Redeposition of the carbon in the SOL of the T-10 tokamak and its influence on reflectivity of the in-vessel mirrors.

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Erosion and redeposition of plasma-facing materials in modern tokamaks result in the formation of the carbon films and dust [1-3]. These processes can lead to the degradation of the in-vessel optical elements of plasma diagnostics. In particular, for ITER the degradation of first mirrors is one of the most critical problem. Experiments at ITER-relevant conditions are necessary for measurements of erosion and deposition rates, investigation of composition and morphology of deposits, and identification of redeposition mechanisms[4-7]. This information is very important for the development of methods for the protection and cleaning of in-vessel optics. Additionally for a fusion reactor, the accumulation of deuterium and tritium in hydrocarbon films and dust is a problem in terms of both radiation safety and fuel inventory.

The redeposition of the carbon, sputtered from the graphite limiters was investigated on the T-10 tokamak, by exposure of the stainless steel (SS) and molybdenum (Mo) mirrors and silicon (Si) samples in the SOL at the different distance from the graphite limiters. Energy and particle fluxes in the SOL of the T-10 are close to the values predicted for the ITER SOL. Two diagnostic arrays were installed on the T-10 tokamak for introducing of the samples into the vacuum vessel, there exposition in the SOL and there extracting for the analysis. The samples were exposed during the day (working discharges) or night (conditioning discharge) and than removed from the T-10 vessel. These cycles were repeated for achieving proper exposure time. The radial exposure position in our experiments were in the vicinity of the vessel wall position (0.1 m from the plasma border).

The diagnostic arrays were placed on T-10 in two different toroidal positions: position “A” close (0.1 m) to the T-10 graphite limiters; and position “B” – far (2.5 m) from them. The ring and rail graphite limiters are the sources of the redepositing carbon in the T-10. The view of the diagnostic array and the scheme of arrays positioning at the T-10 is presented on Fig.1

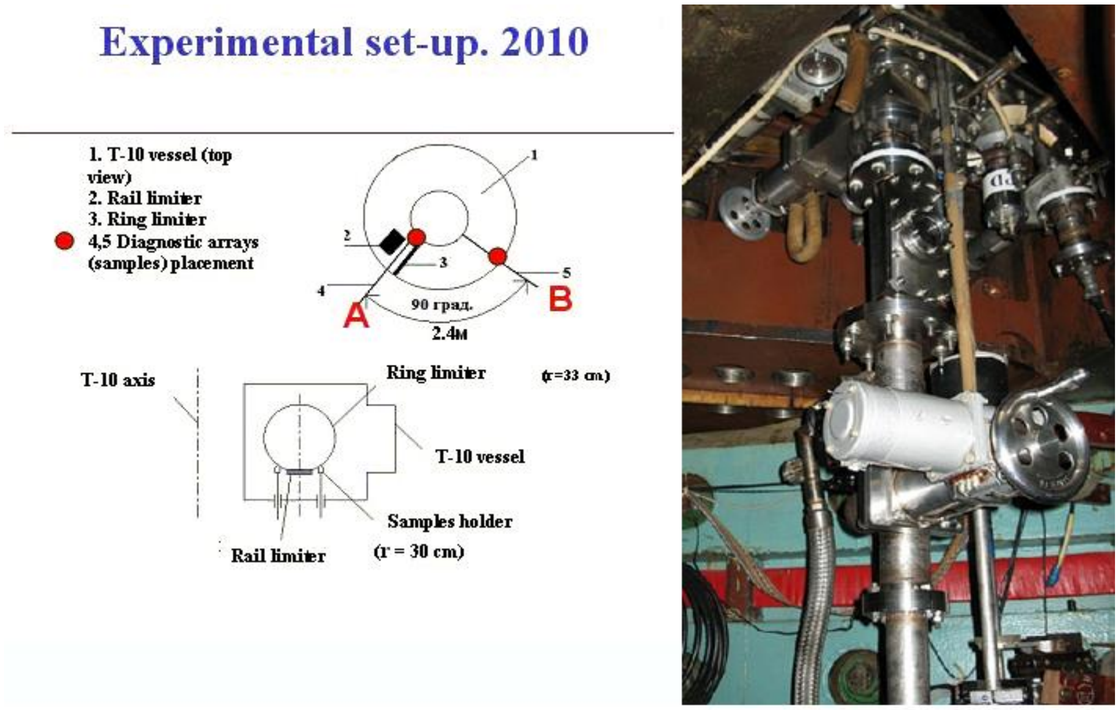

Fig.1 The view of the diagnostic array “B” and scheme of the arrays positioning at the T-10.

