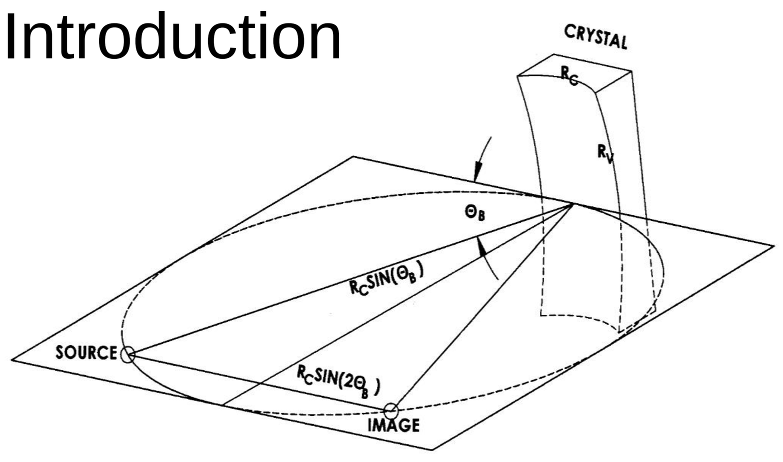
Curved Crystal Assemblies for X-ray Focusing

Introduction



Configuration Showing the Focusing Geometry of an Elliptically Bent Crystal.

Diffracted X-rays Satisfy the Bragg Condition: $n\lambda = 2d \sin(\theta_B)$

Inrad Optics curved crystal x-ray assemblies consist of a high precision curved backing with thinned high-quality crystals optically contacted to the surface. The lack of adhesive in the assembly results in excellent conformation of the crystal to the desired shape. Inrad Optics has manufactured spherical, ellipsoidal, and other aspheric shaped assemblies. In the configuration shown to the left the crystal is bent into an ellipsoidal shape, hence it has two foci and is suitable for imaging.

Crystal optics of this sort are typically used with hard x-rays and are used to capture x-rays over an angular range of several degrees – divergent x-rays. These optics are highly curved, with sags measured in mm.

Applications

X-Ray Photoelectron Spectroscopy, XPS

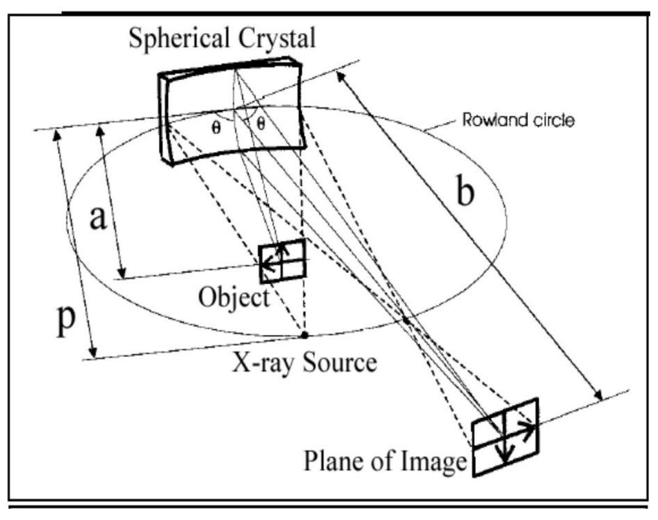
In this application, an electron beam is focussed onto a target to create x-rays, located at one of the foci of the ellipsoid. The x-ray monochromator images the x-ray source onto a sample-under-test (SUT) to be analyzed, located at the other focal point of the ellisoid. Monochromatic imaging leaves all of the debris generated at the source behind, transferring only the x-rays onto the SUT. By analyzing the energy of the electrons ejected from the source, the nature of the material can be analyzed – in terms of elemental composition, as well as, in some cases material thickness and uniformity.

