Deposition and Qualification of Tungsten Coatings Produced by Plasma Deposition in WF_6 Precursor Gas

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Tungsten is the plasma facing candidate for future fusion devices

Additional R&D needed to

- Qualify tungsten under high power loads (cracking, fatigue, melting)
- Develop W materials with improved ductility and reduced grain grow
- ***Study further the compatibility with all plasma scenarios and heating schemes***

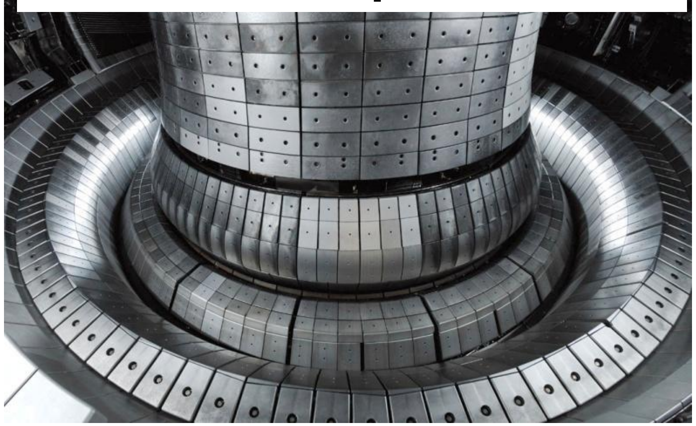
Aim of the work

Develop **an in situ** **method to deposit W- coatings on the first wall of fusion devices**

Provide an environment to study W- PFCs with all plasma scenarios and heating schemes.

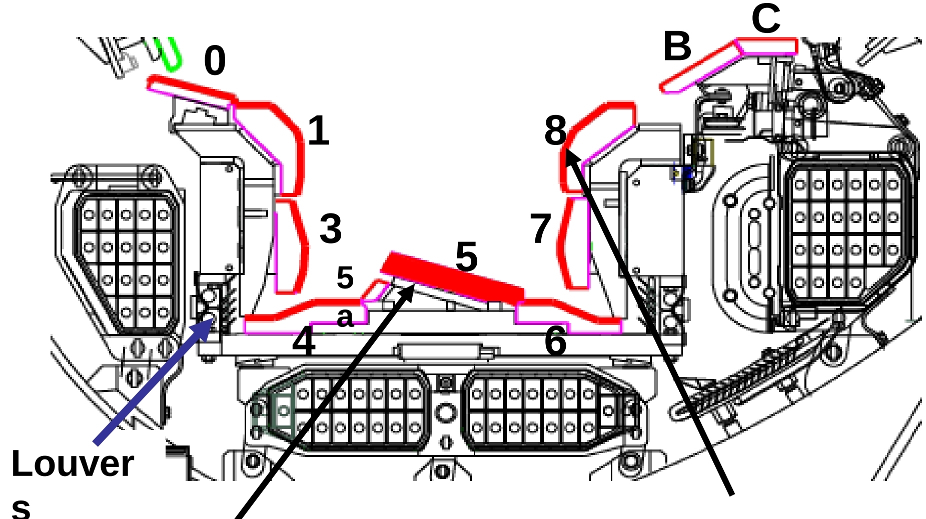
→ Discussion ongoing on the need for a full W wall in JET and ITER, also for EAST and JT60-SA → to qualify W for DEMO

AUG full W experiment



Main chamber: 3-5 µm (PVD)
Divertor: 10 µm (PVD+ CMSII)

JET ILW experiment



W-bulk

10- 25 µm W on CFC by CMSII

WF_6 as precursor gas

WF_6 is used for chemical vapour deposition (CVD) by thermal decomposition at hot surfaces (400-800°C)

WF_6 has also been used in lab experiments for plasma assisted W deposition (e.g. A. Cambe, E. Gauthier , J. Nuc.Mat (2001) 331)

Plasma deposition method like boronisation/ siliconisation used in present tokamaks

Approach

1. Define the deposition process parameters
2. Coating properties : density , purity, adhesion, heat flux and thermal shock capability
3. Identify and minimise the (negative) role of Fluor

↓

4. Large scale deposition experiment
5. Injection of (smaller) amounts of WF_6 in TEXTOR

↓

6. Pilot experiment of in situ W coating in TEXTOR

Coating Process

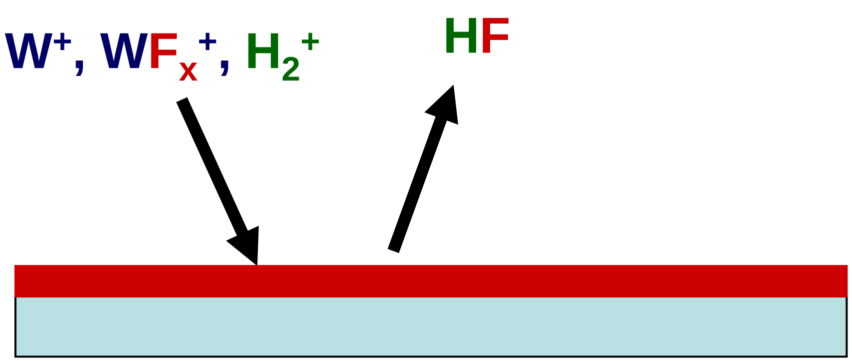
RF – assisted DC glow in 95% H_2 & 5 % WF_6

RF Power: 60 W, **Bias Voltage:** 200 – 300V , **Substrate Temp:** 200 C , **Pressure:** 0.06 mbar, **Plasma Exposure:** up to 5 hours

