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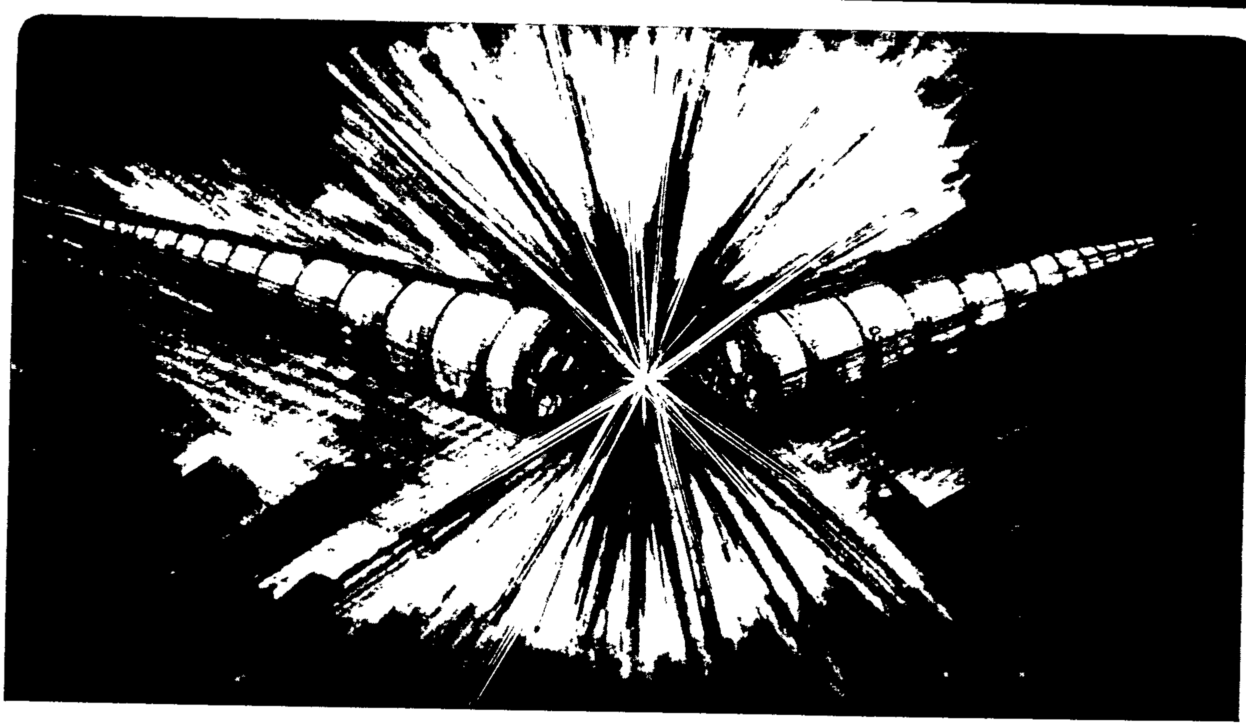

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Design and Performance of the ALS Double-Crystal Monochromator

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Abstract

A new "Cowan type" double-crystal monochromator, based on the boomerang design used at NSLS beamline X-24A, has been developed for beamline 9.3.1 at the ALS, a windowless UHV beamline covering the 1-6 keV photon-energy range. Beamline 9.3.1 is designed to simultaneously achieve the goals of high energy resolution, high flux, and high brightness at the sample. The mechanical design has been simplified, and recent developments in technology have been included. Measured mechanical precision of the monochromator shows significant improvement over existing designs. In tests with x-rays at NSLS beamline X-23A2, maximum deviations in the intensity of monochromatic light were just 7% during scans of several hundred eV in the vicinity of the Cr K edge (6 keV) with the monochromator operating without intensity feedback. Such precision is essential because of the high brightness of the ALS radiation and the overall length of beamline 9.3.1 (26 m).

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Introduction

Third-generation synchrotron-radiation sources provide a unique opportunity for advancements in x-ray spectroscopy of atoms, molecules, and solids, owing to the high brightness available.[1] In order to take full advantage of this opportunity, a stable monochromatic x-ray beam is required, which in turn requires a high-precision mechanism for scanning photon energy with the monochromator. This challenge is exemplified in beamline 9.3.1 at the Advanced Light Source (ALS), a windowless beamline covering the 1-6 keV photon-energy range designed for use by the ALS x-ray atomic and molecular spectroscopy program. Beamline 9.3.1 is designed to achieve the goals of high energy resolution and high flux as well as to preserve the high brightness of the ALS source radiation. Design details of this beamline are presented elsewhere.[2]

