First studies of ITER diagnostic mirrors in a tokamak with all-metal interior: results of first mirror test in ASDEX Upgrade

A. Litnovsky[1], M. Matveeva[1], A. Herrmann[2], V. Rohde[2], M. Mayer[2], K. Sugiyama[2], K. Krieger[2], V. Voitsenya[3], G. Vayakis[4], A. E. Costley[4], R. Reichle[4], G. De Temmerman[5], S. Richter[6], U. Breuer[7], L. Buzi[8], S. Möller[1], V. Philipps[1], U. Samm[1], P. Wienhold[1] and ASDEX Upgrade Team

[1]Institute of Energy and Climate Research – Plasma Physics, Forschungszentrum Jülich, Trilateral Euregio Cluster, Association EURATOM- FZ Jülich, D-52425 Jülich, Germany;
[2]Max-Planck-Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany;
[3]IPP, NSC Kharkov Institute of Physics and Technology, Kharkov 61108, Ukraine;
[4]ITER Organization, Route de Vinon sur Verdon, 13115 St. Paul Lez Durance, France;
[5]FOM Institute DIFFER-Dutch Institute for Fundamental Energy Research, Association EURATOM-FOM, Partner in the Trilateral Euregio Cluster, Postbus 1207, 3430BE, Nieuwegein, The Netherlands;
[6]Central Facility for Electron Microscopy, RWTH Aachen, D-52056, Aachen, Germany;
[7]Central Division of Analytical Chemistry, Forschungszentrum Jülich, D-52425 Jülich, Germany;
[8]Department of Applied Physics, Ghent University, B-9000 Ghent, Belgium.

E-mail contact of main author: a.litnovsky@fz-juelich.de

PACS: 52.40.Hg, 52.77.Dq, 52.70.-m, 42.25.Gy.

Abstract.
In ITER, mirrors will be used as plasma-viewing elements in all optical and laser diagnostics. In the harsh environment mirror performance will degrade hampering the operation of associated diagnostics. The most adverse effect on mirror performance is caused by the deposition of impurities. It is expected that the most challenging situation will occur in the divertor. With the envisaged changes to all-metal plasma-facing components (PFCs) in ITER, an assessment of mirror performance in an existing divertor tokamak with all-metal PFCs is urgently needed.
Molybdenum and copper mirrors were exposed for nearly nine months in ASDEX Upgrade which has all-tungsten PFCs. Mirrors were located at the inner wall, under the dome and in the pump-duct. During exposure, the mirrors were heated to temperature in the range 145°C-165°C. This was made to approach the expected level of heating due to absorption of neutrons and gammas on mirrors in ITER divertor. After exposure, degradation of the reflectivity was detected on all mirrors. The highest reflectivity drop was measured on mirrors under the dome facing the outer strike point, reaching -55% at 500 nm. The least degradation was detected on mirrors in the pump duct, where the reflectivity was preserved in the range 500-2500 nm and the largest decrease was about -8% at 250 nm. On all contaminated mirrors carbon fraction did not exceed 50 at.% while the major contaminants were metals and oxygen. The degradation of exposed mirrors underlines the necessity for urgent R&D on deposition mitigation and *in-situ* mirror cleaning in ITER.

1. Introduction and motivation

Mirrors will be used as plasma-viewing elements in all optical and laser diagnostics in ITER. Plasma radiation in the wavelength range from a few nanometers up to one hundred microns will be observed via mirror-based systems. In the harsh environment of ITER, the performance of mirrors will degrade thus hampering the operation of the associated diagnostics. The strongest adverse impact on mirrors is caused by the deposition of impurities eroded from the plasma-facing components [1]. It is expected that the most challenging situation will happen in ITER divertor. With an envisaged change to all-metal plasma-facing components (PFCs) in ITER, an assessment of diagnostic mirror performance in existing divertor tokamak with all-metal PFCs is urgently needed.

The first dedicated test of ITER-candidate diagnostic mirrors in ASDEX Upgrade tokamak (AUG) with all–tungsten PFCs was proposed in 2006 by the International Tokamak Physics Activity (ITPA) Topical Group on Diagnostics, supported by the Specialists Working Group on First Mirrors and has been carried out in the frame of collaboration between Forschungszentrum Jülich (FZJ) and IPP Garching. During this test, sets of ITER-candidate molybdenum and copper mirrors were installed under the dome in the divertor, on the upper baffle area and in a remote area – at the entrance of a pump-duct and exposed for the entire experimental campaign of ASDEX Upgrade 2010-2011. Optical and surface properties of mirrors were studied before and after exposure.

