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TITLE: PERFORMANCE OF MULTILAYER DISPERSION ELEMENTS FROM 80 to 500 eV

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Performance of multilayer dispersion elements from 80 to 500 eV

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Abstract

We have measured the reflectivity of several multilayer dispersion elements between 80 and 500 eV. Two samples of ReW-C and one of Ni-C with 2d spacing of approximately 70 Å and 150 Å were tested at angles of incidence between 10° to 80°. Measurements were made by fixing the incident and reflected angles (Bragg) and scanning the photon energy. Theoretical analyses of these multilayers have also been made and the results are compared with the experimental measurements.

Introduction

Recent advances in thin film technology have made it possible to make multilayer structures with high reflectivity and moderate resolution in the soft x-ray domain. This development has led to considerable interest in using multilayer dispersion elements (MDEs) to construct new and useful x-ray optical elements.

As x-ray photons penetrate a multilayer structure, they encounter a spatially periodic array of scattering layers (alternate layers of high and low Z material). The photons coherently scatter from this periodic structure and Bragg diffraction occurs. The advantages of multilayer structures over natural crystals are that one can vary the constituent materials and period (effective 2d spacing) over a wide range and the coatings can be placed on arbitrarily figured surfaces.

The reflecting properties of multilayer structures are determined by the optical constants and spatial distribution of the constituent materials, by the sharpness of the boundaries between the layers, and by the number of reflecting layers.[1] Calculations based on the optical constants for a ReW-C system predict good performance in the soft x-ray region (100-500 eV) and measurements around 8000 eV have shown that it is possible to fabricate this system with sharp boundaries (effective roughness = 2 - 3 Å). A recent compilation of the soft x-ray optical constants[4] for Ni and C also predicts very good reflectivity for this multilayer system provided that the boundaries can be made sufficiently sharp.

We report here measurements of the reflectivity of these two system, ReW-C and Ni-C, between 80 and 500 eV and at angles of incidence between 10 and 80°. From these reflectivity measurements we also determine the resolving power of these multilayer systems.

Experiment

The ReW-C and Ni-C multilayers used in this experiment were fabricated by electron beam evaporation.[5] An in situ reflectometer with a BN target x-ray tube as a source ($\lambda_{K\alpha}$ = 31.6 Å or $\lambda_{K\alpha}$ = 67.6 Å) was used to continuously monitor the multilayer reflectivity during fabrication.[6] The intereference maxima and minima observed in the reflectivity allowed us to optimize the thickness of each layer. The ratio of the thickness of the constituent materials is such as to give the fastest increase in reflectivity with increasing number of layers. This approach produces a quasi-periodic structure where the thickness ratio of low Z to high Z material increases toward the surface of the multilayer structure. The performance of the MDEs has been calculated relying on tabulated optical constants,[4] assuming an ideal periodic structure, and ignoring dispersion across the diffraction peak. The calculation is based upon a procedure outlined by Born and Wolf.[8]

We measured the performance of these multilayer systems between 80 and 500 eV using a grazing incidence type monochromator at the Stanford Synchrotron Radiation Laboratory.[9] A refocusing mirror at the output of the monochrometer and an aperture inside the experimental chamber restricted the vertical beam divergence to 2 mrads. Five samples could be mounted in the ultra high vacuum chamber and aligned with precision vacuum feed through manipulators.

The measurements were performed by fixing the angle of the sample and detector and scanning the energy of the incident photon beam $I_o(E)$. S polarization was used in all measurements. The diffracted beam, I(E), was detected by a channel electron multiplier biased to prevent the detection of photon electrons. By removing the sample from the incident beam, $I_o(E)$ was measured with the same detector that measured I(E).

Results

The characteristic parameters and performance of the multilayers tested in this experiment are summarized in Table 1. Figures 1a, b, and c are examples showing the calculated reflectivity versus energy for three samples.

Table 1

System	d_1 (Å), d_2 (Å)	N_p	R_c	R_m	E(eV)	E/ΔE
Ni-C	32,44.5	16	0.11	0.11	100	14.[illegible]
Ni-C	32,44.5	16	0.22	0.15	174	14.[illegible]
Ni-C	32,44.5	16	----	0.23	205	15.[illegible]
Ni-C	32,44.5	16	0.35	0.25	250	14.7
ReW-C	24,51	16	0.14	0.09	93	[illegible]
ReW-C	24,51	16	0.12	0.05	112	[illegible]
ReW-C	14,26	64	0.18	0.09	160	64.0
ReW-C	14,[illegible]	64	0.20	0.08	165	77.0
ReW-C	14,26	64	0.12	0.07	406	[illegible].4

d_1 and d_2 are the effective thickness of heavy and light materials respectively.
N_p is the number of periods.
R_c and R_m are the calculated and measured reflectivity at the energy E.
ΔE is the energy half-width of the reflectivity curve.
E/ΔE is the resolving power.

The Ni-C system gives the highest measured reflectivities, up to 0.25. The results are within approximate 30% of the calculated value over the energy range from 100 to 250 eV. The best relelctivity measured in the ReW-C system was about 0.10. The measured results were about 50% of the calculated values over the energy range from 93 to 406 eV. Only measurements in energy ranges where the monochrometer output is smooth and no absorption edges interfere are included.

