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EFFECT OF THIN CONTAMINATING COATING ON REFLECTANCE OF METALLIC MIRROR PLACED INSIDE THE VACUUM CHAMBER OF A FUSION DEVICE

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The practice of use of diagnostic mirrors inside the fusion devices revealed the appearance of a deposit on the mirror surface. Such deposit is a result of condensation of the erosion materials of those inner components that are subjected to the strongest plasma impact. Another reason for deposit growth is the wall conditioning procedures like carbonization and boronization. Appeared on the diagnostic mirrors and windows the contaminating films deteriorate the optical properties of these diagnostic elements, i.e., the mirror reflectance and window transmissivity. The object of this paper is to investigate an influence on reflectance of metal mirrors of thin films of the materials that are most probable in fusion devices under operation (boron and carbon) or can be promising in a fusion reactor (beryllium).

1. Introduction

The widespread application of low-Z materials for the first wall protection in nowaday fusion devices is caused by an objective to reduce the metal atom influx from the vessel walls into the plasma and to improve the discharge performance. Since carbonization on tokamak TEXTOR had successful result **[1]**, this method became a usual procedure in many fusion devices. The idea to use boron based films **[2]** for coating the internal surfaces like inner walls and structures was tested for the first time on the same facility. Today the boronization procedure is used practically in all experiments at the more or less large-scale fusion devices together with the graphite protection for those first wall areas, which are subjected to the strongest plasma impact. Thus, the deposit appearing on all inner surfaces of vacuum chamber is the carbon-boron-based film. It was found that the definite portion of hydrogen **[3]** is accumulated inside the boron-carbon film deposited on the inner surfaces of a fusion device. On the remote inner components, like mirrors and windows, the film has to grow not only during boronization process, but during the working discharges also **[2, 4]**. The experimental data on transmissivity of a deposit grown on windows of TFTR and JT-60U tokamaks during the campaign when carbonization was regularly used are presented in papers **[5, 6]**. It was determined in **[6]** that deposited film has chemical composition of the *polyacrylonitrile* type. As follows from the literature, up to now there were no publications devoted to the topic of the deposit influence on reflectance of mirrors situated inside the chamber of a fusion device. The aim of this paper is to investigate the deposit role in the degradation of optical properties of the in-vessel mirrors. The main our interests are around a subject of boron-carbon films, which do frequently appear in the large-scale fusion devices. In addition, the effect of thin beryllium film deposited on the surface of metal mirror is analyzed because of the prospect for this material to be chosen as a protection of the first wall in a fusion reactor. The studied wavelength range is 200-1000 nm that is of practical interest for plasma diagnostics in fusion devices under operation.

2. Effect of thin film on specular reflectance (experiment and calculation)

The equations for the effective reflectance of the metal mirror coated with thin partly-transparent film of any given thickness, d, with known refraction $n(\lambda)$ and absorption $k(\lambda)$ optical indices of the substrate and the film are represented in **[7]**. In present work we have applied more practical relationships from **[8]**, which gives the effective reflectance of the metal mirror coated with thin partly transparent film at the normal incidence of light. The optical indices of films and substrates were obtained from the ellipsometric measurements and from the literature **[9]**.

The film optical properties depend on conditions of deposition. For example, the contaminating carbon-based film on the diagnostic window of JT-60U **[6]** has the indices n=1.8-2.0, k=0.15-0.17 measured at the wavelength of the He-Ne laser (632.8 nm). These data are different from the values n=2.63, k=0.35 **[10]** determined for arc-evaporated carbon film at the same wavelength.

In our experiments, the spectral dependences of optical indices for the substrates (stainless steel, SS, and molybdenum), for the carbon films deposited on these substrates due to the arc discharge between two graphite electrodes, and the film thickness, were all determined from the ellipsometric measurements. In the SS substrate case the carbon films were of d=11 and 21 nm thick. The measured n and k values for these films were not too different as compared with data presented in work **[10].** The differences for n and for k values were found to be maximal (~14%) near the lowest wavelength, while for the visible light n and k values differed on ~5%. It could be a consequence of similarity of film deposition methods (arc discharge between graphite electrodes) in paper **[10]** and in our research.