2. Mirror test in ASDEX-Upgrade

2.1. Mirrors: description and details of optical and surface characterization

Four molybdenum and four copper mirrors were used in the experiment. The mirrors were 22 mm in diameter, the diameter of the polished surface was 18 mm and the thickness of the mirror sample was 4 mm. The view of a mirror is shown in Fig. 1.

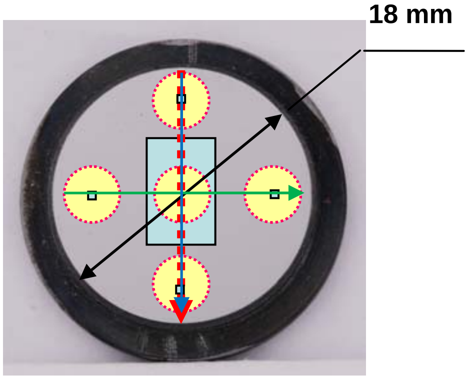


Figure 1. View of a diagnostic mirror and locations of measurements: cicrles – locations of measurements of total reflectivity, rectangular spot in the middle of the sample – location of measurement of diffuse reflectivity, small squares – locations of measurements made by Secondary Ion Mass Spectrometry (SIMS), dashed arrow – the location of the scan by Electron Probe MicroAnalysis (EPMA). Solid arrows show the locations of scans using ion-beam analyses (IBA).

Optical and surface properties of mirrors were characterized. The characterization comprised measurements of total (R_{tot}) and diffuse (R_{diff}) reflectivity before and after exposure in ASDEX-Upgrade. The difference between total and diffuse reflectivity gives the specular reflectivity:

$$R_{spec} = R_{tot} - R_{diff}.$$

Specular reflectivity of mirrors is responsible for the transmission of radiation from the plasma towards the detectors in associated diagnostics. A double-beam spectrophotometer Perkin Elmer Lambda 950 at the MirrorLab* was used for reflectivity measurements. Reference Mo and Cu mirrors from the same manufacturing batch were kept in desiccators for the entire duration of the experiment to provide data on initial surface elemental composition.

Surface characterization performed on the mirrors after exposure, comprised:

i. Secondary Ion Mass-Spectrometry (SIMS) measurements performed at the FZJ with ION-ToF IV facility operating with 25 kV Bi_3^+ analyzing beam and 2 keV Cs^+ sputtering beam. SIMS measurements yielded in the depth-resolved elemental distribution of impurities on the mirror surface.
ii. Profiling of SIMS craters performed with a stylus profiler Dektak 6M at the MirrorLab. Profiling provided quantitative data on the thickness of deposits.

---

* MirrorLab Website: https://tec.ipp.kfa-juelich.de/mirrorlab/, access details: mirrorlab@fz-juelich.de

iii. Measurements of areal concentration of tungsten (W), boron (B), oxygen (O) and carbon (C) were performed using the Electron Probe MicroAnalysis (EPMA) technique with CAMECA Camebax SX 50 facility at the RWTH Aachen operating with 10 µm electron beam.

iv. Quantitative investigations of elemental composition of deposited layers were performed at the IPP Garching using ion beam analyses techniques (IBA). For investigations of carbon, deuterium and boron content, the Nuclear Reaction Analyses (NRA) were performed with 2.5 MeV $^{3}He^{+}$ ions. For measurements of tungsten areal concentration, the Rutherford Back Scattering (RBS) technique was used with 2.0 MeV $^{4}He^{+}$ ions.

The areal elemental concentration was determined with EPMA and IBA techniques by averaging corresponding measurements performed along the line scans shown in figure 1 with arrows. In addition, the reference Mo mirror was measured with EPMA and IBA techniques described above. Corresponding background levels of B, C and W were subtracted from results obtained during measurements made on mirrors exposed in ASDEX Upgrade. The locations of measurements are shown in figure 1.

2.2. Installation in ASDEX Upgrade: mirror locations

Pre-characterized copper and molybdenum mirrors were installed in pairs in the stainless steel holders. Each holder was fitted with custom-made active heater and a thermocouple for monitoring the mirror temperature. The scheme of the mirror locations is provided in Figure 2. One holder (5/1) installed on the upper baffle of the AUG with mirrors facing the plasma. Two mirror holders were installed under divertor dome: one holder was facing the inner divertor (2), whereas the other one (3) was installed facing the outer strike-point. One holder (4) was installed at the entrance of the pump-duct located just behind the outer divertor. This was made to investigate the effect of the long-term exposure on the mirrors distant from the plasma.