In order to maintain high brightness at a distant sample while scanning the photon energy, it is desirable to have the monochromator mechanism as precise as possible. For spectroscopy applications, in fact, it is best to operate the monochromator without the usual intensity feedback system to eliminate any possible intensity variations induced by the feedback circuit. In addition, even small feedback corrections can alter the path of the beam through the optical system of the beamline, leading to changes in image quality at the sample. This desire for feedback-free running necessitates the use of a mechanical linkage in the monochromator mechanism. In order to attain the high precision necessary, it also is desirable to have as simple a drive mechanism as possible. Hence, the boomerang design[3,4] used at beamline X-24A at the National Synchrotron Light Source (NSLS), in which a single linear motion actuates scanning of the monochromator, was taken as a model. An added benefit of this design is that it readily accomodates operation at low photon energies [e.g., near 2 keV with Si(111) crystals].

Performance of the beamline X-24A monochromator mechanism has been documented.[4] Photon-energy scanning is accomplished from outside vacuum by a single linear motion with 15 cm of total movement. One benchmark for measuring the performance of this device is the degree of non-parallelism, in the dispersion plane, of the two monochromator crystals as a function of this linear motion. Measurements on the original mechanism before it was placed in beamline X-24A exhibited an error of approximately 2 arcsec/cm of linear travel. In practice, actual results were a little worse (4 arcsec/cm of linear travel).[5] Nevertheless, as far as we know, this is as good or better than other existing mechanisms.

Design of the ALS Double-Crystal Monochromator

The basic design principles[6] of the new and improved "Cowan type" monochromator are identical to the original design,[3] but several significant enhancements have been introduced. The primary change is the removal of all bearings from the mechanism, particularly the crossed-roller bearings used in the original design. Movement of the crystal mounts along the boomerang arms as well as all other linear motions use dovetail slides made of aluminum/bronze sliding on bases made of 304 stainless steel, with both surfaces treated chemically with a vacuum-compatible lubricant. This combination of materials is known not to seize even in ultra-high vacuum, and the hardness of the materials permits high-precision repetitive motion. We believe that replacement of the crossed-roller bearings is the primary reason for improved performance of the new design relative to the original.

Other design modifications include a significant reduction in the number of parts and use of more robust components. Reduction in the number of parts was accomplished by eliminating the crossed-roller bearings, by eliminating unneeded adjustments in the mechanism,[5] and by consolidating multiple pieces into integrally machined components wherever possible. Photograph of the assembled monochromator including the crystal mounts in the small angle configuration is shown in Fig.1. Robustness was achieved simply by making many parts heavier or larger or using ribs for added strength in some larger components. Ease of alignment also has been enhanced by liberal use of fiducial marks throughout the mechanism, its support base, and the monochromator vacuum chamber. Finally, all precision parts were machined using numerically controlled techniques with specially prepared and matched machine tools. This latter effort was necessary to guarantee precise mating of the dove-tail slides.

Performance of the Monochromator

To test the precision of the monochromator while scanning, a bench-top approach was used. A two-axis auto-collimator was aligned (< 1 arcsec) with respect to a right-angle mirror. The monochromator, equipped with mirrors in place of the two crystals, was positioned between the right-angle mirror and the auto-collimator with the axis of its linear motion parallel (10–20 arcmin) to the axis of the auto-collimator. As the monochromator is scanned, angular misalignments between the two mirrors riding on the mechanism, both parallel (theta) and perpendicular (chi) to the diffraction plane, can be measured using the auto-collimator.

Results of this test illustrate that the desired precision in theta has been met. For example, over 15 cm of linear travel in the boomerang mechanism, the two crystals (mirrors) remain parallel to within 10 arcsec. This is at least 3 times better than the original design for the same amount of linear motion.[4,5] In addition, the change in angle is smooth and monotonic over this range. Over the entire range of motion of the new boomerang (23 cm), performance degrades by a factor of 2. Additional adjustment and testing is underway to improve these results.

Tests with x–ray synchrotron radiation were performed at beamline X–23A2 at the NSLS. Absorption spectra at the Cr and Ti K edges taken with the new mechanism are shown in Figs. 2–3. These results agree very well with standard spectra at these edges. Both measurements were taken with unfocused synchrotron radiation, thus only providing a test of theta alignment. Nevertheless, these spectra were recorded with the piezoelectric feedback system turned off, and the measured monochromatic flux varied by only 7–10% over the photon–energy ranges of the scans.