The comparison of measured spectral reflectance, R(λ), at normal light incidence and R(λ) calculated by means of the equation **[8]**, using n and k values measured and taken from **[10]**, is shown in **Fig.1.**

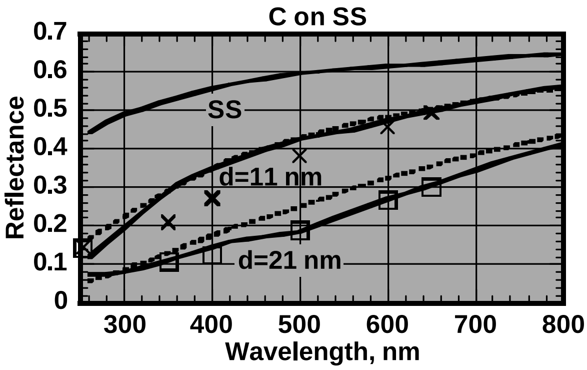

*Fig.1. C film on SS mirror. The spectral reflectance: the dotted lines (calculated from **[10]**) and the solid lines (calculated from ellipsometry). The points (X,) present measured reflectance. The thickness of film is marked near every group.*

One could observe that the agreement between calculated data and results of measurements is quite reasonable almost in the whole spectral range where experiments were carried out. The **Fig.1** demonstrates that the carbon film of the order of 10 nm in thickness caused the strong degradation of reflectance of the SS mirror. The result obtained with this coating should be comparable qualitatively with the result of any other metal mirror coated with a carbon-based film of the same thickness.

Molybdenum is one of the candidate materials for the in-vessel first mirrors in a future fusion reactor. It possesses a low sputtering yield and has a rather high reflectance in the range of interest for plasma diagnostics. That is why the effect of contamination of molybdenum mirror by a carbon film of different thickness was studied by similar procedure as SS mirror. Three sectors of the molybdenum mirror (diameter 22 mm) were coated by carbon layers of thickness d=23, 35 and 56 nm in similar conditions as the SS mirror. One sector of Mo mirror remained free of coating. The n and k values determined by ellipsometry for the first carbon film (d=23 nm) were slightly different from those for the second film (d=35 nm), probably because of film structure modification when its thickness is increasing.

For the thickest film, the ellipsometric measurements were problematic due to low reflection and optical indices were taken as average values measured for thinner films. The molybdenum optical indices obtained by the ellipsometric technique were used for calculation of the R(λ) dependence shown in **Fig.2** as solid line (upper curve) along with reflectance measured at normal
incidence (open circles and dotted line). Graphs of R(λ) calculated for the coated parts are plotted by solid lines with solid markers. The measured reflectance values for the same Mo sample areas are shown as the

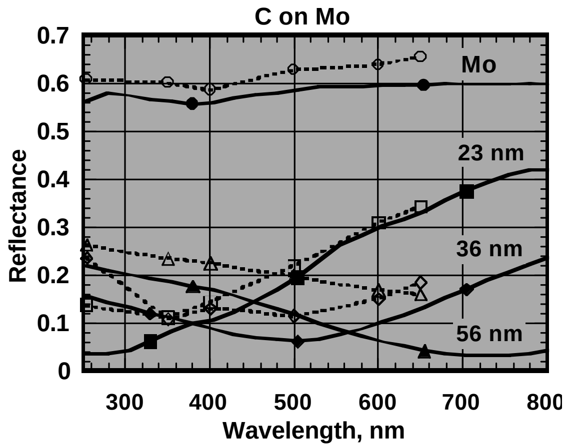

Fig.2. The spectral reflectance for C film on Mo mirror. Solid lines and solid data markers represent the results of calculations while the dotted lines with open markers depict the corresponding measured data. The film thickness is marked near every group.