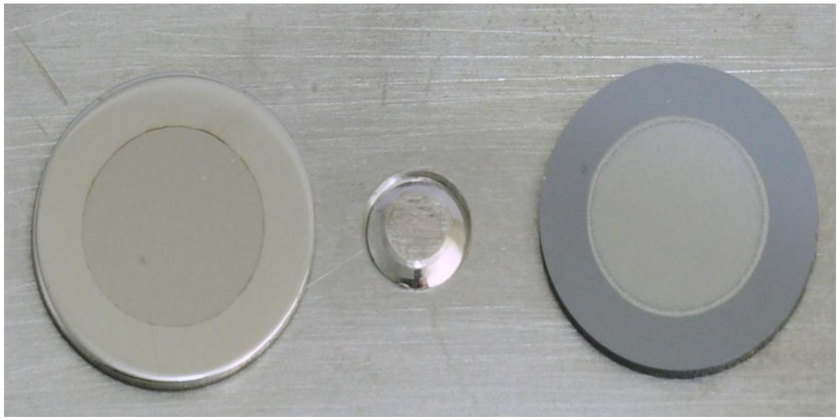
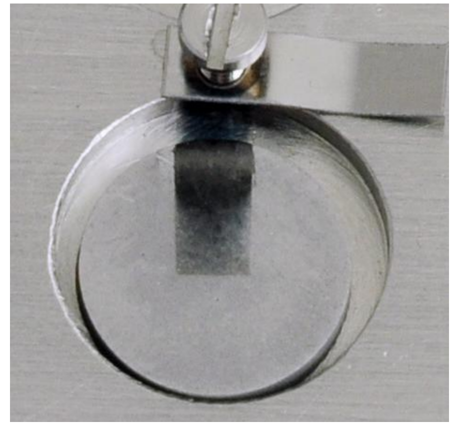
Samples: Silicon, Stainless steel, Graphite(EK98)

small scale lab experiment

$$WF_6 + 3\,H_2 \longrightarrow W + 6HF$$



Promising W coatings have been obtained on small scale samples

steel silicon graphite

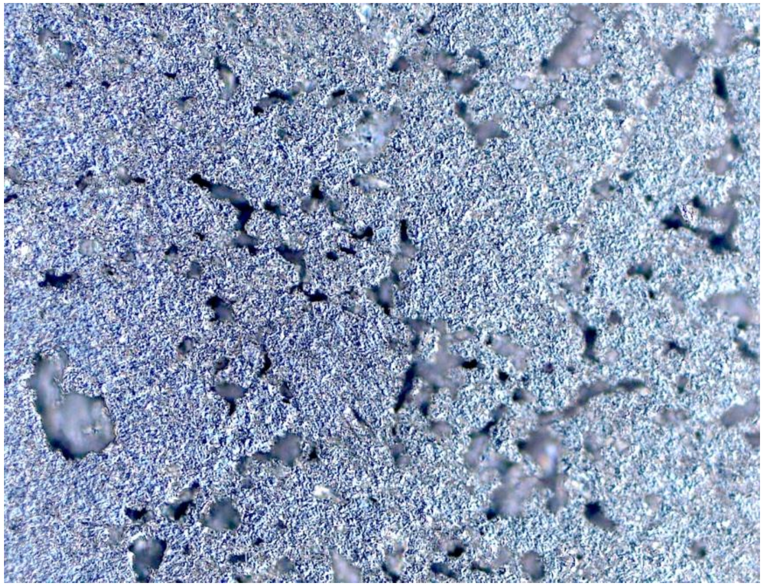
Deposition rate : 95 nm / hr.

Coatings up to 0.5 µm achieved

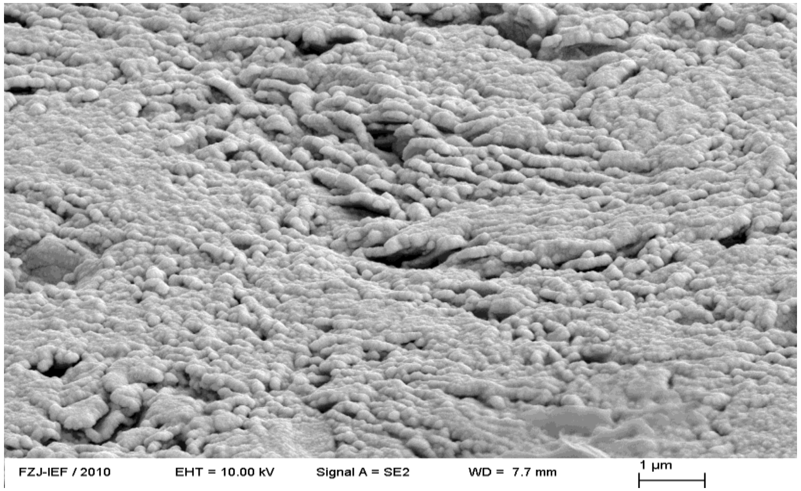
≈ 5 h operation, no physics limit identified

