EXPERIMENTAL MODELLING OF THE EFFECTS OF CXA BOMBARDMENT ON IMAGE QUALITY OF THE FIRST MIRRORS IN ITER

V.G. Konovalov, A.N. Shapoval, O.Yu. Volkova, V.S. Voitsenya
Institute of Plasma Physics, NSC KIPT, 61108, Kharkov, Ukraine

In optical methods of plasma diagnostics in large fusion devices (FD) the use of first mirrors (FM) is supposed. To make the right choice of FM material the modeling studies are needed of the degradation rates of reflectance and image transmission quality (ITQ) under sputtering in FDs. In the present paper the method is suggested and applied for evaluation of ITQ. The use of scheme with photoelectrical registration of the luminous object image allows measuring the dynamics of the change of the contrast and resolving power of mirror depending on the depth of layer eroded due to bombardment with deuterium ions. As an example, the comparative results are presented on degradation of optical properties of two Cu mirror samples with coarse-and small-grain structures.
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INTRODUCTION

Optical methods of plasma diagnostics are routinely used at fusion devices. In the reactor-grade fusion devices (e.g., ITER) the optical systems have to include such in-vessel components as the first mirrors (FM). The main demand to FM is the high resistance to damaging factors in a harsh ITER environment. Such factors are: gammas, neutrons, x-rays, and charge exchange atoms (CXA). As was shown previously in NSC KIPT, for metallic FMs the most critical factor is bombardment by CXA leading to development of the roughen surface, i.e., to degradation of reflectance and deterioration of the mirror ability to transmit an image.

At the present day the FM program in NSC KIPT is based on modeling experiments with investigation of effects of long-term bombardment by deuterium plasma ions on optical properties of mirrors from different materials with different structure.

To control the quality of the image transmission by tested mirror, the resolving power was measured earlier by means of the collimating system OSK-2. Such measurements are not vivid and have a rather subjective character. Recently, the special optical stand was designed and built up with the scanning arrangement and a photomultiplier giving a possibility to measure the profiles of the strongly enlarged image of the incandescent lamp filament by means of the scheme that includes the mirror under the test. To demonstrate the prospects of such an approach, the first comparative results were obtained on the dynamics under ion bombardment of an image transmission quality (in terms of resolving power and contrast) for two copper mirrors: with fine- and coarse-grained structures.

TEST STAND

Fig. 1 shows the main components of the stand: 1) incandescent lamp SI6-40 (the width of the W ribbon is 0.66 mm), 2) diaphragm with a round aperture, 3) the mirror under consideration, 4) objective, 5) standard spectral slit, 7) photomultiplier.

The luminous flux from the lamp falls at angle of 45° on the mirror sample through the diaphragm aperture intended for suppression of a parasitic background; after reflection from the sample the light passes through an objective which focuses the enlarged image (m≥7) of the incandescent lamp ribbon in the form of a rectangle in the plane of a scanning slit.

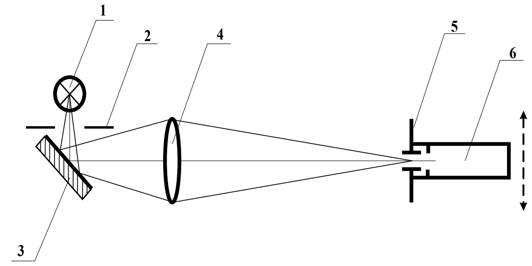

Fig. 1. The block representation for investigation of the image quality of the tested mirrors

A spatial scan in the plane of the light source image was provided by simultaneous moving of the slit - photomultiplier block fixed at a special table with a reading scale. Before providing measurement with the mirror samples, the initial characteristics of the whole optical scheme itself were studied. For that an "ideal" mirror (Al film on a high optical quality quartz substrate) was installed instead of the test mirror, and the image of the light source was measured. As seen (Fig. 2), the image is not strictly rectangular. The smeared edges (i.e., the side transition regions along the X axis) are due to imperfection of the resolving power of the objective and mirror and due to diffraction on the slit in front of the photomultiplier. The image shown in Fig. 2 can be taken as an instrumental function of the optical scheme of the stand.

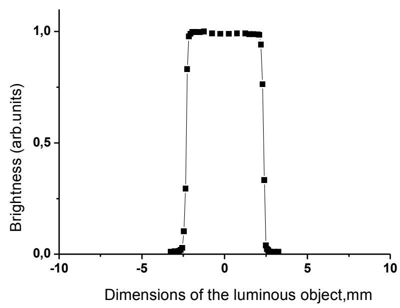

Fig. 2. Distribution of brightness of an enlarged image of the incandescent lamp ribbon at a transverse scanning with an ideal mirror (Al) in use

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The quantitative estimations of resolving power were provided in accordance with the Raleigh criterion.

