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A Streaked X-Ray-Transmission-Grating Spectrometer

N.M. Ceglio, M. Roth and A. Hawryluk

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A Streaked, X-Ray-Transmission-Grating Spectrometer*

N.M. Ceglio, M. Roth
Lawrence Livermore Laboratory

A.M. Hawryluk
Massachusetts Institute of Technology

Abstract

A free standing x-ray transmission grating has been coupled with a soft x-ray streak camera to produce a time resolved x-ray spectrometer. The instrument has a temporal resolution of ∿ 20 psec, is capable of covering a broad spectral range, 2-120 Å, has high sensitivity, and is simple to use requiring no complex alignment procedure. In recent laser fusion experiments the spectrometer successfully recorded time resolved spectra over the range 10-120 Å with a spectral resolving power, $\lambda/\Delta\lambda$ of 4-50, limited primarily by source size and collimation effects.

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A free standing x-ray transmission grating is a linear, periodic grid of gold wires or bars with sub-micron spatial period. The grating structure is supported by a coarse grid orthogonal to the grating lines. Because of its simple geometry, the TG is a uniquely versatile spectroscopic dispersion element. It accepts radiation at all angles of incidence, thereby requiring no detailed angular alignment in its operation. It can, therefore, be easily coupled to instruments of high temporal resolution. In addition the TG's have high efficiency, and provide continuous spectra with moderate resolution over a broad spectral range.

Fig. 1 shows a simple x-ray transmission grating spectrometer viewing a small laboratory source. In such a configuration the spectral resolution (limited by source size and degree of collimation) is given by

$$\Delta\lambda = {}^{d}/_{L}\ (S + A) + {}^{d}/_{D}\ (A) \qquad (1)$$

where d is the grating period, D is the grating to detector distance, L is the grating to source distance, S is the source size, and A is the collimation aperture opening. When

$$D \gg \frac{A}{(S + A)} L \qquad (2)$$

the second term in Eq. (1) may be neglected. However, in many applications involving limited detector size (such as the slit of a streak camera) Eq. (2) cannot easily be satisfied. The spectral range of the spectrometer is typically limited by detector characteristics[1]. The maximum wavelength that can be recorded is

$$\lambda = \frac{d}{D} T \qquad (3)$$

where T is the linear size of the detector[2] (e.g. for a streak camera T would be the slit length). The minimum wavelength that can be distinctly recorded will be limited either by spatial resolution at the detector, or by source size and collimation (leading to overlap of the D.C. and first order spectral line). When detector spatial resolution limits λ_{min}, then its value is given by Eq. (3) using the detector spatial resolution as the value for T. When source size and collimation limit λ_{min} then $\lambda_{min} = \Delta\lambda$ given by Eq. (1).

A time integrated x-ray spectrum from a laser illuminated, SiO_2 disk target is shown in Fig. 2. The spectrometer configuration of Fig. 1 was used with photographic x-ray film as the detector. In this configuration the spectrometer characteristics were:

d = 3000 Å	S ≈ 100 μm
D = 63 cm	A = 100 μm
L = 74 cm	film resolution ≈ 10 μm

yielding a spectral resolution (Eq. (1)):

$$\Delta\lambda \approx 1.3 \text{ Å}$$

The spectral range was limited in this case at low energy by the carbon absorption of the polymer overcoat on the x-ray film, and at high energy by source size and collimation effects.

A free standing x-ray transmission grating has been coupled to a soft x-ray streak camera, and used to record the first time-resolved (∿ 20 psec resolution), continuous, soft x-ray spectrum from a laser produced plasma. The experimental arrangement used is the same as that shown in Fig. 1 with the slit of the x-ray streak camera serving as the detector. Fig. 3 is a schematic representation of the experiment along with the data record from a gold disk target. In this time-resolved configuration the spectrometer characteristics were:

d = 3000 Å	S ≈ 100 μm
D = 31 cm	A = 100 μm
L = 76.6 cm	Streak camera resol. ≈ 150 μm

The spectral resolution, limited primarily by collimation, was

$$\Delta\lambda \simeq 2\ \text{Å}$$

The long wavelength limits to the spectral range were the finite slit length (1.3 cm), and absorption due to the 50 μgm/cm^2 carbon window at the streak camera slit. In each case the long wavelength limit was around 120 Å. The short wavelength limit, around 2 Å, was established by collimation limitations, and the limited spatial resolution of the streak camera.

