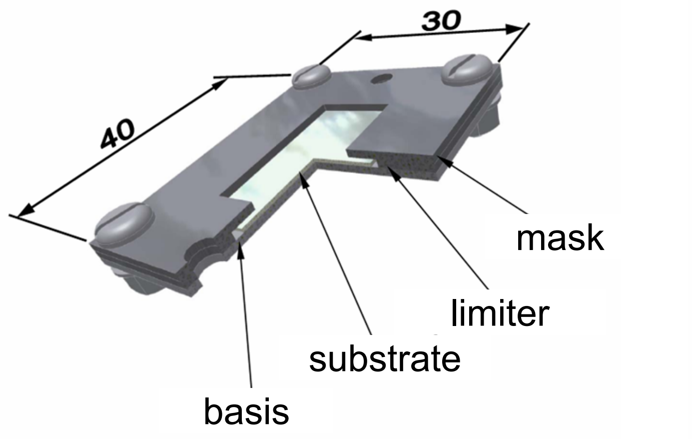
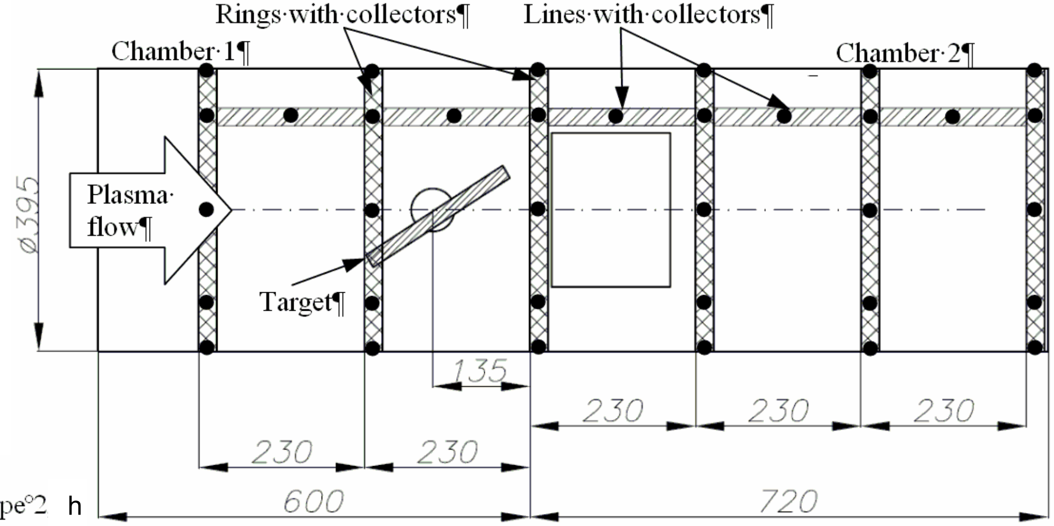
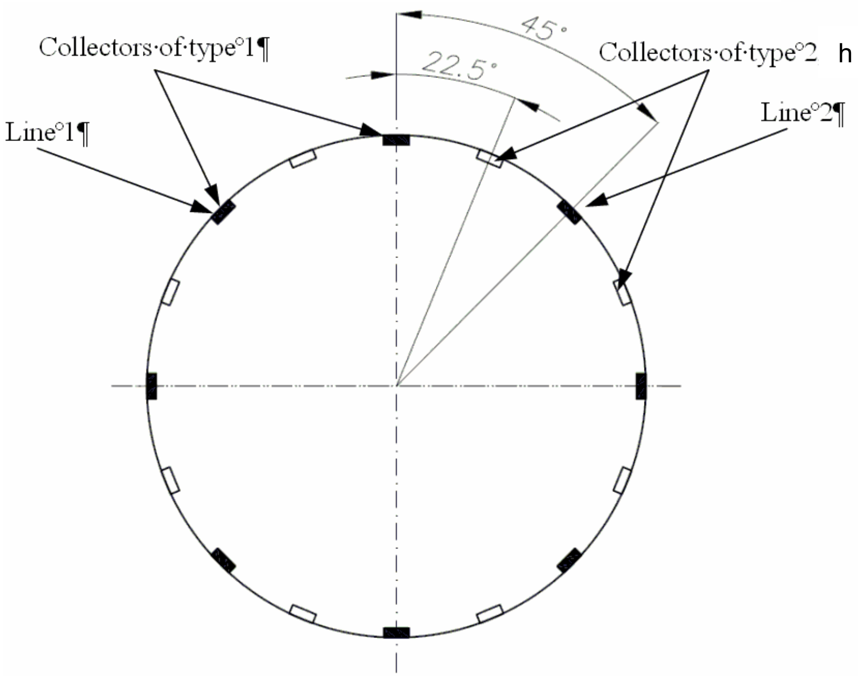
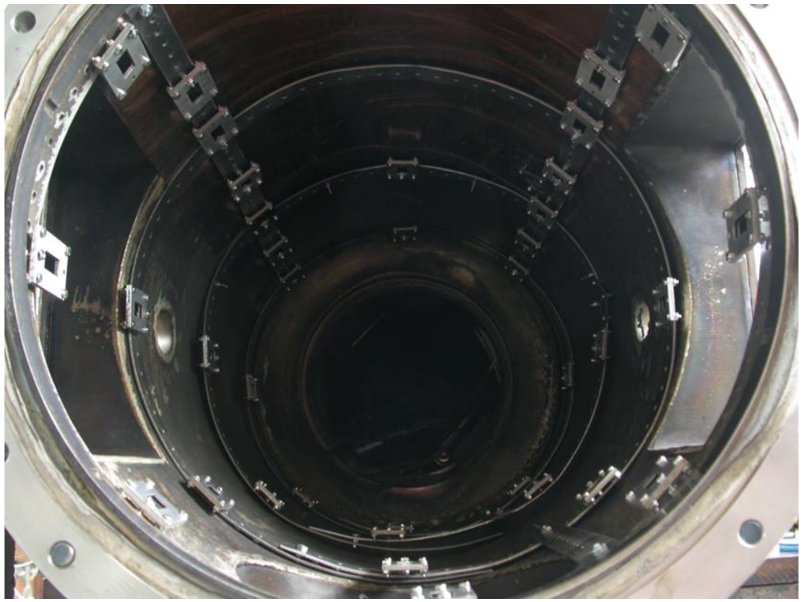
Scheme of dust collectors placement









