

The deposition of contaminants on the in-vessel mirrors in T-10 tokamak

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1. Introduction

The deposition of contaminants is a considerable problem in fusion reactor environments. In particular, difficulties can emerge with the proper operation of optical diagnostics in ITER [1] because of degradation of the in-vessel mirrors. In order to solve this problem it is necessary to study deposition processes in modern fusion devices and to find the ways to protect mirrors from contamination or to clean them. Such researches are provided now on several tokamaks: JET, TEXTOR, Tore-Supra, NSTX and T-10. The goals of the experiments on T-10 described in this report are to investigate the degradation of the in-vessel mirrors, to estimate the deposition rate, to study the composition and morphology of deposits and laser ablation of the deposited films.

2. Experiments on T-10 during 2002 and 2003 campaigns

Polished mirror samples of SS316 ($10 \times 10 \text{ mm}^2$ and $20 \times 20 \text{ mm}^2$, 4 mm thick) were used for experiments. They were exposed in diagnostic port of limiter section of T-10 at different distances from plasma as shown in Fig.1.

Thin SS shield covered a part of each sample with $\sim 0.1 \text{ mm}$ gap between shield and mirror surface. Samples fixed in 1-3 positions were shutter-protected during vacuum vessel (VV) conditioning. The mirrors in positions 1-6 were located frontally to plasma equally in 2002 and 2003 campaigns. Besides, in 2003 mirrors 8-9 were placed edgewise to plasma and one mirror in position 7 was located frontally in shadow of sample 5.

The typical parameters of T-10 discharge are

following: working gas – deuterium; plasma current – 200-400 kA, shot duration 1 s; toroidal field – 2.8 T; central electron temperature $T_e(0) \approx 1 \text{ keV}$ for the Ohmic phase and up to 2.5 keV at ECRH; line averaged electron density $1-6 \times 10^{19} \text{ m}^{-3}$; central ion temperature 450-700 eV. Conventional configuration with ring and movable limiters from graphite

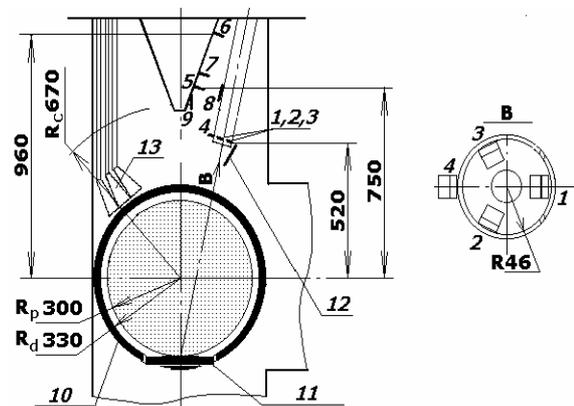


Fig.1. The layout of experiments. 1-9 – exposed mirrors, 10 - ring carbon based limiter, 11 - movable graphite limiter, 12 - shutter, 13 – ECRH antenna. R_c – radius of toroidal magnetic coils; R_p – plasma radius; R_d – radius of ring limiter.

MPG-8 was used in 2002. In 2003 the ring limiter was taken away and only movable limiter from graphite RGT-91 was used. Central plasma parameters were remained practically at the same level but the intensity of plasma wall interaction greatly increased. Every experimental campaign started from VV cleaning by heating up to 200°C, inductive H₂ or D₂ discharges and He or Ar glow discharges. During experiments these procedures of VV conditioning were used every night. The total duration of VV conditioning modes and plasma discharges are given in Table I.