The time resolved TG spectrometer has been used in a number of different geometrical configurations (varying resolution and spectral range) to address the important issues of radiation production and plasma transport in laser fusion experiments. Fig. 4 shows time resolved spectral data recorded from a laser irradiated Al-Ti disk target. In this case the directly irradiated aluminimum disk was surrounded by an unirradiated annular ring of titanium. The difference in temporal characteristics (e.g. turn-on time) between the Al-K-lines and Ti-L-band provides important insight into radial plasma transport phenomena.

CONCLUSION

A marriage of two powerful technologies has provided a new spectroscopic capability. An x-ray transmission grating has been coupled with an x-ray streak camera to provide time resolved (∿ 20 psec), continuous x-ray spectra over a broad spectral range. This new spectroscopic tool offers insight to the key issues of radiation production and plasma transport in laser fusion experiments.

ACKNOWLEDGEMENTS

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1. The other possible limit to spectral range is the transparency of the grating material at high x-ray energy. In this case, using gold gratings greater than 0.5 μm thick, grating transparency is not the limit to spectral range. Streak camera characteristics: finite slit length, finite spatial resolution at the slit, reduced sensitivity at high x-ray energy, and low energy x-ray absorption by the carbon window, provide the limiting factors in time resolved applications.

2. We have in practice not found spectral overlap with higher orders to be a limit to λ_{max} in our laser fusion experiments. This is in large part due to the reduction in diffraction efficiency in higher order.

Figure Captions

Fig. 1 A simple x-ray transmission grating spectrometer design.

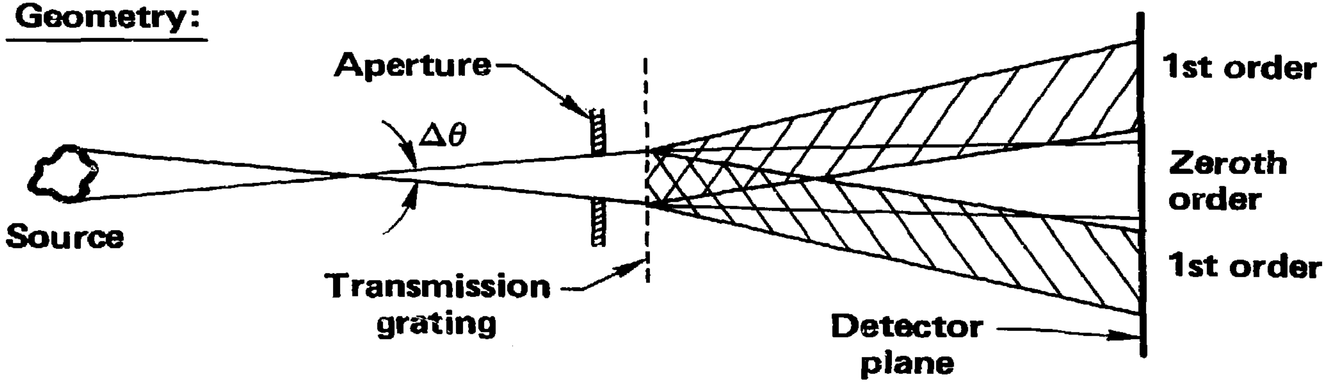
Fig. 2 A time integrated x-ray spectrum from a laser produced plasma, recorded by a transmission grating spectrometer.

Fig. 3 A time-resolved transmission grating spectrometer.

Fig. 4 Time resolved x-ray spectrum from a "plasma transport" laser target.

