*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-5.134 (2006)*

The properties of contaminated films deposited on in-vessel mirrors in Large Helical Device, Tore Supra, TCV and TRIAM-1M

V.S. Voitsenya[1], A. Sagara[2], M. Lipa[3], G. De Temmerman[4], H. Zushi[5], A.I. Belayeva[6], V.N. Bondarenko[1], Konovalov[1], N.I. Naidenkova[1], R.A. Pitts[7], I.V. Ryzhkov[1], B. Schunke[3], A.N. Shapoval[1], K.A. Slatin[6], Ch. Gil[3], V.G. A.F. Stan[1].

[1]Institute of Plasma Physics, NSC KIPT, Akademichna St. 1, 61108 Kharkov, Ukraine;
[2]National Institute for Fusion Science, 322-6 Oroshi-cho Toki-shi 509-5292, Japan;
[3]CEA/DSM/DFRC, CEA Cadarache, F-13108 Saint-Paul-Lez-Durance, France;
[4]Institute of Physics, University of Basel, CH-4056 Basel, Switzerland;
[5]Res. Institutes for App. Mechanics, Kyushu University, Kasuga 816-8580, Fukuoka, Japan;
[6]National Technical University 'KhPI", Kharkov, 61002 Kharkov, Ukraine;
[7]CRPP, Association EURATOM, Conférédation Suisse, EPFL, 1015 Lausanne

1. Introduction

Recently, besides the simulation laboratory experiments [1], the investigations of environment effects on in-vessel mirrors were provided at several fusion devices [2-4]. The experimental conditions, the plasma parameters, the total duration of plasma impact, the locations of mirrors, etc., were very different. In Tore Supra (TS) and TCV the samples from different materials were located close to each other, whereas in LHD and TRIAM-1M similar stainless steel (SS) mirror samples were positioned at different locations. Majority of mirrors became coated with C-based film during exposure inside fusion device. Only one SS mirror exposed in LHD near the plasma showed the net erosion [2]; mirrors in TS were eroded but at the same time coated with film of complicated composition [3]; mirrors in TCV [4] and TRIAM-1M also became coated. The postmortem measurements show very different film characteristics.

In this paper the comparative analysis of the properties of deposited films from these devices is provided with an attempt to find a correlation with the experimental environment.

2. Experimental

2.1. LHD

Three SS mirrors were mechanically polished, rinsed in an ultrasonic bath with acetone, and exposed in LHD for the whole 3rd campaign (for details of operating regimes see [5]) without protection from glow conditioning discharges. Sample #1 was positioned near the divertor region, #3 – close to the plasma border, and #5 – deeply in the diagnostic port (Fig. 1).

After the samples were removed from LHD, their reflectance was again measured, and the surface of samples was analyzed by several methods [2]. From the initial identical level, reflectance, R, of mirrors #1 and #5 dropped strongly Fig. 2, whereas the reflectance of #3 increased significantly [2]. The reductions of R of samples #1 and #5 were due to absorption

of light by the contaminating films, composed from ~40% Fe and ~40% C for #1 and ~90% C for #5 (the rest – O and H). The thickness of films was, correspondingly, ~30 nm and ~50 nm with optical indices $n_1 \approx 2.5$, $k_1 \approx 0.33$ and $n_5 \approx 2.45$, $k_5 \approx 0.74$. The rise of R for sample #3 is due to erosion inside LHD of organic film appearing during the rinsing procedure . Similar organic films on samples #1 and #5 were mainly buried under the new deposit.

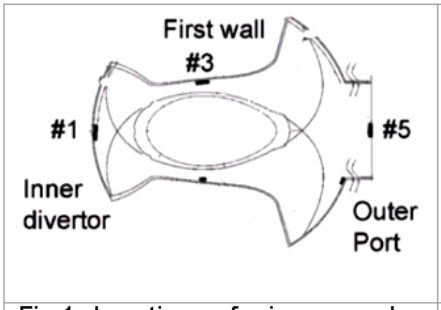

Fig.1. Locations of mirror samples inside the LHD vessel.