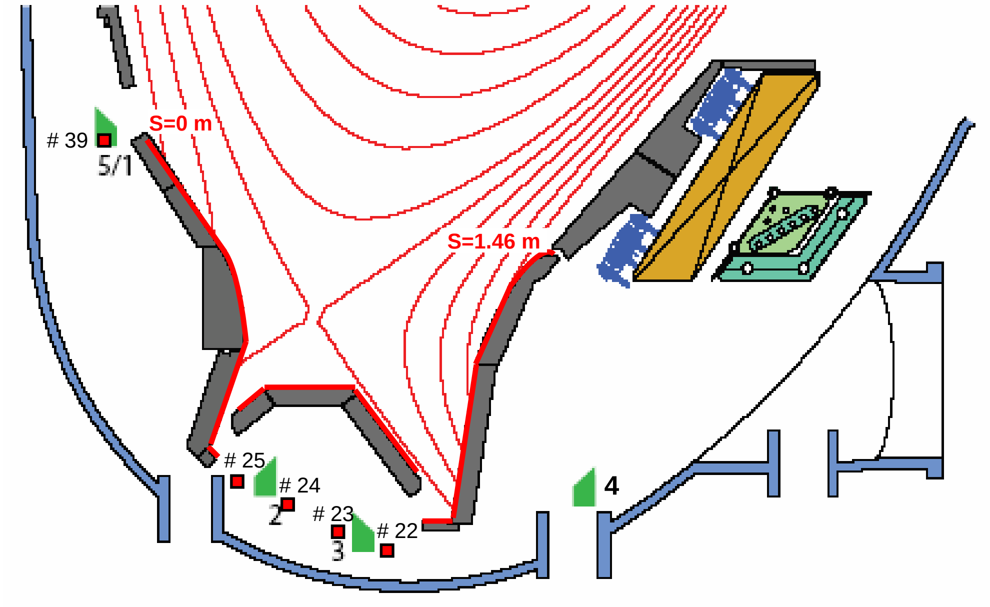


Figure 2. Locations of holders with mirrors in ASDEX Upgrade (shown with green wedges): 5/1 – upper baffle facing the plasma, 2 – inner divertor, facing inner leg, 3 – outer divertor facing the outer strike point and 4 – pump-duct. Each holder contains one copper and one molybdenum mirror. Locations of non-heated Si samples are shown with red squares. The strike-point coordinate (S-coordinate) in divertor is shown with bold red line. Coordinate S=0 m is located at the inner divertor, S=1.46 m is located at the outer one.

In addition, forty two silicon (Si) samples were exposed under the dome of the AUG divertor. Some of these samples were exposed nearby the mirrors. Si samples were not actively heated during the exposure in ASDEX Upgrade.

2.3 Mirror exposure in ASDEX-Upgrade

The mirrors were exposed in ASDEX Upgrade for nearly nine months from December 2010 till August 2011. In total, the exposure time was about 5360 seconds in divertor configuration. Seven boronizations were carried out in ASDEX Upgrade during the exposure period. The mirrors were permanently heated and their temperature was kept between 145^{o}C and 165^{o}C to approach the conditions expected for mirrors in ITER located below the dome. These mirrors are expected to be heated by neutrons and secondary gammas to about 120^{o}C assuming an active cooling [2].

3. Results of exposure in ASDEX Upgrade

3.1. Visual observations

After the exposure, mirrors were dismounted from the holders and inspected. The view of the mirrors after exposure is shown in figure 3. The majority of the mirrors were affected by deposition. Visibly the largest deposition was found on mirrors located under the dome and facing the outer strike point. The smallest, hardly visible deposition was observed on the mirrors mounted in the pump-duct. On baffle, dome and pump-duct mirrors the deposition pattern was fairly homogeneous, which may imply the deposition by neutrals as observed earlier in ASDEX Upgrade [3]. In contrast, the deposition pattern on the mirrors exposed under the dome facing the outer strike point was significantly inhomogeneous. Such an inhomogeneous deposition may be due to the direct view of the mirror 3 to the outer strike point acting as an impurity source [4].

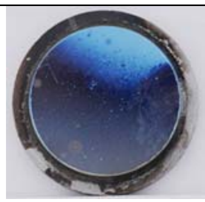
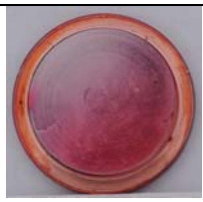
Mirrors/Location	5/1 Upper baffle	2 Dome, facing the inner divertor	3 Dome, facing the outer strike point	4 Pump-duct
Mo				
Cu				