TRANSMISSION GRATING SPECTROMETER:

Geometry:



Characteristics:

- Spectral resolution: limited by source size and collimation

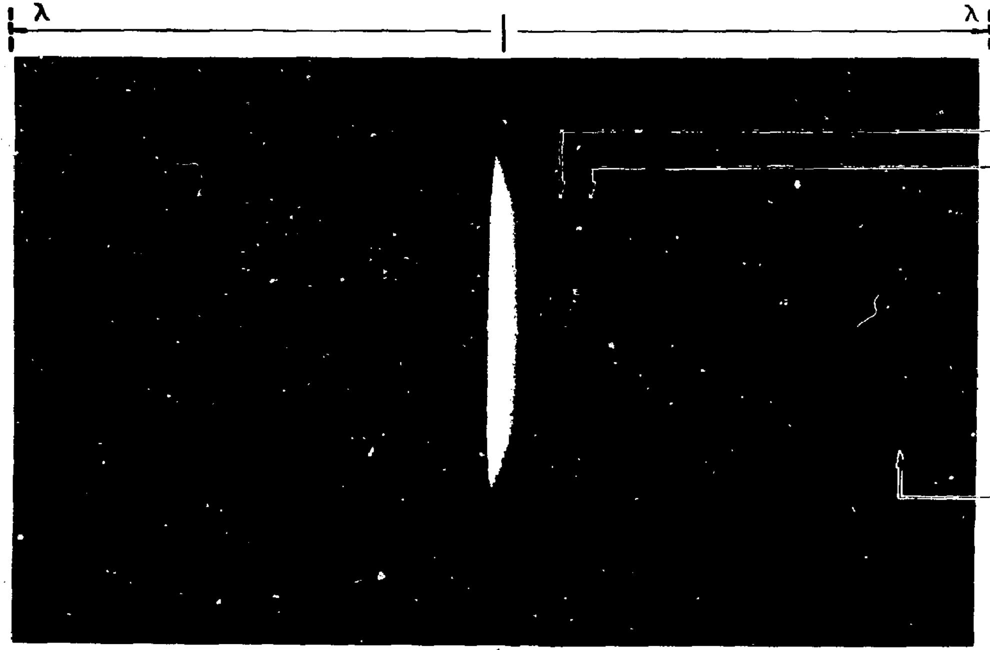
$$\frac{\Delta\lambda}{\lambda} = \Delta\theta \frac{d}{\lambda}$$

- Spectral range: limited by transparency of grating material at high energy. (e.g.) Rλ ~ (2-3000) Å
- Sensitivity: direct trade-off between dΩ and $\Delta\lambda$

