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D. T. ATTWOOD
L. W. COLEMAN

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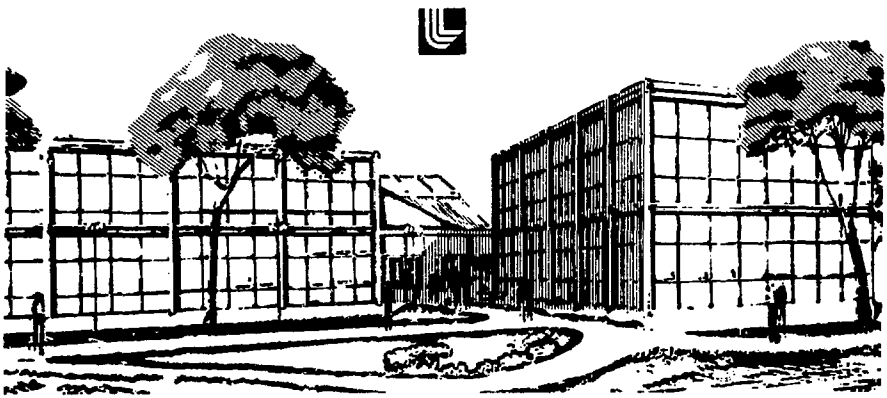

PICOSECOND X-RAY SPECTRAL STUDIES*

D. T. Attwood and L. W. Coleman
Lawrence Livermore Laboratory, University of California
Livermore, California 94550

Abstract

Temporally and spectrally resolved x-ray emission is an important diagnostic tool for the study of target heating and compression induced by sub-nanosecond laser pulses. In this paper we describe the use of the Livermore 15 psec x-ray streak camera to record x-ray emissions in the 1-10 keV range. In particular, we report significant progress during the past year in defining the camera as a quantitative diagnostic instrument, and its implementation for multi-channel, time resolved K-edge filter measurements.

Data will be presented which describe x-ray emission from a laser imploded 87 μm diameter glass shell. Channels centered at 2.6, 4.0 and 5.3 keV provide temporal information which we relate to the absorption and compression phases of laser heating. The relative spectral content is found to be in agreement with standard, time integrated measurements.

Introduction

Experiments designed to confirm the concepts of laser induced fusion are under way in a number of laboratories. The essential feature of this process, which is to be studied in these experiments, is the compression and heating of matter to thermonuclear conditions.(1-3) A typical experiment involves the irradiation of an approximately 100 μm diameter glass shell by an approximately 100 psec, terawatt pulse from a neodymium laser. Because of the high densities and temperatures attained, an important aspect of these experiments is the observation of temporally and spectrally resolved x-ray emission. Time integrated spectral data has been available from compression experiments for some time[4]. Figure 1 is an example of time integrated x-ray data showing the spectral range of interest in a fusion target implosion experiment. Such data has played an important role in understanding preliminary implosion experiments in that they provide a measure of thermal and non-thermal processes occurring therein.

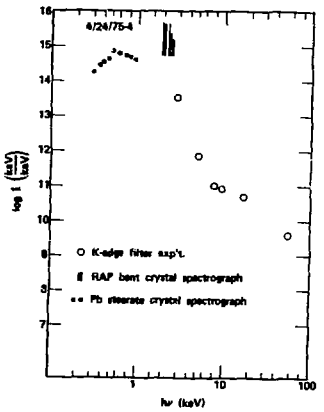

Figure 1. Time integrated x-ray spectrum from a laser compressed target.

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The need to extend these measurements to appropriate temporal scales has lead to the development of picosecond resolution instruments and techniques. [5-8] In this paper we discuss the extension of previous work to time resolved spectral measurements in the 1-10 keV range via application of our developed x-ray streak camera capability. Specifically, x-ray emission bands centered at 2.6, 4.0 and 5.3 keV, resolved to 15 psec, are presented. These are the first observations of x-ray emission from laser irradiated targets with sufficient temporal resolution to display features associated with heating and compression phases. Such observations provide measures of the implosion time and, indirectly, of the average implosion velocity, and as a consequence provide data heretofore unavailable. In addition, such data provides further definition of the performance characteristics of the x-ray streak camera.