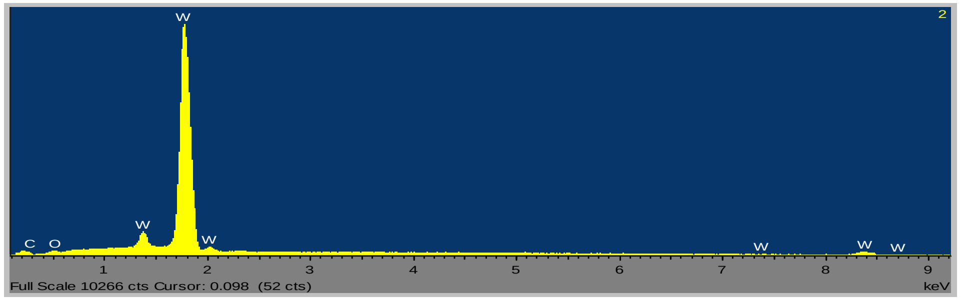
Coating properties

Optical microscopy

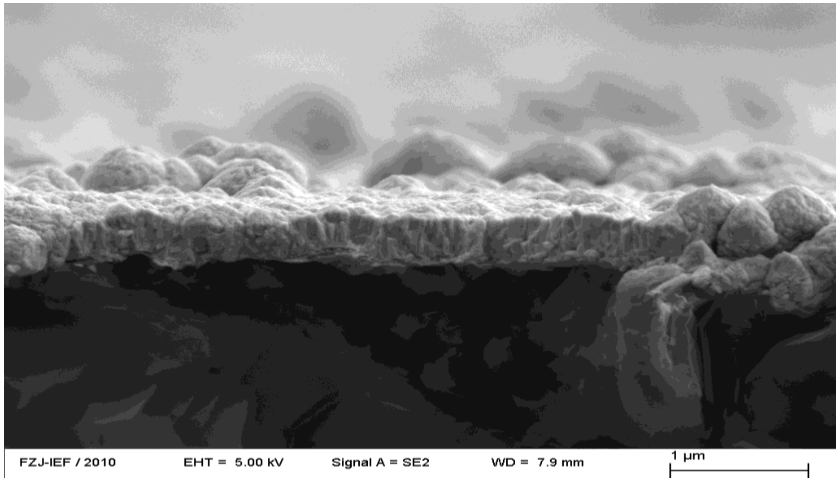


SEM





Element analysis

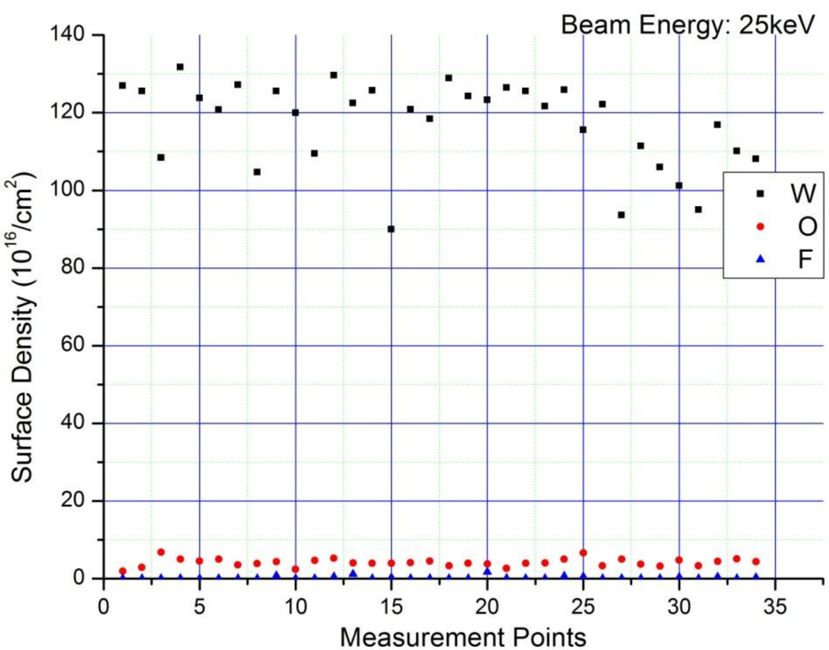


SEM on cross section

Coating properties (2)

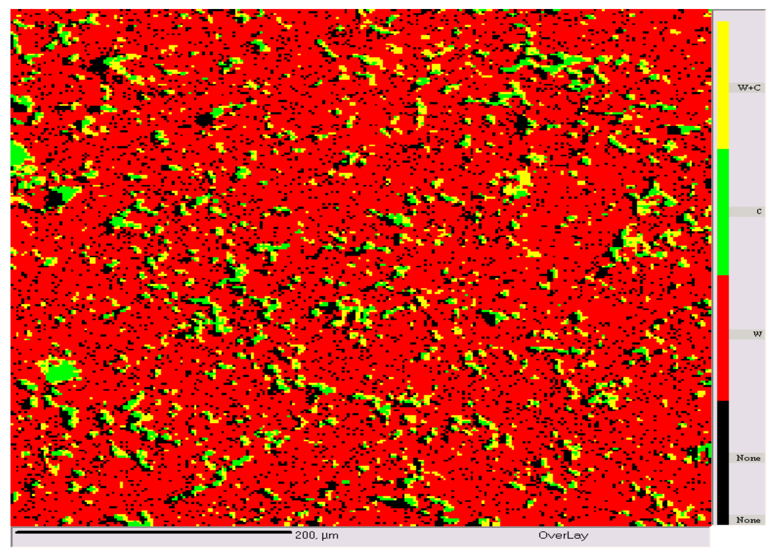
Layer analysis by Electron induced X- ray emission

Beam energy: 7 keV (range ≈ 100 nm), 25 keV (2µm)



W layer with few impurities, some oxygen , free of Fluor

Beam energy : 7.5keV



C-signal (green spots) W-signal (red spots)

→ no closed coverage, due to surface porosity

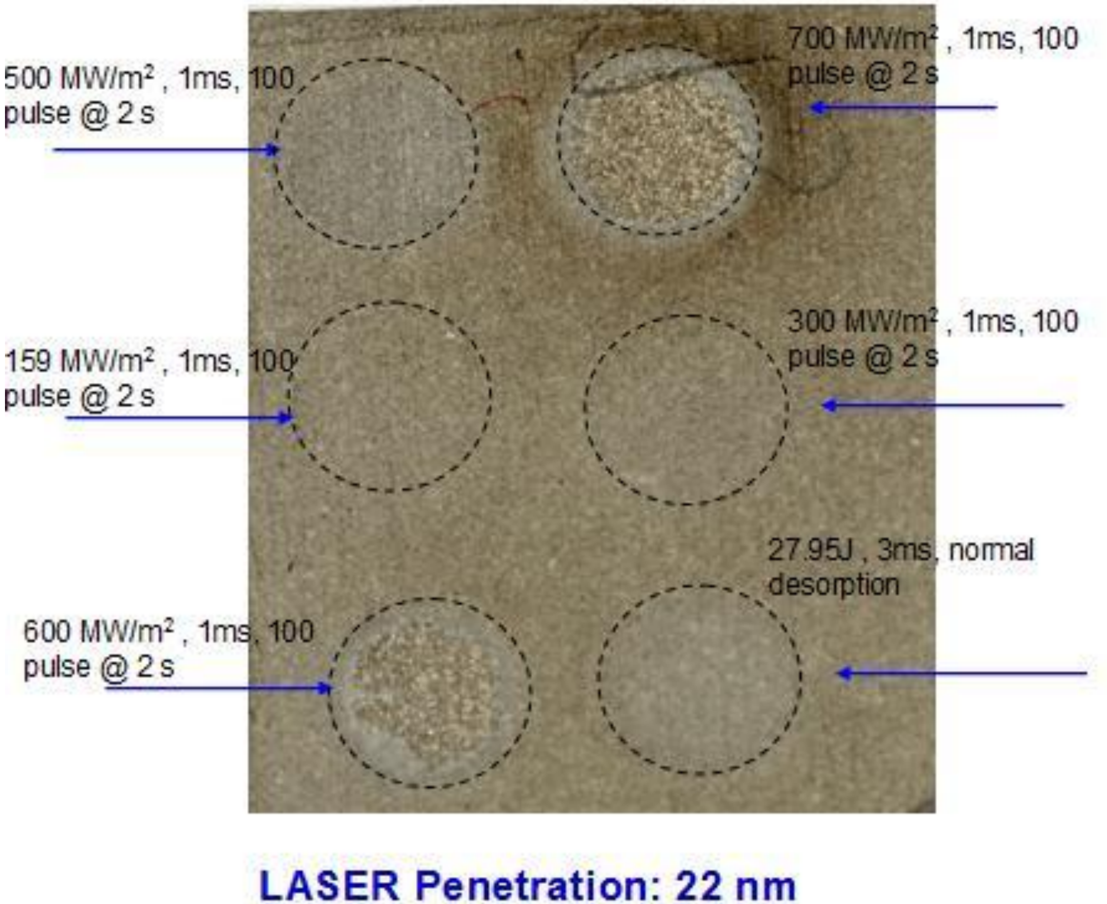
Heat flux resistance

Test of coatings (on C, EK98) in e-beam JUDITH facility in ELM-like tests, up to 160 MW/m^2, 1ms