SELECTED CRYSTAL PLANES

Crystal	Plane	2d
α-Quartz	(5052)	1.623 Å
	(3035)	1.719 Å
	(2243)	2.024 Å
	(2023)	2.749 Å
	(1120)	4.913 Å
	(1011)	6.687 Å
	(1010)	8.509 Å
Germanium	(400)	2.829 Å
	(220)	4.000 Å
	(111)	6.532 Å
Silicon	(840)	1.214 Å
	(220)	3.840 Å
	(111)	6.271 Å

Backlighter Plasma Imaging

The diagram below shows the scheme for using x-rays, generated by a laser impinging on a target, to image an object, in this example, it is a fusion fuel pellet. The laser-driven x-ray source is located at one focal point, the expanding x-rays pass by the fuel pellet, and are imaged through the other focal point of the ellipse, and observed on an image plane.



Concept Proposed in mid-1990s.

S.A. Pikuz, *et al*, Rev. Sci. Instrum. 68, 740 (1997)

A 1.865 keV backlighter built at NRL

Y. Aglitsky *et al*. Rev. Sci. Instrum. 70, 530 (1999)

Crystal imaging techniques proposed for microscopy/backlighting on NIF

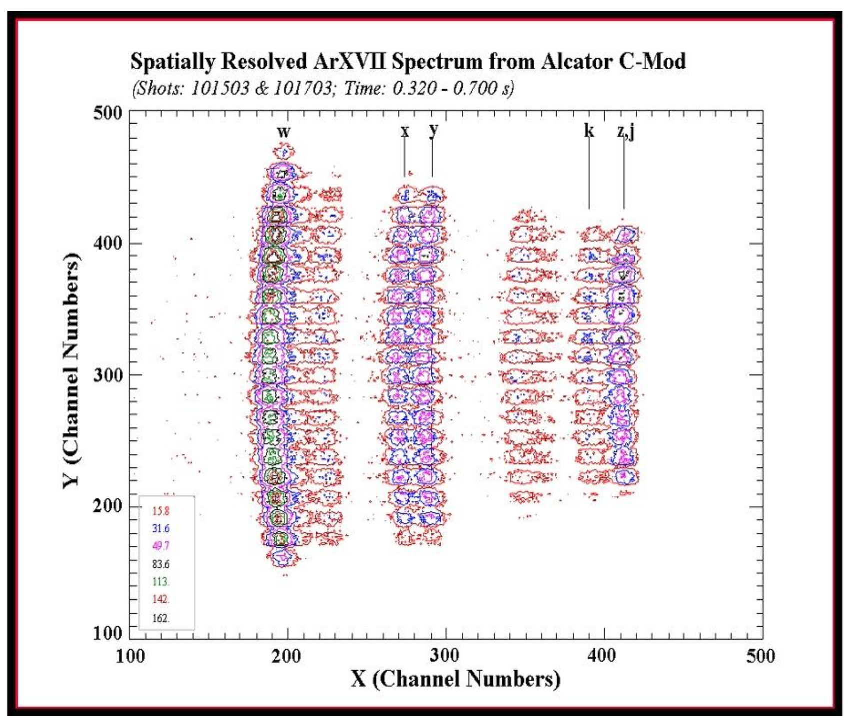
J.A. Koch *et al*. Rev. Sci. Instrum. 70, 525 (1999)

