Mitigation of hydrocarbon film deposition on in-vessel mirrors

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1. Introduction

Erosion of plasma-facing components in fusion devices with a carbon based in-vessel elements leads to the creation of redeposited C:H films. The deterioration of diagnostic mirrors is one of consequences of this process. Deposits on the mirrors not only reduce the intensity of reflected radiation, but also change its spectrum [1, 2]. So, a mitigation of the deposition is necessary for the normal operation of ITER optical diagnostics, where a high number of in-vessel mirrors will be used.

In order to develop techniques for the mitigation a study of deposition processes have been carrying out on JET, TEXTOR, Tore-Supra and T-10 [1, 2, 3]. In particular, stainless still mirrors were undergone of a long-term exposure within a diagnostic port of T-10 [2, 4]. In the report the experimental results are analysed with relation to decreasing of the deposition. The temperature dependence of C:H film growth is considered on the base of data from [5] and results of magnetron deposition experiments. The last study was done by sputtering of carbon cathode of dc magnetron device in argon-methane discharge.

2. Experiments on T-10

Polished samples made of SS316 were exposed in the upper diagnostic port located above of carbon faced limiters of T-10 at distances 22 – 66 cm from the plasma surface. Some samples were covered during vacuum vessel conditioning by a shutter, part of the samples was installed slantwise to the plasma surface, and one mirror was even screened from it. Thin SS foils covered a part of each sample. The gap between shield and mirror surface was ~0.1 mm. The temperature of the samples was not monitored, but probably not exceeded 100°C during plasma discharges.

The typical parameters of T-10 discharge are: working gas – deuterium; plasma current – 200-400 kA, shot duration - 1 s; toroidal field – 2.0-2.8 T; $T_e(0)\approx 1$ keV; $n_e(0)=1\text{-}6\times10^{19}$ m^{-3}; $T_i(0)=450\text{-}700$ eV. Conventional configuration with ring and movable limiters faced by graphite MPG-8 tiles was used in the first experimental series, and before the next campaign the ring limiter was taken away and only movable limiter faced by RGT-91 graphite was used. Central plasma parameters changed slightly, but the concentration of carbon at the plasma periphery was increased because of high erosion of the carbon surface of the limiter. The detailed description of the experiments is given in [2, 4].

C:D films, discovered on the mirrors in result of exposure, were thoroughly studied. The screened parts of mirrors did not changed by sight. Reflectance of mirrors inclined in relation to the plasma surface changed slightly, and for screened mirrors it was not changed at all. It is a consequence of the fact that only a very thin (>0.1 μm), transparence films formed on these mirrors and also on screened parts of mirrors. The thickness of films on opened part of other mirrors was changed from 0.2 to 12 μm depending on distances and degree of screening from the plasma, plasma periphery properties and so on. The deposits not only decrease the reflectance of the mirrors, but also make the reflected spectrum strongly non monotonic because of interference, as shown in Fig.1.

The Rutherford Back Scattering (RBS) and Elastic Recoil Detection Analyses (ERDA) were used for analysis of deposits' composition. According to RBS data the deposits basically consist of carbon, hydrogen isotopes, and of 5-8% of oxygen. The D/C ratio was equal 0.2-0.35 in first experiment when hard films were obtained in usual experiment conditions. But at the next experimental campaign (without aperture limiter) D/C ratio was increased up to 1.3-2 (soft films). No wonder that optical properties of the films in these two cases differs: at the same film thickness mirrors have a different reflectance. The other important result is that the growth rate also increased about 20 times in last experiment.

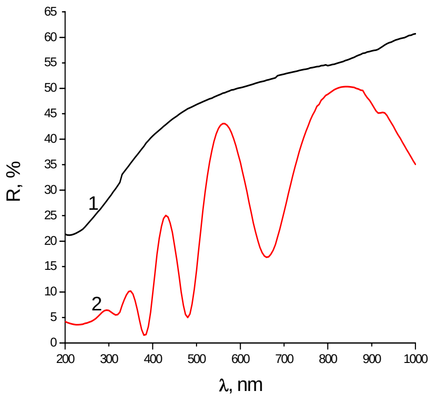
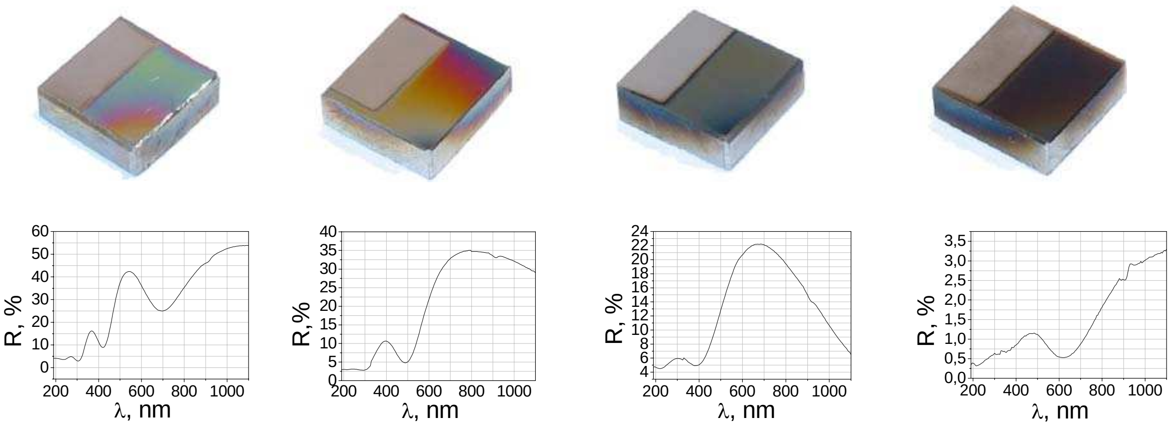


