Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

Schlussbericht 06.12.2016

Plasma-Wand Wechselwirkungen von Fusionsreaktormaterialien

Auftraggeber:

Bundesamt für Energie BFE
Energieforschung
CH-3003 Bern
www.bfe.admin.ch

Staatssekretariat für Bildung,
Forschung und Innovation SBFI
CH-3003 Bern
http://www.sbfi.admin.ch/

Auftragnehmer:

Firma Departement für Physik der Universität Basel
Strasse Klingelbergstrasse 82
CH-4056 Basel
http://nanolino.unibas.ch/pages/research/fusion.htm

Autoren:

Dr. Laurent Marot, laurent.marot@unibas.ch
Lucas Moser, lucas.moser@unibas.ch
Prof. Dr. Ernst Meyer, ernst.meyer@unibas.ch

BFE-Bereichsleiter:	Dr. Michael Moser
BFE-Programmleiter:	Xavier Reymond, SBFI
BFE-Vertragsnummer:	SI/500044-04

SBFI -Bereichsleiter:	Xavier Reymond
SBFI-Vertragsnummer:	1315000002

Für den Inhalt und die Schlussfolgerungen sind ausschliesslich die Autoren dieses Berichts verantwortlich.

Zusammenfassung

Eine der grössten Herausforderungen von ITER liegt in der Wechselwirkung von Plasma-exponierten Komponenten mit dem Fusionsplasma. Die rasche Degradierung der optischen Eigenschaften von den ersten Spiegeln aufgrund von Erosion und Beschichtung ist ein wichtiger Punkt, weil es die Diagnose des Plasmas erschwert. Das Ziel ist es die optischen Eigenschaften von Spiegeln im ITER-Betrieb zu erhalten und den Staub, der von den Wänden kommt wieder zu entfernen, ohne die Spiegeleigenschaften zu beeinträchtigen. Mit der heute favorisierte Methode sollen die Spiegel ohne Ausbau mit Ionenbestrahlung im Vakuum gereinigt werden. Die Reinigung ist effektiver mit einem magnetischen Feld aber auch unregelmäßiger. Es wurden bis zu 34 Reinigungszyklen geprüft, ohne dass eine Änderung der optische Eingaschaften festgestellt werden konnte.
Ein zweiter Utersuchungsgegenstand war das Wachsen von faserigem Wolfram bei der Bestrahlung von heissem Wolfram mit Helium. Dies spielt beim so genannten Diverter eine Rolle. Wir konnten zeigen, dass die Wachstumsrate, bei konstanter Bestrahlung mit Heliumionen, zur Quadratwurzel der Zeit proportional ist..

Résumé

Dans le cadre de l'étude de l'interaction plasma -paroi dans ITER, un point a été spécialement étudié à l'Université de Bâle: il s'agit de l'étude de nettoyage de miroirs utilisés pour réfléchir la lumière du plasma vers les diagnostiques d'ITER. Ce nettoyage peut être réalisé de manière répétitive sans dégrader les propriétés optiques du miroir. Les tests conduit avec un champ magnétique jusqu'à 3.5T ont démontré la faisabilité mais révèlent des taux d'érosion différents sur la surface du miroir en fonction de l'angle entre la surface de ce dernier et le champ. L'intégration dans ITER de cette technique est de plus en plus avancée et est désignée comme une procédure concrète pour les futurs opérations d'ITER. Un autre sujet a aussi été étudié: la formation de structure filamentaire lorsque du tungstène est exposé à un plasma d'hélium. Il a été démontré que la croissance et proportionnelle à la racine carré du temps d'exposition.

Summary

First mirrors of optical diagnostics in ITER were exposed in Magnum-PSI linear plasma device and JET-ILW tokamak. For JET-ILW the mirrors with a rhodium (Rh) or a molybdenum (Mo) coating exhibited a decrease of the reflectivity according the location in the torus and especially the amount of beryllium (Be) deposited on them. Under very harsh erosion conditions in Magnum-PSI, Rh thick coated mock ups, cooled or not, for a high flux exposure the films underwent delamination. Cleaning of mirrors was extensively studied during this period, with magnetic field in collaboration with the SPC Lausanne, or in term of repetitive cleaning till 34 cycles. No degradation of the optical properties of single and nanocrystalline mirrors was demonstrated. Test under magnetic field (3.5T) revealed the non-uniform erosion of the mirrors according the orientation between the field and the mirror but is effective. All this tests bring to a suitable schematic of the implementation of this technique in ITER.
Investigations on formation of tungsten fuzz were carried out either in Basel using a new setup or in Pilot-PSI. These thickness measurements showed the fuzz growth is in square root dependence to time or fluence.

Abstract

First mirrors of optical diagnostics in ITER were exposed in Magnum-PSI linear plasma device and JET-ILW tokamak. For JET-ILW the mirrors with a rhodium (Rh) or a molybdenum (Mo) coating exhibited a decrease of the reflectivity according the location in the torus and especially the amount of beryllium (Be) deposited on them. No delamination of the coated reflective film was observed. Under very harsh erosion conditions in Magnum-PSI, Rh thick coated mock ups, cooled or not, for a high flux exposure the films underwent delamination. Mo coating on water cooled mock up mirrors exhibited a high diffuse reflectivity after H_2/Ar plasma exposure inducing an important decrease of the specular reflectivity and show important oxidation of the surface.
Cleaning of mirrors was extensively studied during this period, with magnetic field in collaboration with the SPC Lausanne, or in term of repetitive cleaning till 34 cycles. Polycrystalline molybdenum mirror shows a high diffuse reflectivity after cleaning cycle and clearly demonstrate that they are not suitable for this purpose. Coated Rh or Mo mirrors like single crystal maintained good reflectivity. Test under magnetic field revealed the non-uniform erosion of the mirrors according the orientation between the field and the mirror. All this tests bring to a suitable schematic of the implementation of this technique in ITER and was deeply explained. The cleaning of the Be contaminated mirrors will be carried out using new parameters in December 2016.
Investigations on formation of tungsten fuzz were carried out either in Basel using a new setup or in Pilot-PSI. These thickness measurements showed the fuzz growth is in square root dependence to time or fluence. From the results in Pilot-PSI, it has been shown that time was a critical parameter for the development of He-induced morphology changes and one needs to keep that factor in mind.