→ no visible damage (no further detailed analysis done)

→ further ELM like tests in laser heating

Laser ELM simulation



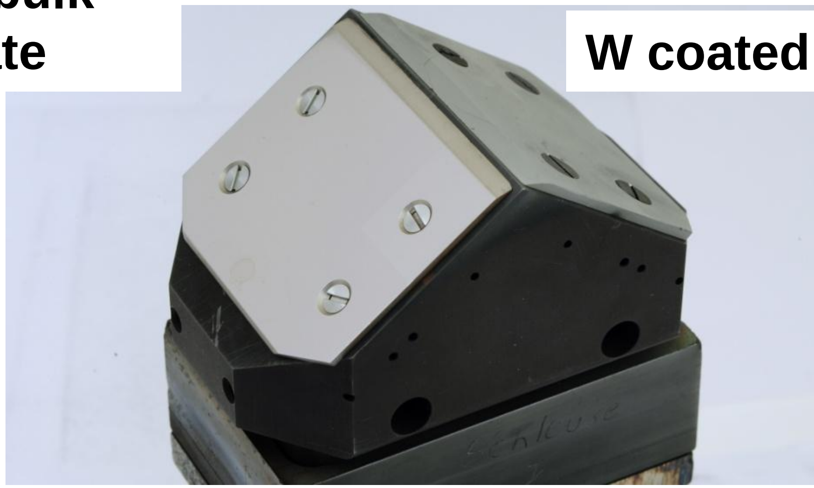
JET W coatings (20µm) analysed under same conditions: failure at 200-300 MW/m^2

- **No visible damage (buckling or cracking) up to 500 MW/m^2**
- **> 600 MW/m2 : surface roughing and start of melting on some spots**
- **Larger melting at 700 MW/m^2**

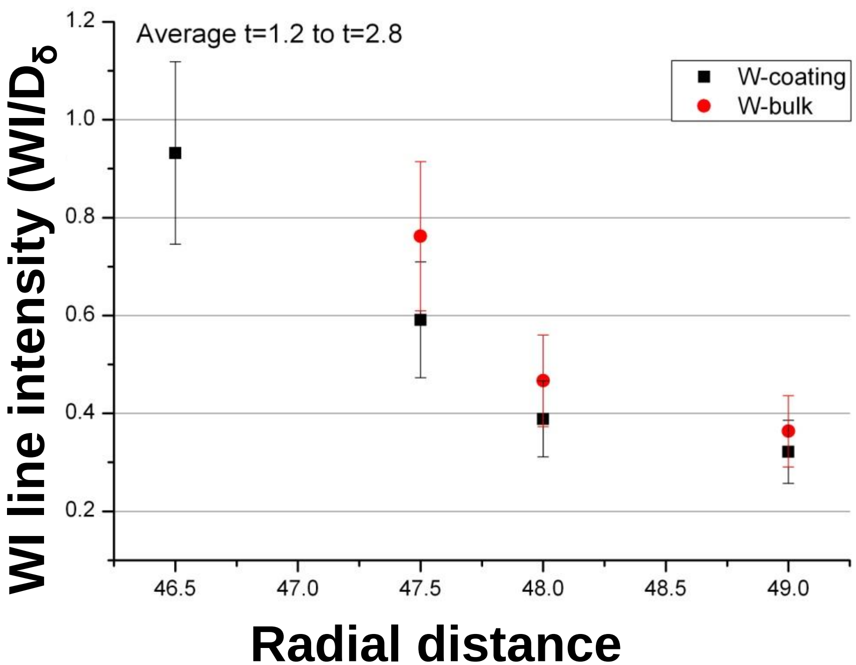
Calculated temperature using bulk W data: 1500 K → heat conductivity of layer and /or heat transfer to graphite reduced

Exposure on TEXTOR testlimiter, comparison with bulk W

W bulk plate

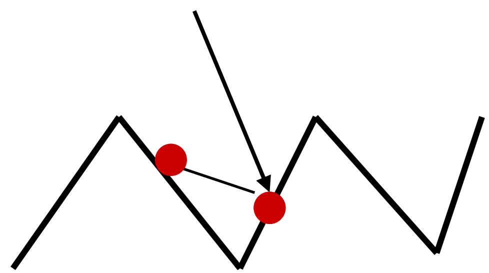


W coated C



- Temperature excursions up to 3000C (poor contact of plate to graphite holder)
- No visible damage of W layer
- Slightly reduced W erosion

Larger surface roughness of W coating lead to increased redeposition on rough structures