Dust investigation

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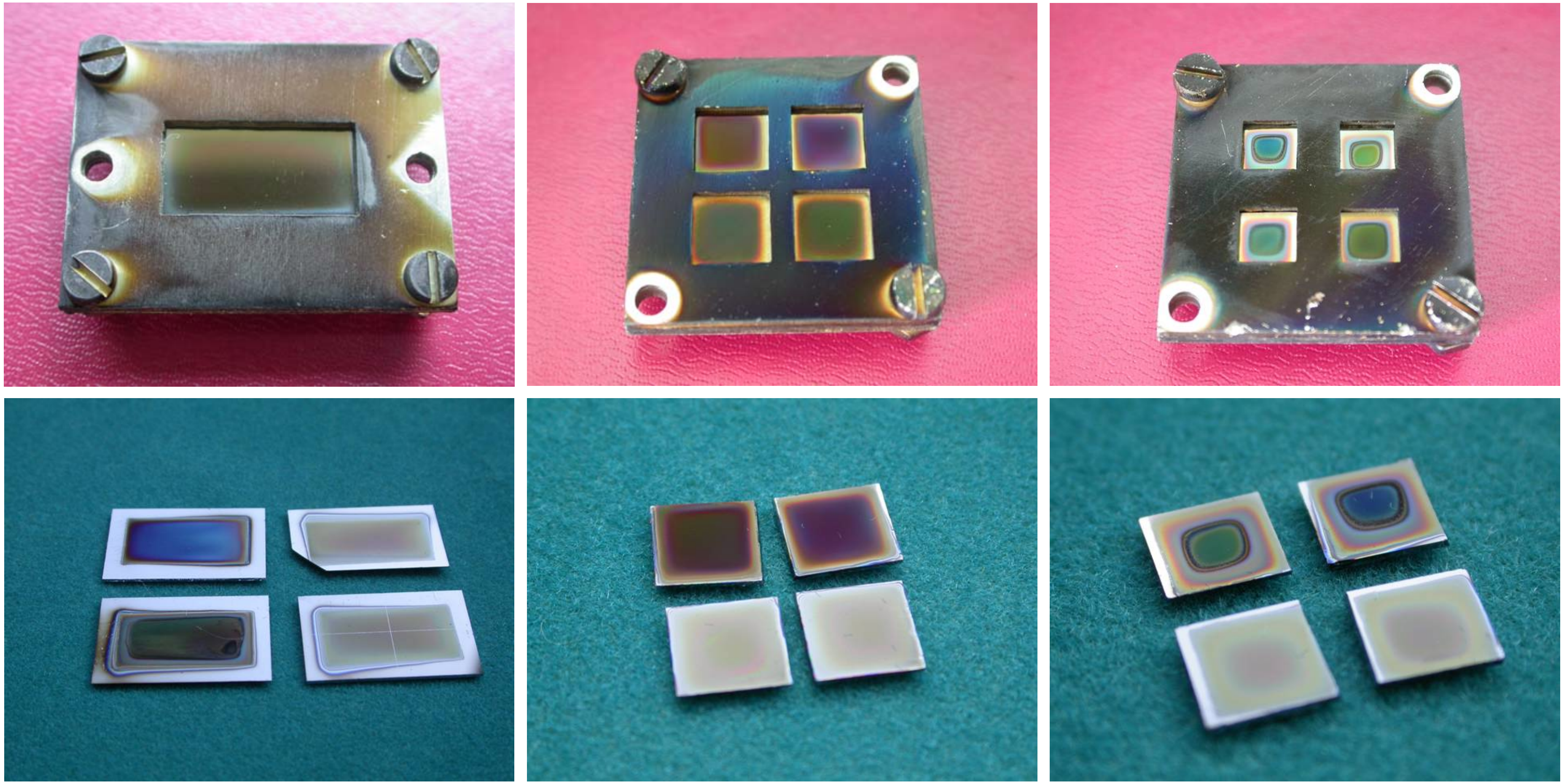
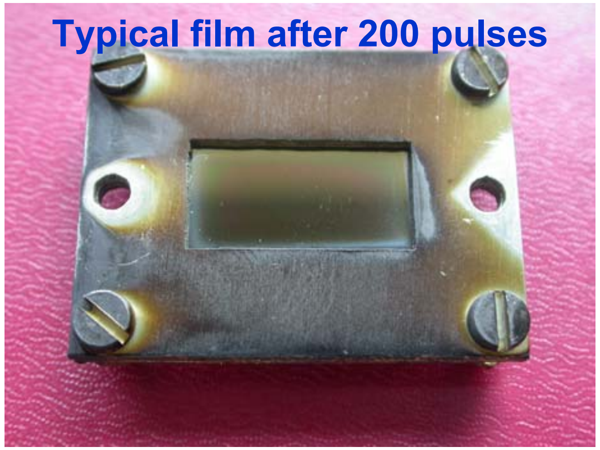
Typical view of the collector after deposition of CFC erosion products

