1998 SUMMER RESEARCH PROGRAM FOR HIGH SCHOOL JUNIORS

AT THE

UNIVERSITY OF ROCHESTER'S

LABORATORY FOR LASER ENERGETICS

STUDENT RESEARCH REPORTS

PROJECT COORDINATOR

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Laboratory Report 300

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University of Rochester
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During the summer of 1998, 11 students from Rochester-area high schools participated in the Laboratory for Laser Energetics' Summer High School Research Program. The goal of this program is to excite a group of high school students about careers in the areas of science and technology by exposing them to research in a state-of-the-art environment. Too often, students are exposed to “research” only through classroom laboratories that have prescribed procedures and predictable results. In LLE’s summer program, the students experience all of the trials, tribulations, and rewards of scientific research. By participating in research in a real environment, the students often
become more excited about careers in science and technology. In addition, LLE gains from the contributions of the many highly talented students who are attracted to the program.

The students spent most of their time working on their individual research projects with members of LLE's technical staff. The projects were related to current research activities at LLE and covered a broad range of areas of interest including optics, spectroscopy, chemistry, diagnostic development, and materials science. The students, their high schools, their LLE supervisors and their project titles are listed in the table. Their written reports are collected in this volume.

The students attended weekly seminars on technical topics associated with LLE's research. Topics this year included lasers, fusion, holography, nonlinear optics, global warming, and scientific ethics. The students also received safety training, learned how to give scientific presentations, and were introduced to LLE's resources, especially the computational facilities.

The program culminated with the High School Student Summer Research Symposium on 26 August at which the students presented the results of their research to an audience that included parents, teachers, and members of LLE. Each student spoke for approximately ten minutes and answered questions. At the symposium an Inspirational Science Teacher award was presented to Mr. David Crane, a chemistry teacher at Greece Arcadia High School. This annual award honors a teacher, nominated by alumni of the LLE program, who has inspired outstanding students in the areas of science, mathematics, and technology.
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<th>High School</th>
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A total of 91 high school students have participated in the program since it began in 1989. The students this year were selected from approximately 60 applicants. Each applicant submitted an essay describing their interests in science, a copy of their transcript, and a letter of recommendation from a science or math teacher.

LLE plans to continue this program in future years. The program is strictly for students from Rochester-area high schools who have just completed their junior year. Applications are generally mailed out in February with an application deadline near the end of March. For more information about the program or an application form, please contact Dr. R. Stephen Craxton at LLE.

This program was supported by the U.S. Department of Energy Office of Inertial Confinement Fusion under Cooperative Agreement No. DE-FC03-92SF19460.
INVESTIGATION OF THE X-RAY DIFFRACTION PROPERTIES
OF A SYNTHETIC MULTILAYER

by

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Investigation of the X-Ray Diffraction Properties of a Synthetic Multilayer

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1998 Summer High School Program

Abstract

In this investigation spectroscopy was used to evaluate the x-ray diffraction properties of a synthetic WB₄C multilayer for possible use in the OMEGA gated monochromatic x-ray imager (GMXI). The multilayer was placed on a diffractometer, and measurements were made with a lithium-drifted silicon [Si(Li)] x-ray detector, connected to a multi-channel analyzer. The properties of the multilayer were inferred from gaussian fits to the measured diffraction curves. A multilayer with a 2d spacing of 25Å was tested at energies from 1.7 to 4.5 keV.

Introduction

X rays are high-energy electromagnetic waves of wavelength 10² to 10³ Å and corresponding energies per photon of 10² to 3x10⁶ eV. Characteristic line emission is produced when electrons make transitions from higher to lower energy levels. X ray production in the laboratory involves the bombardment of targets by an electron beam (e-beam). The electrons are ejected by thermionic emission from a resistively heated semiconductor filament and accelerated by an electric field to a specified energy. The final energy corresponds to the high voltage setting of the accelerating supply (e.g. 10keV for 10 kV). The e-beam is steered by an electromagnet to the target. The electron path is curved and thus filament debris is filtered out of the e-beam. The collisions eject inner shell electrons of the target, leaving a vacancy. Subsequent transitions to lower shells result in the emission of x rays. The energy of such x rays is characteristic of their originating transition. A transition from the L-shell to the K shell results in Kα radiation; a transition from the M shell to the K shell produces Kβ
radiation. Although x rays produced by inner shell transitions are at a well defined energy, additional processes yield a continuum of x rays which must be separated from the line emission in experiments.

The x-ray diffraction is dependent on both the layering of the diffractor and the wavelength of the incident x rays. When an x-ray beam impacts a crystal the scattering of radiation is dependent on the angle at which the beam hits the crystal surface. The resulting scattered x rays form constructive or destructive interference. The angle at which a diffracted beam of x rays will have the highest intensity is given by Bragg’s law:

$$n\lambda = 2d \sin \theta$$  \hspace{1cm} (1)

where $n$ is the order of diffraction, $\lambda$ is the wavelength of x rays, $d$ is the distance between the consecutive layers of a diffractor, and $\theta$ is the incident angle.