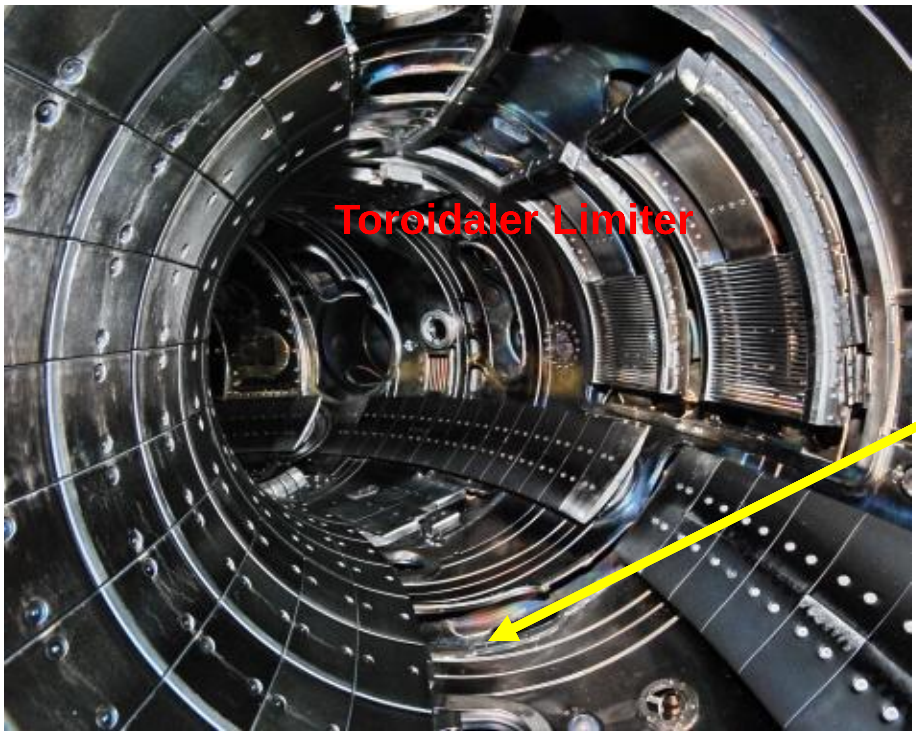


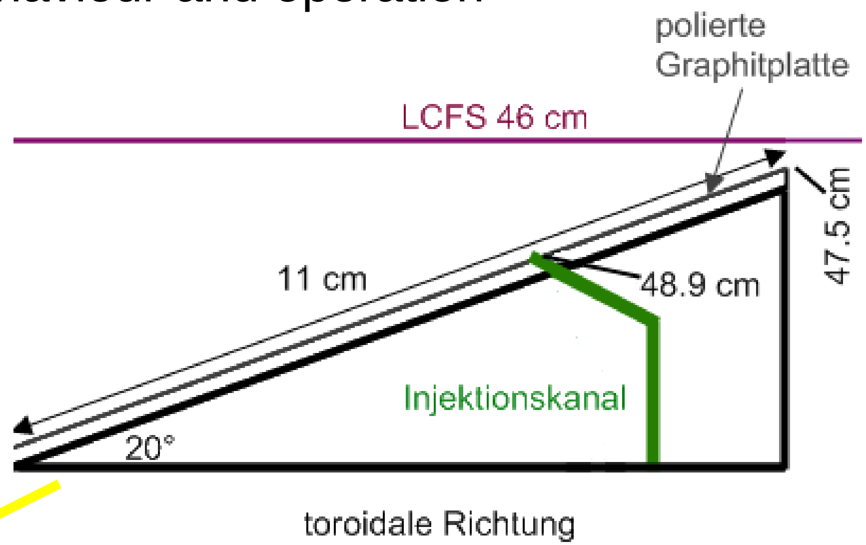
Injection of WF6 in TEXTOR

Study W migration

Study WI line emission

Study the impact of Fluor on plasma behaviour and operation



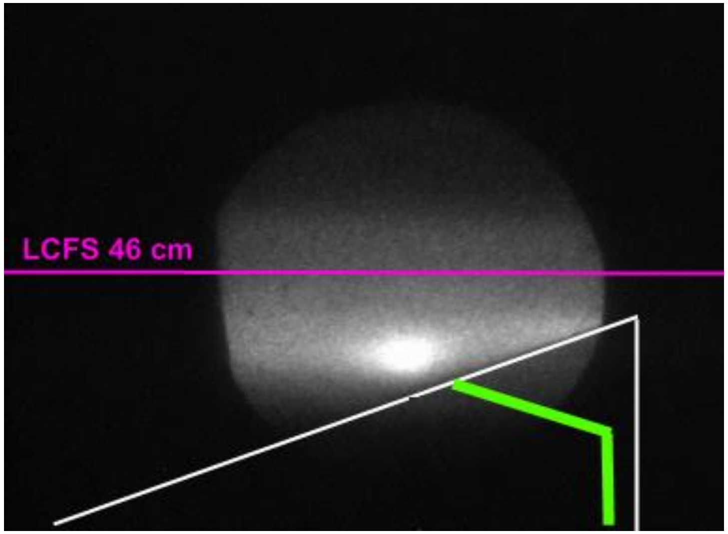


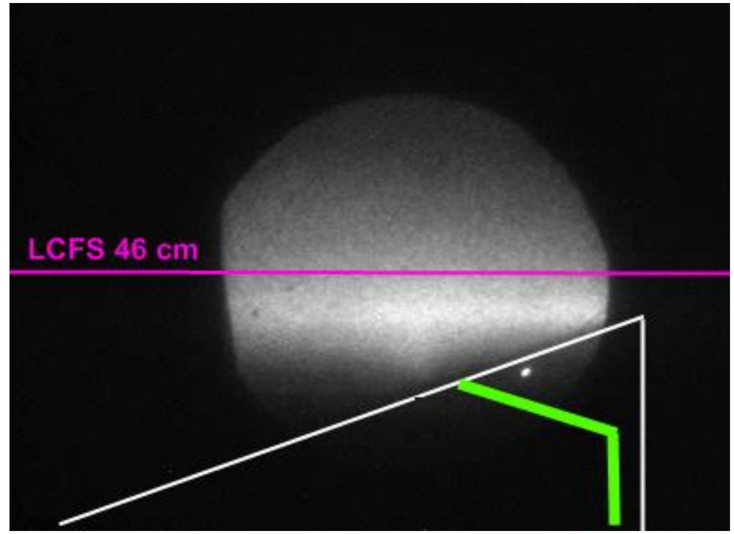
7 WF6 injections with 3 x 10^{19} WF_6

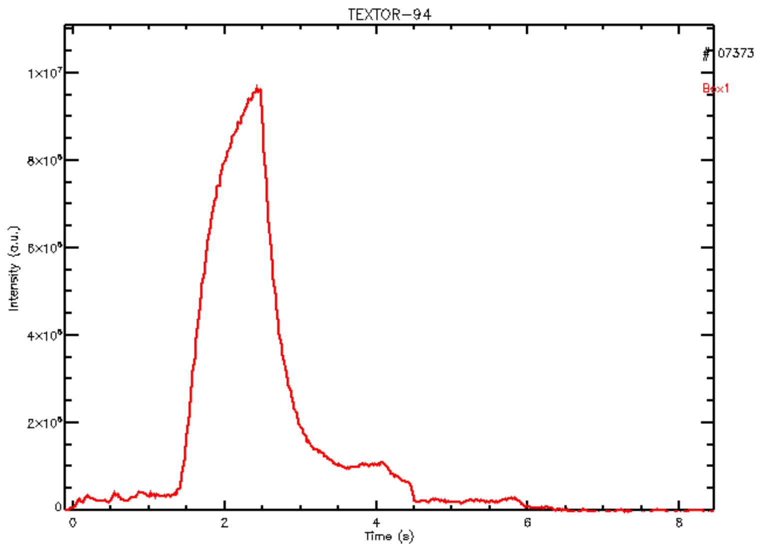
Each: 2 ·x 10^{20} WF_6 molecules

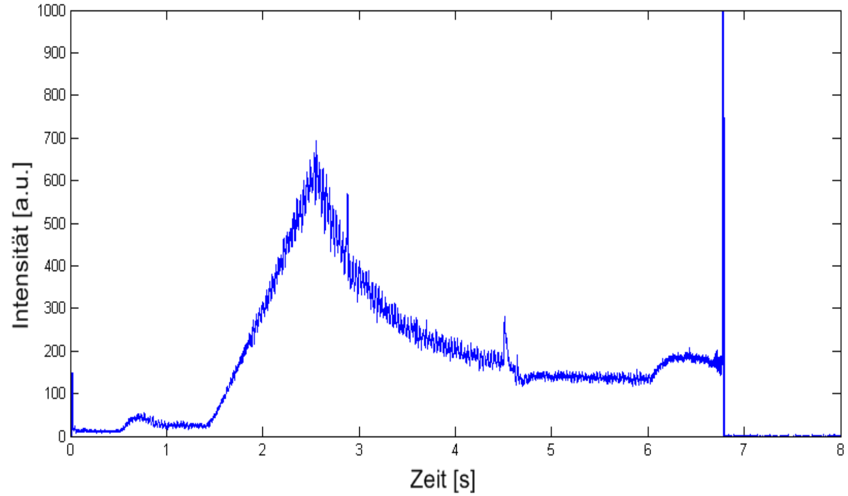
WI at 400.8 nm