The diffraction curves provide a direct measure of the resolving power, E/ΔE, of the MLS. The present set of structures has been designed so that all the layers participate in the diffraction process below the carbon edge. The measurements indicate that the resolving power is about equal to the number of layer periods in the sample. This result agrees with simple theory and the calculations shown in Fig. 1 assuming full penetration of the sample. Above the carbon edge we expect an increase in absorption in the carbon in the MLS to cause a reduction in the number of layers that can contribute to the diffraction process. This effect is seen in the 64 layer ReW-C sample at 406 eV where E/ΔE << N_p. Calculations indicate that the higher order structure seen in the wings of several of the experimental profiles could be a result of the aperiodicity of the multilayer structures, i.e., the thickness of the layers varies with depth.

Conclusion

The reflectivity and resolving power of three sets of MDE's were measured. The measured resolving power of the MDE's agreed with the expected value based on the number of layer pairs in the sample. Calculations of the reflectivity are in approximate agreement with experiment although we note that the measured reflectivities are consistently somewhat lower. This could be due to the effects of interfacial roughness not accounted for in the calculation. Even so the measured MDE's reflectivities are among the highest recorded to date in the soft x-ray region.

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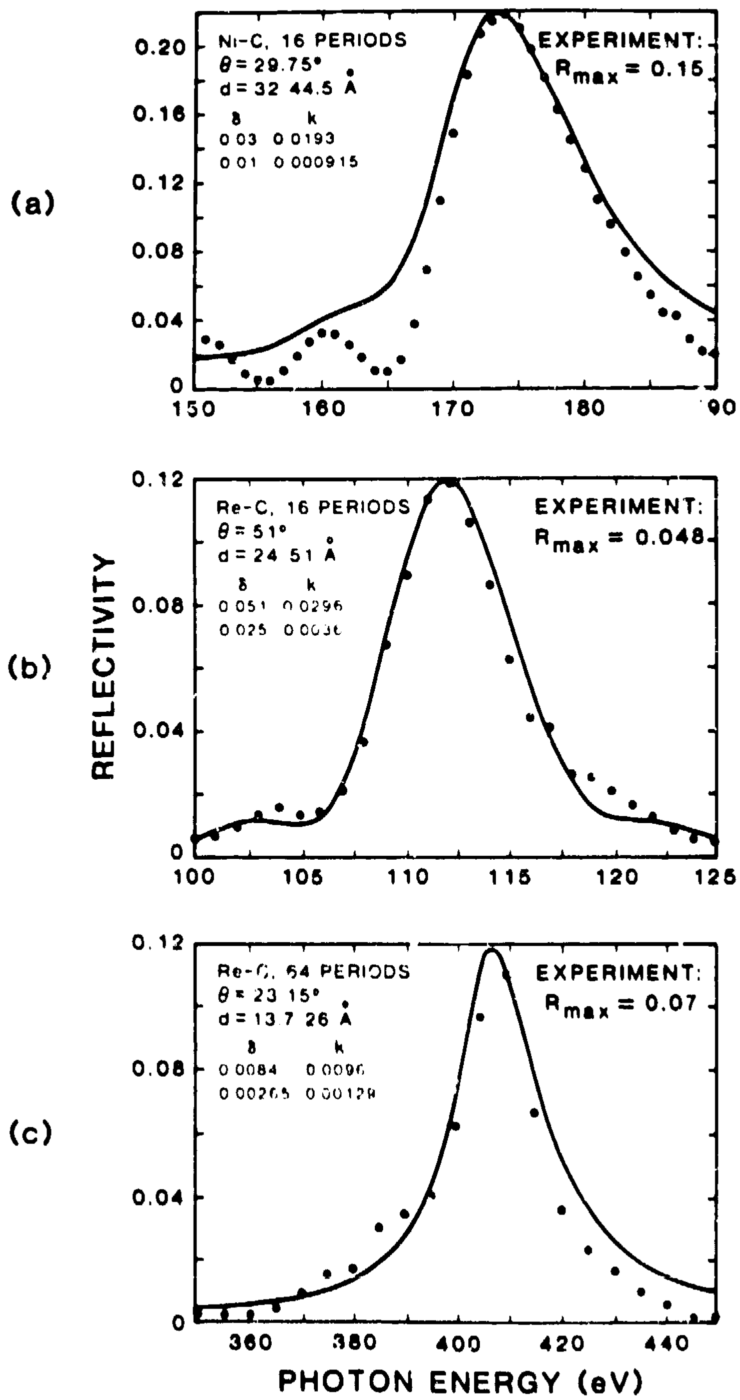

Figure 1. Reflectivity vs. energy for three MDEs. a) Ni-C with 16 periods, b) ReW-C with 16 periods, and c) ReW-C with 64 periods. The solid line represents the calculational result based on the layer thicknesses, d, and the optical constants, δ and k, at the angle θ for the MDE indicated. The ● represents the experimental results scaled to agree with the calculation at the peak. The measured peak reflectivity, R_{MAX}, is shown in each figure.