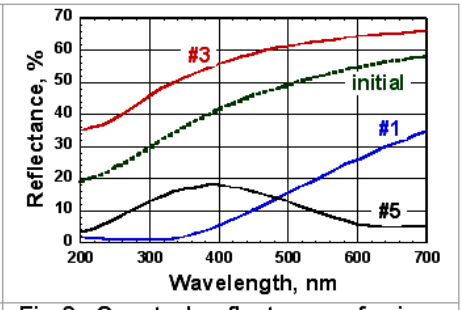

Fig.2. Spectral reflectance of mirror samples after exposure inside LHD.

When being cleaned by low energy D^+ plasma ions, the film on sample #1 was more resistant than the film on sample #5, probably due to high level of Fe in its composition. The film on sample #5 can be characterized as "soft" C film [7] in contrast to former one.

2.2. Tore Supra

Six mirrors from Mo, SS, and Cu have been installed in two CuCrZr holders on the inner wall of torus with centres located at poloidal angles of 7.6° and 15.4° above the central plane (Fig. 3) and positioned ~14 cm from the LCFS (last closed flux surface).

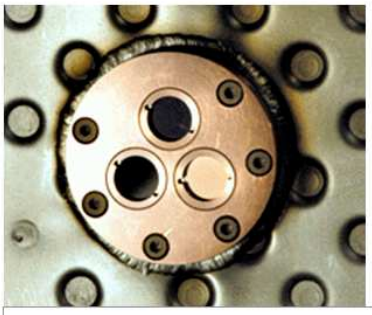

Fig.3. One of holders with mirror samples fixed to the inner wall of Tore Supra vacuum vessel.

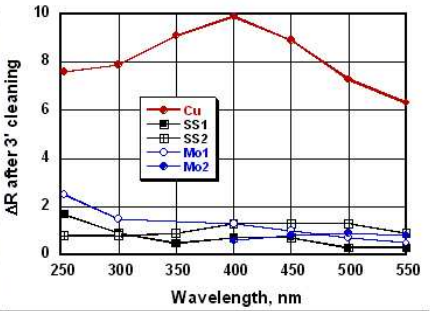

Fig.4. Increase of reflectance of mirror samples exposed inside Tore Supra after 3 minute cleaning with low energy H^+ plasma ions.

During exposure (March 2003 - April 2004) a total pulse length of working discharges (mainly in D_2) reached 7 h 10 min with central density of plasma $n_{e0} \sim (2\text{-}4) \cdot 10^{19}$ m^{-3}. During this time the wall conditioning procedures were performed with glow discharges in He (t=362 h) and in D_2 (t=606 h), and also ~13 h of boronization. From calculations, the temperatures of mirrors did not exceed ~150 °C for a typical TS discharge.

Due to exposure, the reflectivity of all mirrors dropped, especially for Cu mirrors [3]. Within the accuracy of the 3D profile measurements, a net-erosion depth of ~0.12 μm was found for Mo, ~0.22 μm for SS and ~2.5 μm for Cu mirrors. At the same time, all samples were coated with some contaminating film ~10 nm thick, containing C, B, O, H and D [3].

All samples were cleaned by hydrogen plasma of ECR discharge [6]. The first exposure lasted 3 min with grounded mirror holder, when due to sheath potential an ion energy did not exceed 15 eV. The effect of this exposure shown in Fig. 4 does evidently indicate that Cu mirror was contaminated with a film which was easily taken off from its surface just due to chemical erosion. In contrast, such low energy of H^+ ions has no effect on cleaning the Mo and SS mirrors. The reflectance of Mo and SS mirrors became to rise only after the energy of ions was increased to 100 and 200 eV, and the total cleaning procedure took much longer time, in spite all mirrors were exposed in TS in close each to other. This fact gives grounding to make an important conclusion that the properties of film depend on the material of substrate.

2.3. TCV

In the TCV tokamak (90% carbon coverage of the wall) the mirror samples were exposed by pairs in the divertor floor region [4] at the depth 10-50 mm below the surface of the graphite tiles. The arrow in Fig. 5 shows approximate location of samples in the TCV during a standard single null lower diverted discharge. The material of samples, the depth of their location, as well as the number of shots and duration of glow discharge conditioning procedures are shown in the Table 1 together with the thickness of deposited layers measured by different methods.