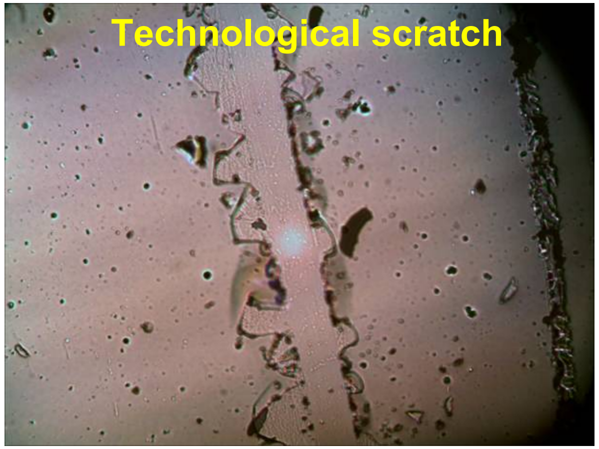
Collectors of type I | Collectors of type II | Collectors of type II

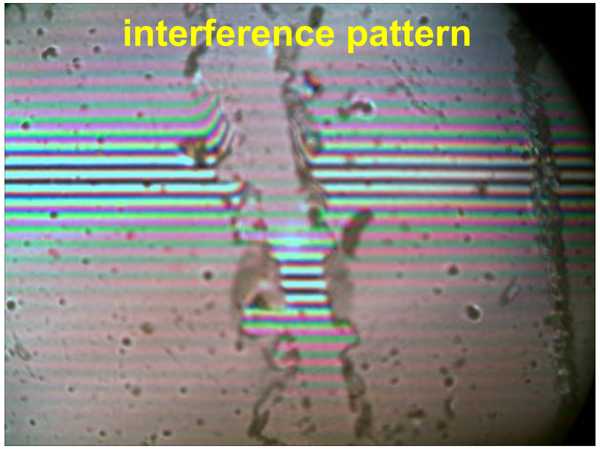


Dust investigation

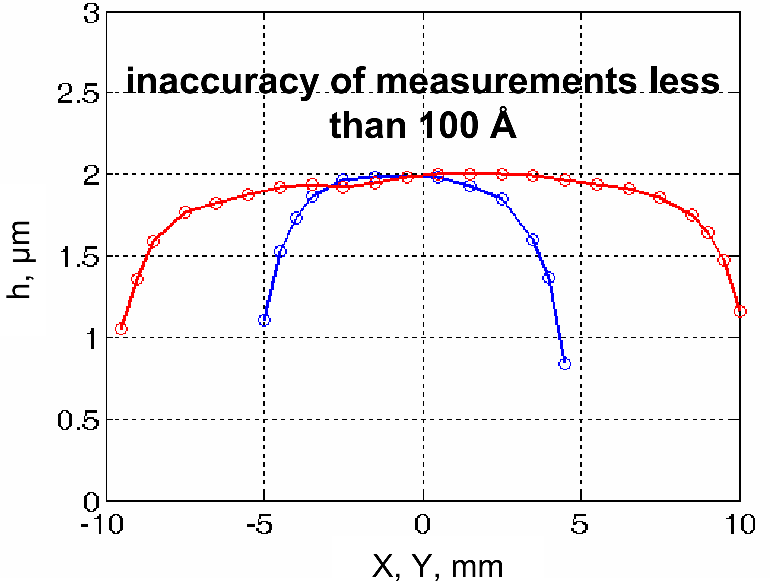
Density of the film



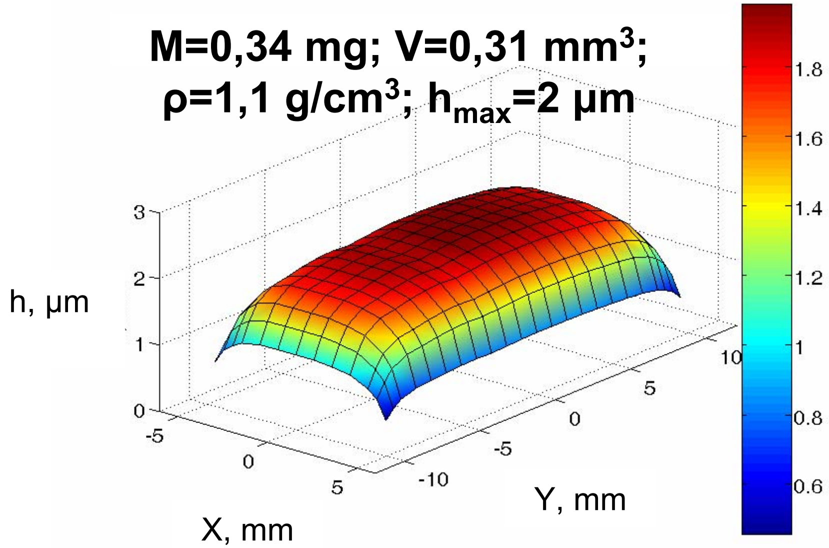




Thickness profiles along and across the sample



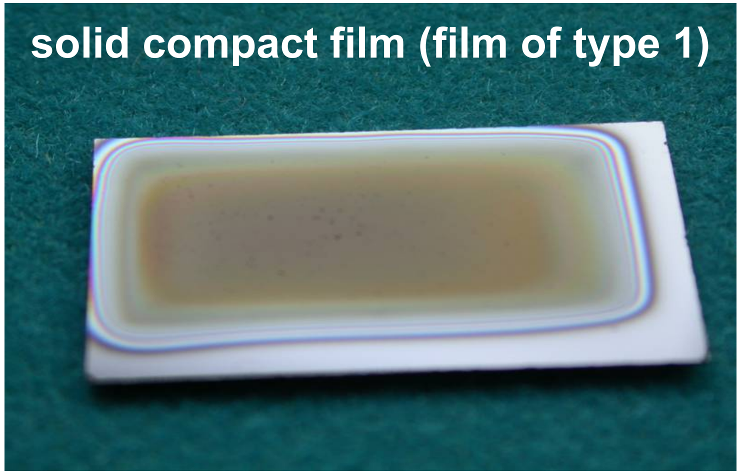
Thickness distribution and film characteristics