FI at 696.6 nm









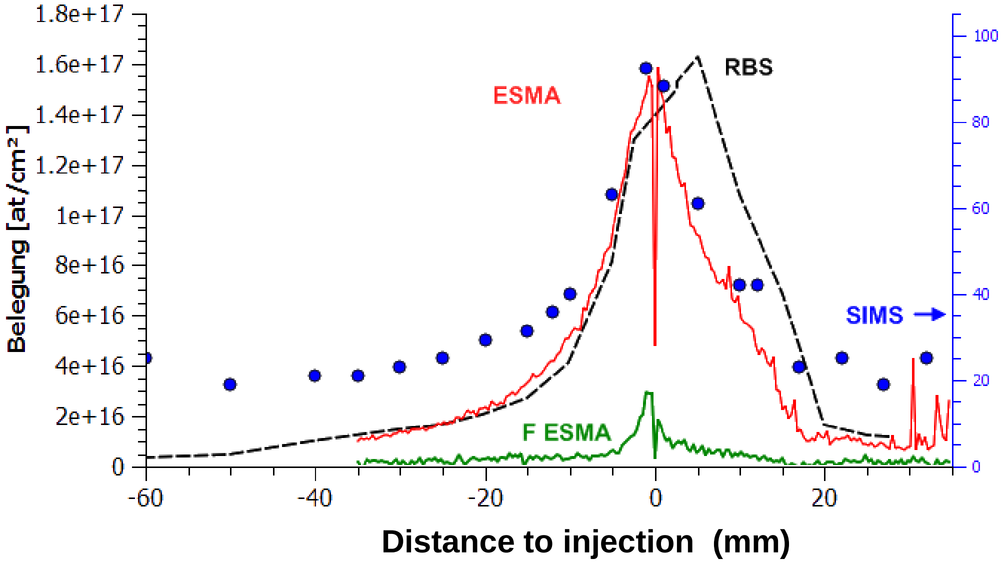
WI line at 400.8 nm

Fluor main plasma line (53,521nm)

Deeper penetration of Fluor & larger memory effect

Post mortem analysis of deposited W layer

(RBS, SIMS, EPMA)



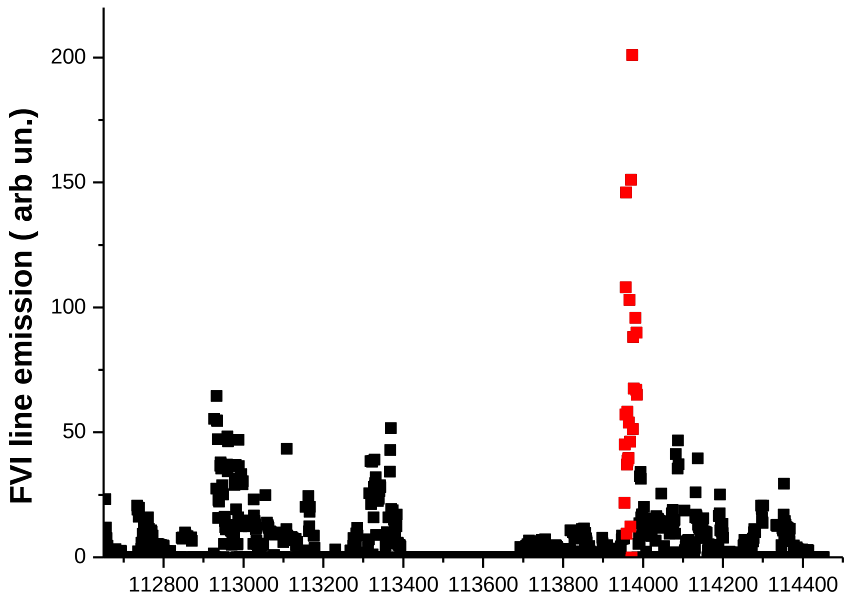
Local deposition of a "pure " W layer with low amount of Fluor

Small W local deposition efficiency

(about 1 % of W found on plate, 30% found on main TEXTOR limiter after immediate TEXTOR)