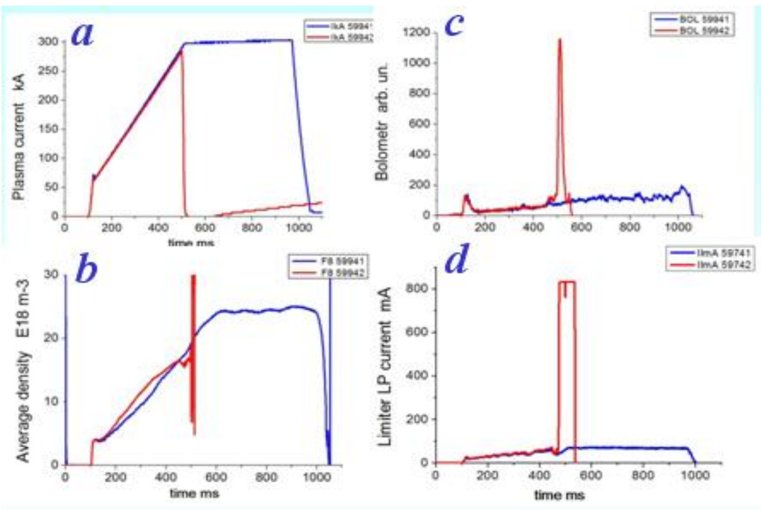

Fig.2 Characteristics of the stable T-10 shot (№59741 blue) and disruptive shot (№59742 red).Bт = 2.4 ; ***a.*** plasma current, ***b.*** average electron density, ***c.*** radiation looses, ***d.*** current of the limiter Langmuir probe (ion flux to limiter).

Redeposition was investigated in working as well as in conditioning discharges of T-10. The temperature of the vessel wall as well as the samples was 20 C during the working discharges and 200 C during the conditioning. Characteristics of the tipical stable and disruptive T-10 shots presented on Fig.2

Composition of the films was determined by EPMA. Surface structure and morphology were investigated by Electron and Atomic Force Microscopes (AFM) and by profilometer. Thickness and optical parameters of the films (reflectance and absorption coefficients) were estimated by ellipsometry with λ = 632 nm. Reflective coefficient of mirrors before and after exposition was measured by spectrophotometer in the wave range 190 – 1100 nm. The samples and the mirrors exposed in the SOL of T-10 are presented on the Fig.3

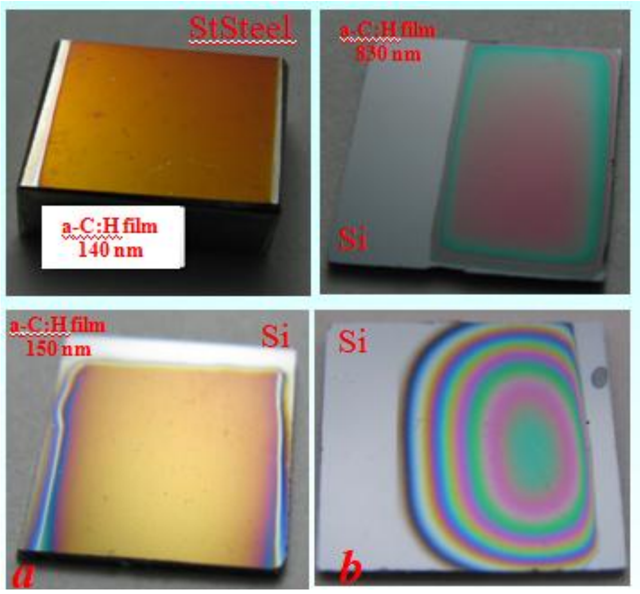

Fig.3 Si samples and SS mirror exposed in the SOL of T-10. Radial position – 40 cm (wall); ***a.*** working discharge -300 shots, position “A” close (0.1 m) to the graphite limiters, samples temperature -20 C; ***b.*** conditioning – 32 hours of inductive discharge in deuterium, position “B” – far (2.5 m) from the graphite limiters, samples temperature -200 C

Hard, diamond like amorphous hydrocarbon a-C:H films are deposited during the working shots in T-10. Deposition rate was about 0.08 nm/s at the position “B” far from the graphite limiters. But it was increased several times up to 0.5 nm/s in a close vicinity to the limiter (position”A”). It seems that the toroidal transport of the sputtered carbon is not very pronounced in the SOL of T-10. Deposition rate for disruptive discharges is 1.5-2 times higher than for the stable ones.