X-Ray Streak Camera

The x-ray streak camera, previously described in Reference 5 is shown schematically in Figure 2. X-rays emitted by the laser irradiated target strike a 100 Å thick gold photocathode evaporatively deposited on an 8 μm thick beryllium substrate. The exposed cathode area is defined by a 0.1 by 10 mm slit. Slow secondary electrons are emitted by the transmission photocathode, accelerated, and imaged on the output phosphor screen. A properly timed ramp voltage sweeps the "slit" of electrons quickly across the phosphor surface; trigger jitter with our avalanche transistor circuit is less than 100 psec. The streak speed across the phosphor is 24 μm/psec. The fibre optic coupled image intensifier shown in Figure 2 is used to amplify the phosphor image to a photographable level. The spatial and temporal resolutions of the x-ray streak camera are 130 μm and 15 psec, respectively.

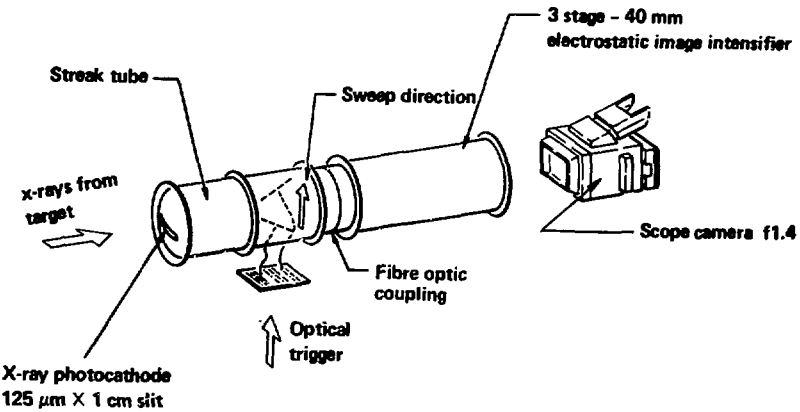


Figure 2. Schematic diagram of the Livermore x-ray streak camera.

The spatial value has been determined by backlighting x-ray absorbing metal wires. The temporal value is based on detailed studies of the secondary electron emission spectra from our gold photocathode, as measured by Henke et al., [9] and presented here in Figure 3. The small photoelectron energy dispersion of 4 eV FWHM gives a transit time dispersion value of 12 psec for the fields (3kV/cm at the cathode) and geometry of our streak tube. Additional factors [10] lead to a temporal resolution of 15 psec, as quoted above. The direct measurement of such short temporal resolution, in the Rayleigh sense, is difficult in the x-ray case because of the long temporal tails generally encountered. This point is discussed in the literature by Brukhnevitch et al., [6] and by Bradley and his colleagues [7]. We do observe, however, that the experimentally observed fast rising x-ray emissions reported herein are consistent with predicted target emission profiles [11] and our calculated temporal resolution.

In order to record the spectrally resolved x-ray emission from laser irradiated targets, we employ a set of simple K-edge absorbers placed over the streak camera slit as shown in Figure 4. X-ray filtering materials of aluminum, chlorine, titanium, cobalt, zinc and

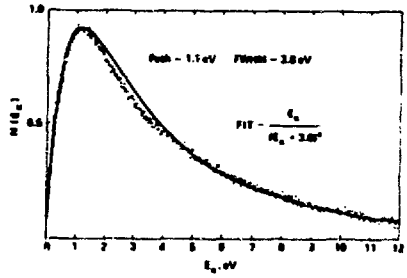


Figure 3. Secondary electron emission spectra from an x-ray irradiated (1487eV) gold photocathode. B. L. Henke et. al. (Ref. 9)

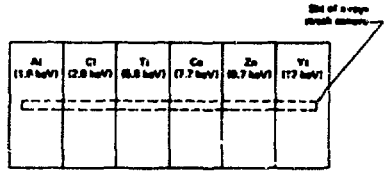


Figure 4. Slit of x-ray streak camera showing overlay of K-edge absorption filters.