Figure 3. View of molybdenum and copper mirrors after exposure in ASDEX Upgrade

3.2. Optical and surface characterization

All exposed mirrors demonstrated a decrease of their specular reflectivity. The strongest decrease, ~ 55% maximum at the wavelength 550 nm, was detected on molybdenum mirrors facing the outer divertor. On copper mirrors the strongest decrease of ~ 35% was detected at the wavelength of 500 nm. The least decrease, ~9% maximum at the wavelength 220 nm, was observed on the molybdenum mirrors installed in the pump-duct. The characteristic behavior of specular reflectivity as a function of the wavelength on the example of molybdenum mirror 3 exposed under the dome facing outer strike point and pump-duct mirror is provided in figure 4. It should be also noted, that the reflectivity of the mirror 3 demonstrated the decrease over the whole measured wavelength range. This observation is in contrast with previous studies made in tokamaks with carbon plasma-facing components, where the ultraviolet (UV) and visible (VIS) wavelength ranges were affected the most, and the smallest changes were usually detected in NIR region. The most possible reason for such an unexpected decrease is a new elemental composition of the deposits formed on the mirror after the exposure in 2010-2011. The change to all tungsten PFCs in ASDEX Upgrade obviously affected the elemental composition of deposits as described in details later in this paper.

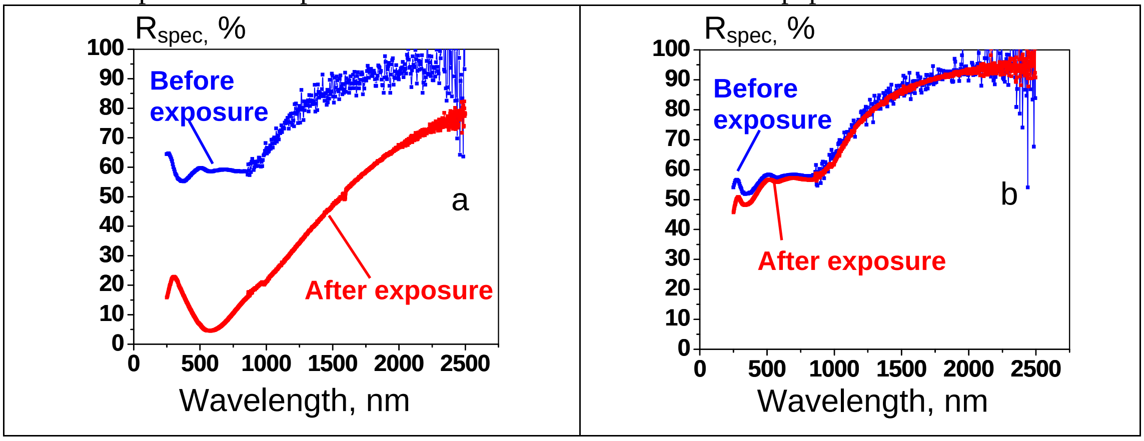


Figure 4. The evolution of the specular reflectivity of molybdenum mirrors as a function of the wavelength: a) for the mirror exposed under the dome facing the outer strike point and b) for the mirror exposed at the pump-duct.

SIMS investigations were performed on all mirrors after exposure. Each mirror was measured at five locations, shown on figure 1. The main elements constituting the deposit both on copper and molybdenum mirrors were found to be oxygen, deuterium, tungsten oxide and boron. Since very similar deposits were detected on the copper and molybdenum mirrors we will focus our subsequent analysis on molybdenum mirror samples. An example of the SIMS depth profile from the mirror exposed under the dome facing the outer strike point is shown in figure 4. From the depth profile, it can be concluded that the deposit constituents are mainly tungsten oxide (curve WO_3) and boron (curve B) with a minor fraction of carbon (curve C). Slight traces of molybdenum oxides are also noticed (curve MoO_3). Oxidation of molybdenum at the interface between the bulk material and the deposit was detected on all mirrors. Having analyzed the location of molybdenum oxide peaks the conclusion can be made that the molybdenum oxidation happened prior to exposure in AUG, mainly because of the air storage of the mirrors immediately before installation.

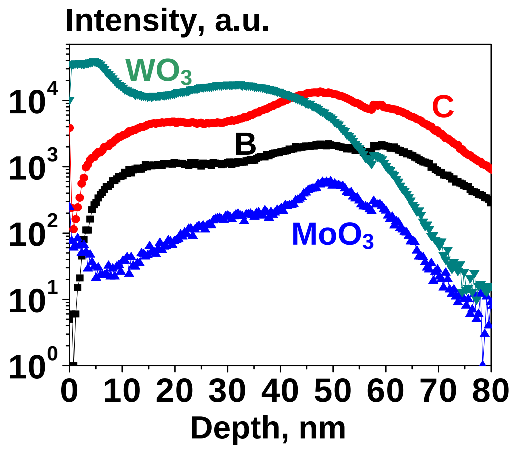


Figure 5. Elemental distribution along the depth of the deposit formed on molybdenum mirror located under the dome facing the outer strike point. The deposit thickness is approximately 70 nm

EPMA measurements were made on all mirrors as line scans along the mirror surface (figure 1). According to the results of these measurements, most of the deposition was detected on mirrors facing the outer strike point. Remarkably, carbon was present in almost all deposits. The highest areal carbon atom concentration of ~$2*10^{16}$ at/cm^2 was detected on the mirrors facing the outer divertor, whereas tungsten and boron concentrations exceeded $4.7*10^{16}$ at/cm^2 and $6.8*10^{16}$ at/cm^2

correspondingly on the same mirror. Therefore, carbon does not any longer represent the major fraction of the deposit.