This work deals with a WB$_4$C synthetic multilayer diffractor which consists of alternating layers of tungsten and boron carbide on a substrate of silicon. The approximate distance between the layers is 12.5 Å. The multilayer was manufactured by OSMIC Inc. The diffraction curve is of a finite width, much less than 1°, and is best represented graphically by a Gaussian curve. The multilayer reflectivity ranges from ~5% to ~50%. The multilayer diffractor was evaluated for possible use in the gated monochromatic x-ray imager (GMXI) on the OMEGA laser system.

**Experiments**

Multilayer spectroscopy involves the analysis of an x-ray beam which is diffracted off of the multilayer, specifically its energy in relation to its angle of impact. The x rays are produced by a tungsten electron source and various target plates, including Ti, Al, Si, Mo, CaF, and Ag.

For accurate determination of the multilayer angular response the collimated x-ray beam must be nearly parallel. The angular dispersion of a collimator is given by:
\[ \theta = 2 \tan^{-1}(a/d_c) \] (2)

where \( a \) is the aperture size and \( d_c \) is the distance between the slits (Figure 1).

![Collimation Schematic](image)

**Fig. 1** Schematic of Collimator

The beam is collimated to a dispersion angle of less than 0.01° by two ~200\(\mu\)m slits positioned ~2.43m apart. The side of the collimator closest to the target was in vacuum with the x-ray source, while the exit side of the collimator was outside of the vacuum system. An x-ray transparent, vacuum window separated the two ends of the collimator. X-ray attenuation was minimized by placing a plastic bag over the diffractometer and detector and then flushing the interior volume with He gas in a high vacuum chamber. The collimator slits were aligned, by reflecting a HeNe laser off of a mirror into the main vacuum chamber; the laser beam passed through the slits which were adjusted to be parallel to each other and the table upon which the diffractometer was placed.

After collimation, the x-ray beam is incident on the multilayer crystal which is positioned on the diffractometer. The diffractometer consists of two concentric rotary tables driven by stepper motors positioned on top of a linear table (Figure 2). The upper turret turns the multilayer, while the lower turret turns a metal arm, which holds the Si(Li) detector. The detector is thus set up to allow the x rays, incident on the crystal to rotate in angle for the determination of the optimum angle of diffraction as defined by Bragg's law. For every degree \( \theta \) that the crystal turns, the detector must turn 2\(\theta \).
To align the diffractometer with the x-ray beam, the stepper motors are each made to move through a number of steps, during which time the rate of photons absorbed by the detector is recorded by the terminal. The count rate, which is proportional to the position of the detector and the multilayer, is used to determine the optimum positioning of the crystal and detector. For rotational positioning, the optimum position produced the maximum count rate; for lateral positioning, the optimum position was at half of the maximum count rate.

The diffracted x-ray beam is recorded by a Si(Li) detector. In order to minimize electronic noise, the detector must be cooled by liquid nitrogen. X rays detected by the Si(Li) detector are recorded by a multichannel analyzer (MCA) and output in the form of a histogram (spectrum) of the number of incident photons of various energies (keV). When interpreting output various emission lines such as Kα, Kβ, and Lα lines are analyzed. The characteristic emission lines are discernable as peaks in the spectra.

The multilayer was tested at the energies of the emission lines listed in Table 1. To interpret the data in terms of its peak intensity, standard deviation, full width half maximum, and reflectivity, a
Gaussian curve is fit to the calculated reflectivity data of each line by the Scientist™ curve fitting program using a least squares fitting algorithm, the equation for which is as follows:

$$R = R_p \exp\left(-\frac{(\theta - \theta_0)/\sigma}{2}\right), \quad \sigma = \frac{\Delta \theta_{FWHM}}{2\ln 2}$$  \hspace{1cm} (3)

where $R$ is the reflectivity at a particular energy, $R_p$ is the peak intensity, $\theta$ is the angle, $\theta_0$ is the peak angle, $\sigma$ is the standard deviation, and $\Delta \theta_{FWHM}$ is the full width half maximum. Integrated reflectivity was calculated using the following equation:

$$R_c = R_p \cdot \sigma \cdot (\pi)^{1/4}$$  \hspace{1cm} (4)

where $R_c$ is the integrated reflectivity. The offset angle was calculated to be 0.1143° for Mo Lα and, because of readjustment, was recalculated to be 0.1951° for the other emission lines. The offset angle was calculated by using the Mo Lα and Si Kα lines and the following equation:

$$\frac{\lambda_{Si}}{\lambda_{Mo}} = \frac{\sin(\theta_{Si} - \theta_{off})}{\sin(\theta_{Mo} - \theta_{off})}$$  \hspace{1cm} (5)

where $\lambda$ is the wavelength of the emission line, $\theta$ is the observed peak angle, and $\theta_{off}$ is the offset angle. By using the offset angle and the Bragg equation in relation to a specific emission line, the actual 2d spacing of the multilayer was calculated to be 26.53 Å.

