Soft X-ray Reflectivity and Structure Evaluation of Ni/Ti and Ni-N/Ti-N Multilayer X-ray Mirrors for Water-Window Region

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INTRODUCTION

The development of highly-reflective multilayer mirrors for use in the water-window region has been desired for x-ray microscopy and x-ray photoemission spectroscopy, for example. For these applications, reflectivity is one of the most critical parameters determining the performances of multilayer mirrors. Ni/Ti-based multilayers are appropriate candidates for such mirrors because the combination of Ni and Ti theoretically has high reflectivity at just above the Ti absorption edge (around 2.8 nm) because of the optical constants of Ni and Ti. The reflectivity of multilayer mirrors is also related to their structures. The interface roughness, intermixed widths, and the thickness ratio between each layer are important facts affecting the performances of multilayer mirrors.
We have designed Ni/Ti and Ni-N/Ti-N multilayer mirrors to make an x-ray micro-beam with high reflectivity, We used grazing-incident type optics, such as ellipsoidal mirrors, and have fabricated the mirrors using a sputtering technique. We evaluated the structures and reflectivity of these multilayers using a soft x-ray reflectometer.

DESIGN AND FABRICATION OF NI/TI-BASED MULTILAYERS

We calculated the soft x-ray reflectivities of many kinds of multilayers (Ni/Ti, Ni/Sc, W/Ti etc), assuming that the multilayers had an ideal structure. The calculations were performed using the Fresnel equation and Henke's optical data. Each of these multilayers has 20 layer pairs, at a wavelength of around 2.76 nm, with the peak reflectivity at a 9 degree grazing

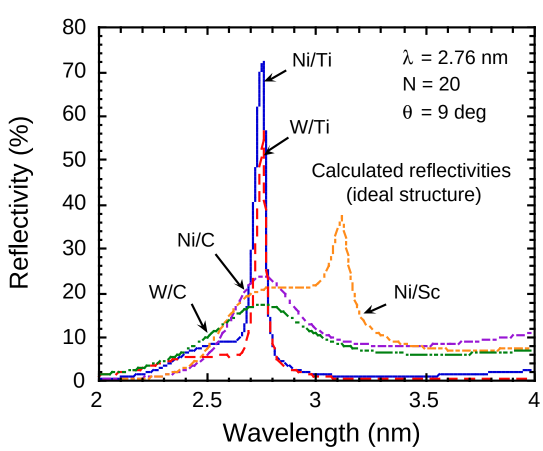

FIGURE 1. Calculated reflectivies of multilayers at wavelengths around 2.76 nm at grazing incidence.

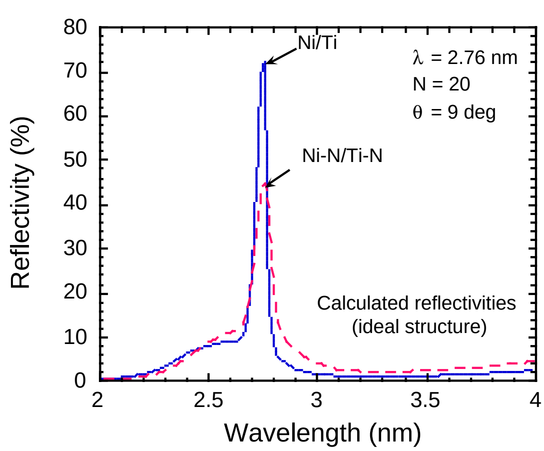

FIGURE 2. Calculated reflectivies of Ni/Ti and Ni-N/Ti-N multilayers at wavelengths around 2.76 nm at grazing incidence

incidence. The periodic length was around 9.2 nm and the thickness ratio between the high-Z layer and the low-Z layer was almost 0.35: 0.65. The calculated peak reflectivities of the high-Z /Ti multilayers have high reflectivities at 2.76 nm. For example, the peak reflectivity of a Ni/Ti multilayer is a 78%, and that of a Co/Ti multilayer is also almost the same value. Figure 1 shows the reflectivity profiles for five multilayer material combinations as examples.

A magnetron sputtering deposition system was used to fabricate the Ni/Ti-based multilayers[1]. It basically consists of three fixed-source targets, a rotating substrate table, a substrate rotation-speed control system, and a shutter-opening and -closing controller synchronized with the substrate rotation. The Ni/Ti multilayer was deposited on Si wafers under an Ar gas atmosphere. In the Ni/Ti multilayer, the periodic length of this multilayer was about 9.2 nm, and the thickness ratio between the Ni layer and the Ti layer was about 0.35 : 0.65. The layer pairs were 20. In addition to this multilayer, we had also fabricated an Ni-N/Ti-N multilayer under in an Ar +N2 (80% / 20%) gas atomosphere.