November 2016

Deliverables from the contract and achievements:

1. Test of metallic mirrors in MAGNUN PSI and at JET: evaluation of the lifetime of potential materials
1.2 Lifetime of mirrors in linear plasma facility: MAGNUM PSI
This part is completed and scientific paper was published in one of the highest impact factor for this field: Nuclear Fusion 56, (2016), 066015.

1.3 Lifetime of mirrors in tokamak: JET
The measurements were carried out.

2 Assessment of the effectiveness of in-situ cleaning techniques of contaminated mirrors by plasma cleaning
We plan to investigate the possibility of in-situ cleaning of first mirrors in ITER by plasma technique by developing and testing a method in our laboratory and by assessing the feasibility of such technique for ITER at JET.
2.2 Repetitive cleaning
This task was completed and reported at the 31th Meeting of the ITPA Topical Group on Diagnostics ITER – France, November 7-10 2016.

2.3 Cleaning of beryllium coated mirrors
Due to the non-availability of the JET BeHF, it was not possible to perform this task at JET. For a shorter time range, we agreed with C. Lungu at INFLPR to do the cleaning in their beryllium facility. The vacuum chamber which was in the BeHF at CCFE was sent to Bucharest and a new electrode compatible with 60MHz excitation is under preparation. The tests are scheduled for December 2016 and middle 2017.

2.4 Implementation of the FM plasma cleaning in ITER
The work was performed and published in peer review journal.

2.5 Cleaning of aluminum coated mirrors
In collaboration with the Swiss Plasma Center in Lausanne and ITER, it was tested plasma cleaning of two mirrors facing each other in a 3.5T magnetic field. This task was completed and reported at the 31th Meeting of the ITPA Topical Group on Diagnostics ITER – France, November 7-10 2016.

With all these results the in situ plasma cleaning of first mirrors in ITER is foreseen to be in the ITER operational baseline. A document presenting these is available on the ITER IDM: https://user.iter.org/default.aspx?uid=T3B5C5

3 Investigations of the properties of tungsten as a plasma-facing material for ITER and for future fusion devices (DEMO)
3.2 Effect of flux and fluence of tungsten helium plasma exposure
**A new system was developed in Basel to achieve goal. It was successful and studied.
The samples were exposed in Pilot-PSI and characterised and compared with the results in Basel.**

Contents

1. Test of metallic mirrors in MAGNUN PSI and at JET: evaluation of the lifetime of potential materials

1.1 Motivation

We plan to investigate the lifetime of potential mirror materials in linear plasma facility and in tokamaks.

1.2 Lifetime of mirrors in linear plasma facility: MAGNUM PSI

This part is completed and scientific paper was published in one of the highest impact factor for this field: Nuclear Fusion 56, (2016), 066015. No further exposures are scheduled.

1.3 Lifetime of mirrors in tokamak: JET

Test mirrors were retrieved from JET-ILW after the 2013-2014 experimental campaign. The total plasma exposure time was 70013 s, including limiter (21373 s) and divertor (48640 s) configurations, i.e. fairly similar to the operation time in the first ILW campaign in 20011-2012. Rhodium (Rh) and molybdenum (Mo) coated mirrors were deposited in Basel and were exposed in a cassette with and without fins to see the effect on the redeposition on the mirrors. The total reflectivity of Rh mirror decreased by few percent in the range 250-2500nm, in comparison Mo mirrors show a decrease of more than 20% especially at 250nm. XPS on Mo mirrors shows an oxidation of the surface responsible of this reflectivity decrease. Rh surface was always metallic after exposure. The diffuse reflectivity is mostly not affected. Secondary Electron Microscopy (SEM) images revealed that the Rh and Mo nanocrystalline on the surface were not damaged. Ducts help to cancel beryllium (Be) deposition and to suppress carbon transport. Fins work in short ducts; in longer ducts the effect of fins is small.

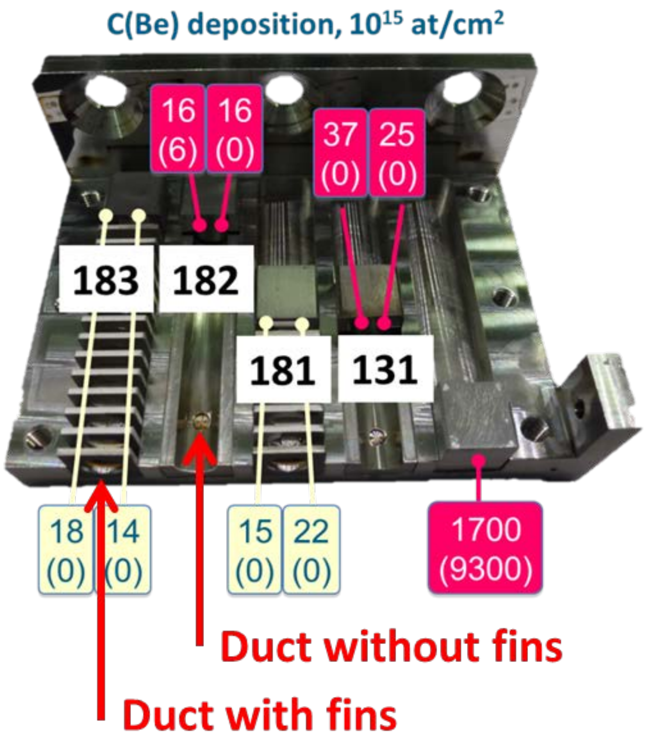

Figure 1: Mirror cassette with fins (base) installed on outer wall exposed in JET-ILW. Amount of carbon on each mirror are plotted on top for two locations, on bottom is the amount of Be.

1.4 Conclusion of the tests of metallic mirrors in MAGNUN PSI and JET

For JET-ILW the mirrors with a Rh or a Mo coating exhibited a decrease of the reflectivity according the location in the torus and especially the amount of Be deposited on them. No delamination of the coated reflective film was observed. Under very harsh erosion conditions in Magnum-PSI, Rh thick coated mock ups, cooled or not, for a high flux exposure the films underwent delamination. Mo coating on water cooled mock up mirrors exhibited a high diffuse reflectivity after H_2/Ar plasma exposure inducing an important decrease of the specular reflectivity and show important oxidation of the surface.

2 Assessment of the effectiveness of in-situ cleaning techniques of contaminated mirrors by plasma cleaning

2.1 Motivation

We plan to investigate the possibility of in-situ cleaning of first mirrors in ITER by plasma technique by developing and testing a method in our laboratory and by assessing the feasibility of such technique for ITER at JET.