Fig. 5.

Experiment	Material of sample	Distance below the tile surface (mm)	Number of shots	Glow discharge (hrs)	Deposit thickness (mm)
1	Mo	15	323	33.44	4.7
2	Mo/W	10	19	1.47	1.0
3	Mo/W	50	214	21.54	0.85
4	Mo/Si	50	223	24.5	1.3/16
5	Mo/Si	50	820	90.5	4/24

Table 1. Experimental conditions and data for samples exposed in TCV.

It is seen from the Table that there is only weak correlation of the film thickness with the depth of samples location, with the number of shots or total time of conditioning. The reason of this is that sample exposures are integrated across short experimental campaigns, being therefore exposed to a variety of plasma configurations. We would note, as it is seen from two lower rows, that the rate of film deposition on Mo and Si samples does very strongly differ each other. This result is in agreement with that observed in the mirror experiment in Tore Supra.

2.4. TRIAM-1M

Table 2. Reflectance of mirror samples and characteristics of contaminating films.

Sample	Time of cleaning, min	Ion energy, keV	R after exposure, %	R after cleaning, %	Thickness of film, nm	Refraction index of film	Extinction index of film
Mo	60	0.06	38	55.7	27	2.15	0.14
SS-1	35	0.1-0.2	45	62	12	2.77	1.69
SS-2	20	0.06	56.6	61.6	2-3	2.6	2.0
SS-3	20	0.1-0.2	53	60.4	4.5	2.84	3.06
SS-4	35	0.1	46.1	59	16	2.34	1.85

The film thicknesses, as well as their optical indices, were very different, as is shown in Table 2. For cleaning samples the procedure described above was applied, and all films were found to be quite differently resistant to erosion by H^+ plasma ions: to clean film from Mo the ion energy was 60 eV, but ion energy has to be increased up to 100 or 200 eV for samples SS1, SS3 and SS4. From optical indices one may conclude that the films on SS were composed from big portion of metal, probably, - Mo as it was the material of poloidal limiters [8].

All films deposited in TRIAM-1M were found very smooth and homogeneous, without introduction of any measured distortion when transmitting an image of a bright object (the W ribbon filament of incandescent lamp). At the same time, the SS mirrors exposed in TS gave a significant contribution into diffusive component of reflected light accompanied by a distortion of the image of filament.

3. Conclusion

Several important conclusions can be drawn from the presented data.

1. Both main reasons of degradation of properties of mirrors exposed in fusion devices, i.e., development of surface roughness due to sputtering (mainly by ions of glow discharges used for the wall conditioning) and the deposition of contaminants, manifested themselves with evidence.

2. Location of mirrors inside the fusion device is an important factor defining the time behavior of their optical properties.

3. The rate of carbon deposit growth depends on the mirror material, which therefore can be rated as the second important factor influencing the rate of mirror degradation.

References

[1] V. S. Voitsenya, A. E. Costley, V. Bandurko et al. – Rev. Sci. Instrum. 72 (2001) 475.
[2] V. S. Voitsenya, A. Sagara, A.I.Belyaeva et al. – Plasma Devices Operations. 13 (2005) 291.
[3] M. Lipa, B. Schunke, Ch. Gil et al. – Fusion Engin. Design. 81 (2006) 221.
[4] G. De Temmerman, M.J. Rubel, J.P. Coad et al. Paper P1-076, ECA Vol. 29C (2005).
[5] T. Hino, A. Sagara,Y. Nobuta et al. – Nucl. Fusion. 44 (2004) 496.
[6] A.F. Bardamid, V.T. Gritsyna, V.G. Konovalov et al. Surface Coat. Technol. 103-104 (1998) 365.
[7] W. Jacob. – Thin Solid Films. 326 (1998) 1-42.
[8] T.Hirai, K.Tokunaga, T.Fujiwara et al. – J. Nucl. Mater. 258-263 (1998) 1060.