NOTICE

PORTIONS OF THIS REPORT ARE ILLEGIBLE. It has been reproduced from the best available copy to permit the broadest possible availability.

CONF-840387--9

UCRL--90335

DE84 012593

Diagnostics for an XUV/Soft X-ray Laser

R. L. Kauffman, D. L. Matthews, N. Ceglio, and H. Medeck

**Second Topical Meeting on Laser Techniques
in the Extreme Ultraviolet
March 3-7, 1984
Boulder, Colorado**

March 5-7, 1984

**Lawrence
Livermore
National
Laboratory**

This is a preprint of a paper intended for publication in a journal or proceedings. Since changes may be made before publication, this preprint is made available with the understanding that it will not be cited or reproduced without the permission of the author.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

R. L. Kauffman, D. L. Matthews, N. Ceglio, and H. Medeck
Lawrence Livermore National Laboratory, Livermore, CA 94550

ABSTRACT

We have begun investigating the production of an XUV/soft x-ray laser, using our high-powered glass lasers as drivers. A major diagnostic for lasing is the measure of the absolute power produced in the lasing line. I have developed a spectrograph to time-resolve lasing lines in the energy range from 50 eV to greater than 200 eV. The spectrograph combines a transmission grating and x-ray streak camera to produce a flat field instrument. A cylindrical mirror is used in front of the grating to image the source and act as a collecting optic. The efficiency of the components is calibrated so that absolute intensities can be measured. I will compare the performance of this instrument with reflection grating systems. I will also discuss planned improvements to the system which should increase total throughput, image quality, and resolving power.

The soft x-ray region has proven to be a formidable barrier for extending lasing to shorter wavelengths.¹ Techniques used at longer wavelengths, such as resonance cavities, cannot be extended to soft x-ray wavelengths because ordinary reflective and refractive optics are not available for this regime. Usual methods for diagnosing lasing and establishing its characteristics also cannot be extended directly from the optical regime for similar reasons. The lasing medium itself differs greatly for soft x-ray lasers. Most lasing schemes use excited states of multiply-charged ions, requiring the medium to be a high energy density plasma pumped by pulsed high-powered sources. The nature of these sources also makes the task of diagnosing lasing difficult.

At LLNL we have concentrated on measuring the output power directly from a long cylindrical plasma.² The diagnostics are absolutely calibrated to measure output efficiencies directly. Our systems are designed to have high gain lengths so that in the exponentiation region small variations in gain translate into large changes in the signal, making the output intensity a sensitive diagnostic. We also can test exponentiation of a particular system by correlating the signal with changes in the plasma length. Saturation levels are predicted to be well above the fluorescence levels of the system and are easily observed by an absolute intensity measurement. Our measurements are also time-resolved, aiding in comparing our observations with predictions, since all systems are pulsed and lasing is predicted at only certain times during the pulse. Time resolution also helps in background suppression since background emission times are much longer than lasing times.

*This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

EWB

Fig. 1 Schematic of the transmission grating streaked spectrograph.

The principal diagnostic for measuring the lasing output is a transmission grating streaked spectrograph (TGSS). A schematic of the instrument is shown in Fig. 1. Components of the spectrograph are a cylindrically-curved x-ray mirror for light collection, a transmission grating for wavelength dispersion, and a soft x-ray streak camera for x-ray detection. The instrument is designed to have high spectral resolution, $E/dE > 200$, continuous wavelength coverage from 80 Å to 300 Å, good time resolution, ~ 20 ps, and high sensitivity, $\sim 10^{20}$ photons/sec-sr. In addition, we have designed an optical alignment system pointing the instrument to the target with an accuracy of better than 0.1 mrad.

The TGSS characteristics can be compared to a grazing incidence grating spectrograph, which is normally used in this energy region.³ The transmission grating, the dispersing element for the TGSS, is separate from the cylindrical mirror focusing element, compared with the grazing incidence spectrograph where the dispersing and focusing elements are combined into a single element. This allows the TGSS to have a nearly flat field, normal incidence detection plane, in contrast to the grazing incidence spectrograph whose detection plane must lie on a Rowland circle. The TGSS geometry is much more conducive to being used with active detectors (like x-ray streak cameras or silicon diode arrays) where the incident x-rays must pass through a cathode substrate, or detector dead layer, before reaching the active detection region.

