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Manufacturing of XEUV mirrors with a sub-nanometer surface shape accuracy

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A B S T R A C T

In this paper, first results of finishing EUV mirror substrate surface shape to given parameters using correction methods such as vacuum thin films deposition and local ion-beam etching through the mask are presented. For spherical mirror substrate with radius of curvature R=260 mm and a diameter of 130 mm, obtained values of PV=4.7 nm and RMS=0.6 nm.

1. Introduction

Microelectronics future, reducing a size of a chip topological element down to 20–30 nm and even less is associated with development of the projection lithography with working wavelength laying in a range of the extreme ultraviolet (EUV) and soft X-ray (SXR) radiation, first of all with a wavelength of 13.5 nm. In spite of high scientific and technologic progress in the field of X-ray multilayer optics, photoresist development [1] and generation of EUV radiation [2], Russian EUV projection lithography program was retarded by absence of technologies for production of substrates for EUV mirrors with necessary accuracy their surface shape. The short working wavelength demanded an extra accuracy of the form of reflecting surfaces, as a rule aspherical ones, up to sub-nanometer level (by calculations the maximal deviation of the form of a substrate from a given aspherical surface should not exceed 0.27 nanometers [3]). Thus, new methods and approaches for correction (finishing) the form of initial surfaces (substrates) up to sub-nanometer scale accuracy have been the subject of these experimental studies. One of specific demand to the methods is keeping a microroughness of a substrate under correction at an initial level.

Today in applied optics, a lot of different methods for surface asphherisation are used. In general, they are mechanical methods: local diamond cutting of the surfaces, mechanical local deformation and polishing with spherical polishers of different radius of curvature [4], but those procedures cannot provide required surface shape accuracy. More progressive directions are processes of vacuum thin films deposition and ion etching. At this moment in the literature, there are data on achievement of accuracy of the surface shape of corrected substrate with a diameter of 150 mm RMS $\approx$8 nm (root-mean-square) by means of ion-beam etching [5]. ZEISS reports of application of an ion-beam etching method for correction of the aspherical substrates with sub-nanometer accuracy and atomic smoothness of surfaces. However, neither ion-beam etching setup nor characteristics of the ion beam were not presented [6]. In this investigation to lead up a surface up to specified one are used both methods: a local ion-beam etching [7] and thin film deposition [8]. Using the method of local ion-beam etching in aggregate with the method of thin films deposition by magnetron sputtering, it became possible to receive the results allowing already make substrates for objective of the EUV nanolithographer with the required surface shape accuracy.

2. Methodology

The method of aspherisation by vacuum thin film deposition is used for manufacturing surfaces with a small deviation from spherical shape. It consists of deposition an additional layer of variable over substrate thickness by magnetron sputtering onto initial spherical substrate.

At this moment, in Institute for physics of microstructures RAS (IPM RAS) are turned out a technique of manufacturing of multilayered structures (MS) with ultrashort periods [9], it stays a start position for development of the thin film deposition correction technology. As a pair of materials Cr/Sc MS is used. In IPM RAS deep study of the given structure was lead [10]. It was shown, that the Cr/Sc deposited onto a substrate does not develop the microroughness of a substrate, that does not allow degradation reflection coefficients of X-ray mirrors. Using a thickness ratio of the Cr and Sc layers 1:1 in MS, there is no stress; that does not

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provide deformation of substrate surface after deposition of the correcting coatings on it. Another reason of using the Cr/Sc MS is a possibility of chemical removing the layer without substrate surface roughness degradation.

Procedure of the correction by the vacuum deposition thin films through a mask is schematically shown in Fig. 1. Characteristics of the experimental setup and the technological process parameters of thin film deposition are in Ref. [11].

Ionic processing is a controlled process of formation of optical surfaces with the given characteristics and topography, based on physical process of atomic emission from a target surface under bombardment by high energy particles (ions). Ion-beam etching method is more interesting than mechanical ones because it allows performing etching in a set point on a set extra-low (less than 1 nm) depth. A schematic sketch of the experimental facility is shown in Fig. 2.