The areal elemental concentration of deposits measured on the molybdenum mirrors by the EPMA and IBA techniques is presented in table 1. The IBA results qualitatively confirm EPMA findings, showing low deposition levels (< 70 nm) and confirming the minor contribution of carbon in the formed deposits. It should be noted that the measured levels of impurities on the majority of the samples were about 10^{16} at/cm^2 or lower, corresponding to the deposition thickness of less than 10 nm These low levels gave difficulties for reliable detection and this is probably the reason for the quantitative deviations of the IBA and EPMA results observed on some samples.

Table 1. Areal concentration of impurities on deposited layers measured on molybdenum mirrors by EPMA and IBA techniques.

Mirror samples (145^{o}C-165^{o}C)	B, 10^{16} at/cm^2		C, 10^{16} at/cm^2		W, 10^{16} at/cm^2	
	EPMA	IBA	EPMA	IBA	EPMA	IBA
5/1 inner baffle	0.1	1.0	0	0.6	0.5	0.2
2 dome facing inner divertor	0.3	0.7	0.7	0.5	0.4	0.1
3 dome facing outer strike point	6.8	8.9	1.9	2.9	4.7	4.9
4 pump duct	0.2	0.2	0.0	0.5	0.3	0.1

4. Analyses and extrapolations to ITER conditions

4.1. Impurity deposition and contamination of mirrors

The results of the first tests of ITER-diagnostic mirrors in the tokamak with all-metal PFCs revealed the degradation of all exposed heated mirrors due to impurity deposition. The main impurities constituting the deposits on mirrors were tungsten oxide, oxygen and boron. Carbon is not the dominant impurity on mirrors. Carbon detected in the deposits originates from residual carbonaceous deposits remaining in the plasma-shadowed areas after the change to tungsten plasma-facing components. An additional source of carbon might be the uncoated part of the graphite tiles, i.e. their rear sides or leading edges where hydrocarbons can be formed [5, 6]. Some of the gaps are exposed directly to plasma and become eroded. For the detailed investigation of elemental composition of deposit and the amount of deposited material, the co-exposure of Si samples has provided the crucially important information. The comparison of impurity deposition on the mirrors and their corresponding Si samples is provided in table 2.

At the upper baffle on the high field side, the deposition on the mirror 5/1 could be compared with contamination of Si sample # 39 which was mounted nearby. A factor of 3 reduction of carbon content was detected on the mirror. Some traces of tungsten were detected on the mirror and on Si-sample, whereas boron and carbon content was reduced on the mirror due to the reasons explained later in the paper.

Impurity transport and the corresponding deposition in the sub-divertor structure under the dome is of particular interest for the mirrors. The respective scheme of mirrors and Si samples below the dome of ASDEX Upgrade is provided in the figure 2, the distribution of impurity areal concentration is presented in Figure 6. The quantitative comparison of impurity deposition on the mirrors and relevant Si-samples is shown in the table 2. For the direct comparison the IBA data was used.