A grazing incidence grating has much higher spectral resolution than the TGSS. Resolutions for commercially available instruments can be greater than 10^4 in the soft x-ray range. These resolutions, in practice, are limited by the slit, or source, size and the number of periods of the grating that is sampled, assuming the instrument is well aligned. For a grazing incidence grating, the number of periods sampled is quite large. Slit, or source, sizes are set by the desired resolution and sensitivity. For the TGSS the number of periods sampled and the dispersion is much smaller because the grating is illuminated at normal incidence. For a 2000 Å period grating with a detector plane 1 m away, the grating dispersion is 2 Å/mm. For 10^3 resolution the image size must be less than 50 μm, and at least a 200 μm aperture of the grating must be illuminated to sample a sufficient number of periods. A simple slit imaging system cannot be used to obtain even these moderate resolutions. Instead high resolution x-ray optics must be employed, as well as aperturing of the source.

The TGSS is a high-efficiency, medium resolution instrument. Small period gratings have been made with apertures of 5 mm diameter⁴, which, when coupled with large aperture collection optics, produce high throughput instruments. Reflection gratings can also be made to have high efficiency, but the source must be placed close to the slit, or the source itself must be the limiting aperture. Sometimes this is impractical because it moves the grating close to the source, and it requires precise alignment of the instrument to the source. If the source is larger than the slit, then source broadening will degrade the resolution. External mirrors can also be used to relay the source image for a grazing incidence spectrograph, but these are also subject to high alignment tolerances.⁵

Our instrument at LLNL has been designed specifically for the x-ray laser experiment. It optimizes efficiency, while maintaining high resolution required for resolving the x-ray line above the background continuum emission. As illustrated in Fig. 1, x rays from the target are collected and focused at the detection plane by a cylindrically-curved grazing incidence x-ray mirror. The mirror acts like one element of a Kirkpatrick-Baez x-ray microscope producing a line focus perpendicular to the plane of dispersion.⁶ The mirror has an 9.75 m radius of curvature and operates at an angle of incidence of 40° . It is 58 cm from the target, nearly midway between the target and detection circle. This produces a magnification near unity. Spherical aberrations for these conditions are estimated to be less than $10\text{ }\mu\text{m}$, which is much less than target sizes, although off axis, finite source size aberrations may degrade the attainable resolution. The transmission grating is placed directly behind the mirror and disperses the x rays from the zeroth order, established by the reflected direction of the mirror. The grating has a periodicity of $2000\text{ }\text{\AA}$ and a line-to-space ratio of 1.9. The grating is 62 cm from the detection plane for a dispersion of $3.2\text{ }\text{\AA}/\text{mm}$. The active area of the grating is about 3 mm diameter, and the dimensions of the mirror overfill the grating area with x rays.

An LLNL-designed soft x-ray streak camera is used as a detector.⁷ The camera is designed to pivot around the grating from the D.C. to 90° to allow continuous coverage through the desired wavelength region. The LLNL streak camera has a temporal response of 20 psec, providing good time resolution for the experiment. The entrance slit of the streak camera is aligned with the dispersion plane of the grating. With the 1.2 cm slit, a $38\text{ }\text{\AA}$ portion of the spectrum is measured at one time. To cover other regions of the spectrum, the streak camera must be moved along the detection circle. The cathode has a $100\text{ }\mu\text{m}$ spatial resolution corresponding to a wavelength resolution of $0.32\text{ }\text{\AA}$. Neglecting source size effects, the resolving power, $E/\Delta E$, is 250 for $80\text{ }\text{\AA}$ and increases for the longer wavelengths.

The instrument has been absolutely calibrated to determine its overall efficiency. The efficiency of the system is the throughput of the system combined with the efficiency of each component of the system. The mirror is coated with Ni and has a reflectivity calculated to be 75% or greater at these angles and energies. Reflectivity measurements at higher energy agree with the calculated efficiency. The grating efficiency has not been measured, but it is calculated to be 10% diffracted into first order. Because of a super structure support grid on the grating, this efficiency is reduced to an

efficiency of 2.5% of the incident light.

Calibrating the streak camera is the most difficult part of the instrument. Well characterized x-ray sources with sufficient brightness do not exist in this energy region. We have calibrated the instrument at higher energy and extrapolated the calibrations to energies of interest using measured quantum yields for the streak camera photocathode modified for the streak camera geometry.