40-90-0681-1579

Fig. 1

X-RAY TRANSMISSION GRATING SPECTRUM FROM LASER PRODUCED PLASMA

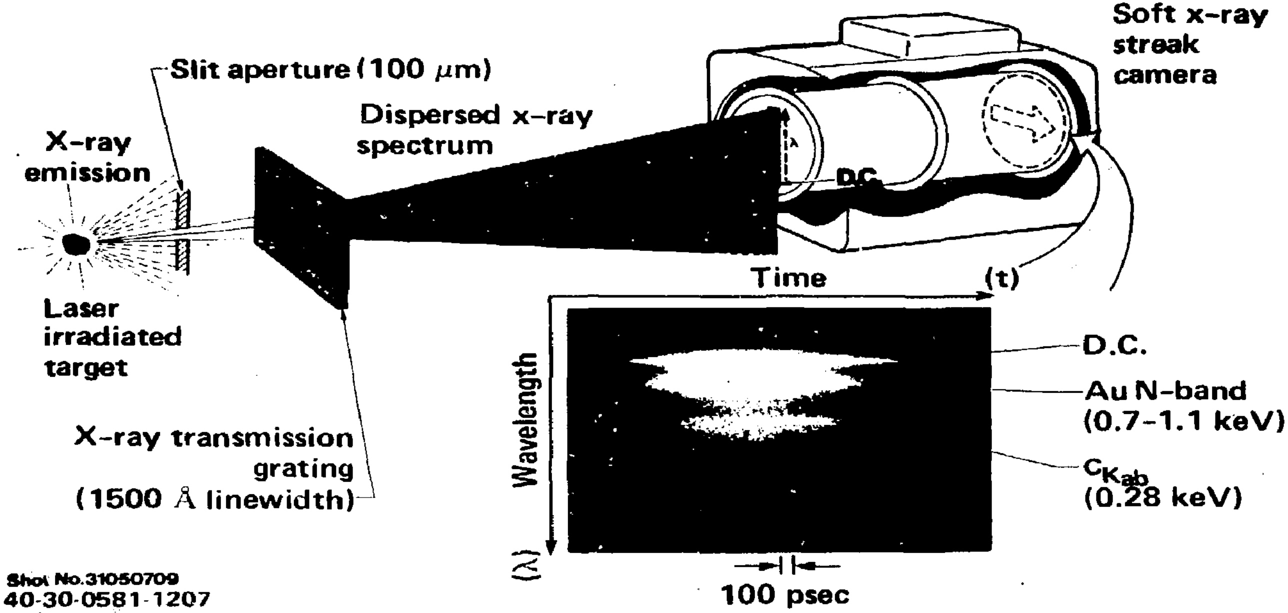


Argus shot No. 31040606
40-90-0481-1132

Fig. 2

TIME RESOLVED SOFT X-RAY SPECTROMETER: DEMONSTRATION

A free standing x-ray transmission grating is coupled with a soft x-ray streak camera to provide time resolved (~20 psec) continuous x-ray spectra over a broad spectral range (0.1-1.5 keV).

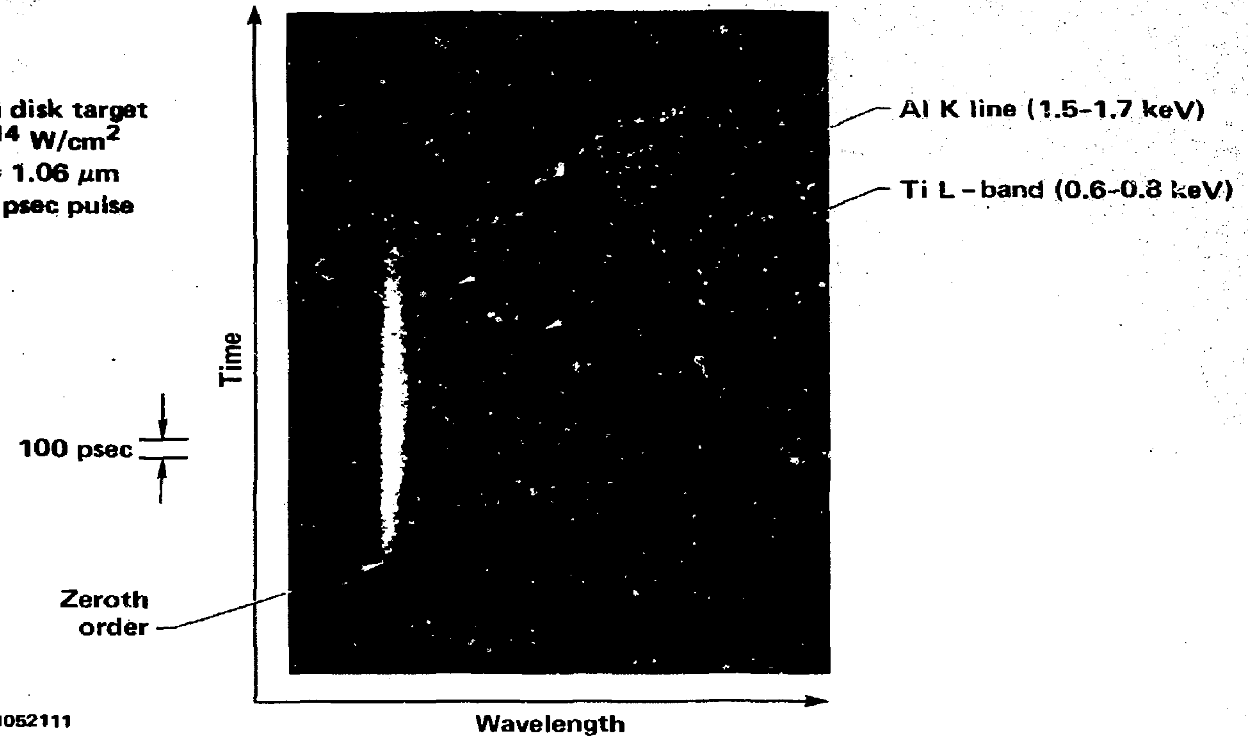


Shot No.31050709
40-30-0581-1207

Fig. 3

TIME RESOLVED X–RAY SPECTRA ADDRESS PLASMA TRANSPORT ISSUES

Al–Ti disk target
10^{14} W/cm^2
λ = 1.06 μm
700 psec pulse



Argus shot No. 31052111

Fig. 4