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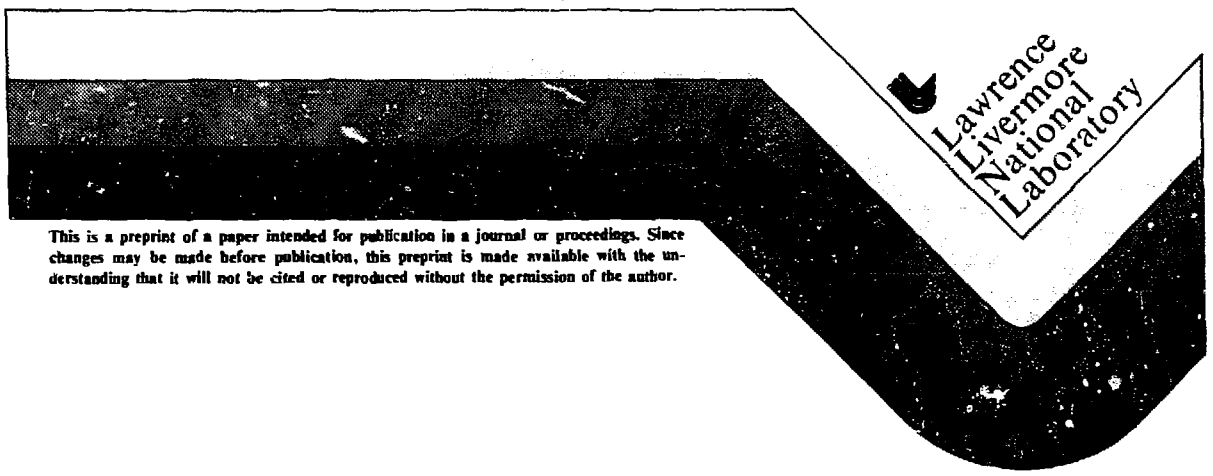

X-ray Streak Crystal Spectography*

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Abstract

We have built an x-ray streaked crystal spectrograph for making time-resolved x-ray spectral measurements. This instrument can access Bragg angles from 11° to 38° and x-ray spectra from 200 eV to greater than 10 keV. We have demonstrated resolving powers, $E/\Delta E > 200$ at 1 keV and time resolution less than 20 psec. A description of the instrument and an example of the data is given.

We have combined a Bragg diffraction crystal with an x-ray streak camera in order to time resolve the x-ray spectra from laser-produced plasmas. The resolution is sufficient to resolve individual lines in the x-ray spectra and measure their time history. These x-ray spectral measurements can be an important plasma diagnostic. Relative intensities of various x-ray lines can be used to infer plasma temperatures and densities.[1] Also, if there is sufficient energy resolution, stark-broadened individual line profiles are a plasma density diagnostic.[2] The streaked spectrograph can also assist in developing a short-pulsed x-ray line source. Such a short-pulsed x-ray line source is needed for making time-resolved short-pulsed absorption measurements, such as those proposed for measuring the core size of an ICF pellet.[3]

The instrument discussed here has been developed at LLNL for use on our Novette laser system. It uses an elliptical curved crystal focusing design to concentrate the x-ray spectrum onto the streak camera slit.[4] With such a design we have obtained moderately high resolving powers of $E/\Delta E > 200$ at x-ray energies around 1 keV. The instrument is versatile, being able to cover spectral regions from 200 eV to 10 keV. This is accomplished by using various geometries which change the Bragg angle in the range from 11° to 38° and by using various diffracting crystals. For the first application, whose results we present here, we have measured spectra in the 1 keV range using a KAP crystal (2d=26.632Å). The final and most important feature of the instrument is that it uses an existing LLNL streak camera with little modification.

The spectrograph design takes advantage of the point-to-point focusing properties of an ellipse. X rays emitted from the laser-produced plasma placed at one of the foci of the ellipse will be reflected from the elliptical surface converging on the other focus of the ellipse. This is shown schematically in Fig. 1. A Bragg diffraction crystal is elastically bent to conform to the elliptical surface. Each ray is reflected from the surface at their unique Bragg angle, providing wavelength selection. The streak camera is then placed in the far field behind the focal spot and measures the dispersed spectrum. The dispersion of the system depends on the geometry of the ellipse and the distance of the streak camera slit from the focal spot.