yttrium are used. The K-absorption edges are indicated in Figure 4. Except for chlorine, the filters consist of high purity metal foils, typically 25 m thick. The chlorine filter consists of commercially available polyvinylchloride (PVC). Double thicknesses of PVC and titanium are generally used to provide exposure latitude, increased recording range, and to check camera linearity in specified spectral ranges. Figure 5 shows, as an example, the spectral region sampled by the chlorine K-edge filter. This curve is obtained by folding the foil transmission characteristic with the photocathode spectral sensitivity [12] and with the steeply falling x-ray emission spectrum, as typified in Figure 1. The higher energy channels are chosen so as to sample wide spectral ranges, thus compensating for the dual problems of rapidly declining emission spectrum and photocathode sensitivity. Typical spectral widths for the remaining channels are as follows: 1.7 keV centered at

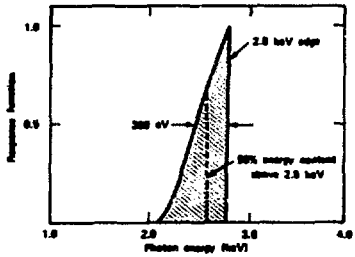


Figure 5. Spectral response of the chlorine filter.

K-edge filters.

Zn (9.7 keV)

Co (7.7 keV)

Ti (5.0 keV)

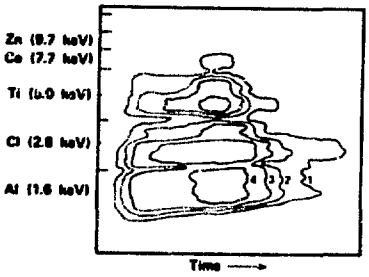
Cl (2.8 keV)

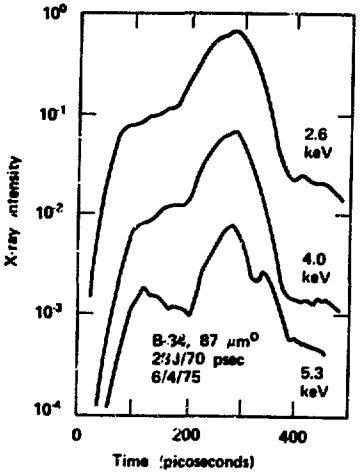
Al (1.6 keV)

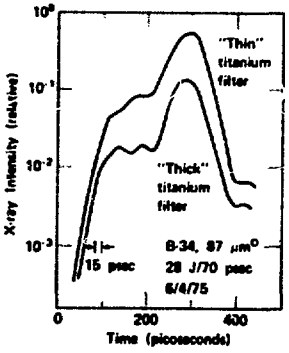
5/20/76
40 3/59 psec

15 psec

Time →


Zn (9.7 keV)
Co (7.7 keV)
Ti (5.0 keV)
Cl (2.8 keV)
Al (1.6 keV)
4
3
2
1
Time


X-ray intensity
2.6 keV
4.0 keV
5.3 keV
B-34, 87 μm
2?J/70 psec
6/4/75
Time (picoseconds)


X-ray intensity (relative)
"Thin" titanium filter
"Thick" titanium filter
15 psec
B-34, 87 μm
28 J/70 psec
6/4/75
Time (picoseconds)

of Figures 8 and 9 (explicitly displayed in Figure 9) is that the late time burst in the temporal signatures is not saturation limited, but rather provides a profile of x-ray emission through the entire recording period.

Interpretation of X-Ray Temporal Signatures

The measured x-ray temporal profiles presented in Figure 8 are readily identified with general features of present day target irradiation experiments. As discussed elsewhere, (16-19) these targets are of the "exploding pusher" type in that they are rapidly and uniformly heated by a short, untailored optical pulse, as opposed to the ablatively driven compressions (1) planned for later experiments with longer pulses and larger targets. In these exploding pusher experiments laser energy is absorbed and heats the glass shell (pusher) before significant hydrodynamic expansion takes place. According to numerical simulations of this process (11,18), this rapid heating results in an explosion/implosion of the glass pusher in a relatively short acceleration period, followed by a period in which the glass shell drives the contained fuel inward at relatively constant velocity, reaching a final stagnation near the target center, and finally a post-compression target disassembly. The general features of kilovolt x-ray emission from such a compression experiment can be seen in Figure 8. In all three channels one observes the rapid rise in emission associated with shell heating, the plateau region in which laser heating and acceleration play a diminishing role, the secondary peak which corresponds to stagnation near the target center, and the final decay as the target eventually disassembles. The target implosion time can be estimated from Figure 8 with the aid of numerical simulations of this target experiment.(11) The time from the peak of the laser pulse (estimated to occur at t = 100 psec in Figure 8) to the implosion peak gives an implosion time of 180 psec. Using a final target radius as recorded by a time integrated x-ray microscope (14), an average implosion velocity of 2×10^7 cm/sec is deduced. This result is in good agreement with computer calculations of this target experiment (11, 18). A significant spectral feature observed in Figure 8 is the relatively rapid decay of emission in the highest energy (5.3 keV) channel between the first crest and the final peak. We interpret this spectrally sensitive data as experimental evidence of target cooling during the period extending from peak laser power to final stagnation.