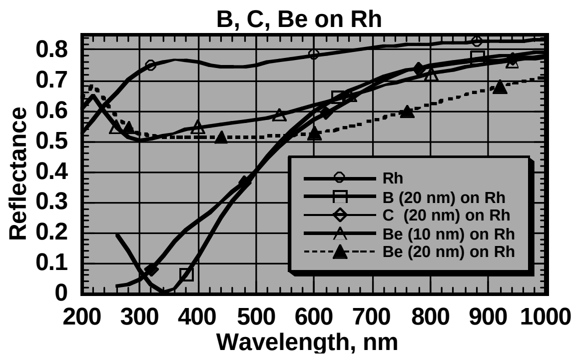

Fig.3. The calculated spectral reflectance values of clean and contaminated Rh mirror. Each combination is marked near the related curve.

dotted lines with open markers.

Quite reasonable qualitative agreement between measured and calculated values of reflectance is observed again. For the film of 23 nm thick, there is also quite good quantitative agreement, i.e., the average difference between calculated and measured values is approximately 5%. For thicker films (35 nm or 56 nm) the difference in absolute meanings of calculated and measured R values is high enough, however, qualitatively the behavior of dependences remains similar. It could be inferred that increase of difference between the measured and the calculated R values with increasing film thickness is associated with inhomogeneity of the film along the mirror surface.

Rhodium as well as Mo is a prospect material for the first mirrors of plasma diagnostics in ITER **[11]**, therefore the effect of contamination of rhodium mirror is of great interest. The curves of **Fig. 3** indicate the spectral reflectance calculated for the most probable contaminating films (Be, C, B) of 20 nm thick.

The optical indices for Rh and Be were taken from **[9],** the carbon and boron indices were determined by ellipsometric measurements. Since the metallic films have higher absorption index than C and B films, the appearance of Be film leads to much stronger changes of reflectance for any metallic substrate. In the case of Be layer, the dependence R(d) shows that Be coating with thickness $d \geq 20$ nm on any metal substrate has $R(\lambda)$ behavior the same as bulk beryllium mirror.

3. Discussion

The results obtained show the strong influence of the deposition of thin (≥ 10 nm) boron-carbon film on the effective reflectance of a metal mirror in the visible and in the nearest UV ranges. The film appeared on the in-vessel mirror changes the mirror reflectivity stronger than the transmissivity of diagnostic window because of longer path of reflected light beam passing through a film on the mirror. The rate of reflectance change due to deposit growth depends on the light wavelength, the chemical composition of film and its thickness. Starting from the thickness $d \geq 35$ nm for the carbon layer on Mo substrate, the optical properties of the film become inhomogeneous across the film coated surface. It is probably hard to predict the variation of optical properties of film with increasing the film thickness because new phases appear in the film when it continues to grow.

A problem of carbon-boron deposit growth can be effectively solved by methods of surface cleaning. For the optical windows, the efficiency of chemical cleaning by using the local ECR discharge in hydrogen was demonstrated in **[12]**, in addition to laser ablation method **[6,13,14]**. For the in-vessel mirrors the methods of the boron-carbon deposit removal were not suggested yet.

4. Conclusions

–The reflectivity of mirrors and transmissivity of windows depends in a high degree on the deposition of thin contaminating films on their surfaces. The thickness, the chemical and the structural composition of such film has the strong influence on the reflectance of mirror that also actually depends on wavelength of an incident light.

–The adequate prediction of a final result of film deposition on the mirror surface requires more knowledge of film optical properties even with known thickness. The data for films must be studied according to variation of chemical and structural composition in a wide range to follow the most probable composition in fusion devices.

–The simple and reliable methods for the regularly provided *in-situ* calibration and control of reflectance of the in-vessel mirrors, as well as the methods of deposits cleaning have to be developed. The plasma properties of an ECR discharge in hydrogen (or deuterium) look rather promising for both these applications. However, the special experiments in large-scale fusion devices have to be carried out to optimize the characteristics of ECR discharge to solve the problem of low Z material deposition on the working characteristics of the in-vessel mirrors.

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