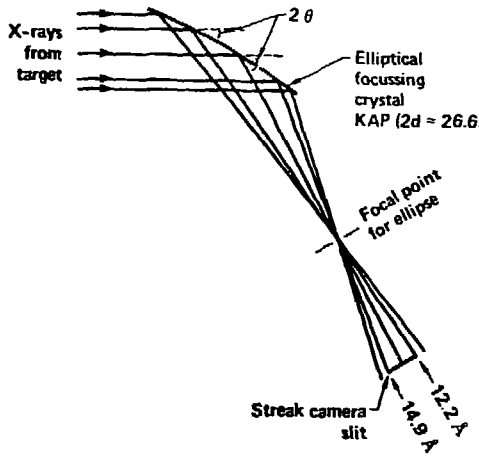

Fig. 1 Schematic of the spectrograph design.

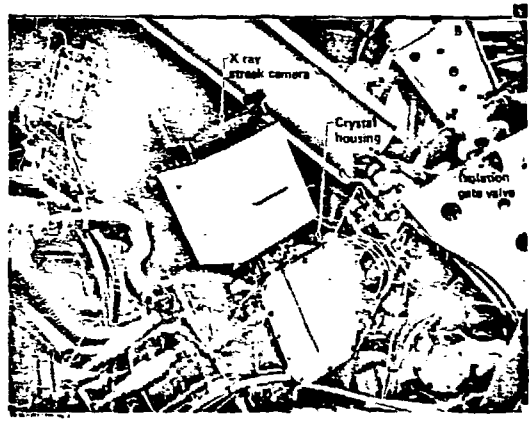

Fig. 2 The spectrograph shown mounted on the Novette target chamber.

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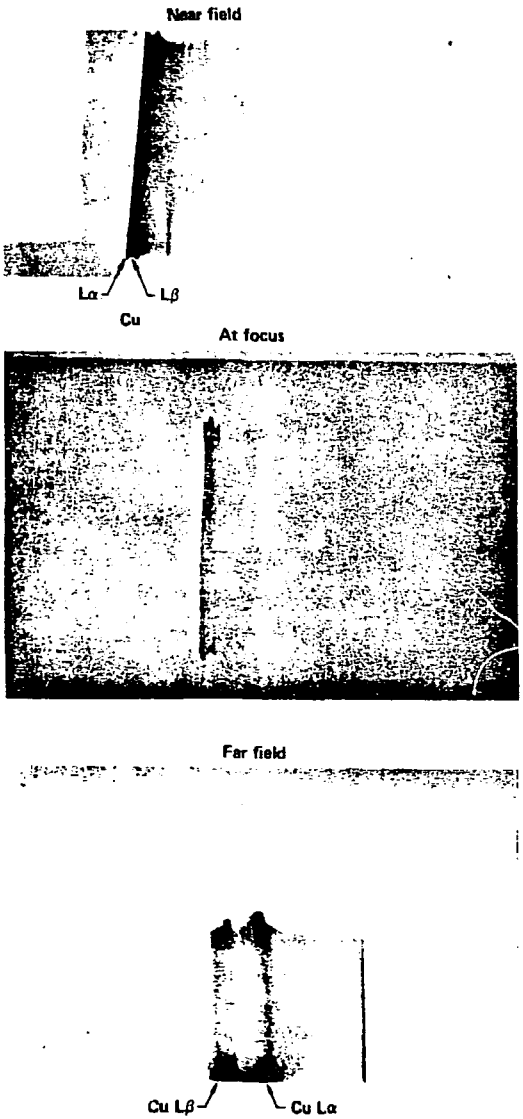

Fig. 3 Demonstration of the focusing properties of the elliptical crystal.