2.2 Repetitive cleaning

In order to validate the technique of plasma cleaning, repetitive cleaning has to be tested. This is going on in Basel under a contract of F4E. More than 30 mirrors were manufactured including stainless steel (SS) mirrors, molybdenum (Mo) as single crystal (Sc) and as polycrystalline (Pc). On top of SS were deposited nanocrystalline rhodium (NcRh) and Mo (NcMo) by magnetron sputtering. The specular reflectivity of all Mo and Rh mirrors were comparable to the reference one. Also on top of SS, aluminium / zirconium oxide (Al/ZrO_2) coatings were deposited by magnetron sputtering. Deposition of ZrO_2 films were performed using either a direct current (DC) or a radio frequency (RF) excitation. The optical index of ZrO_2 film was optimised using different oxygen mixture to be similar as the literature value. All films thicknesses were cross checked by quartz microbalance and cross section secondary electron microscopy (SEM).

Deposition of 25nm of aluminium oxide (Al_2O_3) and or aluminium tungsten film (Al/W) were deposited on top of mirrors as dust film. The plasma cleaning was carried out by applying RF excitation either 13.56 or 60MHz using helium (He) or argon (Ar) gas. After more than 16 cleaning experiments it was decided to use Ar and 60MHz for test of multiple cycles.

Two sets of electrodes and shutters were manufactured to fix 5 or 6 mirrors simultaneously and allow depositing half of the mirror (Figure 2). Using this new equipment, 20 cycles of cleaning on mirrors procured by University of Basel were carried out. The diffuse and the roughness of the PcMo increased significantly at the end which is not the case for ScMo. For Al/ZrO_2 mirror, after 3 cycles the film of ZrO_2 was sputtered away. For both NcMo and NcRh the specular reflectivity after 10 cycles was similar as the pristine one. Due to film thickness, for 20 cycles the entire NcRh and NcMo were sputtered away.

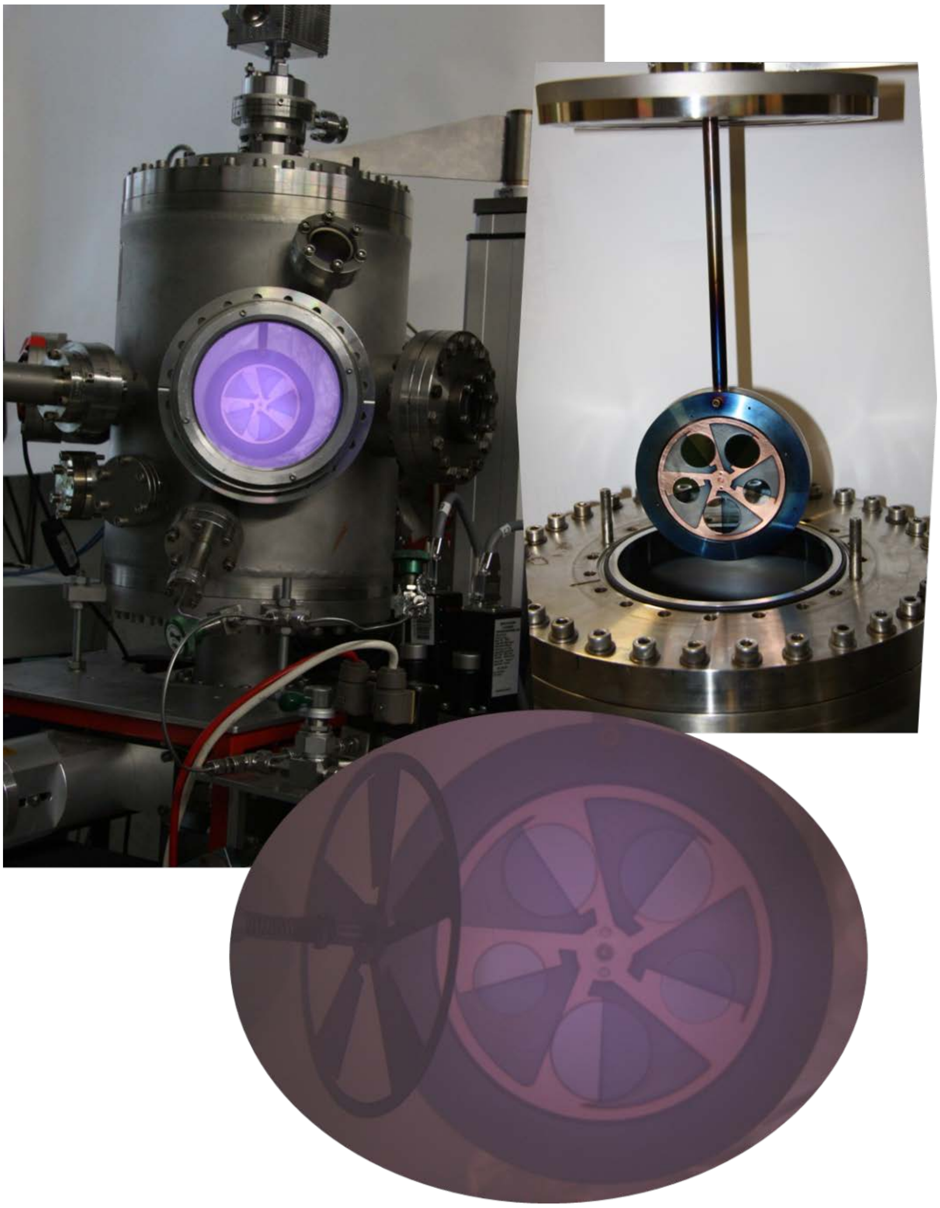

Figure 2: New electrode with 5 mirrors was constructed, including a shutter to deposit a dust film on half of the mirror to be able to carry out cleaning cycle.

Two experiments using 6 Al/ZrO_2 and 6 Rh mirrors from industrial companies were carried out for 3 and 6 cycles, respectively. In case of Al/ZrO_2 mirrors, depending the company and deposition technique the thickness of ZrO_2 was in the range 28-82nm. The thickness eroded after 3 cycles was ranging from 27-39nm on the not coated part and 14-20nm on the coated part. Due to the different thickness of ZrO_2 films the specular reflectivity always changes in comparison to pristine. For Rh mirrors after 6 cycles, the evaporated NcRh film from SESO was sputtered away and also pulse laser deposited (PLD) from Fraunhofer. In case of PLD the thickness measured by focus ion beam (FIB) was 120nm instead of 300nm explaining that the film was completely sputtered away. For all the other Rh films the specular reflectivity was mostly not affected after 6 cycles.