The deposition in the inner divertor is the highest, as it can be deduced from the comparison of Si samples #24 and # 25 facing the inner divertor with samples # 22 and #23 installed towards the outer divertor (figure 6 and Table 2). Near the inner divertor, the deposition on non-heated Si samples is still obviously dominated by carbon as it can be seen on Si samples #24 and # 25. Remarkably, the carbon represents the non-dominant fraction on mirror 2 facing the inner divertor. The reason of almost complete suppression of carbon is the temperature-enhanced re-erosion of carbon deposits by hydrogenic atoms. The temperature effect has already been shown to have the highest impact on the deposition efficiency in divertor conditions. During earlier studies in ASDEX Upgrade by M. Mayer et al [4], the 40-fold decrease of carbon deposition was measured on Si samples heated up to 150^{o}. The temperature effect on carbon deposition on the mirrors was demonstrated during studies in DIII-D where the temperature rise to 165^{o}C was able to completely suppress the carbon deposition on the mirrors exposed in divertor [8]. The gradual decrease of deposition from the sample # 25 towards the sample # 24 agrees well with results of previous studies in ASDEX Upgrade showing the e-folding decay of deposit amount as the distance from the inner divertor increases [7]. Interestingly, deposits detected on the Si sample # 24 located behind the mirror reveal small, but still measurable amounts of boron and tungsten, whereas on the mirror 2 these elements were just above the background levels. Neither boron nor tungsten under experimental conditions was known to be prone to any kind of temperature-activated re-erosion. Most probably, the observed suppression of boron and tungsten is due to the substrate itself. The substrate effect in the divertor conditions with low energy radicals and atoms involves the complex surface chemistry and yet lacks the explicit physics understanding. The substrate effect is responsible for the “delay” in deposition: when the surface of a substrate is modified so far to accept and keep the impurity atoms on it – the deposition starts. As soon as the first several monolayers are deposited, the substrate does not play a role anymore: the particles are being deposited on the impurity layer. The dedicated studies were performed in the divertor of TCV, where the Si, W and Mo samples were exposed recessed under the divertor floor and under identical conditions. Two exposures were made: the shorter one lasting 223 discharges and the longer one lasting 820 discharges. After the shorter exposure, Mo samples revealed a factor 11 less deposition than the Si ones. After the longer exposure, the difference in deposition efficiency was less pronounced: Mo samples contained 6 times less deposition than the Si one [9]. It can therefore be expected, that the substrate effect reveals itself most explicitly at the very thin deposits of order of 1-5 nm, as in the case of mirror 2 and Si sample #24.

In contrast to the inner divertor, the deposition at the outer one is clearly dominated by boron and tungsten (figure 6 and Table 2). Such a difference between the inner and outer divertor is due to the fact, that the inner divertor is mostly detached whereas the outer one is mostly attached, contributing to the impurity source of sputtered tungsten from the PFCs while boron originates from regular boronizations. The mirror 3 facing the outer strike point shows the suppression of carbon deposition as compared with Si sample # 22. Such suppression was expected for a heated mirror and can also be enforced by the e-folding decrease of deposit thickness as the distance from the outer strike point increases. When compared with the samples # 23 located behind the mirror 3, no significant reduction of boron or tungsten was detected on the molybdenum mirror due to the substrate effect as it was observed for the mirror 2 located in the inner divertor. This is, however, not surprising, since the mirror 3 contained 12 times more boron and more than 40 times more tungsten than the mirror 2: this means that the deposition is started and then substrate effect levels-off with increase of deposit thickness.

It is important to compare the total deposition observed during the present exposure with earlier results obtained when ASDEX Upgrade was operating with carbon target plates. A set of heated samples was exposed facing the outer strike point for the experimental campaign 2002-2003 at the location identical to that of mirror 3. The sample heated to 150^{o}C had a carbon deposit density of $2*10^{17}$ at/cm^2, which is ten times higher than the density of carbon detected on the mirror 3. A measured 10-fold decrease in deposition carbon is due to change to all-tungsten PFCs in ASDEX Upgrade. At the same time, during the exposure 2010-2011, the carbon was a minor fraction of the deposit. The total deposition of carbon, boron and tungsten yields to $1.67*10^{17}$ at/cm^2, which is only 17% less than the total deposition measured after the campaign 2002-2003.