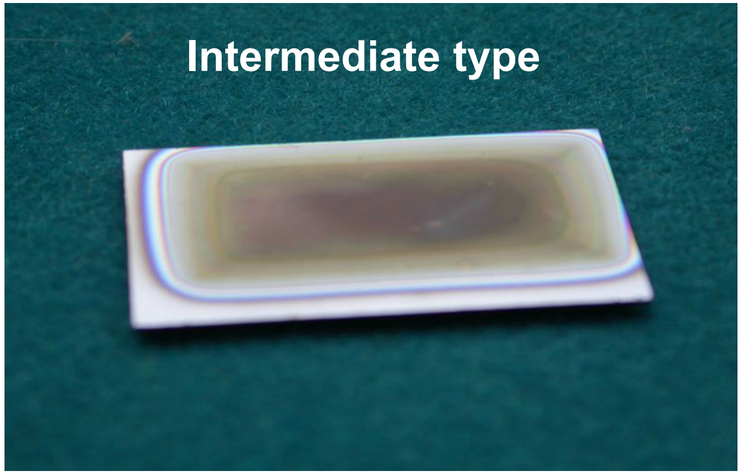


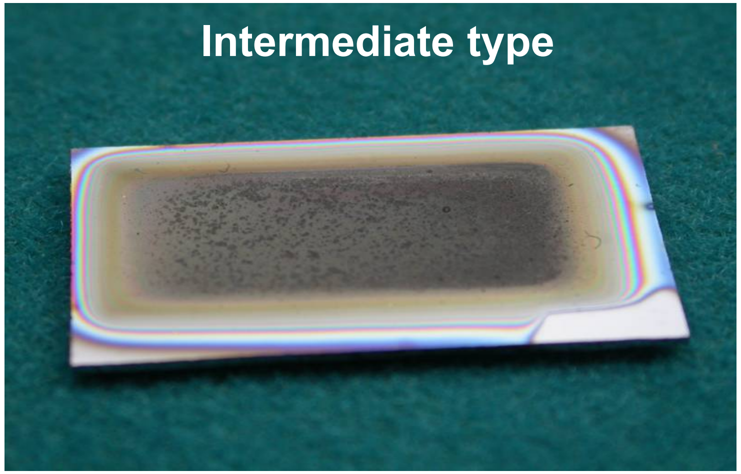
Typical density varied in the range from 0.5 g/cm³ (flake-like films) to 2 g/cm³ (solid compact films).