2.3 Cleaning of beryllium coated mirrors

In the framework of the WPJET 2 of EUROfusion, cleaning of Be contaminated mirrors are scheduled. Due to the non-availability of the JET BeHF, it was not possible to perform this task before middle of 2017. For a shorter time range, we agreed with C. Lungu at INFLPR during our visit in January 2016 (Figure 3) to do the cleaning in their beryllium facility. The vacuum chamber which was in the BeHF at CCFE was sent to Bucharest and a new electrode compatible with 60MHz excitation is under preparation. The test are scheduled for end of 2016

Figure 3: Marwa Ben Yaala in the Be handling facility at the INFLPR, Bucharest.

2.4 Implementation of the FM plasma cleaning in ITER

First mirrors of optical diagnostics in ITER are subject to charge exchange fluxes of Be, W, and potentially other elements. This may degrade the optical performance significantly via erosion or deposition. In order to restore reflectivity, cleaning by applying radio frequency (RF) power to the mirror itself and thus creating a discharge in front of the mirror will be used. The plasma generated in front of the mirror surface sputters off deposition, restoring its reflectivity. **Although the functionality of such a mirror cleaning technique is proven in laboratory experiments, the technical implementation in ITER revealed obstacles which needs to be overcome:** Since the discharge as an RF load in general is not very well matched to the power generator and transmission line, power reflections will occur leading to a thermal load of the cable. Its implementation for ITER requires additional R&D.

This includes the design of mirrors as RF electrodes, as well as feeders and matching networks inside the vacuum vessel. Mitigation solutions will be evaluated and discussed. Furthermore, technical obstacles (i.e., cooling water pipes for the mirrors) need to be solved. Since cooling water lines are usually on ground potential at the feed through of the vacuum vessel, a solution to decouple the ground potential from the mirror would be a major simplification. Such a solution will be presented below.

Numerous FMs need water cooling. The water cooling lines may pose a difficulty for RF power as they are either on ground potential at the feed through and affect the impedance of the mirror (Figure 4) or they are electrically insulated through the vacuum vessel. Several techniques have been considered for mirror cooling: (i) Electrical insulation of the mirror but good thermal contact with a water cooled surface, (ii) electrical insulation of the cooling water line at the feed through, and (iii) integration of the water cooling line into a stop band filter and considering the additional impedance. Solution (i) has the advantage that the electrical behaviour of the mirror is almost the same as without cooling. The thermal contact is a critical point and efficient cooling of the mirror may be compromised. (ii) has the advantage that the thermal contact is good, but conductivity of the cooling water can lead to unpredicted cur- rents and changes in the overall impedance. This is due to the possible increase of ions in the cooling water, leading to increased conductivity. The water conductivity may affect the bias voltage and consequently the cleaning process. There is also a risk of dissociation of water molecules leading to hazardous gases in the cooling water system. (iii) has the advantage that a good thermal con- tact is obtained, the cooling water lines can be at ground potential at the feed through. However, there will be no bias on the mirror surface, since the cooling water line forms a DC ground to the mirror. As a consequence, also the ion energy is reduced. The functionality for case (iii) has already been demonstrated.

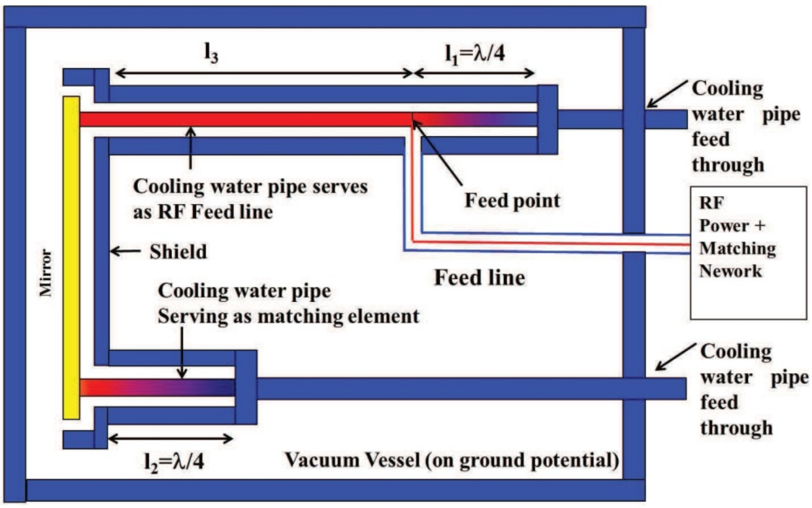

Figure 4: Schematic of a RF cleaned FM with cooling water lines inside the vacuum vessel. Yellow: Mirror, blue: Metal parts on ground potential, red: RF potential. The distance between mirror and vacuum vessel is not to scale.

2.5 Cleaning of aluminum coated mirrors

In collaboration with the Swiss Plasma Center in Lausanne and ITER, it was tested plasma cleaning of two mirrors facing each other in a 3.5T magnetic field.

The main results are the following.

Strong cleaning patterns observed with B field for certain configuration. In some case, we have region without net erosion (redeposition of Mo and Cu). At 90°, we have similar erosion as for case without B field. Edge effects appear again. Working at 180° phase shift was necessary. For anti-parallel configuration, we observed redeposition region when working at 13.56MHz. They disappeared when going to 60MHz. Edge effects are present. In this configuration it was possible to work with 0° phase shift. Using a Notch filter (zero bias on the sample): in anti-parallel configuration we observed no erosion with 3.5T B-field. Redeposition experiments with glass in between the electrode were not successful.

2.6 Conclusion of plasma cleaning for ITER

In summary concerning the plasma cleaning technique it was demonstrated that repetitive cleaning up to 34^{th} cycles does not degrade the optical properties of single and nanocrystalline mirrors. Cleaning of Be contaminated mirrors, even it was not investigated during this period, showed the capability to clean Be, BeO and BeW as previously reported in the final report 2014 and also published (part 4). Test under magnetic field (3.5T) revealed the non-uniform erosion of the mirrors according the orientation between the field and the mirror but is effective. All this tests bring to a suitable schematic of the implementation of this technique in ITER and was deeply explained. With all these results the in situ plasma cleaning of first mirrors in ITER is foreseen to be in the ITER operational baseline. A document presenting these is available on the ITER IDM: https://user.iter.org/default.aspx?uid=T3B5C5

Further work will be to study more in detail plasma cleaning using the notch filter meaning with a mirror without negative bias as it is the preferred way for ITER. Moreover the plasma cleaning of Be contaminated mirror using deuterium gas is a great importance as it is foreseen to work with lower bias voltage to sputter the BeD formed and not damage the mirror.