1.865 and 6.151 keV diagnostics successfully implemented on Z-facility

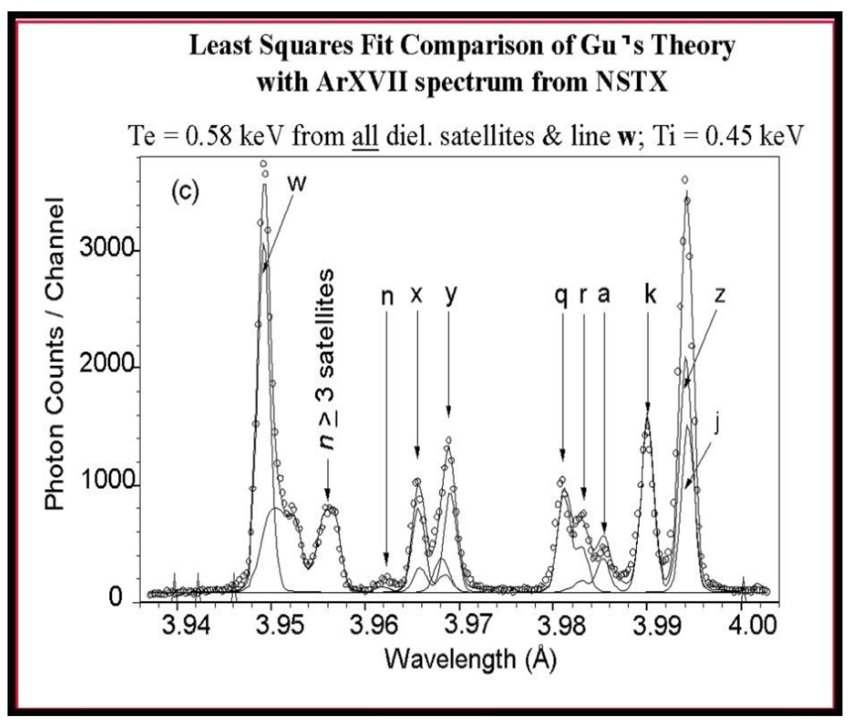
D.B. Sinars *et al*. Rev. Sci. Instrum. 75, 3672 (2004)

Spectroscopy

Here, the curved crystal is used as a monochromator to provide spatial information for emitting plasma species. This is made possible by a combination of the imaging and monochromatic properties of the curved crystal.



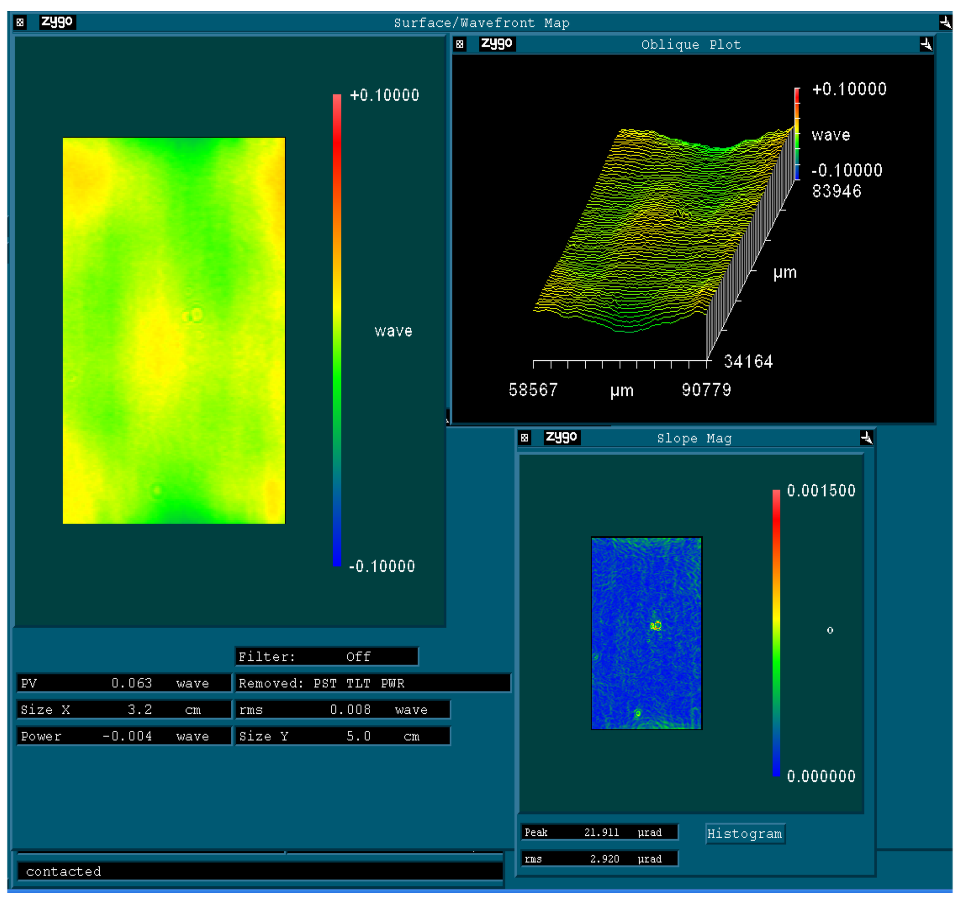
Spatially resolved spectra of He-like Argon from an ALCATOR C-MOD tokamak plasma. Same spherically bent crystal as at right.