**Results**

The results of measurements of the multilayer reflectivity at each emission line given in Table 1 are shown as graphs in Figures 3(a-e). For comparison, the measurement of the Ti Kα LiF reflectivity is shown as a graph in Figure 3f. The best fit Gaussian curves are shown as solid lines and the measured data points are shown as open symbols. Summaries of the best fit values of $R_p$, $\Delta \theta_{FWHM}$, and $R_c$ are given in Table 1. These best fit values versus energy are shown in Figures 4(a-c).

To relate the angular offset of the system to a known angular position of another crystal, a Ti Kα line was diffracted off of a LiF crystal using the same setup. The results of the Gaussian fit were within predicted limits and are presented in Table 1.
Conclusions

The results proved accurate and statistically valid. The multilayer is a highly reflective diffractor for energies of ~1.7 to ~4.5 keV; therefore the observed and calculated data can be used as the foundation for further work with the W/B₄C multilayer.
Acknowledgements
I would like to thank Thomas Ohki, who instructed me through all of the x-ray experiments, and Dr. Frederic Marshall for their guidance, patience and interest in the project. Additionally, I would like to thank the LLE staff, Dr. R. Stephen Craxton for welcoming me into the program, and the Laboratory for Laser Energetics. Special thanks goes to my high school science and math teachers who taught me to aspire to greater heights: Mr. Stephen Whitman, Mrs. Deborah Reynolds, and Mr. Kevin Hanna.

References
Figures 3(a-e): WB₄C multilayer diffraction curves for Si Kα (1.740 keV), Mo Lα (2.292 keV), Ag Lα₁ (2.984 keV), Ca Kα (3.690 keV), Ti Kα (4.509 keV). For comparison Figure 3f shows the graph of Ti Kα diffracted off of a LiF crystal.
Gaussian Fit of Mo Lα Reflectivity

Figure 3b.
Gaussian Fit of Ag Lα Reflectivity

Figure 3c.
Gaussian Fit of Ca K\textsubscript{α} Reflectivity

Figure 3d.
Gaussian Fit of Ti Kα Reflectivity

Figure 3e.
Gaussian Fit of Ti Kα Reflectivity, LiF (200)

Figure 3f.
X-Ray Diffraction Properties of Synthetic WB₄C Multilayer Crystal

<table>
<thead>
<tr>
<th>Line</th>
<th>E (keV) ¹</th>
<th>λ (Å)</th>
<th>θ₀ (deg)</th>
<th>R₀ (%)</th>
<th>FWHM (deg)</th>
<th>Rₑ (mrad)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si Kα</td>
<td>1.740</td>
<td>7.127</td>
<td>15.5x84</td>
<td>15.658</td>
<td>0.055</td>
<td>0.161</td>
</tr>
<tr>
<td>Mo Lα</td>
<td>2.292</td>
<td>5.410</td>
<td>11.766</td>
<td>5.263</td>
<td>0.078</td>
<td>0.076</td>
</tr>
<tr>
<td>Ag Lα1</td>
<td>2.984</td>
<td>4.155</td>
<td>9.011</td>
<td>11.617</td>
<td>0.063</td>
<td>0.135</td>
</tr>
<tr>
<td>Ca Kα</td>
<td>3.690</td>
<td>3.360</td>
<td>7.276</td>
<td>26.573</td>
<td>0.044</td>
<td>0.219</td>
</tr>
<tr>
<td>Ti Kα</td>
<td>4.509</td>
<td>2.750</td>
<td>5.950</td>
<td>45.016</td>
<td>0.033</td>
<td>0.276</td>
</tr>
<tr>
<td>Ti Kα, LiF (200)</td>
<td>4.509</td>
<td>2.750</td>
<td>43.077</td>
<td>14.149</td>
<td>0.159</td>
<td>0.418</td>
</tr>
</tbody>
</table>

Table 1: Summary of results for WB₄C multilayer diffractor. Result with LiF crystal at Ti Kα is shown in last row.
Figures 4(a-c): Best fit values of $R_p$, $\Delta \theta_{FWHM}$, and $R_c$ versus energy for WB$_4$C multilayer
Full Width Half Maximum vs. Energy

Figure 4b.
Line Energy vs. Integrated Reflectivity

Figure 4c.