3 Investigations of the properties of tungsten as a plasma-facing material for ITER and for future fusion devices (DEMO)

3.1 Motivation

We plan to investigate the properties of tungsten exposed to He plasma.

3.2 Effect of flux and fluence of tungsten helium plasma exposure

3.2.1 Samples prepared in Basel

An unbalanced magnetron (UBM) was constructed in order to produce a nanostructured tungsten surface consisting of tendrils, so called fuzzy tungsten, by bombardment with helium ions. The UBM was constructed with a coil in such a way that the ion flux could be controlled independent of the ion energy. This independence was checked by measurements with a retarding field energy analyser (RFEA) which made it possible to measure the ion energy and flux at the same time in the sample position. The results show that the ion flux grows linearly with the coil current and also confirmed that the ion energy is indeed not influenced by this.

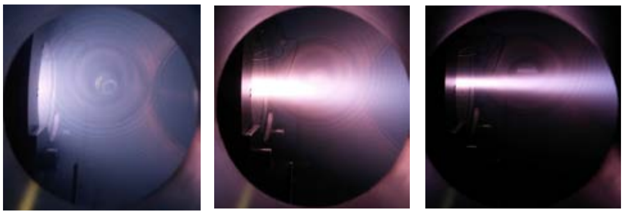

Figure 5: Plasma outside the UBM for several current applied to the additional coil: at Icoil = 0A (left), Icoil = 2A (center), Icoil = 5A (right)

Several experiments were performed with the constructed UBM in order to proof that the UBM-setup is able to produce fuzz. In these experiments tungsten substrates were heated to 1200K and then exposed to the UBM plasma in pure helium. It was confirmed that fuzzy tungsten is formed with a scanning electron microscope.

A temperature gradient was seen on the substrates due to the construction of the sample holder. Because of this gradient the influence of different temperatures on the formation of fuzz could be studied for the samples.

The fuzz thickness was also studied by using a focused ion beam (FIB) in order to cut through the fuzz layer. This cut was then looked at with the SEM and the thickness was measured in this way (Figure 6). These thickness measurements showed the fuzz growth is in square root dependence to time or fluence. The experimental parameters of the mentioned sample are below.

Sample	**P**$[W]$	**Bias**$[V]$	$\mathbf{I}_{Coil}[A]$	**T**$[K]$	**t**$[h]$	**W depo.**$[nm]$	**Fluence**$[m^{-2}]$
A1	150	-60	1	1189	19.95	48.12	3.35E+24
A2	150	-40	1	1205	19.82	47.80	2.46E+24
A3	150	-60	0.5	1204	11.00	31.28	9.36E+23
A4	150	-60	1.5	1203	4.87	9.20	1.17E+24

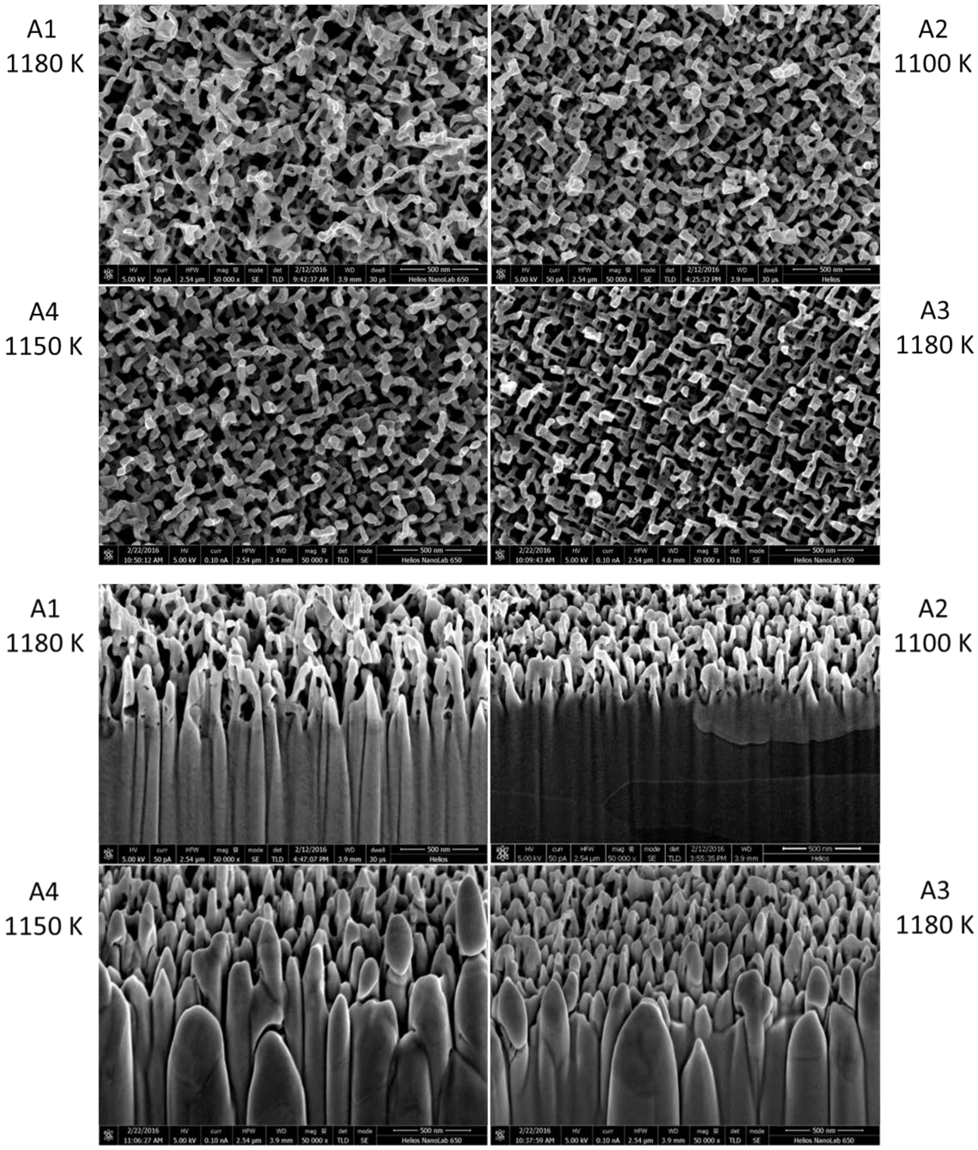

Figure 6: Comparison of the fuzz from all four samples. The four pictures on top show the SEM images and the four pictures on the bottom show the FIB cuts at the same positions on the samples as in the four top images

3.2.2 Samples exposed in Pilot-PSI

The samples were first prepared in Basel as describe in the following table and exposed in Pilot-PSI.

