Interface engineering method for ultra-thin Cr/Ti soft X-ray multilayer

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Abstract

We intentionally incorporated B and C into ultra-thin Cr/Ti soft x-ray multilayers by co-deposition of B_4C at the interfaces. The effect on the multilayer structure and composition has been investigated using x-ray reflectometry, x-ray photoelectron spectroscopy, and cross-section electron microscopy. The B and C is mainly bonded to Ti sites, forming a nonstoichiometric TiB_xC_y composition, which hinders the diffusion of Cr into the Ti layers and dramatically improves the interface quality of Cr/TiB_xC_y multilayers. As a result, the near-normal incidence soft x-ray reflectivity increases from 4.48% to 15.75% at wavelength of 2.73 nm.

Introduction

Reflectivity is one of the most critical parameters of a multilayer. The theoretical reflectivity of Cr/Ti are very high in the "water window" wavelength range (2.4–4.4 nm) but is extremely sensitive to interfacial imperfections for the ultra-short periods (Λ~1.4 nm) used[1]. To reduce interface width of multilayers, the intentional incorporation of light-element impurities into multilayers is used. In this work, we intentionally incorporated B and C and investigated the effects of B and C impurities on the microstructure and optical performance of the multilayers.

Experiments and discussion

We deposited four series of Cr/Ti multilayers with period number N=50. B4C was incorporated at both Cr-on-Ti and Ti-on-Cr interfaces in the first series, at only Cr-on-Ti interfaces in the second series, and at only Ti-on-Cr interfaces in the third series. A fourth series containing four pure Cr/Ti multilayers without B4C were also deposited for comparison.

All the multilayers were characterized by low angle x-ray reflectometry (XRR). The measurements were performed on a Bede D1 diffractometer with a Cu x-ray source (λ=0.154 nm). The result is shown in Fig.1.

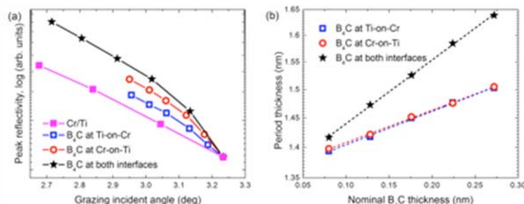

Fig. 1: (a) Peak reflectivity versus peak angle of the first order Bragg peaks in the XRR curves of the Cr/Ti multilayers. Symbols represent the data and solid lines are only guide for the eye. (b) Period thickness versus nominal B4C thickness of the Cr/Ti multilayers. Symbols represent the data and dashed lines the linear fit.

In order to study the interface stoichimetry we used x-ray photoelectron spectroscopy (XPS) measurements on two samples. One had no B4C incorporated and the other had 0.13 nm of B4C at both interfaces. The measurements were performed on a Thermo Scientific K-Alpha system with an Al Kα source. The B 1s and C 1s spectra of the multilayer with B4C are shown in Fig. 2 along with the spectra of a B4C monolayer reference sample.

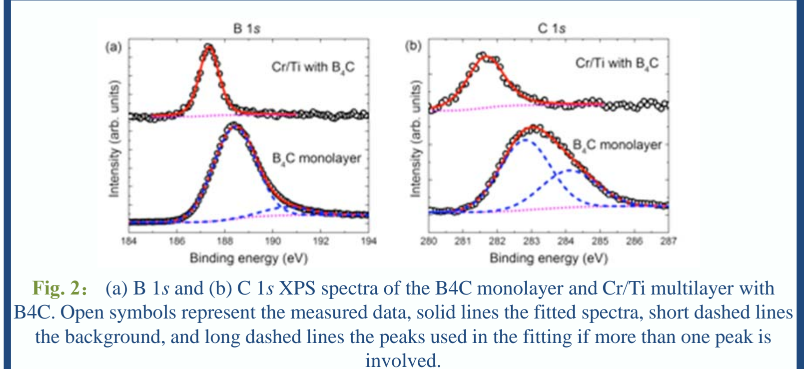

Fig. 2: (a) B 1*s* and (b) C 1*s* XPS spectra of the B4C monolayer and Cr/Ti multilayer with B4C. Open symbols represent the measured data, solid lines the fitted spectra, short dashed lines the background, and long dashed lines the peaks used in the fitting if more than one peak is involved.

Encouraged by the preliminary results, we then deposited two Cr/Ti multilayers, one without B4C and the other with 0.13 nm of B4C at both interfaces, with periodic number N=600 and designed period Λ=1.38 nm as high reflection mirror for wavelength λ=2.73 nm (photon energy E=453.5 eV). Figure 3 shows the cross-section transmission electron microscopy (TEM) graphs for the two samples measured using an FEI microscope (Tecnai G2 F20).

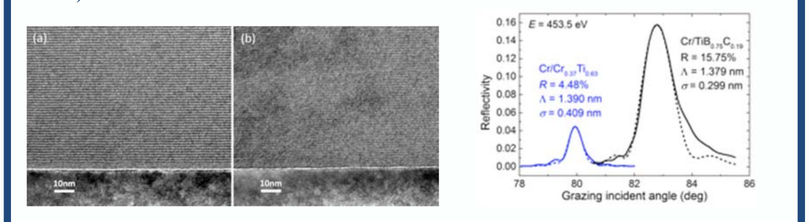

Fig. 3: Cross-section TEM graphs of Cr/Ti multilayers (a) with and (b) without B4C.

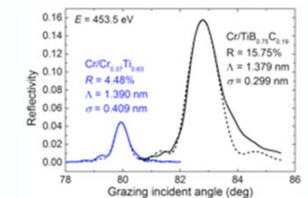

Fig. 4: Soft x-ray reflectivity from the Cr/Ti multilayers with and without B4C.

The soft x-ray reflectivity measurements were performed by using a high precision polarimeter on Beamline I06 at the Diamond Light Source, United Kingdom[2]. The reflectivity is plotted in Fig. 4 as a function of the incidence angle.

Summary

It is shown that pure Cr/Ti multilayers with ultra-short period (Λ~1.4 nm) have an excess of Cr located in the Ti layers due to Cr diffusion that can be described as Cr/Cr0.37Ti0.63. We intentionally incorporated B and C into Cr/Ti multilayers by depositing ultra-thin B4C at the interfaces. We found that incorporating 0.13 nm of B4C at both interfaces dramatically affects the structure and composition of the Cr/Ti multilayers. The B and C incorporated during deposition is mainly bonded to Ti, forming Cr/TiB0.75C0.19 multilayer structures. The formation of nonstoichiometric TiB0.75C0.19 composition hinders the diffusion of Cr and improves the interface quality of Cr/TiB0.75C0.19 multilayers. As a result, Cr/TiB0.75C0.19 multilayers (with periodic number N=600) exhibit ~250% higher near-normal incidence soft x-ray reflectivity (absolute reflectivity R=15.75%) than pure Cr/Ti multilayers.

References

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