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X-RAY-DIFFRACTION PROPERTIES AND APPLICATIONS OF LAYERED
SYNTHETIC MICROSTRUCTURES IN THE 1- TO 10-ANGSTROM REGION

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X-RAY-DIFFRACTION PROPERTIES AND APPLICATIONS of LAYERED
SYNTHETIC MICROSTRUCTURES IN THE 1-TO 10-ANGSTROM REGION*

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ABSTRACT

Layered synthetic microstructures have been built and tested for use as medium-resolution x-ray diffraction monochromators, in the 1 to 10 angstrom wavelength region. They can be employed to good advantage in spectrometry and imaging instruments that are used to determine the nature of the x-ray emission of high-temperature plasmas. When the micro-structures are used in spectrometers, we find that they gather much more light than natural crystals and are not troubled by high order diffraction response, yet have better spectral resolution than that provided by spectrometer channels formed by Ross filter or filter/fluorescer techniques. For use in imaging instruments such as the grazing-incidence reflection Kirkpatrick-Baez microscope microscope, the microstructures provide high reflectivity at wavelengths shorter than the practical limit of total external reflection. We will present calibration data that describes the diffraction properties and piece-to-piece uniformity of microstructures built especially for use in the 1 to 10 angstrom region. We will also describe in detail two instruments that will be used at the Shiva laser system to determine the spectral and spatial distributions of x-rays radiated by inertial confinement fusion targets.

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1. INTRODUCTION

The layered synthetic microstructure (LSM) is a man-made x-ray interference mirror built by vapor desposition techniques. Alternating thin layers of high and low z elements are deposited on a smooth substrate. The current state-of-the-art allows layer thicknesses as small as 7 Å to be deposited. An LSM that has been found to be useful for x-ray spectroscopy in the 1-10 Å region consists of a stack of from 60 to 250 layer pairs built up on a silicon single-crystal substrate, where each pair contains a layer of tungsten and of carbon. The LSM typically has high x-ray reflectivity (peak reflectivities in the 30-50% range) and medium spectral resolution ($\frac{E}{\lambda E}$ of the order of 30-100). The LSM is stable and durable, and single pieces can be as large as several tens of cm². The unique properties and applications of the LSM in the 1-10 Å region are:

1) the x-ray dispersion properties of the LSM can be controlled by the construction and composition of the structure,

2) higher-order diffraction response can be suppressed by specific fabrication techniques,

3) when used in spectrometers and monochromators, the LSM collects more light than natural diffraction crystals and has better spectral resolution than that obtained with channels defined by Ross filter techniques, and

4) the LSM can be built on curved substrates, allowing it to be used as an x-ray optic element at wavelengths less than the practical limit for total external reflection ($\lambda < 4$ Å).

We will describe experimental measurements of the response of an LSM built specially for use in the 1-10 Å region and describe two instruments that will use this structure for spectroscopy and imaging of laser-irradiated targets.

EXPERIMENTAL MEASUREMENTS

The LSM samples tested for this work were tungsten/carbon structures consisting of 138 Å layer pairs, built on 1" x 3" silicon single-crystal substrates. Each layer of both elements was nominally 11.0 Å thick. We expected from the kinematic theory that predicts the diffraction behavior of an LSM that building the structure with equal layer thicknesses would suppress even-order responses. The first-order dispersion of the LSM is controlled by the Bragg condition: $\lambda = 2d \sin \theta$, for a

grazing angle of incidence θ . For our samples, d is the layer-pair thickness, equal to 22 Å.

Experimental measurements were taken using a vacuum diffractometer fitted with a Henke demountable x-ray tube. A Si(Li) detector monitored the spectra incident on and reflected by the LSM sample. The x-ray beam was collimated to one-arcminute in the plane of dispersion by widely-spaced fine slits. The x-ray tube was fitted with a titanium anode, so that the spectral region between 5 and 14 keV would be continuous.

The procedure for obtaining reflection efficiency data consisted of rotating the sample so that the x-ray beam struck it at a particular angle of incidence θ in the range from 1° to 2° . At each value of θ , a spectrum of the reflected beam was taken. The reflection efficiencies were calculated by dividing the reflected spectra by an incident spectrum recorded when the LSM sample was removed from the diffractometer.

Four samples, nominally identical, were tested and found to have the same response, within experimental error. No higher-order diffractions were observed, and the average d -spacing was 22.6 ± 0.2 Å. The average resolving power of the samples

$$\frac{E}{\Delta E} = 42.2 \pm 2.3 \text{ over the photon energy range from 7 to 13 keV.}$$

Tabulated below are typical peak and integrated reflectivities observed for these samples. These data show that the LSM samples are quite efficient in this energy region, with only a minor decrease in reflectivity at energies just above the tungsten L_{III} edge.

LSM SPECTROMETER

An x-ray spectrometer, using LSMs for channel definition, has been designed and is being built for use at the Shiva laser facility. This instrument is designed to measure the level of the x-ray continuum radiation emitted by laser-irradiated targets. Two channels are provided, at 8 and 11 keV, by allowing well-collimated beams to strike the LSMs at 2.0° and 1.4° , respectively. The radiation reflected from the structures falls on plastic scintillator/photomultiplier tube detectors.

X-RAY MICROSCOPE LENSES

For the purpose of imaging the sources of monochromatic radiation emitted by laser-irradiated targets, we plan to use Kirkpatrick-Baez microscope lens elements as the substrates for LSMs. For example, the line radiation of highly-ionized nickel

(Helium-like) will be imaged with a 22.5 Å d-spacing LSM built up on a lens substrate. For this application, the LSM's will have rather poor resolution ($\frac{E}{\Delta E}$ of the order of 20) so that the instrument can better tolerate misalignment of the source and optics. We have found that the surface smoothness required for good LSM fabrication (15 Å rms roughness) can be achieved for the figured lenses using available techniques.

TABLE

Reflection Efficiency of a Tungsten/Carbon LSM

x-ray energy (keV)	peak reflectivity	integrated reflectivity (keV)
7.6	.389	.109
9.2	.441	.140
10.5	.296	.116
11.5	.296	.130
13.1	.305	.159

NOTES

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