Nano-crystalline W coatings:

Sample	Temperature	Base pressure	Gas	Gas flow	Working pressure	Deposition rate	Thickness (estimated)
Name	(K)	(mbar)		(SCCM)	(mbar)	(nm/s)	(nm)
Nc W 1	RT	7.4*10-8	Ar	40	1.1*10-2	0.57	400
Nc W 2	RT	1.85*10-7	Ar	40	1.1*10-2	0.58	200

W coatings with He as working gas

Sample	Temperature	Base pressure	Gas	Gas flow	Working pressure	Deposition rate	Thickness (estimated)
Name	(K)	(mbar)		(SCCM)	(mbar)	(nm/s)	(nm)
W He 1	Ca. 1000-1100	2*10-6	He	120	4*10-2	0.014	100
W He 2	Ca. 1000-1100	1.07*10-6	He	120	4.02*10-2	0.014	100

It is interesting to note that there are some differences between the samples exposed in Pilot. Comparing the results with Basel exposure there are not so much change taking into account the factor 1000 for the flux. The fluence for Pilot is higher as the one in Basel but all together the surfaces are not so different. While the Pilot fluences are much higher than those from experiments in Basel, the exposure time is much shorter. It has been shown that time was a critical parameter for the development of He-induced morphology changes and one needs to keep that factor in mind.

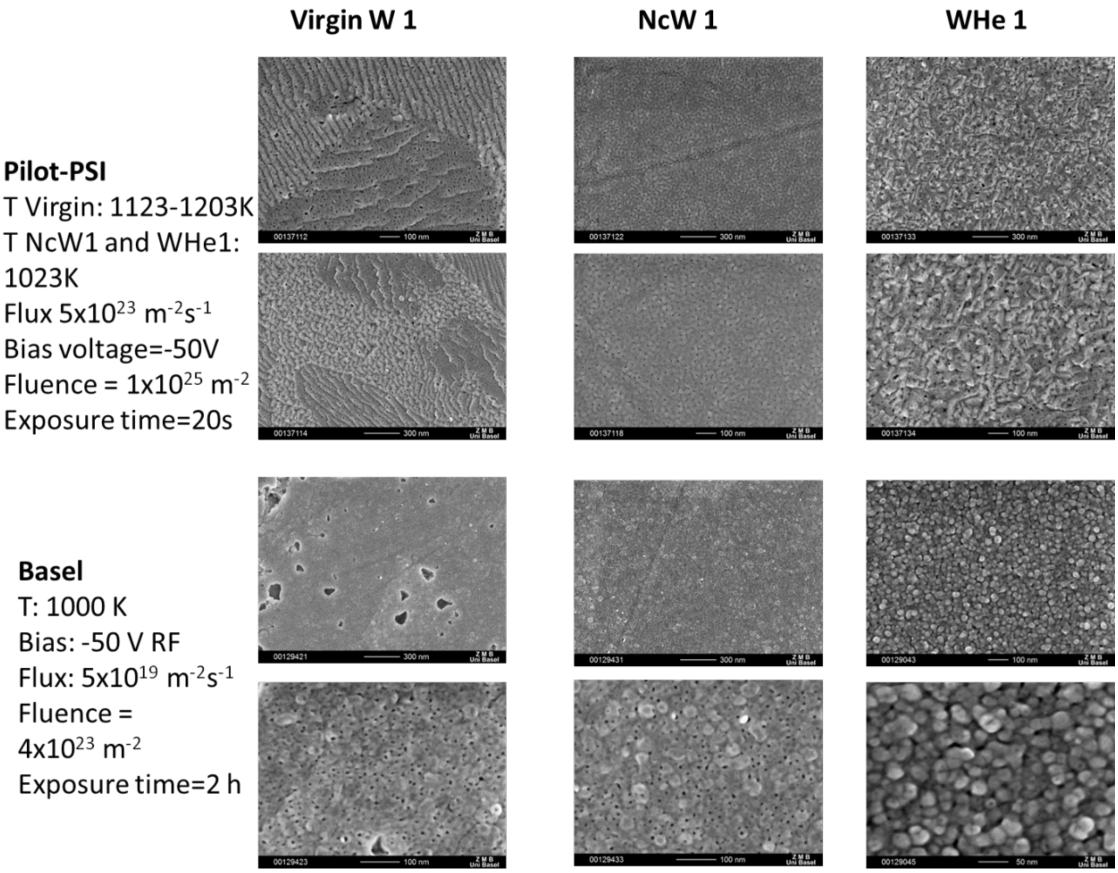

Figure 7: Comparison of samples exposed in Pilot-PSI and in Basel.

3.2.3 Conclusion of tungsten as a plasma-facing material

Using our new setup (unbalanced magnetron sputtering), the formation of the fuzz thickness using He is in square root dependence to time or fluence. The main idea now is to test if adding gases will change this growth rate. For example nitrogen is foreseen to be sued to spread the plasma load at the divertor and the effect of nitrogen on fuzz growth is unknown.