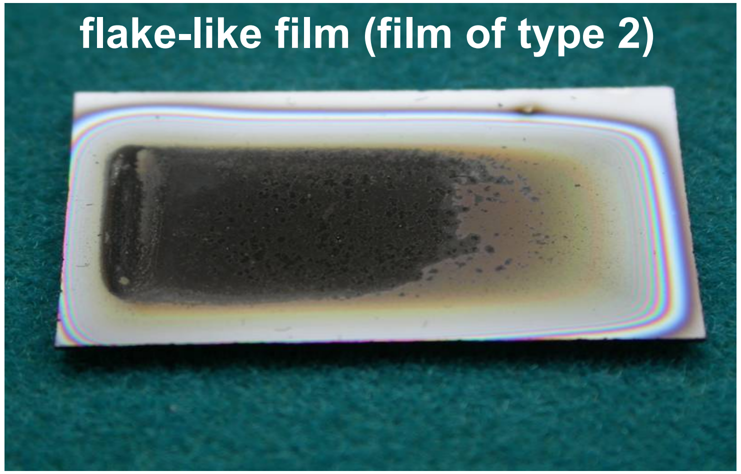
Dust investigation

Various dust films observed on the collectors at the QSPA-T





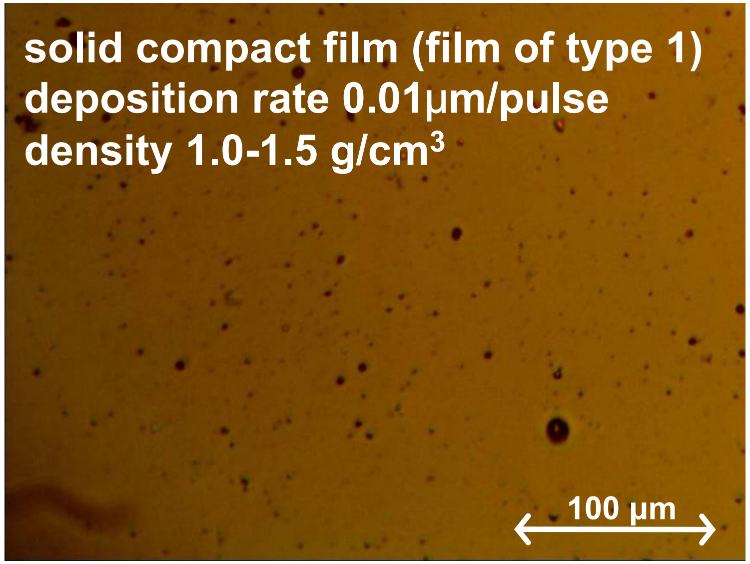


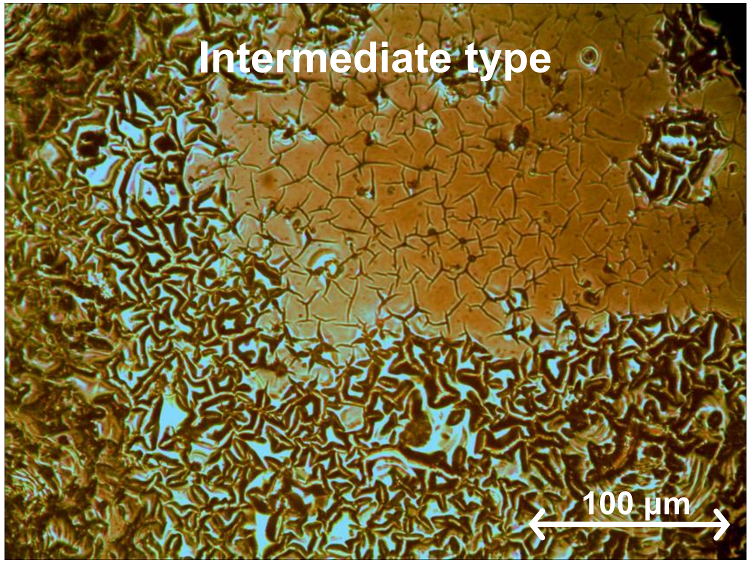


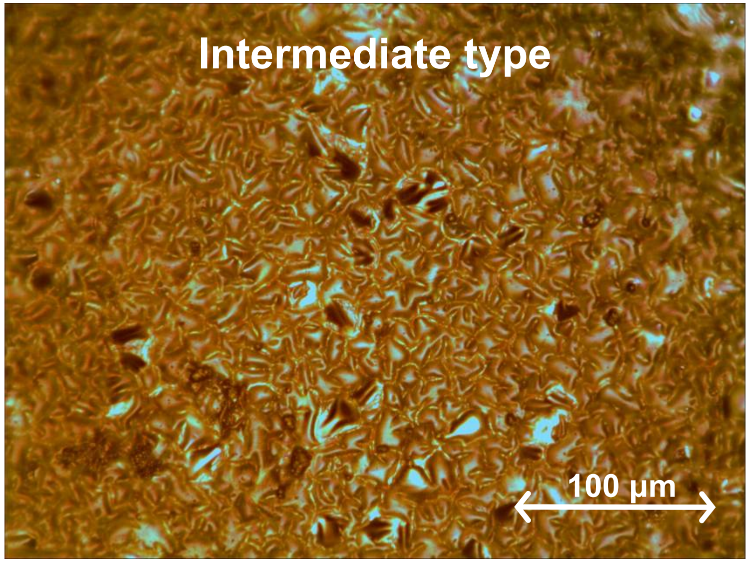
More detailed information about optical properties of the films were presented in poster presentation of I. Arhipov et al.