For these experiments the photocathode is 900 Å CsI film deposited on a 1000 Å parylene substrate. A 50 Å layer of Al is placed over the parylene to increase electron conduction. CsI has been shown to have high sensitivity in previous studies.⁸ For streak cameras photoemission occurs at the rear surface of the cathode after passing through the substrate. Most photoemission measurements are from the front surface. We have estimated the quantum efficiency of the cathode using the measured front surface yields of CsI¹⁰ and the expression by Henke, et. al.,⁹ to translate these to rear surface yields needed for x-ray streak camera efficiencies. The calculated rear surface quantum efficiency including substrate absorption is shown in Fig. 2, as well as the back-to-front surface ratio. The large increase in the CsI yield, around 100 Å, observed in the front surface yield is moderated in the rear surface yield. This increased yield is due to increased absorption in the CsI near the surface where electrons can more easily escape. For the streak camera geometry, the photons must traverse the cathode before reaching the electron emitting surface, so that more are absorbed away from the cathode surface and do not contribute to the quantum yield.

The streak camera is calibrated using a laser-produced plasma as an x-ray source. Details of the calibration technique have been described elsewhere.¹⁰ The streak camera response is compared to absolutely calibrated x-ray diode signals. Broad band emission channels for both instruments are defined using K- and L-edge transmission filters in the range from 200 eV to 800 eV. An example of the calibration data for the 200 eV channel is shown in Fig. 3. The

Fig. 2 Energy dependence of the CsI cathode response and the predicted rear surface to front surface secondary electron yield.

Fig. 3 X-ray streak camera calibration versus an x-ray diode monitor.

data demonstrates the linear response of the streak camera. The slope of the data gives the correlation between intensity, or exposure, on film to current density from the photocathode. This quantity, coupled with the cathode response, determines for the x-ray response of the x-ray streak camera.

An example of the data and demonstration of the instrument performance is shown in Fig. 4. The spectrograph is viewing the edge of a Formvar foil irradiated on both sides by 100 ps pulses of 450 Joules of $0.525\text{ }\mu\text{m}$ light, focused in a cylindrical spot 2 mm by 12 mm. The intense line feature in the middle of the cathode is the 3-2 transition from O VIII at $102.4\text{ }\text{\AA}$. The line turns on early

Fig. 4 Example of the raw data from the TGSS.

during the irradiation pulse and persists for about 2 ns. Spectra at two different times are shown in Fig. 5. The upper trace is early in time during the laser pulse. The line is relatively sharp with a high continuum level. Later in time, as shown in the lower trace, the continuum level is reduced, but the line is as intense, although it is slightly broader, due to expansion of the exploding foil.

In summary, we have built a streaked spectrograph for time-resolving laser plasma spectra above 80 Å. It uses a cylindrically-curved mirror for light collection, a transmission grating for spectral dispersion, and a soft x-ray streak camera for time-resolved

Fig. 5 TGSS spectra from during the laser pulse and after the laser pulse, showing the O VIII 3-2 transition.

detection. This configuration produces a versatile, moderate resolution instrument in this region. We have absolutely calibrated the instrument to make power measurements of x-ray line intensities from possible x-ray laser targets. We are presently modifying the instrument to increase its efficiency. The cylindrical mirror is being replaced by a two-dimensional focusing ellipsoidal mirror to increase collection efficiency. We also are increasing the aperture size of the grating for an effective 10 mrad divergence acceptance, which more nearly matches our present experiment.

References

1. R. W. Waynant and R. C. Elton, Proc. IEEE, Vol 64, 1059(1976).
2. D. L. Matthews, et al., this conference.
3. J. R. Sampson, Techniques of Vacuum Ultraviolet Spectroscopy, (John Wiley & Sons, New York, 1967).
4. N. M. Ceglio, R. L. Kauffman, A. M. Hawryluk, and H. Medeck, Appl. Opt. 22, 318(1983).
5. G. Tondello, E. Jannitti, P. Nicolosi, and D. Santi, Opt. Comm. 32, 281(1980).
6. P. Kirkpatrick and A. V. Baez, J. Opt. Soc. Am. 38, 766(1948).
7. G. L. Stradling, D. T. Attwood, and H. Medeck, IEEE J. Quantum Electron. QE-19, 604(1983).
8. B. L. Henke, J. P. Krauev, and K. Premaratne, J. Appl. Phys. 52, 1509(1981).
9. E. B. Saloman, J. S. Pearlmon, and B. L. Henke, Appl. Opt. 19, 749(1980).
10. R. L. Kauffman, G. L. Stradling, D. T. Attwood, and H. Medeck, IEEE J. Quantum Electron. QE-19, 616(1983).