4 Publications 2015-2016

L. Marot, G. De Temmerman, M.A. van den Berg, P-O Renault, G Covarel, M. Joanny, J.M. Travère, R. Steiner, D. Mathys, E. Meyer, **ITER first mirror mock-ups exposed in Magnum-PSI**, Nuclear Fusion 56, (2016), 066015

L. Moser, L. Marot, R. Steiner, M. Newman, A. Widdowson, D. Ivanova, J. Likonen, P. Petersson, G. Pintsuk, M. Rubel, E. Meyer and JET Contributors, **Plasma cleaning of Be coated mirrors**, Physica Scripta T167, (2016), 014069

MFM De Bock, R Barnsley, M Bassan, L Bertalot, B Brichard, IM Bukreev, JM Drevon, F Le Guern, R Hutton, M Ivantsivskiy, HG Lee, F Leipold, P Maquet, L Marot, V Martin, P Mertens, A Mokeev, L Moser, EE Mukhin, S Pak, AG Razdobarin, R Reichle, CR Seon, F Seyvet, S Simrock, V Udintsev, G Vayakis, C Vorpahl, **ITER perspective on fusion reactor diagnostics - A spectroscopic view**, Journal of Instrumentation 11 (2016), P08010

L. Marot, G. Arnoux, A. Huber, V. Huber, Ph. Mertens, G. Sergienko, E. Meyer, and JETEFDA Contributors, **Optical coatings as mirrors for optical diagnostics**, Journal of Coating Science and Technology 2, (2015), 72-78

L. Moser, L. Marot, B. Eren, R. Steiner, D. Mathys, F. Leipold, R. Reichle, E. Meyer, **Towards plasma cleaning of ITER first mirrors**, Nuclear Fusion, 55, (2015), 063020.

İ. Tanyeli, L. Marot, D. Mathys, MCM. van de Sanden, G. De Temmerman, **Surface Modifications Induced by High Fluxes of Low Energy Helium Ions**, Scientific reports, 5, (2015), 9779.

L. Moser, R. Steiner, F. Leipold, R. Reichle, L. Marot, E. Meyer, **Plasma cleaning of ITER First Mirrors in magnetic field**, Journal of Nuclear Materials 463 (2015) 940–943

Submitted:

L. Marot, S. Coda, S. Kajita, L. Moser, R. Steiner, and E. Meyer, **TCV mirrors cleaned by plasma**, Submitted to Nuclear Materials and Energy

A. Maffini, L. Moser, L. Marot, R. Steiner, D. Dellasega, A. Uccello, E. Meyer, M. Passoni, **In-situ cleaning of diagnostic First Mirrors: an experimental comparison between plasma and laser cleaning in ITER-relevant conditions**, Submitted to Nuclear Fusion

A. Garcia-Carrasco, P. Petersson, M. Rubel, A. Widdowson, E. Fortuna, M. Brix, L. Marot, and JET Contributors, **Modification of diagnostic mirrors in JET**, Submitted to Nuclear Materials and Energy

5 Presentations

Marwa Ben Yaala, Laurent Marot, Roland Steiner, Marie-Hélène Aumeunier, Michael Houry, Ernst Meyer, **Wall Reflection Measurements**, Oral presentation at the 31th Meeting of the ITPA Topical Group on Diagnostics ITER – France, November 7-10 2016

Laurent Marot, Zakaria Azdad, Lucas Moser, Marwa Ben Yaala, Roland Steiner and Ernst Meyer, F. Le Guern, U. Walach, G. Counsell, R. Reichle, F. Leipold, C. Vorpahl, **Repetitive cleaning of first mirrors**, Oral presentation at the 31th Meeting of the ITPA Topical Group on Diagnostics ITER – France, November 7-10 2016

L. Moser, L. Marot, R. Steiner and E. Meyer, S. Alberti and I. Furno, Reichle, F. Leipold, C. Vorpahl, **Influence of high magnetic field on plasma sputtering of ITER First Mirrors**, Oral presentation at the 29th Meeting of the ITPA Topical Group on Diagnostics ITER – France, November 2-6 2015

L. Marot, D. Haas, P. Lattner, J. Charmillot, L. Moser, R. Steiner, D. Mathys, E. Meyer, **Nanostructured metallic surface by unbalanced magnetron sputtering**, Swiss Physical Society annual meeting 23 - 25 August 2016 Lugano, Switzerland

L. Moser, R. Steiner, S. Alberti, I. Furno, R. Reichle, C. Vorpahl, F. Leipold, L. Marot and E. Meyer, **Influence of high magnetic field on plasma sputtering of ITER First Mirrors**, Swiss Physical Society annual meeting 23 - 25 August 2016 Lugano, Switzerland

D. Haas, L. Marot, L. Moser, P. Lattner, J. Charmillot, R. Steiner, D, Mathys, E. Meyer**, Nanostructured tungsten by unbalanced magnetron sputtering**, poster contribution at Swiss NanoConvention 20156, Basel, 30 June - 1 July 2016
M. Ben Yaala, L. Marot, R. Steiner, M. Oberkofler, G. De Temmerman, E. Meyer, **Ammonia sticking on metallic surfaces**, Poster presentation at the 22nd International Conference on Plasma Surface Interactions, May 30 June 3, 2016, Rome, Italy.

L. Marot, S. Coda, S. Kajita, L. Moser, R. Steiner, and E. Meyer, **TCV mirrors cleaned by plasma**, Poster presentation at the 22nd International Conference on Plasma Surface Interactions, May 30 June 3, 2016, Rome, Italy.

A. Maffini, L. Moser, L. Marot, D. Dellasega, A. Uccello, M. Passoni, **Cleaning of ITER-like First Mirrors: an experimental comparison between plasma and laser cleaning techniques**, Poster presentation at the 22nd International Conference on Plasma Surface Interactions, May 30 June 3, 2016, Rome, Italy.

A. Garcia-Carrasco, P. Petersson, M. Rubel, A. Widdowson, E. Fortuna-Zalesna, M. Brix, L. Marot and JET Contributors, **Modification of diagnostic mirrors in JET**, Poster presentation at the 22nd International Conference on Plasma Surface Interactions, May 30 June 3, 2016, Rome, Italy.