Fluor plasma impurity lines reach background line intensities in about 10 shots

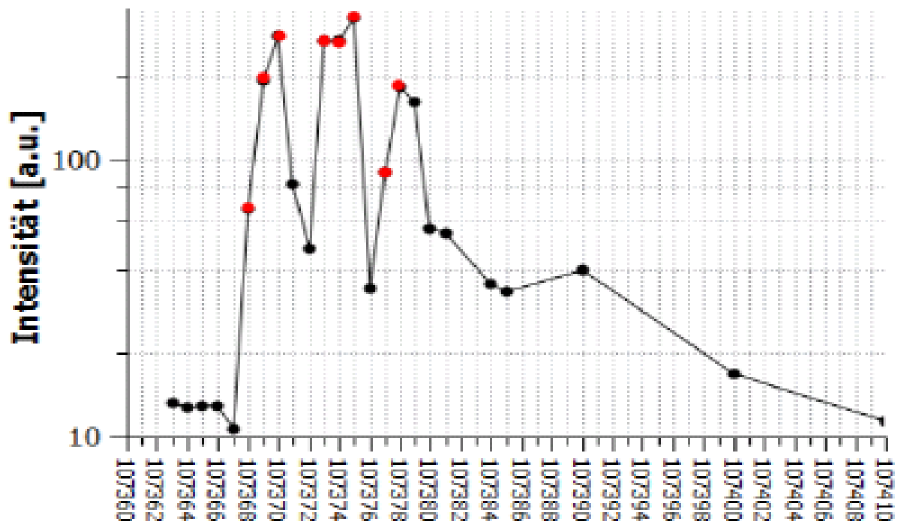
Fluor impurity behaviour in TEXTOR



Shotnumber

Long term behaviour 1600

TEXTOR shots



Shotnumber

Short term behaviour

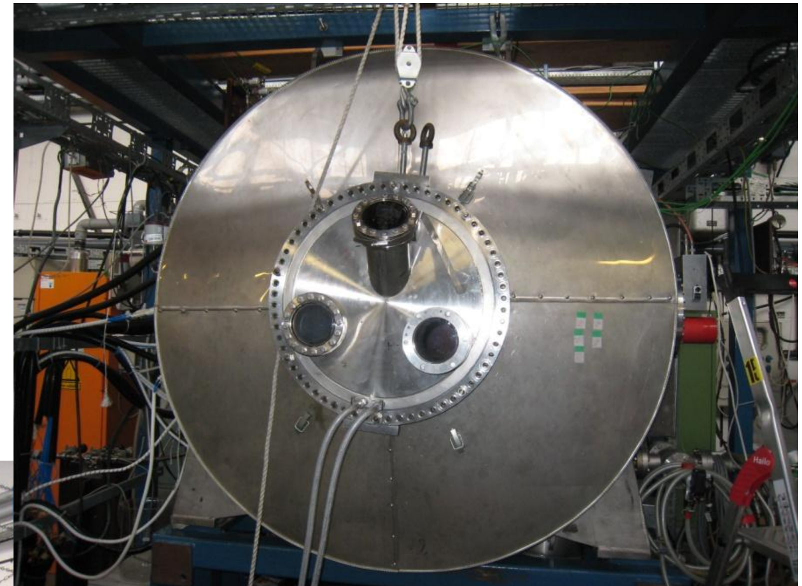
5 shots days in TEXTOR with strong WF6 injection

No particular effect on long term behaviour of line integrated Fluor VI line emission

Large scale W coatings from Wf_6 for TEXTOR application

Large vacuum Test Facility

Represents one octant of the TEXTOR tokamak



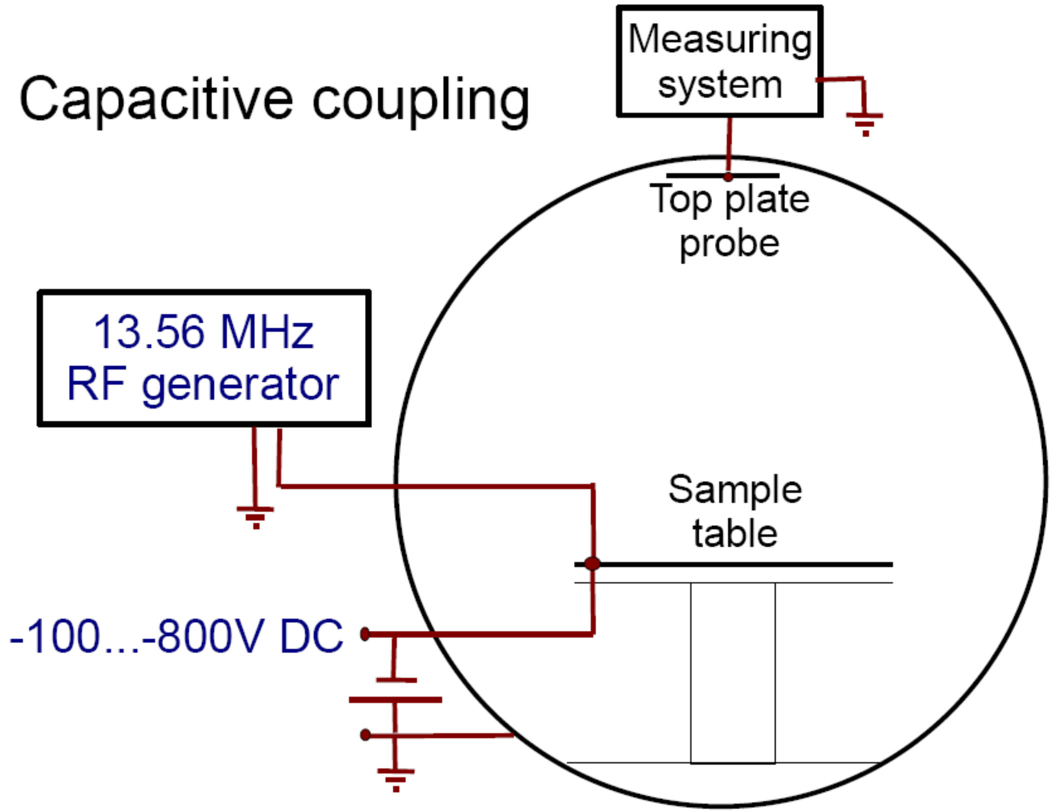
Diameter: 1.3 m
Length : 2m

Volume ~ 2.1 m3

standard TEXTOR configuration
Antenna with 13.56 MHz RF generator with inductive coupling (Anode)
+ DC voltage to wall (cathode)