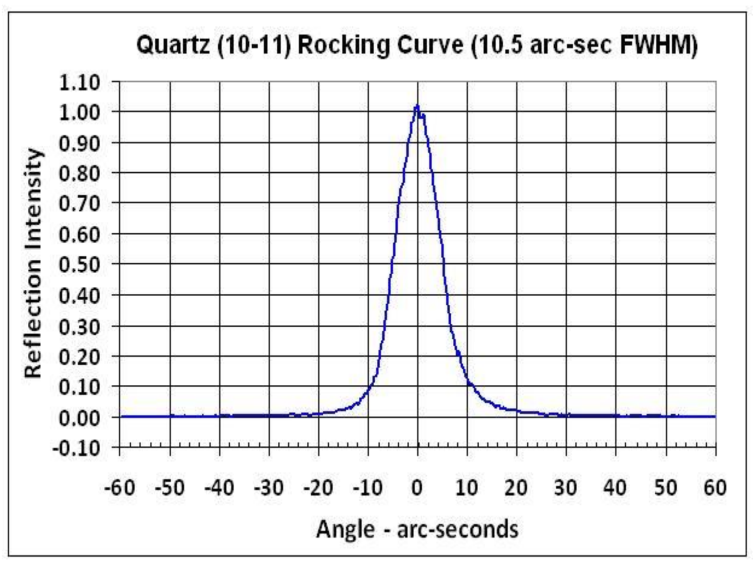


Spectrum of He-like argon from an NSTX tokamak plasma. 100 mm diameter quartz (11-20) crystal with 3888 mm radius of curvature.

Manufacturing and Metrology

Inrad Optics employs visible laser interferometry to measure surface irregularity and slope error of the backing during processing and adjust our manufacturing techniques to produce the best result. For the 50 mm by 30 mm optical surface shown below, the irregularity is less than 0.1 waves at 632 nm, and the slope error is less than 6 μrad.

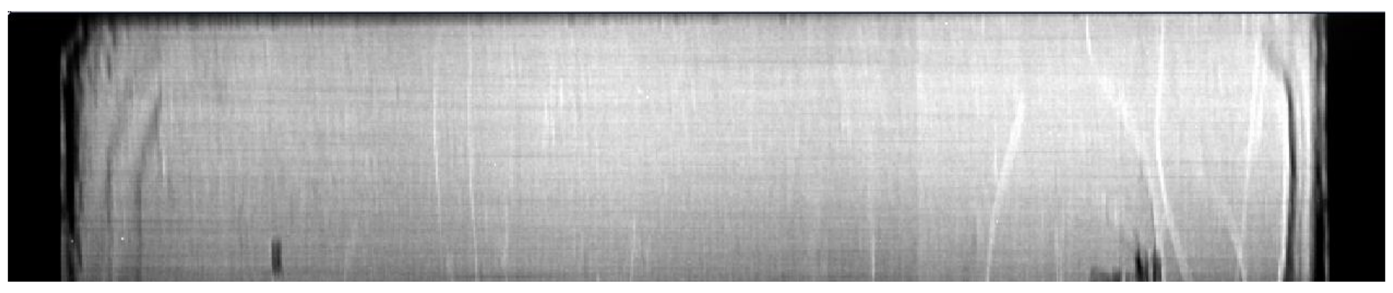




The quality of the thinned crystal is measured by an x-ray topography technique.

The basis of this method can be understood by considering the rocking curve of a given crystalline plane—for quartz (10-10), a popular orientation, the FWHM is 10.5 arcsec. The reflected intensity drops dramatically when the crystal is mis-oriented by even a few arcseconds. By collecting intensity data across the crystal, we can identify deviations from the desired plane.