Table I. Data on VV conditioning modes and plasma discharges

The reflectance of mirrors before and after exposition and deposited film thickness were measured by means of Lambda 35

	Heating up to 200°C (hours)	Inductive discharges (hours)	Glow discharges (hours)	Plasma discharges (s)
2002	897	35 (H ₂) 270 (D ₂)	86 (He)	1620 (D ₂)
2003	367	24 (H ₂) 79.5 (D ₂)	19 (He) 2 (Ar)	212 (D ₂)

spectrophotometer and with TENCOR Instruments profilometer, correspondingly. The surface morphology and microstructure of deposits were investigated with JEOL scanning electron microscope (SEM) and by X-ray diffraction. The Rutherford Back Scattering (RBS) in combination with the resonance elastic scattering were used for analysis of deposits composition. RBS analysis was carried out with 2 MeV protons backscattered from the sample at the angle of 170°. Hydrogen isotopes depth's profiles were measured with Elastic Recoil Detection Analyses (ERDA) by the He⁺-ion beam with the energy of 1.9 MeV.

3. Results and short discussion

The deposited films arose on all samples after exposure in T-10 during both 2002 and 2003 runs. It means predominance of deposition over erosion in the experimental conditions. Results of 2002 campaign are presented in [2]. The surface of mirrors looked shining and smooth and the color of deposits varied from golden-crimson to violet-green. The screened parts of mirrors did not changed by sight. The deposits not only decrease the reflectance of mirrors but also distort the spectrum of reflected radiation because of interference, as shown in Fig.2. Reflectance of mirrors placed edgewise to plasma (8 and 9) was changed only slightly and it was not changed for mirror in position 7. The deposits have a quite homogenous, fine-dispersed structure with inclusions of single spherical particles up to 1-3 μm in size and flakes having dimensions up to 25 μm. Their origination can be explained by brittle destruction of the limiter under plasma disruptions.

According to RBS data the deposits basically consist of carbon, hydrogen isotopes and of about 5-8% oxygen impurity (see Fig.3). Deuterium prevails on the opened parts and its concentration is practically constant inside the film as shown in Fig.4. Hydrogen was found only in the surface layer down to depth <80 nm. The thickness of deposits on screened parts of mirrors did not exceed 40-50 nm.

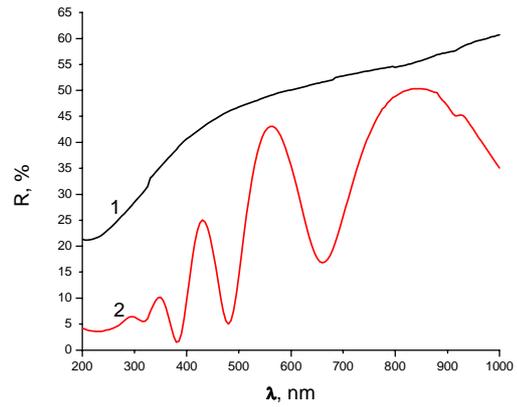


Fig.2. Reflectance of SS mirror: 1) initial, 2) with CD film on sample 2 (2003)

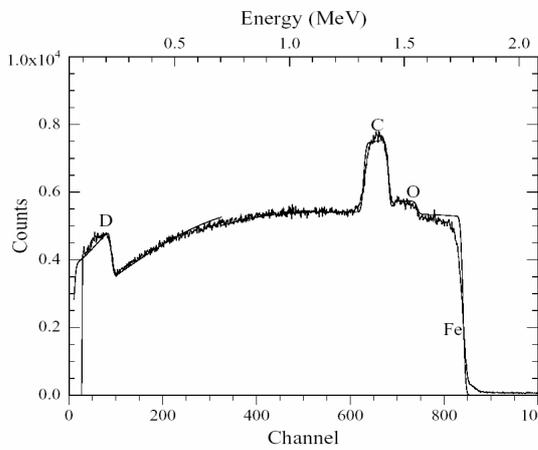


Fig.3. RBS data for deposit on opened parts of mirror 4 (2003)