New arrangement:
Direct capacitive coupling of RF to large sample holder + bias of -100...-500V DC potential

attracts the ions to the holder and prevents coating of walls



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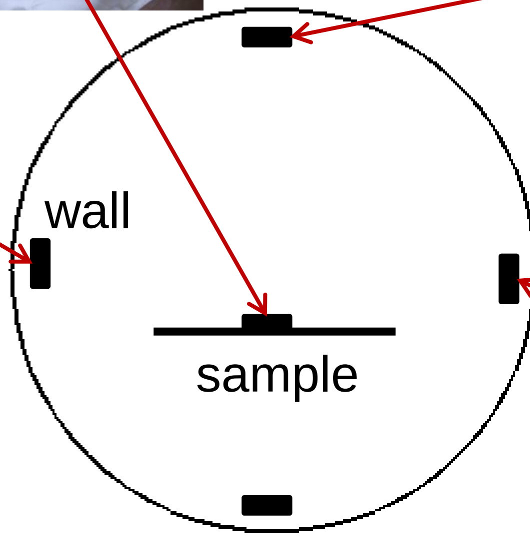
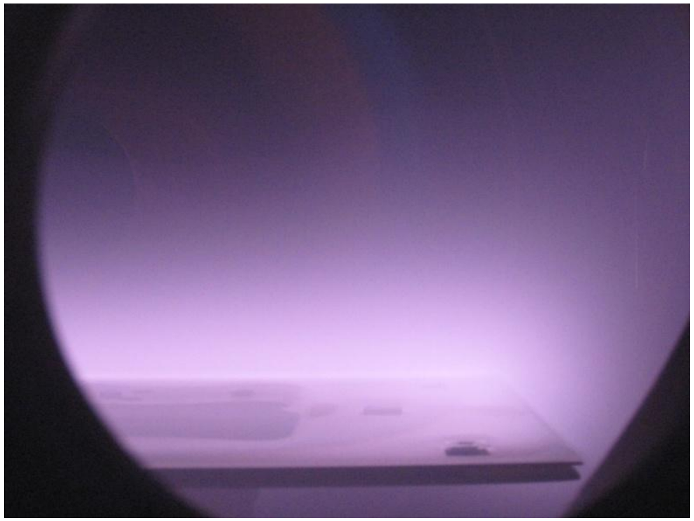
TEST coating with WF6 : Sample arrangement

Sample holder



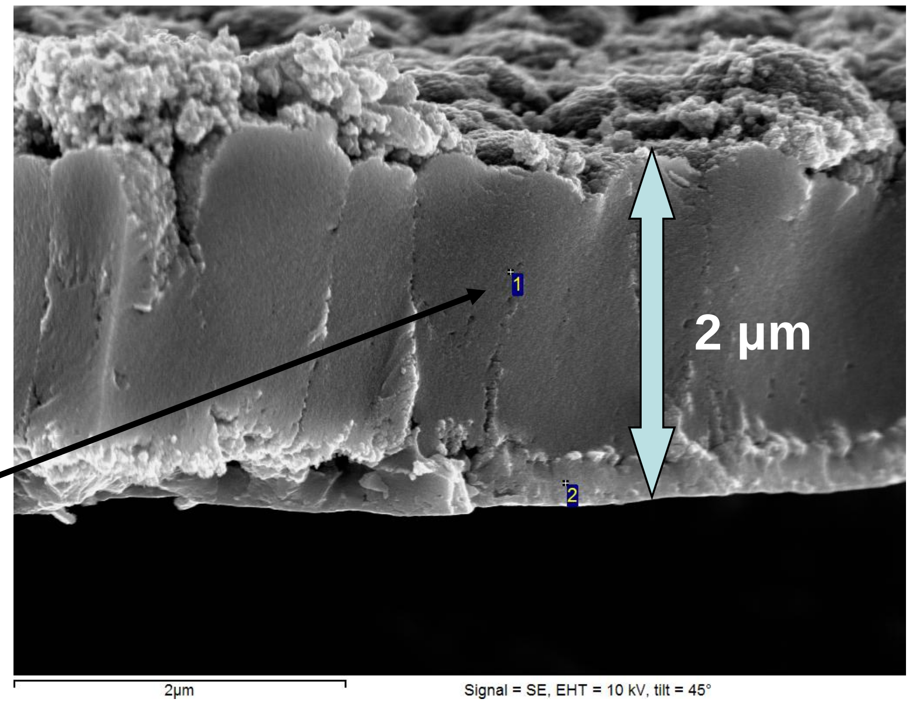
A-c:H layer deposition by CH_4 showed only deposition on the sample holder and no deposition on the walls

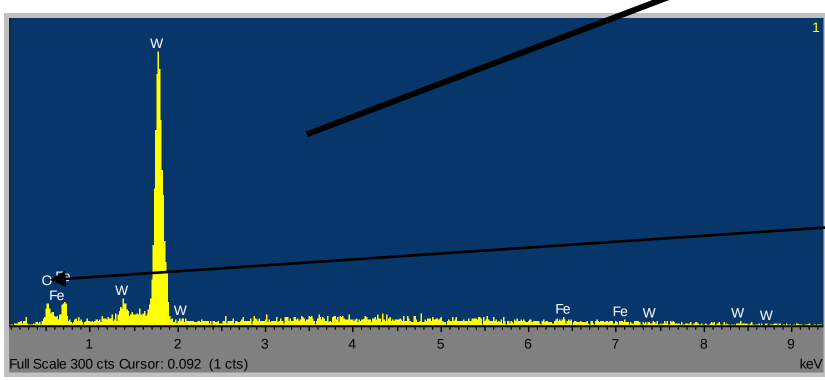
Test coatings with CH_4 showed only deposition on the sample holder and no deposition on the walls



Target holder with capacitive RF + DC bias

RF power = 100 W
DC= -110 V
Sample current 45 mA
23 uA/cm2





Higher oxygen content in first experiments,

Improved by better wall conditioning of system

Summary

W layers have been deposited on graphite by plasma deposition in WF_6 and H_2

Layers with sufficient purity and very low amount of Fluor have been deposited with good adhesion on graphite and promising thermal shock behaviour

Injection of smaller amount of WF6 in running Tetxor shots has resulted in local deposition of pure W layers

Increased Fluor plasma contamination disappeared in less then 20 shots

In a new RF deposition arrangement, local deposition of an C film was achieved with no deposition on the rest of the wall

RF plasma deposition of W layers with DC ion acceleration on graphite appears a promising technique for in situ local W coating of wall tiles

Further optimisation ongoing

Preparation for TEXTOR W coating ongoing