Summary

Beamline 9.3.1 at the ALS is a windowless beamline, covering the 1–6 keV photon–energy range, designed to achieve the goals of high energy resolution, high flux, and preservation of the high brightness from third generation synchrotron radiation sources like the ALS. For atomic and molecular spectroscopy experiments, a stable monochromatic x–ray beam is required. Hence, the beamline has to be equipped with a suitable monochromator. A double-crystal monochromator based on the boomerang design used at NSLS Beamline X-24A has been developed for this beamline. The measured mechanical precision of this new "Cowan type" monochromator shows significant improvement over existing designs, without having to use intensity feedback available with piezoelectric devices. In tests with x-rays, this new mechanism provided monochromatic light with an intensity variation of as little as 7% over several hundred eV in photon energy near the Cr K edge without feedback. We are confident that this monochromator will provide a bright, high resolution, and stable x-ray beam for use in x-ray spectroscopy at the ALS.

Acknowledgments

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Figure Captions

Fig. 1 Photographs of the assembled unit, including the crystal mounts in the small and large angle configurations.

Fig. 2 Chromium K absorption spectrum measured without using an intensity feedback system.

Fig. 3 Titanium K absorption spectrum measured without using an intensity feedback system.

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3. J.A. Golovchenko, R.A. Levesque and P.L Cowan, Rev. Sci. Instr. **52** , 509 (1981).

4. P.L. Cowan, J.B. Hastings, T. Jach, and J.P. Kirkland, Nucl. Instr. and Meth. **208**, 349 (1983).

5. P.L. Cowan (Private communication).

6. A right–angle linkage system (references 3 and 4) was used to avoid the difficulties of independently manipulating the six degrees of freedom for two crystals in vacuum while maintaining the crystals Bragg planes parallel (within a rocking curve width) to each other, as the monochromator is scanned. This is necessary to provide a spatially constant and high throughput beam throughout the full energy range.