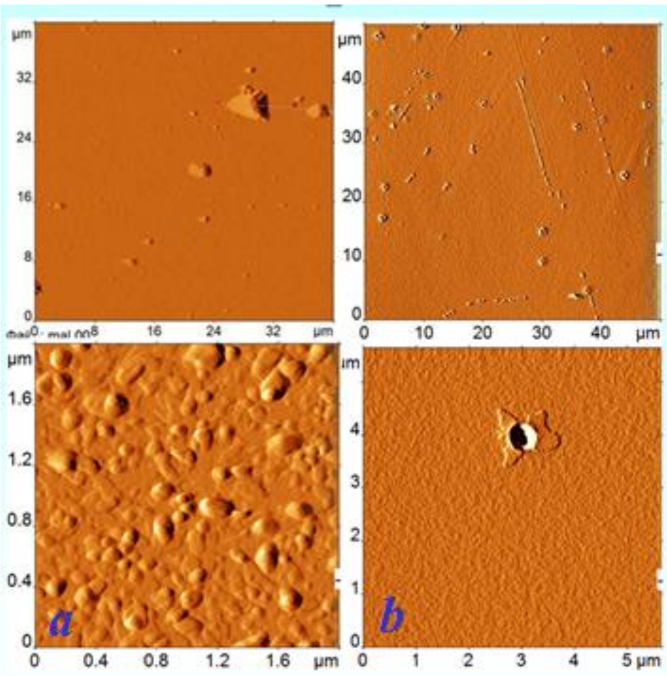

Fig.4 AFM view of the films surface for different regimes of T-10. ***a.*** working discharge -300 shots, position “A” close (0.1 m) to the graphite limiters, samples temperature -20 C; ***b.*** conditioning – 32 hours of inductive discharge in deuterium, position “B” far (2.5 m) from the graphite limiters, samples temperature-200 C

Deuterium content is 30 – 40 at. % . Metallic (Fe, Cr, Ni) impurities are presented as a local particles in the disruptive discharges only. Films surface is complicated and include micro (1.0-5.0 μm) particles as well as globular structures (100- 200 nm). Fig.4 presents the AFM pictures of the films surface for different regimes of T-10.

For the conditioning inductive discharge deposition rate was more than order lower than for the working one. But due to the long duration of the conditioning procedure on T-10 (hundreds hours per experimental campaign) it contributes strongly to the total redeposition of the sputtered carbon and to contamination of the in-vessel mirrors. Films are soft, smooth, micro and nanostructures are not pronounced, hydrogen content is increased (50-55 at. %).

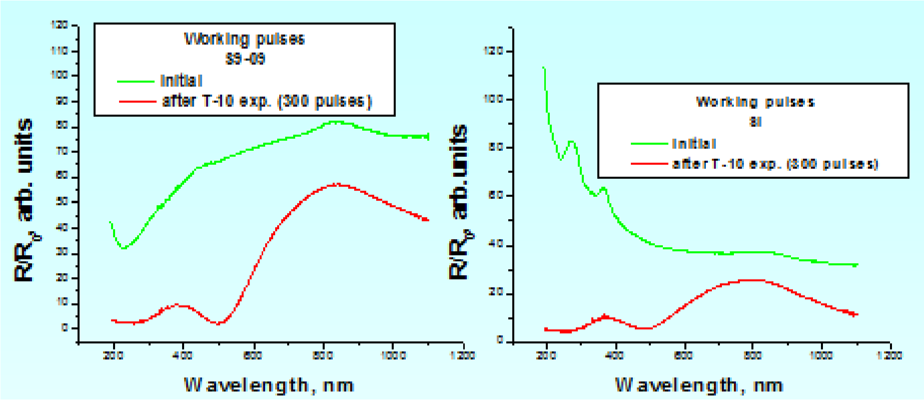

Fig.5 The spectra of relative specular reflectance for Si sample and SS mirror exposed in the SOL of T-10. Position «A», near (0.1 m) the limiter.

The reflectivity of the mirrors decreases strongly with the films deposition, especially in the wavelength range 190-400 nm. For metallic mirrors (SS, Mo) decreasing of the reflectivity was less pronounced than for Si. Increasing of the distance to the sputtered carbon tiles and collimating of the mirrors can reduce strongly the degradation of the mirrors. The spectra of relative specular reflectance for the exposed mirrors presented on Fig.5.

Characteristics of the a-C:H exposed in the SOL of T-10 are summarized in the Table 1.

Table 1. Calibration graphics from [7]

Data	Regime		a-C:H film properties *				
			d, nm	n_f	k_f	D/D+C, at%	ρ, g/cm^3
2010	Working pulses	300	130	2.45	0.20	30	2.4
2009		252	20	1.8	0.04	42	1.5
2002		1620	160	2.1	0.10	35	1.8
2010	Conditioning, hs	32	840	1.54	0.00	47	1.0

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