Fig.1. Reflectance of SS mirror:
1) initial, 2) with C:D film (0.7 μm) on sample 2 (2003) [4]

3. Experiments on magnetron deposition

Preliminary study of C:H films growth rate depending on temperature of SS mirrors was done recently by means magnetron sputtering. SS mirror (10×10 mm^2, 3 mm of thickness) were installed on a heater and after that the vacuum chamber was pumped out to 2×10^{-7} Torr. Then dc magnetron discharge (90 mA, 500 V) was ignited at a pressure about 10^{-2} Torr. Working gas was a mixture of Ar (70%) and methane (CHD_3, 30%). Duration of deposition was 120 minutes. The distance between sample and cathode was 50 mm. The diameter of the cathode was 20 mm. Thin SS foil covered a part of sample during deposition. The temperature was measured by thermocouple. Four samples were deposited one by one at the same discharge parameters at four temperatures (75, 150, 250 and 350 °C). The walls of the vacuum vessel were slightly heated during deposition (up to about 50 °C). Photos of mirrors and their spectra after magnetron deposition at different temperatures are presented in Fig. 2.



A – 75 °C B – 150 °C C – 250 °C D - 350 °C

Fig.2. Photos of mirrors and their spectra after magnetron deposition at different temperatures

One can see that at high temperatures the reflectance decreases and obtained films are practically opaque in visible range at 250 and at 350 °C. The film thickness and, therefore, growth rate of C:H film have nonlinear dependences on the temperature (see Fig.3).

4. Discussion and conclusions

The first result that should be noted is an invariability of reflectance of mirrors screened from plasma during exposure in T-10. Apparently, for these mirrors at the absence of surface bombardment only a physical sorption of several monolayers takes place and then the film growth is stopped. Therefore, the most obvious way to mitigate the growth of the films is to reduce the specific flux of energetic neutrals from plasma onto the first mirror surface. It can be achieved, for instance, by increasing of the distance between a first mirror and entrance pupil, or by inclination of the mirror with respect to optical axis. In both cases, to avoid the optical efficiency degradation, the dimensions of the mirror must be enlarged.

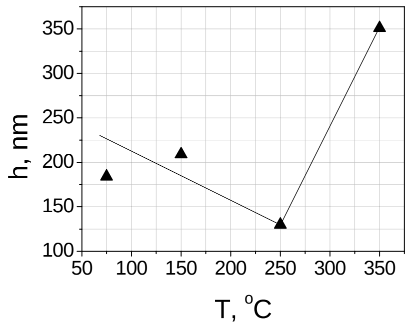


Fig.3. The film thickness depending on the temperature of mirror

In accordance with data [5] C:H film properties are determined by ions bombardment in many respects. For instance, hard, dense C:H films (H/C=0.5) arose in ECR methane discharge at 100 V potential on the sample. Bombardment of samples by ions with the energy about of 10 eV (at floating potential) leads to growth of soft, polymer like films (H/C~1). The refractive index correlates with a film density and the optical property of hard and soft films differs strongly. So, the second important result is that various types of C:H film can be formed at tokamak conditions. Particularly, in T-10 a change of the film type could be connected with decreasing of plasma periphery temperature. To predict a change of mirror reflectance during tokamak operation by calculations it is necessary to determine not only growth rate but also the type of film and, so, to take into account a lot of plasma parameters: CXA fluxes, their energetic spectra and composition, gas pressure, temperature of mirror and so on (see [5]). This task seems a very difficult because plasma parameters will be changed during tokamak operation. In particular, growth rate strongly depends on carbon flux density and, possibly, namely this fact led to significant (about 20 times) increase of the rate during last experiments on T-10.

Considerable influence on C:H film growth rate has the temperature of mirror. As was shown in [5] growth rate is basically determined by two processes: deposition and chemical erosion. The deposition rate only slightly changes from room temperature up to 350 °C. The chemical erosion increases at 250-300 °C, but then sharply falls [5]. So, C:H film growth rate has a minimum at these temperatures that was confirmed in our experiment (see Fig.3). This is a positive result from the point of view of the first mirror problem in ITER because the operation temperature of ITER mirrors will be about 150-200 °C that is close to the minimum of C:H film growth rate. But, on the other hand, the magnetron experiments show that with increase of temperature the reflectance decreases and films, obtained at 250 and 350 °C, are practically opaque. We hope that future experiments on tokamaks help to specify better the optimal working temperature of mirrors in the ITER relevant conditions. In particular, the experiments on T-10 to study the temperature dependence of C:H film growth are scheduled to start in September 2005. Mirrors, heated to different temperatures, will be exposured inside limiter diagnostic port. During exposure emission of H and C spectral lines from limiter region will be monitored by endoscope optical system. Besides, several mirrors will be placed in other cross section of T-10 far off limiters.

References

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