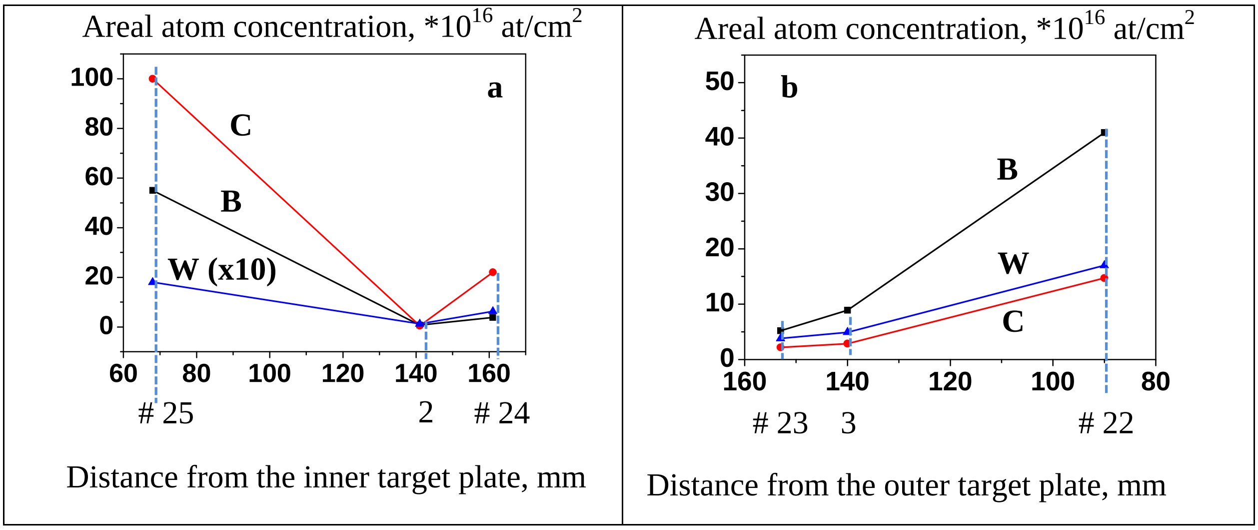


Figure 6. Comparison of deposition on the mirrors (2 and 3) and Si samples (#22-#24) exposed under the dome and facing the inner (a) and outer (b) divertor plates.

4.2. Impact of exposure on mirror reflectivity

The reflectivity of all exposed mirrors was degraded. The strongest degradation was detected on mirrors facing the outer strike point, the least – on the plasma-remote mirrors installed in the pump-duct. The strongest decrease of reflectivity was detected in the UV and VIS wavelength range 250-1000 nm. The near infrared wavelength range of 1000-2500 nm is less vulnerable to deposition. Slight oxidation of molybdenum mirrors happened prior to exposure as evidenced from SIMS and analyses of mirror reflectivity. This oxidation accounts for initial drop of reflectivity not exceeding 5-7% at it its maximum at 250 nm.

Table 2. Comparison of deposition on molybdenum mirrors and corresponding Si-samples

Mirror sample #	Corresponding Si sample #	B, 10^{16} at/cm^2 Mirror / Si-sample	C, 10^{16} at/cm^2 Mirror / Si-sample	W, 10^{16} at/cm2 Mirror / Si-sample
5/1 inner baffle	39	1.0 / 2.2	0.6 / 1.7	0.2 / 0.2
2 dome facing inner divertor	25	0.7 / 55.0	0.5/ 100	0.1 / 1.8
	24	0.7 / 3.8	0.5/ 22	0.1 / 0.6
3 dome facing outer strike point	23	8.9 / 5.2	2.9 / 2.2	4.9 / 3.8
	22	8.9 / 41.0	2.9 / 14.7	4.9 / 17.0

4.3. Extrapolation to ITER conditions

Any kind of extrapolation of the experimental results obtained on the present-day machines to ITER conditions is not straightforward, since multiple significant operational and performance parameters in ITER by far exceed those from the present day fusion devices. The present mirror experiment in AUG is not an exclusion. However, excellent diagnostic coverage makes it possible to relate exposure parameters like fluxes to those expected in ITER and to try to extrapolate the observed phenomena to ITER conditions. Averaged fluence onto the divertor provides a good figure of merit for such an extrapolation. In ASDEX Upgrade, an array of flush-mounted Langmuir probes is installed in the inner and outer divertor. The distribution of fluence along the divertor area as measured with probes is plotted in figure 7. The corresponding values of expected fluence in the ITER divertor are provided in [10, 11]. Due to the fact that the inner divertor in ASDEX Upgrade is almost always detached yielding to the underestimated fluxes, it was decided to use the data from outer divertors only for this direct comparison.

Averaging of measured fluence over the outer divertor target of ASDEX Upgrade leads to the mean ion fluence of $5.6*10^{25}$ ion/m^2 during the whole experimental campaign 2010-2011. The respective estimate using data [11, 12] for the ITER outer divertor (case1514, F57 configuration) yields an averaged flux of $6.3*10^{22}$ ion/m^2 which results in fluence $2.5*10^{24}$ ion/m^2 for one 400 s standard ITER discharge. Comparing obtained fluence values, a simple estimate can be made, that the exposure in ASDEX Upgrade in terms of fluence onto the divertor corresponded to about 22 ITER discharges.

Using this estimate, further assessment of deposition on the mirrors could be made. For a standard ITER operation scenario with 1000 discharges per year, using tungsten and boron deposition as a representative choice, neglecting possible deposition mitigation measures, we may expect deposits with the thickness of about 200-400 nm in remote areas and up to 1500-3000 nm for the mirrors located under the dome and facing target plates. These are intolerable levels of mirror contamination.