In the vacuum chamber, on a stage having three degrees of freedom, the sample (the size of the sample is limited by dimensions of the vacuum chamber and could be less than 230 mm in diameter) is mounted. As a source of the fast ions ion-beam source developed in IPM RAS is used [12]. The beam intensity distribution after 6 mm diaphragm, measured in a place of a processed substrate, is presented in Fig. 3. One can see good localization of the beam that provides simpler automation of the etching process. The surface of the sample is scanned under ion beam with the given speed providing settlement rate of the etching (Ar^+ ions with the energy from 300 to 1500 eV).

For achievement of high reflectivity of the multilayer mirrors deposited onto substrates after ion-beam correction, the micro-roughness of the surfaces should remain at a level of 0.1–0.2 nm. Thus, there was a necessity of studying of influence of parameters of the ion beam to the microroughness of a processed surface.

Fig. 1. Scheme of the correction procedure by the vacuum deposition thin films through a mask.

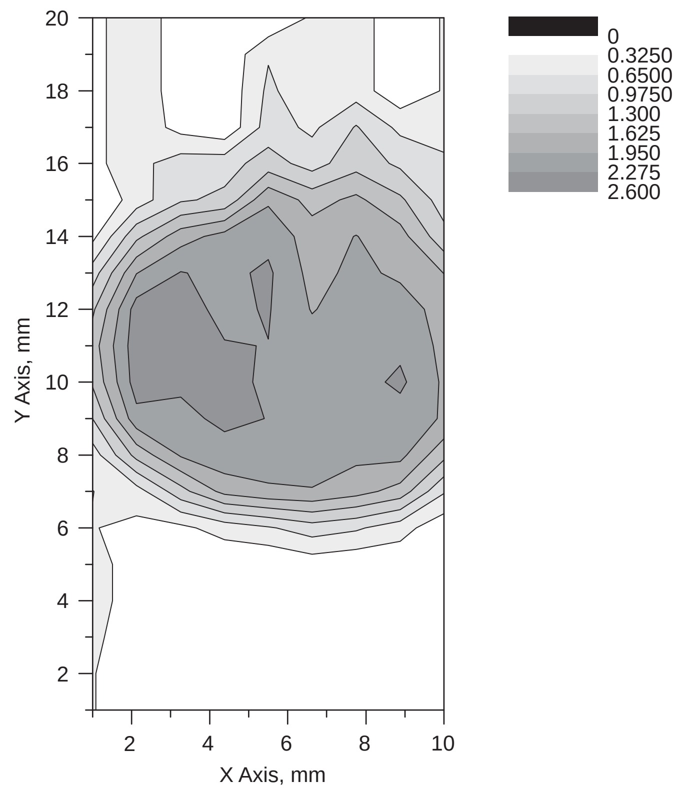

Fig. 3. The ion current density distribution map after 6 mm diaphragm, obtained in a point of incidence of a beam on the sample.

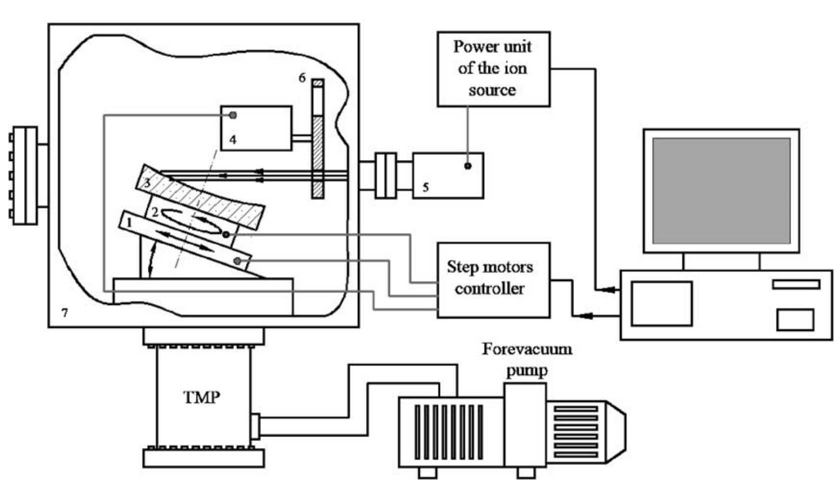

Fig. 2. Experimental setup: 1—linear stage; 2—rotary stage; 3—sample (optical substrate); 4—step motor for changing of diaphragms; 5—ion source; 6—rotating diaphragm set (one position is for the ion current gauge) and 7—vacuum chamber.