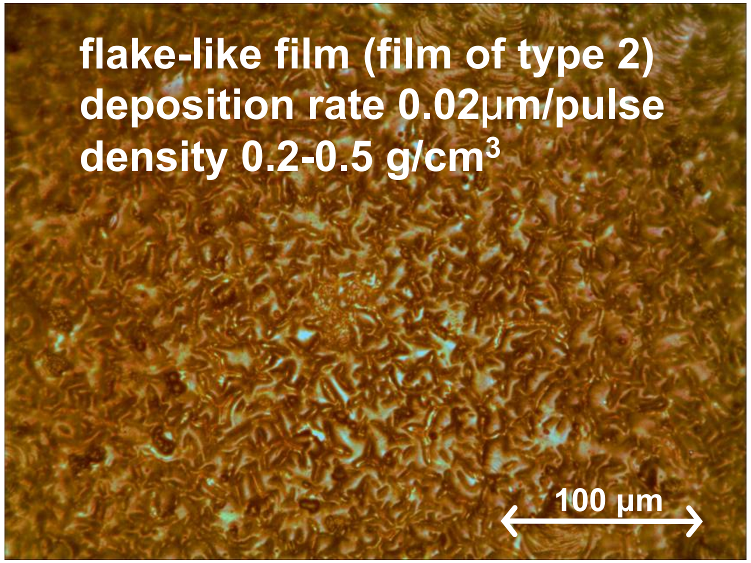
Dust investigation

Optical microscopy of the dust film



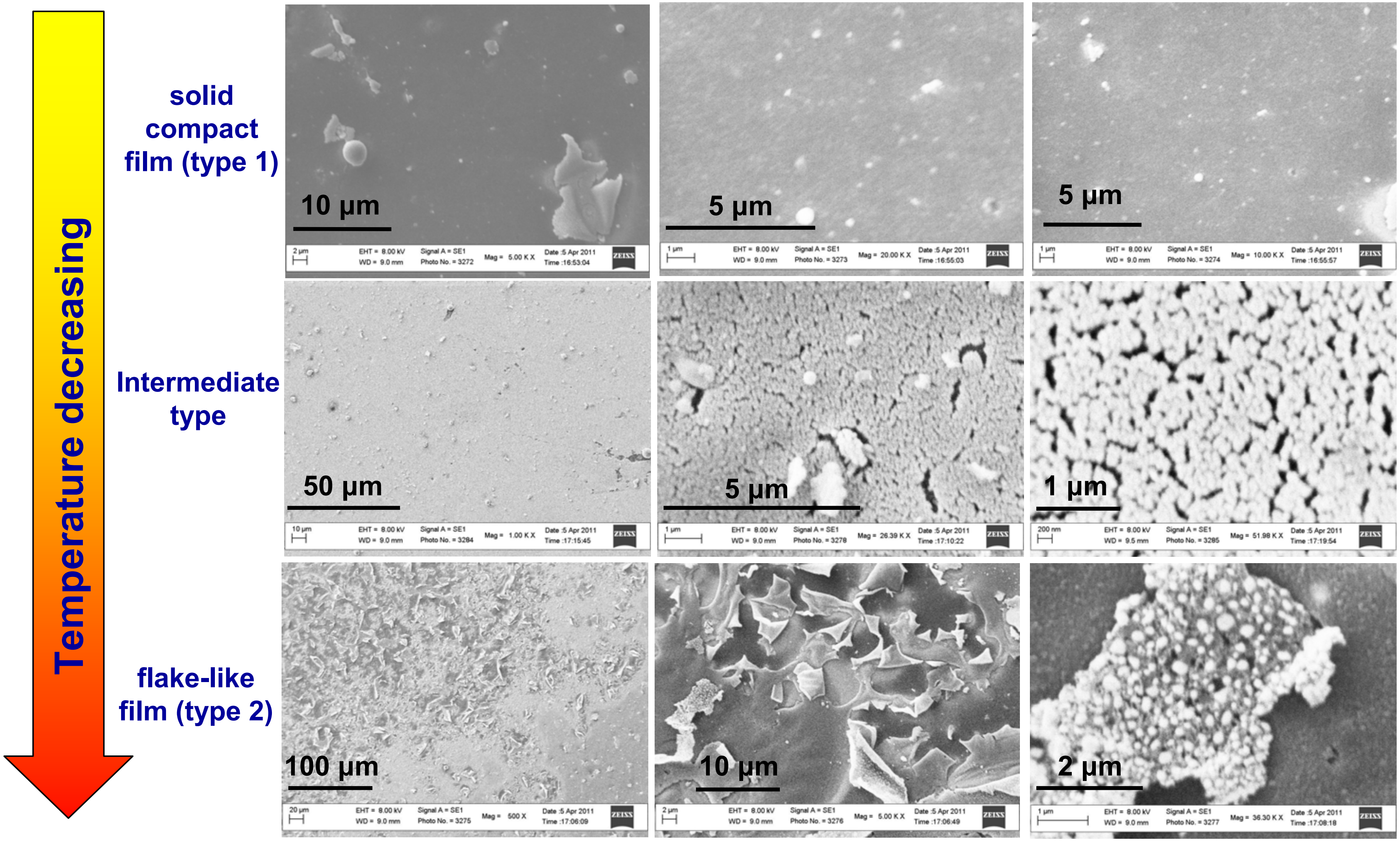






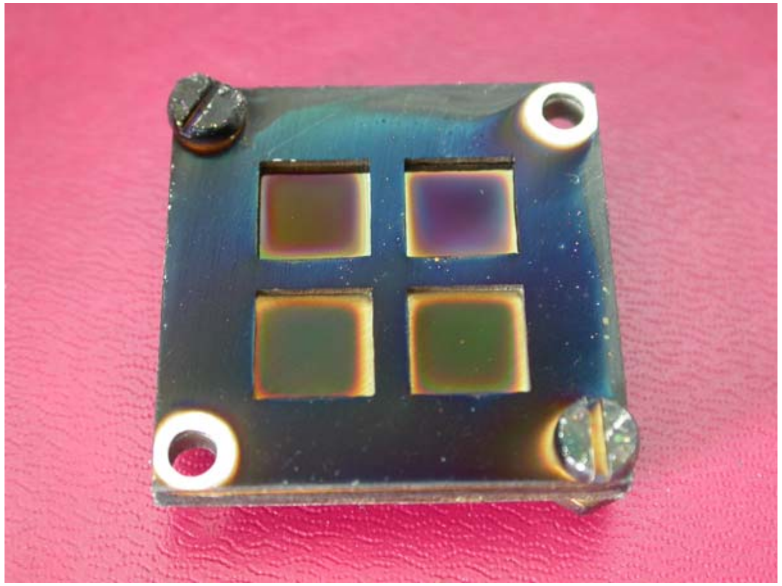
Dust investigation

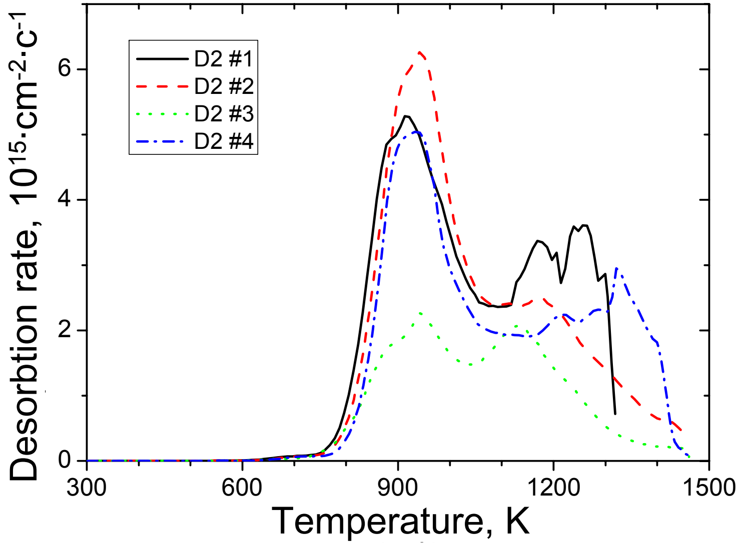
Electron microscopy of the dust film

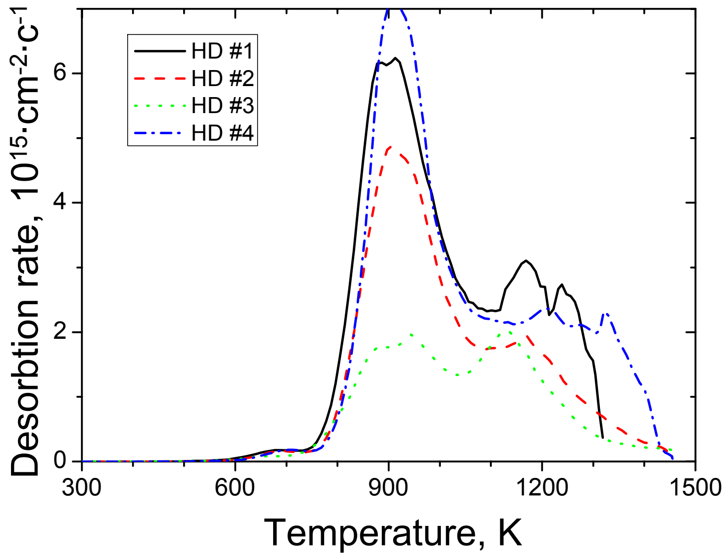


Dust investigation

Thermodesorption spectroscopy obtained by using MICMA facility (MEPHI)







the typical relative concentration of hydrogen isotopes (H+D):C equaled 0.2 for the compact films (density ≥ 1.5 g/cm^3)

Summary

Tungsten erosion

Troitsk Institute for Innovation and Fusion Research