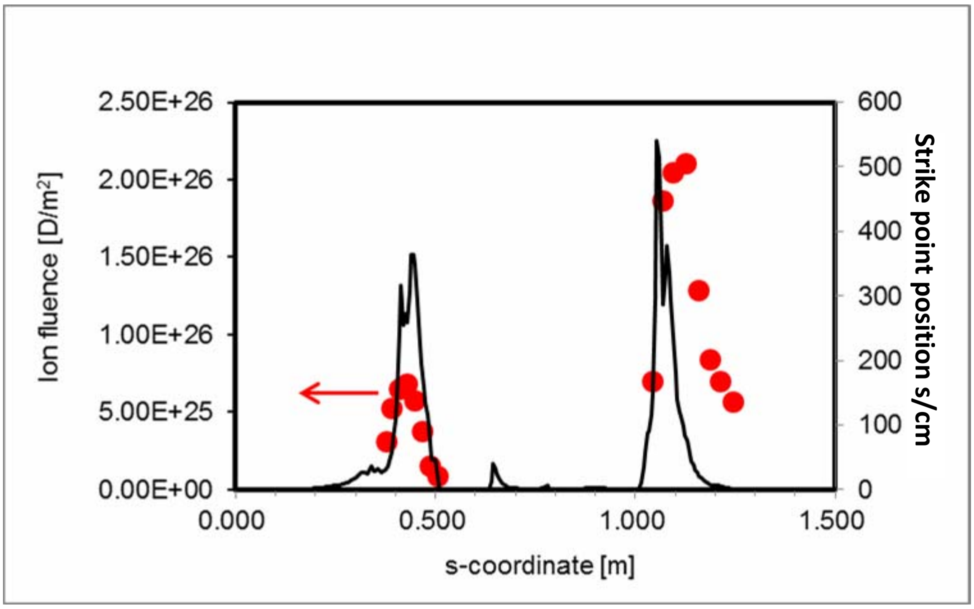


Figure 7. Distribution of ion fluence and the strike point position during experimental campaign 2010-2011 in ASDEX Upgrade. Strike point S-coordinate is plotted in Figure 2.

5. Conclusions and outlook

The optical properties of mirrors exposed under the dome, at the upper inner baffle and in the pump-duct of ASDEX Upgrade have been found to be degraded, despite the use of of active heating of the mirrors, which is known to provide an efficient mitigation of deposition of carbonaceous species [4, 8]. The fact that despite the increased temperatures, the deposition was not fully suppressed outlines the necessity in development of techniques for active mirror cleaning, especially from non-carbon metallic contaminants in ITER.

Present R&D efforts on diagnostic mirrors foresee several passive and active techniques for deposition mitigation. Passive techniques comprise among others, the use of shutters and implementation of shaped diagnostic ducts with baffles. Active techniques envisage *in-situ* mirror cleaning for an active recovery of the mirror surface from deposits. For most of the ITER diagnostic systems, the exploration and integration of mitigation techniques has already started. The application of the deposition mitigation and active recovery techniques will most likely relieve the issue of the mirror lifetime. Despite the undertaken efforts, risks of the failure of divertor diagnostics remain. Back-up measurement channels even with reduced measurement capability to be used in case the failure of main viewing optics should be assessed as an option to ensure reliable operation of optical divertor diagnostics in ITER.

Further activities will be focused on application of both active techniques of mirror recovery and passive measures for mitigation of deposition. It is planned to clean the contaminated ASDEX Upgrade mirrors by plasma sputtering in order to recover their reflectivity and to assess the efficiency of this technique as a cleaning method for metal-containing deposits. A mirror system with passive magnetic shutters and with special shaping of diagnostic ducts is installed in the midplane of ASDEX Upgrade, for studying the efficiency of duct geometry in suppression of deposition on the mirrors. Detailed analyses of the exposed system are planned. Further estimates of mirror contamination in the ITER divertor will be made to provide recommendations for the deposition mitigation strategies and for the recovery of the optical performance.

Disclaimer
Views and opinions expressed herein do not necessarily reflect those of the ITER Organization

References

[1] A. Litnovsky et al., Journal of Nuclear Materials 363-365 (2007) 1395 (inv),
[2] ITER, DDD Diag. EPP, ITER_D_3U8JU7 v3.1 (2007) 48,
[3] V. Rohde et al., Journal of Nuclear Materials, 337-339 (2005) 847,
[4] M. Mayer et al., Nuclear Fusion, 46 (2006) 914,
[5] A. Herrmann, Max-Planck-Institut für Plasmaphysik, Garching, Germany, private communications,
[6] A. Kallenbach et al., Nucl. Fusion 49 (2009) 045007,
[7] V. Rohde et al., Physica Scripta. Vol. T111, 49–54, 2004,
[8] A. Litnovsky et al., Fusion Engineering and Design, 83 (2008) 79,
[9] G. De Temmerman et al., J. Nucl. Mater. 363–365 (2007) 259,
[10] A.S. Kukushkin et al., “Consequences of a reduction of the upstream power SOL width in ITER”, O-12, proceedings of PSI 2012, Aachen, Germany, May 2012, accepted for publication in J. Nucl. Materials,
[11] A.S. Kukushkin, ITER Organization, private communications, 2013.