D. Haas, L. Marot, L. Moser, R. Steiner, D, Mathys, E. Meyer, **A Nanostructured tungsten by unbalanced magnetron sputtering**, Poster presentation at the CCMX annual meeting, Lucern, May, 11 2016

F. Leipold, R. Reichle, C. Vorpahl, E.E. Mukhin, A.M. Dmitriev, A.G. Razdobarin, D.S. Samsonov, and L. Marot, L. Moser, R. Steiner, E. Meyer, **Cleaning of First Mirrors in ITER by means of Radio Frequency Discharges**, Poster presentation at the 21st High Temperature Plasma Diagnostics Conference – USA, June 5-9 2016

MFM De Bock, R Barnsley, M Bassan, L Bertalot, B Brichard, IM Bukreev, JM Drevon, F Le Guern, R Hutton, M Ivantsivskiy, HG Lee, F Leipold, P Maquet, L Marot, V Martin, P Mertens, A Mokeev, L Moser, EE Mukhin, S Pak, AG Razdobarin, R Reichle, CR Seon, F Seyvet, S Simrock, V Udintsev, G Vayakis, C Vorpahl, **ITER perspective on fusion reactor diagnostics - A spectroscopic view**, Oral presentation at the 4th International Conference Frontiers in Diagnostic Technologies 30 March 2016 to 01 April 2016, Rome - Italy

Laurent Marot, Lucas Moser, Marwa Ben Yaala, Roland Steiner and Ernst Meyer, **First mirrors issues for optical diagnostics**, Oral presentation at the National Institute for Laser, Plasma and Radiation Physics - INFLPR – Bucharest, Romania, January 21st 2016

6 Scientific collaborations

National collaborations
- Swiss Plasma Center, EPFL, Lausanne, CH-1015 Lausanne Switzerland
- Swiss Plasma Center, EPFL, PSI, Villigen, Switzerland

International collaborations
- Max-Planck-Institut für Plasmaphysik, Garching, Germany,
- Institut für Plasmaphysik, Forschungszentrum Jülich, Germany,
- Alfvén Laboratory, Royal Institute of Technology, Stockholm, Sweden,
- Culham Science Centre, JET, Abingdon, England,
- Nuclear Fusion Institute, Russian Research Center 'Kurchatov Institute', Moscow, Russia,
- Laboratoire Mécanique, Matériaux et Procédés de Fabrication, 61 rue Albert Camus, Université de Haute-Alsace, F-68093 – Mulhouse Cedex, France,
- Institute of Plasma Physics, NSC KIPT, Kharkov, Ukraine,
- Centre for Energy Research, University of California at San Diego, San Diego, USA,

• Euratom / CIEMAT Fusion Association 28040 Madrid Spain.
• Institute for Magnetic Fusion Research, CEA, F-13108 Saint-Paul-lez-Durance, France
• Dipartimento di Energia, Politecnico di Milano, via Ponzio 34/3, 20133 Milan, Italy

7 International activities in fusion research

• L. Marot is member of the First Mirror Specialist Working Group of the ITPA Topical Group on Diagnostics. https://portal.iter.org/departments/POP/ITPA/Diag/Pages/default.aspx

8 On-going tasks with F4E, EUROfusion and ITER IO support

F4E:

Contract ID F4E-OPE-649, Amendment Nr2: Mirror samples supply and Feasibility Testing of RF Cleaning Method

EUROfusion:

AWP15-EEG-EPFL/Ben Yaala: Plasma-Facing Materials & Components and Diagnostics for Plasma-Wall Interaction Studies, PhD program of Marwa Ben Yaala, May 2015- May 2018

WPJET 2: Analysis of JET ITER-like wall plasma facing components 2014-2018

ITER IO:

IO/CT/14/4300001067: Building and Investigating a Two Mirror Cleaning System In Order to Avoid Re-deposition

9 Advancement of Lucas Moser Thesis

Mr Lucas Moser is first authors of 3 papers in peer review journal and has till March/ April 2017 to complete his PhD. A typical number of papers at the University of Basel are 4 to defend a thesis, meaning that he is under a good path.

Moreover for the end of 2016 Mr Moser will write his thesis manuscript and also complete few papers. The date for submission of his thesis is around March 2017 with a defense in April 2017. To finish his PhD the funding will be covered by the University of Basel.

L. Moser, L. Marot, R. Steiner, M. Newman, A. Widdowson, D. Ivanova, J. Likonen, P. Petersson, G. Pintsuk, M. Rubel, E. Meyer and JET Contributors, **Plasma cleaning of Be coated mirrors**, Physica Scripta T167, (2016), 014069

L. Moser, L. Marot, B. Eren, R. Steiner, D. Mathys, F. Leipold, R. Reichle, E. Meyer, **Towards plasma cleaning of**

ITER first mirrors, Nuclear Fusion, 55, (2015), 063020.

L. Moser, R. Steiner, F. Leipold, R. Reichle, L. Marot, E. Meyer, **Plasma cleaning of ITER First Mirrors in magnetic field**, Journal of Nuclear Materials 463 (2015) 940–943

MFM De Bock, R Barnsley, M Bassan, L Bertalot, B Brichard, IM Bukreev, JM Drevon, F Le Guern, R Hutton, M Ivantsivskiy, HG Lee, F Leipold, P Maquet, L Marot, V Martin, P Mertens, A Mokeev, **L Moser**, EE Mukhin, S Pak, AG Razdobarin, R Reichle, CR Seon, F Seyvet, S Simrock, V Udintsev, G Vayakis, C Vorpahl, **ITER perspective on fusion reactor diagnostics - A spectroscopic view**, Journal of Instrumentation 11 (2016), P08010

Submitted:

L. Marot, S. Coda, S. Kajita, **L. Moser**, R. Steiner, and E. Meyer, **TCV mirrors cleaned by plasma**, Submitted to Nuclear Materials and Energy

A. Maffini, **L. Moser**, L. Marot, R. Steiner, D. Dellasega, A. Uccello, E. Meyer, M. Passoni, **In-situ cleaning of diagnostic First Mirrors: an experimental comparison between plasma and laser cleaning in ITER-relevant conditions**, Submitted to Nuclear Fusion

On EUROfusion pin board:

L. Moser, R.P. Doerner, C.P. Lungu, C. Porosnicu, M. Newman, A. Widdowson, E. Alves, G. Pintsuk, J. Likonen, A. Hakola, M. Rubel, R. Steiner, L. Marot, E. Meyer and JET Contributors, I**nvestigation and plasma cleaning of first mirrors coated with relevant ITER contaminants: beryllium and tungsten**, To be submitted to Nuclear Fusion
http://users.euro-fusion.org/repository/pinboard/EFDA-JET/journal/51060_paper_be_cleaning_lmoser_v1.pdf

Under preparation:

Rong Yan, **Lucas Moser**, Baoguo Wang, Jiao Peng, Christian Vorpahl, Frank Leipold, Jinhua Wu, Junling Chen, Lei Mu, d, Mingzhong Zhao, Roger Reichle, Roland Steiner, Rui Ding, Laurent Marot, **Development of the first mirror in-situ cleaning using radio frequency plasma for ITER**, To be submitted to Journal of Nuclear Materials