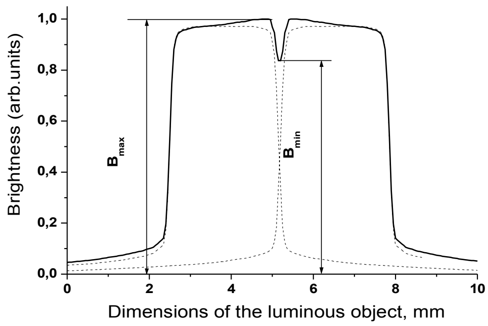

Fig. 3. The scheme of determination of the contrast and the limiting linear (and angle) resolution

RESULTS

The specificity of measurement of resolving power is in the next. After measurement of distributions of the incandescent lamp ribbon image, we conceive these distributions as two independent light sources. By changing the distance between them we shall create the situation when the depth of depression in the total intensity of overlapping contours starts to correspond to requirement of the Raleigh criterion.

An idealized picture is shown in Fig.3. In this figure is also presented the definition of the contrast for our condition as:

$$K=\frac{B_{\max}-B_{\min}}{B_{\min}},$$

where B is brightness of the image, and B_{max} and B_{min} are shown on the graph.

To gain insight about possibilities of the given approach for evaluation of the image transmission quality we compared the dynamics of image transmission for two Cu mirrors with different structures (small grains and large grains) that were subjected to long-term ion sputtering. The results of measurements with abovementioned method are shown in Figs. 4 and 5.

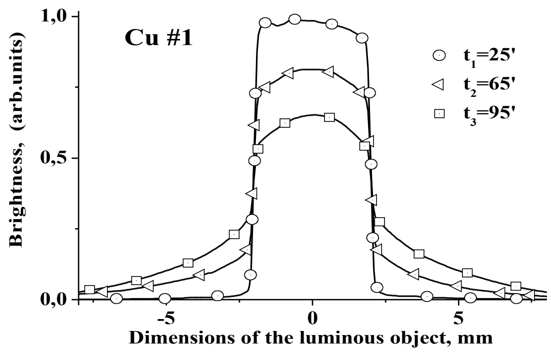

Fig. 4. The set of curves for dependences of light intensity transmitted by the small-grain Cu mirror on the linear size of the light object at successive exposures to ion bombardment. Total times of exposure are in the insert

As seen from graphs of Figs. 4 and 5, the intensity of the central part of image decreases with every next sputtering exposure and at the same time the intensity in wings rises. Such a dynamics of a ribbon image is explained by rising the portion of scattered light because of appearance and development of the roughness on the mirror surface with increasing the total time of ion sputtering. Note that the lateral sides of transmitted images are continuing to be straight lines for both Cu samples, what indicate on partial maintenance of a specular component of the image transmitted by samples. From comparing data for both mirror samples one may conclude that the rate of degradation of transmitted image quality is significantly faster for the small-grain sample (Cu #1) than for the large-grain sample (Cu #2).

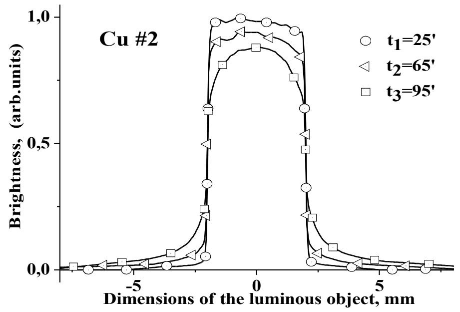

Fig. 5. The set of curves for dependences of light intensity transmitted by the large-grain Cu mirror on the linear size of the light object at successive exposures to ion bombardment

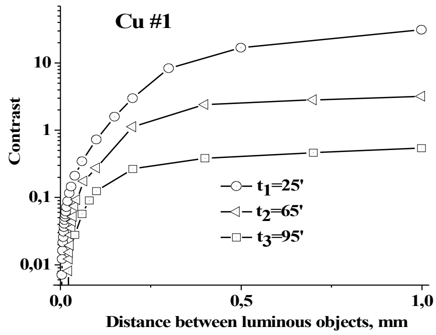

Fig. 6. The image contrast of two objects upon the distance between their opposite points after successive exposures for mirror Cu #1

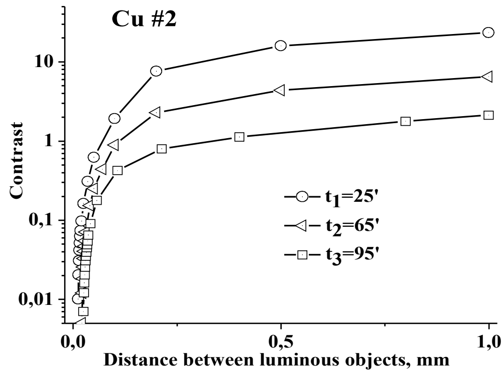

Fig.7. The image contrast of two objects upon the distance between their opposite points after successive exposures for mirror Cu #2

With an aim to obtain a pictorial view on dynamics of resolving power and contrast the data shown in Figs. 4 and 5 were handled by means of the procedure described above, and the final results are presented in Figs. 6-8. In Figs. 6,7 the change of the contrast of image for two objects is shown as functions of increasing distance between their opposite points at successive exposures.