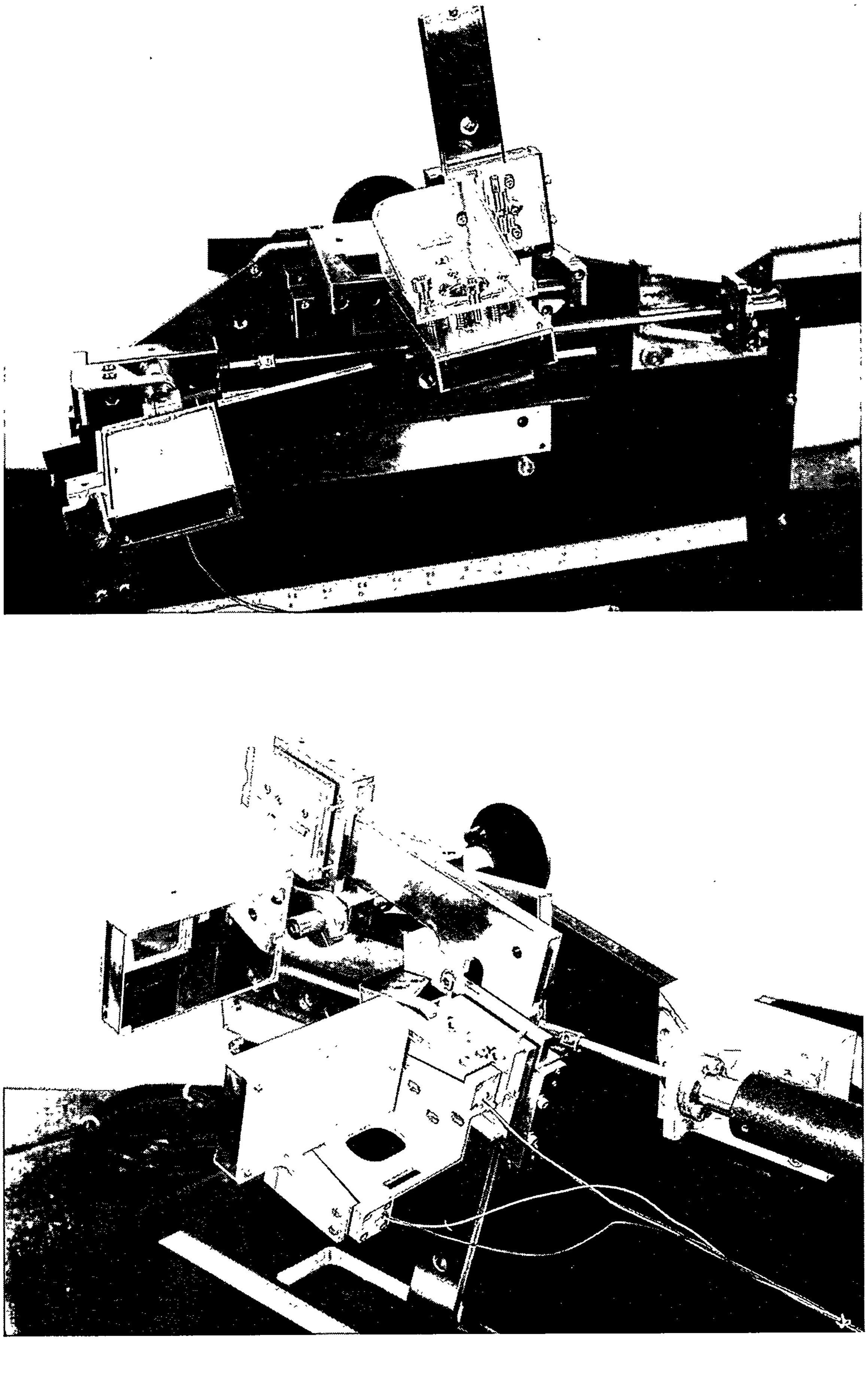


Fig 1

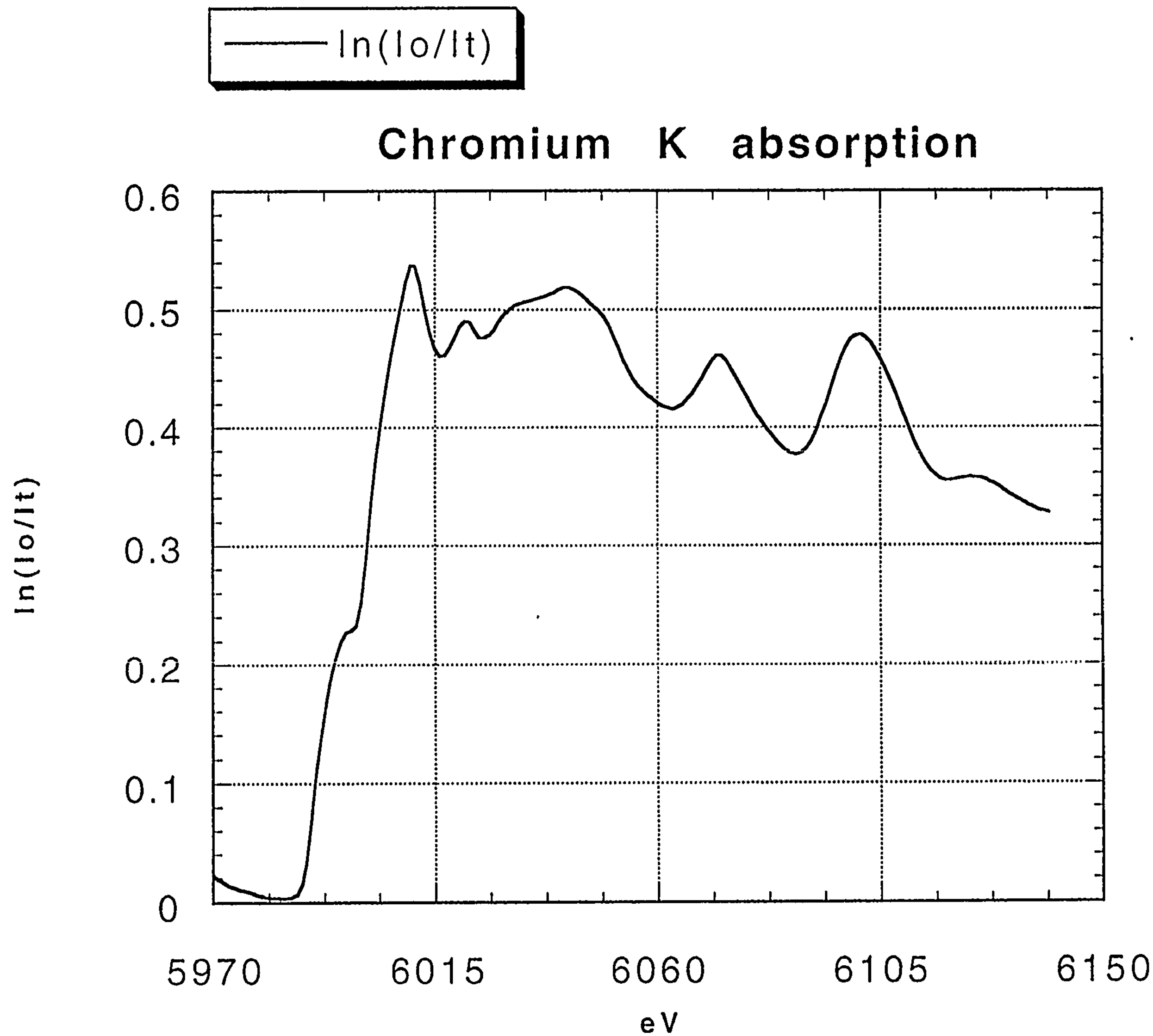
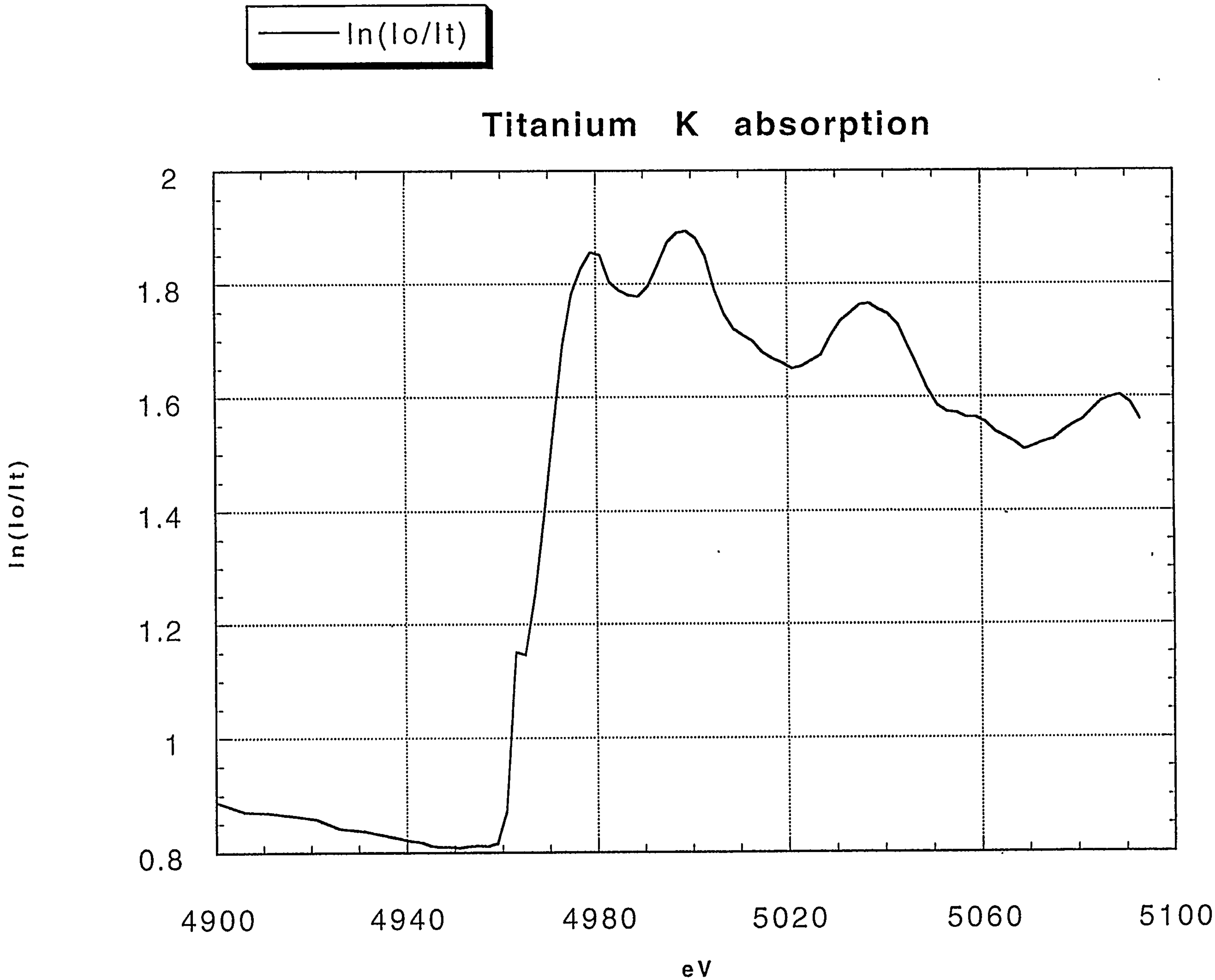

ln(Io/It)
Chromium K absorption
0.6
0.5
0.4
0.3
0.2
0.1
0
ln(Io/It)
5970
6015
6060
6105
6150
eV

Fig. 2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1.6
1.4
1.2
1
0.8
ln(Io/It)
4900
4940
4980
5020
5060
5100
eV

Fig. 2