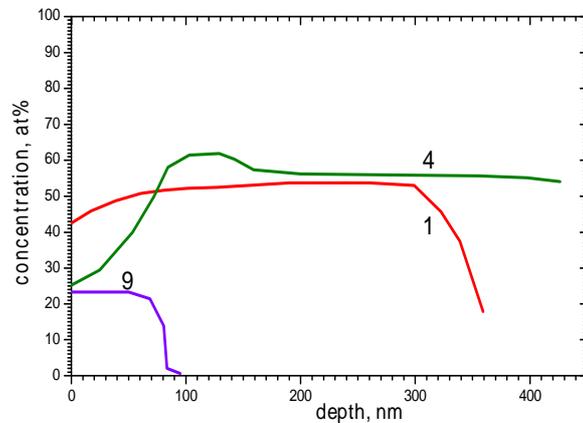


Fig.4. ERDA deuterium profiles on opened parts of mirrors 1, 4 and 9 (2003)

Note that hydrogen, deuterium and carbon were uniformly distributed in the thin film (≈ 80 nm) on the mirror 9. The film thickness, the integral concentrations of deuterium and the D/C ratio in deposits on the opened parts of mirrors are presented in Table II.

Table II. Parameters of deposited films (* samples protected by shutter at VV conditioning)

Sample position	Distance from plasma, cm	Thickness of films on opened part, μm		D integral concentrations (10^{21} m^{-2})		D/C	
		2002	2003	2002	2003	2002	2003
1*	22	0.2	0.3	-	18	-	1.6
2*	22	0.3	0.7	6.5	28	0.2	1.9
3*	22	0.4	0.9	-	-	-	-
4	22	12	2	-	20	-	1.3
5	45	3.9	0.6	-	32	-	2.2
6	66	1.0	0.3	7.5	16	0.35	2
7	47	-	<0.05	-	-	-	-
8	45	-	0.1	-	-	-	-
9	40	-	0.1	-	1.5	-	0.4

The D/C ratio was equal 0.2-0.35 in 2002 but it increased 10 times in 2003 probably due to intensification of the plasma-wall interaction. For the mirrors “protected” during VV conditioning the deposition rate was estimated from known duration of plasma discharges and the film thickness. The deposition rate was about 0.2 nm/s in 2002 and 4 nm/s in 2003. It is important that only thin films were found out on the mirrors placed edgewise to plasma (8 and 9) and the film was practically absent on the surface of mirror 7. It gives hope that in ITER conditions the secondary mirrors will not be covered with contaminating film.

The X-ray analysis showed two lines of CH-crystalline but no free carbon inside the deposits [2]. The 12 μm film (sample 4, 2002) was transformed in friable, black carbon based film as a result of the heating in vacuum step by step from 200°C up to 700°C at fixed temperature within 10-20 minutes. Gas desorption started at 450°C and finished at about 600°C. During vacuum annealing the molecules with different combinations of deuterium and hydrogen with carbon and oxygen were detected. So it may be supposed that the deposits basically contain different C_nD_m compounds.

Recently the ablation of the deposits was investigated under impact of pulsed excimer laser ($\lambda=308$ nm, $F=10$ Hz, $\tau=20$ ns) in high vacuum at 10^{-7} Torr. The laser beam was focused on a surface of mirror in a rectangular spot of 6×2 mm^2 at the energy density 0.05-0.15 J/cm^2 . The total removal of deposits was observed after approximately 20-40 laser pulses at the energy density higher than 0.12 J/cm^2 . When the energy density was a little less (about 0.1 J/cm^2) the deposits were not removed and only the surface flaking was observed. The SEM analysis of laser track showed that deposits have a layered structure.

4. Conclusion

Deposition prevails over erosion for the mirrors located in upper limiter port of T-10. Deposited films not only reduce the intensity of the reflected light, but also strongly change its spectrum. Deposition rate and film composition depend on distance and orientation of mirrors to plasma. Results of 2003 campaign show that deposition rate and D/C ratio can be very high in particular modes of tokamak operation. Considering a possible high deposition rate, two techniques, namely, laser ablation or cleaning by gas discharge, can be treated as realistic ways of keeping the ITER diagnostic mirrors in a suitable state.

References

1. V.Voitsenya et. al. Rev. Sci. Instruments. 72 (2001) 475-482.
2. K.Yu. Vukolov et. al. Exposure of stainless still mirrors in T-10 tokamak. To be published in J. Plasma Devices and Operations. v.4. 2004.