SOFT X-RAY REFLECTIVITIES AND LAYER STRUCTURES

Reflectivity for soft x-rays was measured at Beamline 6.3.2 [2] at the Advanced Light Source at LBNL. In this beamline the reflected beam from the multilayer sample is measured as the current from a Si photodiode. The absolute reflectivities are obtained by dividing the reflected beam intensity by the full beam intensity.

Figure 3 shows the measured and ideal reflectivities of the fabricated Ni/Ti multilayer. The measured peak reflectivity is 39% at a 2.74 nm wavelength at the incident angle of around 9°. This peak reflectivity is sufficient for our grazing incidence x-ray optics.

We estimated the periodic length, the layer thickness ratio, the interface roughness, the intermixed layer thickness, and the density of the fabricated multilayer by using this measured reflectivity. The fitting curve of the measured reflectivity is also shown in Fig. 3. The curve was calculated using the following parameters: a periodic length of 9.21 nm, a layer thickness

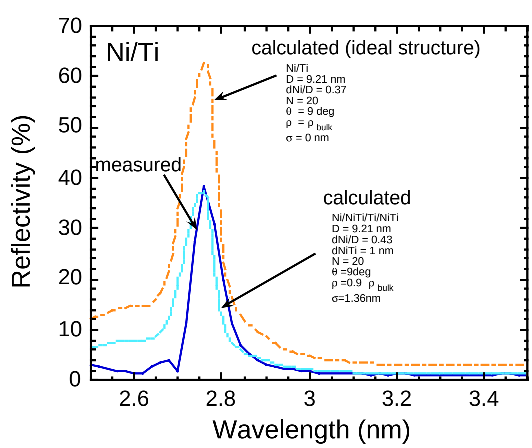

FIGURE 3. The measured and ideal reflectivities of the fabricated Ni/Ti multilayer, and the fitting reflectivity.

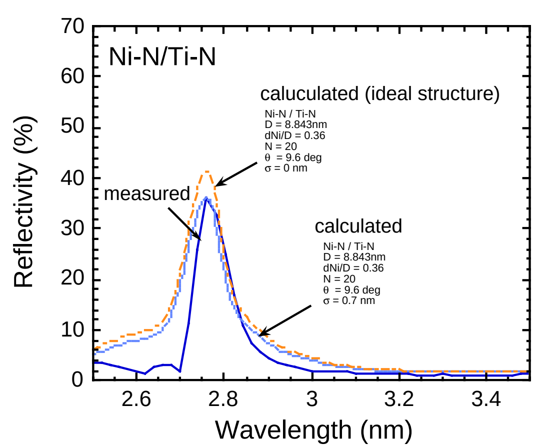

FIGURE 4. The measured and ideal reflectivities of the fabricated Ni-N/Ti-N multilayer, and fitting reflectivity.

ratio of 0.43 : 0.57, an interface roughness of 1.36 nm, an intermixed width of 1 nm, and a density of 0.9 times the bulk of Ni and Ti. In this calculation, we used NiTi as the intermixed layer, because x-ray diffractometer measurements of the annealed (at 500°C, for 1 hour, in an Ar atmosphere) Ni/Ti multilayer showed the existence of a NiTi phase. There is large deviation in the reflectivity between the measured and fitting reflectivity under 2.74 nm. We assume that this is because of the Ti- and Ni-oxide layers on the surface of this multilayer.

Figure 4 shows the measured and ideal reflectivities of the fabricated Ni-N/Ti-N multilayer. The measured peak reflectivity is 36% at a 2.74-nm wavelength and an incident angle of around 9°. This peak reflectivity is slightly smaller than that of the Ni/Ti multilayer. This slightly smaller peak reflectivity may explain the difference in the optical constants between the Ni and Ni-N layers, and of that between the Ti and Ti-N layers.

We estimated the periodic length, the layer thickness ratio, the interface roughness, and the density of the fabricated multilayer by using this measured reflectivity. The fitting curve of the measured reflectivity is also shown in Fig. 4. The curve was calculated using the following parameters: a periodic length of 8.84 nm, and a layer thickness ratio of 0.36 : 0.66, an interface roughness of 0.76 nm, and a density of 0.9 times the bulk of Ni and Ti. We did not consider intermixed layer in this calculation, because x-ray diffraction of the annealed (at 500°C, for 1 hour, in an Ar atmosphere) Ni-N/Ti-N multilayer only revealed Ni and Ti phases. The interface of this multilayer is smoother than that of the Ni/Ti multilayer.

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