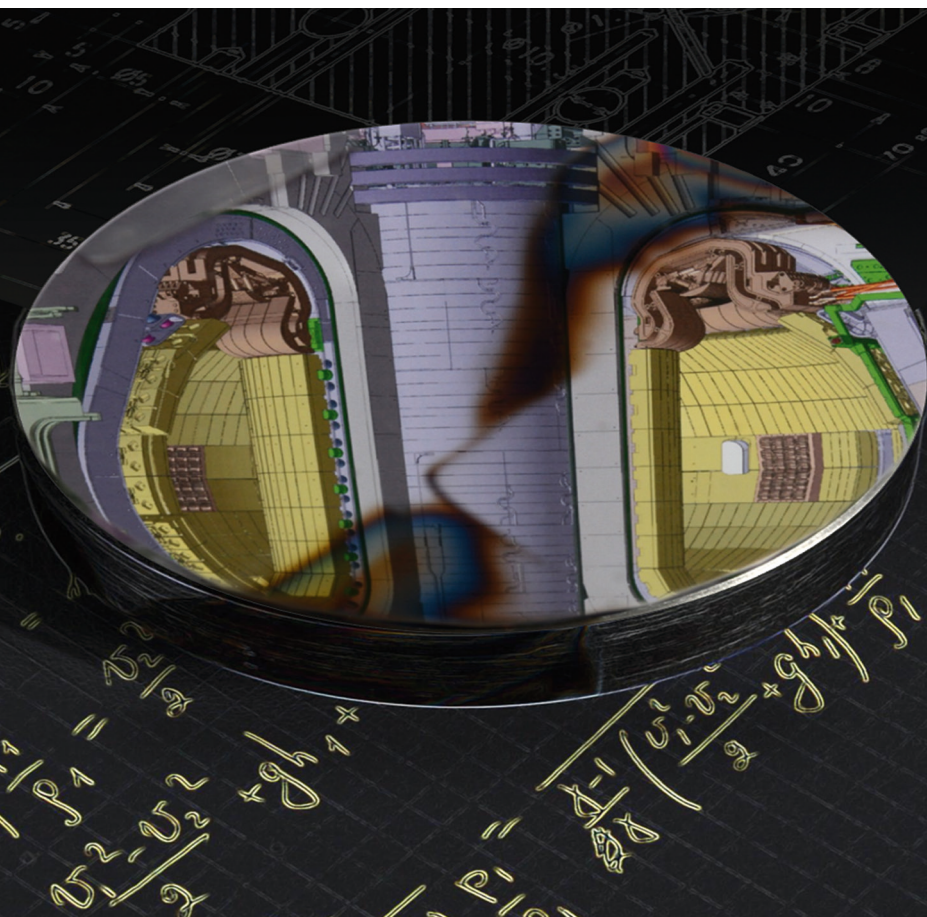


Influence of the surface composition and morphology on the reflectivity of diagnostic mirrors in a fusion reactor

Maria Matveeva



Energie & Umwelt /
Energy & Environment
Band/ Volume 261
ISBN 978-3-95806-051-7

Forschungszentrum Jülich GmbH
Institute of Energy and Climate Research
Plasma Physics IEK-4

Influence of the surface composition and morphology on the reflectivity of diagnostic mirrors in a fusion reactor

Maria Matveeva

Schriften des Forschungszentrums Jülich
Reihe Energie & Umwelt / Energy & Environment

Band / Volume 261

ISSN 1866-1793

ISBN 978-3-95806-051-7

Table of contents

Kurzfassung	5
Abstract	7
Introduction.....	9
Chapter 1. Diagnostic mirrors for a fusion reactor.....	13
1.1 Plasma-wall interactions in tokamaks.....	13
1.2 Diagnostic mirrors in ITER.....	14
Chapter 2. Optical properties of metallic mirrors	17
2.1 Light reflection in geometrical optics	17
2.2 Interaction of electromagnetic waves with medium	17
2.3 Reflectivity of polarized light	19
2.4 Specular and diffuse reflectivity	20
Chapter 3. Processes affecting the mirror properties	23
3.1 Surface erosion by particle bombardment.....	23
3.2 Surface contamination via deposition and impurity implantation	26
3.2.1 Implantation of impurities	26
3.2.2 Formation of deposited layers	27
3.3 Surface modification due to chemical processes	28
Chapter 4. Surface characterization techniques	33
4.1 Optical microscopy	33
4.2 X-Ray photoelectron spectroscopy	33
4.3 Secondary ion mass-spectrometry.....	35
4.4 Surface profiling.....	36
4.5 Scanning electron microscopy	36
4.6 Electron backscatter diffraction	37
4.7 Spectrophotometry	37
4.8 Spectroscopic ellipsometry	38
4.9 Electron Probe Micro Analysis	39
Chapter 5. Exposures of diagnostic mirrors in tokamaks	41
5.1 Exposures under erosion conditions.....	41
5.1.1 Mirror characterization	41
5.1.2 Exposures in TEXTOR.....	43
5.1.3 Results.....	46
5.2 Exposures under deposition-dominated conditions: gas feeding.....	58