Individual Image from X-Ray Camera (~65 μm wide x 13 mm)

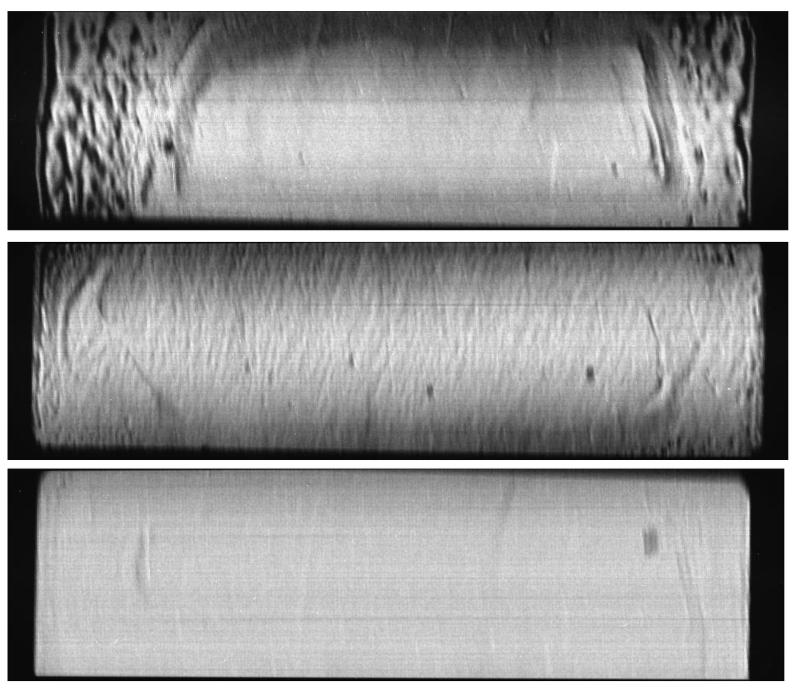


Topographic Image (70 mm width x 13 mm) Resulting From Processing and Stitching Quartz (10-10) Orientation

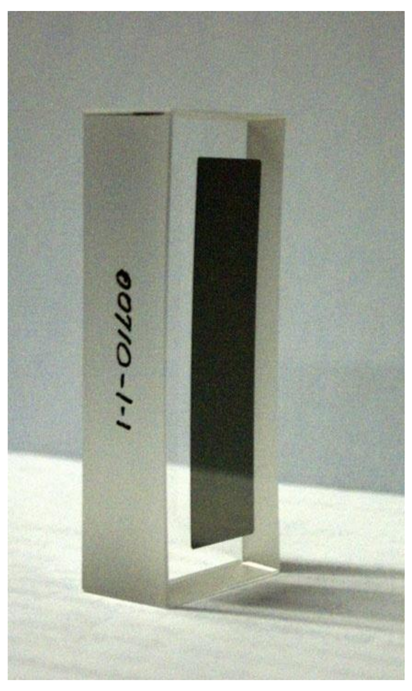
We use an x-ray camera to record the two-dimensional reflection from the output of a standard line focus x-ray tube. The line output passes through a four bounce, channel-cut, monochromator which reduces the divergence of the x-rays to approximately 5.5 arcsec.

An individual frame captured by the x-ray camera is about 65 μm wide and 13 mm in height. To form a complete image of the crystal, the crystal is translated on a high precision air-bearing stage through the x-ray beam while the camera continues to collect data. The full data set is then stitched together.

Intensity variations in this final image correspond to distortions of the crystallographic planes due to material defects and processing-induced non-uniformities. Non-uniform crystals are discarded in order to ensure optimal spot size from the finished x-ray assembly.



*The above crystals were all acceptable based on interferometric observation and optical metrology techniques, but **x-ray topographic analysis revealed the drastic difference** in their quality.*



A finished x-ray assembly

Product Advantages

- Wide Availability of Crystals
- Precise Crystal Orientations
- Non-Outgassing Materials
- Excellent Crystal Thinning Techniques
- Interferometrically Verified Surfaces
- Topographically Verified Crystal Quality
- Large Area Coverage with Mosaic Crystal Patterns
- Optimization for Specific Applications
- High Diffraction Efficiency
- Guaranteed Vacuum Compatibility
- Low Damage to Crystal Planes
- Small X-Ray Spot Size
- Uniform Intensity Profiles
- Efficient X-Ray Collection

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