- Edges melting and cracks formation are the main tungsten erosion processes under plasma action at the heat loads up to 0.5MJ/m^2.
- The distance between newborn transversal (primary) cracks is 300-500 μm. The width of transversal cracks increases with number of plasma pulses. The maximum width value after 500 pulses is less than 20 μm.
- The width of transversal cracks significantly increases after high heat flux testing (HHFT) up to 50-200 μm.
- As a result of HHFT longitudinal cracks are formed. The width of longitudinal cracks lie in the range of 100-400 μm.
- As a result of brittle destruction under HHFT remelted material and bridges are peeled off.

Summary

CFC erosion. Dust film study

- Under ELM and disruption heat loads the CFC erosion was mainly due to PAN-fibers damage. The significant part of eroded materials deposited on the vacuum chamber.

- The maximum deposition rate equaled to $2 \cdot 10^{-2}$ μm/pulse (t_{pulse} = 0.5 ms) was observed in the downstream of plasma at the distance 30-60 cm from the target in the disruption simulation experiments (Q = 2.3 MJ/m^2).

- The typical deposited film density was varied from 0.5 g/cm^3 (flake-like films) to 2 g/cm^3 (solid compact films).

- The typical relative concentration of hydrogen isotopes (H+D):C equaled 0.2 for the compact films (density ≥ 1.5 g/cm^3).

Thanks for your attention