5.2.1	Scheme of experiments and mirror characterization	58
5.2.2	Exposures in TEXTOR.....	60
5.2.3	Results.....	62
5.3	Exposure in oxygen-rich atmosphere.....	68
5.3.1	The thermo-oxidation process	68
5.3.2	Exposure of mirrors in DIII-D	68
5.3.3	Results.....	69
Chapter 6. Plasma induced surface modification and its influence on the reflectivity of diagnostic mirrors: results and analyses		75
6.1	Evaluation of plasma parameters and particle fluxes.....	75
6.1.1	Parameters of background plasma	75
6.1.2	Effect of gas feeding on plasma parameters	77
6.2	Erosion of the surface.....	83
6.2.1	Distortion layer	83
6.2.2	Amount of material removed during exposures under erosion conditions.....	83
6.2.3	Surface roughening: erosion of single crystal and polycrystalline materials ...	91
6.3	Deposition, implantation and diffusion.....	94
6.3.1	Carbon deposition and the effect of gas feeding on the deposit growth.....	94
6.3.2	Implantation and diffusion of carbon and oxygen	95
6.3.3	Implantation of hydrogen and deuterium	111
6.4	Chemical processes	116
6.4.1	Surface oxidation	116
6.4.2	Carbidization of molybdenum mirrors	122
Chapter 7. General discussion		133
7.1	Effects of erosion.....	133
7.1.1	Surface roughening.....	133
7.1.2	Removal of surface adsorbates and oxides	133
7.2	Influence of deposition.....	134
7.3	Effects of particle implantation	135
7.4	Influence of diffusion processes.....	135
7.5	Effects of the surface chemistry	136
7.6	Summary	137
Chapter 8. Extrapolation to ITER.....		139
8.1	Outlook.....	143
8.2	Conclusions	144
Acknowledgements.....		145
Bibliography		147

assumption implies that the samples that are installed on the limiter as shown in Figure 5.5 face the same plasma, i.e. particles with the same energy and flux arriving at the surface along the line corresponding to a given radial coordinate. This also means that the balance of erosion and deposition on the sample holder should be the same for those locations leading to a transition from erosion to deposition zone in form of a horizontal line (poloidally) on the limiter surface. However, observing the inclined deposition pattern on the mirror holder, the poloidal inhomogeneity is visible (Figure 5.5a), and it may be concluded that the upper part of the Mo-coated mirror must have been exposed under conditions similar to those at the center of the Rh-coated mirror, which can be attributed to a variation of plasma parameters within a radial distance of 1 - 2 mm. The variation of plasma parameters can be, in turn, attributed to the finite poloidal radius of the plasma in TEXTOR.

Table 6.1. Average plasma parameters, decay lengths and accumulated particle fluences in mirror experiments.

	Low-fluence	High-fluence	Large SC Mo	Periscope
n_e (m ⁻³)	2.6×10^{18}	3.6×10^{18}	$1.4 / 2.4 \times 10^{18}$	1.5×10^{18}
T_e (eV)	36	31	14 / 20	25
λ_n (mm)	24.1	26.6	26.6	39
λ_T (mm)	28.4	30.2	30.2	26.6
λ_r (mm)	17.0	18.5	18.5	22.5
λ_Q (mm)	10.6	11.5	11.5	12.2
No. of discharges	24	36	37	He: 22, D: 43
Fluence, Φ (m ⁻²)	4.3×10^{24}	10.1×10^{24}	$2.8 / 5.9 \times 10^{24}$	He: 5.2×10^{24} , D: 9.1×10^{24}

6.1.2 Effect of gas feeding on plasma parameters

The experiments with different gases blown in the Periscope system, described in section 5.2, allow marking out the physical processes playing the major role in the mirror protection from deposition. The two gases used for this purpose are helium and deuterium, which have different physical and chemical properties. Helium is a non-reactive gas with the ionization energy of 24.6 eV such that the energy transfer with plasma ions (D⁺) happens mostly in elastic collisions. Deuterium is a molecular gas with the dissociation energy of D₂ molecules of 4.56 eV. Ionization of D₂ molecules happens at 15.1 eV, and D atoms are ionized at 13.6 eV. In this case the energy transfer with D⁺ plasma ions has a resonant character and is dominated by the charge-exchange process. Considering physical sputtering of deposited layers, the threshold energy for sputtering of carbon by impinging He ions is 19.12 eV. In the case of the D₂ gas injection, the rather low dissociation energy of D₂ molecules favours their prompt dissociation. To induce physical sputtering, D atoms have to be ionized and gain energy above 27.7 eV. Due to a lower mass physical sputtering in the case of deuterium is weaker than that for helium. In particular, at an ion energy of 50 eV the sputtering yield of carbon by He is about 4.8×10^{-3} , while it is 1.9×10^{-3} for the case of D impact [Eckstein 2011]. However, in addition to physical sputtering deuterium atoms and ions induce chemical erosion of deposited a-C:D layers. Considering the experimental results (section 5.2.3), namely the fact that the layer pre-deposited on the 1st mirror was not reduced in the case of the He gas injection, allows the conclusion that physical sputtering does not play a substantial role in the mirror protection from deposition under conditions of these particular experiments in TEXTOR. On the contrary, the experiments with the D₂ gas injection

**Energie & Umwelt /
Energy & Environment
Band / Volume 261
ISBN 978-3-95806-051-7**