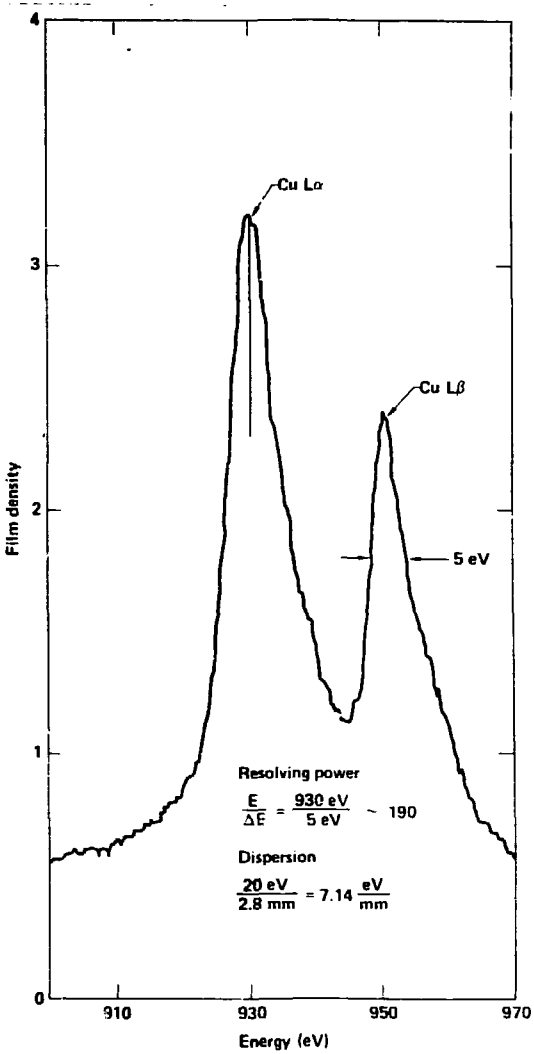

Fig. 4 Measurement of the spectrograph resolving power.

Figure 2 shows the instrument mounted on the Novette target chamber. The crystal is inside of the stainless steel housing, exterior to the main experimental chamber. It is on a rotational slide assembly which varies the geometry to obtain the different Bragg angles. Different crystals must be made for each new crystal setting. The streak camera is mounted at an angle of 57° from the line of sight to the target. The system can be reconfigured so that it is at a 33° angle to the line-of-sight for measurements at lower Bragg angles. Typical distances for this design at Novette are 120 cm from target-to-focus and 10 cm from focus to streak camera slit. These vary depending on the crystal geometry, even though the target and streak camera remain stationary.

The focusing properties have been tested using a standard x-ray source. A Cu L x ray source is placed at approximately the correct target-to-crystal distance, as in the Novette target chamber. The diffracted x rays are recorded on film as shown in Fig. 3. Three exposures are shown in Fig. 3 corresponding to the film being placed at 5 cm, 10 cm, and 20 cm from the crystal. These correspond to positions of the near-field, at-focus, and far-field, respectively. As the film is moved away from the source, the positions of the $L\alpha$ and $L\beta$ lines reverse, indicating the focusing properties predicted by the elliptical geometry.

Densitometer scans have been taken through the spectrum in the far field and are shown in Fig. 4. The energy of the Cu $L\alpha$ and $L\beta$ lines are 930 eV and 950 eV, respectively, indicating a spectral dispersion of 7.14 eV/mm. The Cu $L\alpha$ line exposure slightly saturates the film, but the $L\beta$ line can be used to determine resolution. The measured $L\beta$ line width is 5 eV, which implies a resolving power, $E/\Delta E$ = 190. This includes effects due to the source size, which for these tests is 500 μm. Also, the test geometry does not exactly duplicate the real geometry so that there may be broadening due to aberrations of x-ray optics.

The first tests of the streaked spectrograph have been to measure L-shell spectra from Cu, Fe, and Ni in the 1 keV range produced by 100 ps pulse of 0.52 μm laser light at Novette. Typical intensities on target are 1×10^{14} W/cm^2. An example of the Cr data is shown in Fig. 5. I will not discuss in detail the spectrum, but I will point out that lines from several different charge states are observed. The lowest wavelength feature is a doublet from Li-like Cr at 980 eV. The doublet separation is 3 eV and just barely resolved, implying a resolving power of better than 300. The higher resolving power may be due to the smaller source size for these experiments, or better x-ray optics. The data in Fig. 5 is taken using a modified version of the standard LLNL x-ray streak camera. The modifications are to the front end and not to the electro-optics. The flange-to-cathode distance has been shortened by eliminating the gate valve from the original design. The shorter front end allows a larger range of spectral coverage by moving the slit closer to the crystal. Also, the cathode slit has been extended to 2.5 cm for covering a larger spectral range. This results in the curvature of the image observed in the data. This curvature is a dynamic effect and is not observed in the static mode operation. The curvature is much greater than would be expected by the difference in transit times of the electrons in the tube. A possible explanation is that the electrons near the edge of the slit are affected by non-uniform fringing fields in the deflection plates. These effects are under further investigation.

Fig. 5 Example of time-resolved data from the streaked spectrograph.

In summary, we have built an x-ray streaked crystal spectrograph for making time-resolved x-ray spectral measurements. The instrument uses an elliptically-curved crystal to concentrate and focus the x rays onto a slit of an x-ray streak camera. With this instrument we have demonstrated the ability to make spectral measurements with resolving power greater than 200 and temporal response of 20 psec. Such an instrument will be valuable in diagnosing ICF plasmas.

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