In Fig. 8 for both mirrors the dynamics of degradation of resolving power is shown as function of the depth of layer eroded due to ion sputtering. The resolving power was found as a reciprocal value of the limiting angle [α(sec)] resolution between two luminous objects.

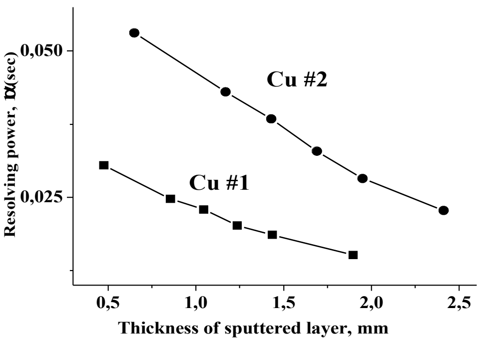

Fig. 8. Degradation of the resolving power of mirror samples Cu #1 and Cu #2 for K=0.25 with increasing the depth of layer eroded by ion sputtering

It is necessary to note that the difference in structure of the mirror samples was found out after preliminary exposure. Therefore, on our regret, the presented results do not relate to the degradation of optical properties beginning from the initial state.

CONCLUSION

It was found that after similar ion fluence the fine-grained copper mirror degraded faster and became to have much higher portion of a diffusive component of reflected light than the coarse-grained mirror.

On our point, the described method allows:

1. To obtain a vivid picture on degradation of the quality of an image transmitted by the first mirror which is being gradually sputtered by charge exchange atoms flux in the ITER environment.

2. To obtain for the given optical channel the quantitative data on the time dependence of degradation of resolving power in the angle (seconds^{-1}) or linear (cross strokes per mm) units.

3. In combination with data on reflectance, to have more complete information on the rate of degradation of the in-vessel mirror being exposed in large fusion devices.

ЭКСПЕРИМЕНТАЛЬНОЕ МОДЕЛИРОВАНИЕ ВЛИЯНИЯ БОМБАРДИРОВКИ ПЕРВЫХ ЗЕРКАЛ ПОТОКАМИ ПЕРЕЗАРЯЖЕННЫХ АТОМОВ НА КАЧЕСТВО ПЕРЕДАВАЕМОГО ИЗОБРАЖЕНИЯ В ITER'е

В.Г. Коновалов, А.Н. Шаповал, О.Ю. Волкова, В.С. Войценя

В оптических методах диагностики на крупных термоядерных установках (ТЯУ) предполагается использовать первые зеркала (ПЗ). При выборе материала для ПЗ необходимы модельные исследования деградации, как коэффициента отражения, так и качества изображения (КПИ) при распылении в условиях ТЯУ. В данной работе предложена и применена методика оценки КПИ с использованием фотоэлектрической регистрации изображения объекта, позволяющая измерить динамику изменения контраста и разрешающей способности по мере увеличения толщины распылённого слоя при бомбардировке образцов потоками ионов дейтериевой плазмы. В качестве примера приводятся результаты исследования деградации оптических характеристик двух медных образцов с крупной и мелкозернистой структурами.

ЕКСПЕРИМЕНТАЛЬНЕ МОДЕЛЮВАННЯ ВПЛИВУ БОМБАРДИРОВКИ ПЕРШИХ ДЗЕРКАЛ ПОТОКАМИ ПЕРЕЗАРЯДЖЕНИХ АТОМІВ НА ЯКІСТЬ ПЕРЕДАВАЄМОГО ЗОБРАЖЕННЯ В ITER'і

В.Г. Коновалов, А.Н. Шаповал, О.Ю. Волкова, В.С. Войценя

В оптичних методах діагностики на великих термоядерних установках (ТЯУ) передбачається використовувати перші дзеркала (ПДЗ). При виборі матеріалу для ПДЗ необхідні модельні дослідження деградації як коефіцієнту відображення так і якості зображення (ЯПЗ) при розпиленні в умовах ТЯУ. В даній роботі запропонована і застосована методика оцінки ЯПЗ з використанням фотоелектричної реєстрації зображення об'єкту, яка дозволяє виміряти динаміку зміни контрасту і роздільної здатності по мірі збільшення товщини розпиленого шару при бомбардуванні зразків потоками іонів дейтерієвої плазми. Як приклад наводяться результати дослідження деградації оптичних характеристик двох мідних зразків з крупною та дрібнозернистою структурами.