Figure 10 shows the spectral behavior at various times in the implosion process, as determined from the data of Figure 9. The cooling behavior referred to above is clearly evident in the slope of the 200 psec line in this plot.

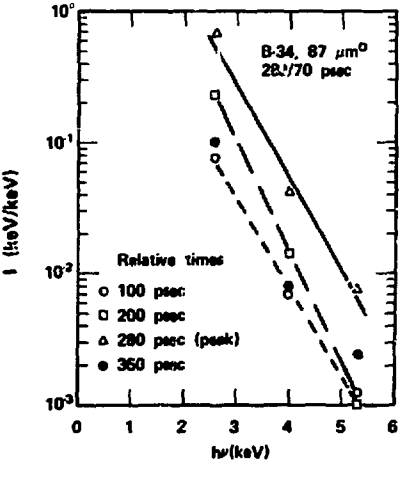


Figure 10. Spectral behavior as a function of time for the laser heated and compressed target.

Conclusions

The Livermore untrafast x-ray streak camera has been shown to have a temporal resolution of 15 psec and to have advanced to the state of a diagnostic instrument useable in a quantitative manner to record spectrally resolved x-ray emission. Specifically, temporally and spectrally resolved x-ray emissions from laser compressed targets have been recorded

which show general features of the implosion process on a picosecond time scale. From this data we are now able to infer time resolved temperatures, implosion times, and indirectly, implosion velocities for such processes, data previously not available in such a direct and simple manner.

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References

1. J. Nuckolls, L. Wood, A. Thiessen, and G. Zimmerman, Nature 239, 139 (1972). J. L. Emmett, J. Nuckolls and L. Wood, Sci. Amer. 230, 24 (1974).
2. P. M. Campbell, G. Charatis, and G. R. Monty, Phys. Rev. Lett. 34, 74 (1975).
3. V. W. Slivinsky, H. G. Ahlstrom, K. G. Tirsell, J. Larsen, S. Glaros, G. Zimmerman, and H. Shay, Phys. Rev. Lett. 35, 1083 (1975).
4. V. W. Slivinsky, H. N. Kornblum and H. D. Shay, J. Appl. Phys. 46 1973 (1975).
5. C. F. McConaghy and L. W. Coleman, Appl. Phys. Lett. 25 268 (1974). L. W. Coleman and C. F. McConaghy, "Ultrafast X-Ray Streak Camera", Proc. 11th Int. Cong. on High Speed Photography, Chapman and Hall, London, 1975, pp. 196-201.
6. G. I. Brukhnevitch, V. K. Chevokin, Yu. S. Kasyanov, V. V. Korobkin, A. A. Malyutin, A. M. Prokhorov, M. C. Richardson, M. Ya. Schelev, and B. K. Stepanov, Phys. Lett. (Amsterdam) 51, 249 (1975).
7. D. J. Bradley, A. G. Roddie, W. Sibbett, M. H. Key, M. J. Lamb, C. L. Lewis, and F. Sachsenmaier, Optics Commun. (Amsterdam) 15, 231 (1975).
8. A. J. Lieber, R. F. Benjamin, H. D. Sutphin and C. B. Webb, Nucl. Insts. and Meth. 127, 87 (1975).
9. B. L. Henke, J. A. Smith (Univ. of Hawaii) and D. T. Attwood (LLL), to be published.
10. E. K. Zavoiskii and S. D. Fanchenko, Dokl. