



Effect of defects on the reflectivity of Cr/C multilayer soft X-ray mirror at 4.48 nm

Songwen Deng, Hongji Qi, Kui Yi, Zhengxiu Fan, Jianda Shao^{*}

Shanghai Institute of Optics and Fine Mechanics, The Chinese Academy of Sciences, Qinghe Road 390#, Jiading District, Shanghai 201800, China

ARTICLE INFO

Article history:

Received 27 October 2008

Received in revised form 26 February 2009

Accepted 5 April 2009

Available online 11 April 2009

PACS:

78.20.-e

81.70.-q

Keywords:

Multilayer structure

X-ray reflectivity

XPS

Interlayer

Contamination

ABSTRACT

Cr/C is a promising material combination for multilayer mirror in the “near water window region” (4.4–6.7 nm). In the present paper, the effect of defects on the reflectivity of Cr/C soft X-ray multilayer mirror deposited by magnetron sputtering was studied. Formation of thin interlayer due to the interdiffusion, rough interface due to the non-sharp layer and contamination of O happened during the deposition process were found by a method combined by XPS, soft X-ray reflectivity at 4.48 nm and grazing incidence hard X-ray reflectivity at 0.154 nm. The XPS results show that both interlayers (Cr-on-C and C-on-Cr) are mixture composed of C sp², C sp³, C–O, C=O, Cr–Cr and Cr–O bondings. No chromium carbide was found at the interlayer probably due to the blocking of oxides’ formation. Through the analysis of X-ray reflectivity, we obtained the multilayer structure parameters (thickness and roughness) and optical constants of each layer at 4.48 nm. Based on those results, a further calculation was carried out. The result shows that the formation of the thin interlayer contributes little to the decrease of the reflectivity, the rough interface decreases the reflectivity most and the contaminant (O) not only decreases the reflectivity but also shifts the position of the peak.

© 2009 Elsevier B.V. All rights reserved.

1. Introduction

Ni-like soft X-ray lasers have been obtained successfully from various materials [1–3] and Ni-like-Ta laser working at the wavelength 4.48 nm provides a possible source in the “near water window” [4] (4.4–6.7 nm), which makes multilayer reflector at this wavelength a hot research spot since it is an indispensable component of soft X-ray optical system. The multilayer mirrors are fabricated by the alternating layer of low-Z (spacer) and high-Z (absorber) materials. In the wavelength range 4.3–6.7 nm, carbon whose K-edge is 4.3 nm is the best spacer and heavy metals such as U, W and transition 3-d metals (such as Fe, Co and Cr) form the absorber material group. Cr/C multilayer mirror has been proved to be the most efficient reflector near the wavelength 4.43 nm (K-edge of carbon). As far as we concerned, a reflectivity of 13% obtained by Cr/C system, which is nearly three times lower than the theoretical value, is the highest in this wavelength range [5,6]. The reasons of low reflectivity are probably as follows: (1) Multilayer is a thermodynamical metastable system. The formation of the interlayer due to the interdiffusion or the compounds formation between the two elements can decrease the reflectivity [7,8]. (2) The layer cannot be fabricated as sharp as assumed in the calculation and

the roughness decreases the reflectivity dramatically [9]. (3) The contaminants such as O and N induced during the deposition decrease the Fresnel reflection of each interface and increase the absorption of the system. Wilson et al. found the contamination of O and the formation of Cr₂C₃ in the Cr-doped diamond like carbon (DLC) film deposited by sputtering [10]. However, similar reports about Cr/C soft X-ray multilayer mirror are scarce limited by our knowledge.

In this paper, multilayer system was deposited by magnetron sputtering. X-ray photoelectron spectroscopy (XPS) was used to examine compositions of the interface. A non-destructive method combined soft X-ray resonant reflectivity at 4.48 nm and grazing incidence X-ray reflectivity at 0.154 nm were used to determine the structure parameters (thickness and roughness) of the multilayer. Then the effect of defects on the reflectivity of the mirror at 4.48 nm was analyzed.

2. Method of reflectivity calculation

In this paper, the multilayer structure parameters and optical constants were obtained by fitting the calculated reflectivity to the measured results. Parratt [11] has given a method to calculate the reflectivity of multilayer system with N layers using recursive formalism. In the X-ray region, the refractive index for matter is defined as

$$n = 1 - \delta - i\beta \quad (1)$$

^{*} Corresponding author. Tel.: +86 021 69918476; fax: +86 021 69918028.

E-mail address: buaa_dsw@163.com (J. Shao).

where δ (dispersion) and β (absorption) are the real and imaginary parts of the complex refractive index, also known as optical constants and can be written in terms of wavelength-dependent atomic scattering factors as

$$\delta = \frac{r_e \rho \lambda^2}{2\pi} (Z + \Delta f'(\lambda)) \quad (2)$$

$$\beta = \frac{r_e \rho \lambda^2}{2\pi} \Delta f''(\lambda) \quad (3)$$

where r_e is the classical electron radius, ρ is the atomic density, λ is the wavelength of incident photon, Z is the number of electron in the atom and $\Delta f'(\lambda)$ and $\Delta f''(\lambda)$ are the dispersion and absorption part of the atomic scattering factor, respectively. In this paper, all optical constants used in the calculation were taken from the database of Henke et al. [12].

For the s-polarized incident wave, the Fresnel reflection coefficient of the interface between the j th and $j+1$ th layer can be given by

$$F_{j,j+1} = \frac{E_j^R}{E_j} = \frac{k_j - k_{j+1}}{k_j + k_{j+1}} \quad (4)$$

with

$$k_j = \frac{2\pi}{\lambda} (n_j^2 - \cos^2 \theta)^{1/2}$$

where E_j and E_j^R are the amplitude of electric vector of incident and reflected waves, respectively on the interface between j th and $j+1$ th layer. Recursion relation of the Fresnel reflection coefficient of different interface can be give by

$$R_{j,j+1} = \alpha_j^2 \frac{R_{j+1,j+2} + F_{j,j+1}}{1 + R_{j+1,j+2} F_{j,j+1}} \quad (5)$$

with

$$\alpha_j = \exp(-ik_j d_j)$$

where d_j is the thickness of the j th layer. The reflectivity of the multilayer system can be written as

$$|R_{1,2}|^2 = \frac{I_R}{I_0} = \left| \frac{E_1^R}{E_1} \right|^2 \quad (6)$$

The recursion method begins from the bottom layer with $R_{N,N+1} = 0$ since there is no reflection from the thick substrate. In a real multilayer system, an error factor must be introduced since the layer is not sharp. The factor, which is to be multiplied with Eq. (5), can be written as

$$EF = \exp(2k_j k_{j+1} \sigma^2)$$

where σ is the root mean square deviation of the layer with respect to a sharp layer.

3. Experiment details

3.1. Sample fabrication

Cr/C multilayer system was deposited on the quartz substrate by a DMD-450 magnetron sputtering system with Cr in DC and C in RF mode. Fig. 1 shows the schema of the inner structure of the vacuum chamber. The substrate facing downward was mounted on a spin holder, which was mounted on a rotating axis driven by a stepping motor with a distance of 80 mm to the target. The rotating velocity of the stepping motor was controlled accurately by computer, through which the thickness of each layer was controlled. The sputtering powers and currents were $P_{Cr} = 210$ W, $I_{Cr} = 0.6$ A, $P_C = 500$ W and $I_C = 0.7$ A. The purities of Cr and C targets

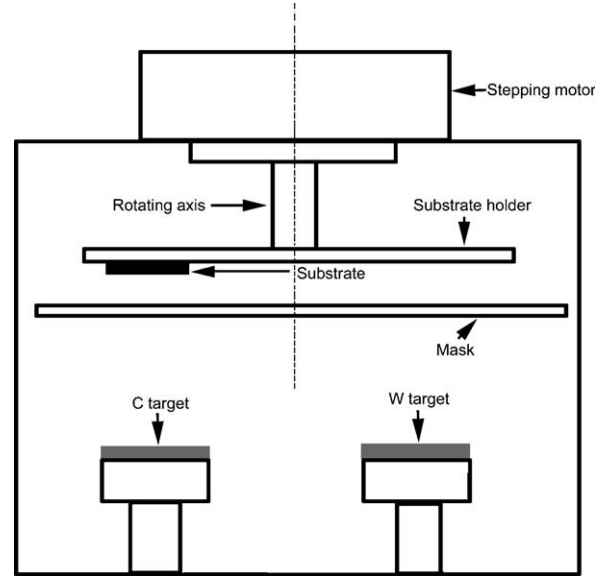


Fig. 1. Schema of the inner structure of the vacuum chamber.

used in the sputtering were 99.99% and 99.95%. The base pressure was 2×10^{-3} Pa and the working gas was Ar with purity of 99.99% at a pressure of 0.2 Pa. The multilayer was designed as follows: Λ (period thickness) = 9 nm, Γ (the thickness ratio of Cr layer to the period) = 0.33 and N (number of period) = 10.

3.2. X-ray reflectivity (XRR)

The soft X-ray reflectivity at 4.48 nm was measured using the 3W1B beam line of Beijing Synchrotron Radiation Facility (BSRF) with the energy resolution $(\Delta E/E) \times 10^{-3}$. The grazing incidence X-ray reflectivity at 0.154 nm was measured using the U7B beam line of National Synchrotron Radiation Laboratory (NSRL) in Hefei, China with energy resolution $(\Delta E/E) 5 \times 10^{-4}$. It is reported that the soft X-ray reflectivity at 4.48 nm near the carbon K-edge has subnanometer sensitivity to the composition change of the layer [13] and the grazing incidence hard X-ray reflectivity of 0.154 nm can be used to determine the multilayer structure parameter such as thickness and roughness of the layer [11].

3.3. X-ray photoelectron spectroscopy (XPS)

XPS of the interfaces were measured to determine the contamination and the composition near the interface. The measurements were taken on XSAM-800 equipment. The surfaces of samples were removed by sputtering until we can get the information of the interface before the measurements.

4. Results and discussion

4.1. Interface analysis

Both interfaces (Cr-on-C and C-on-Cr) contain Cr, C and O (contaminant) through qualitative spectral scan of XPS. Since the surface of the layer had been removed before scanning, we believe that the contamination of O mainly happened during the deposition process due to the relatively poor base pressure (2×10^{-3} Pa). Figs. 2 and 3 are the high resolution regional scan results of Cr-on-C and C-on-Cr interface, respectively. During the fitting, all possible bondings were taken into account. Figs. 2(a) and 3(a) show the regional scan of C. C–Cr, sp₂, sp₃, C–O and C=O bondings with binding energy 283, 284.4, 285.2, 287 and 288.5 eV, respectively are considered in the

Download English Version:

<https://daneshyari.com/en/article/5367078>

Download Persian Version:

<https://daneshyari.com/article/5367078>

[Daneshyari.com](https://daneshyari.com)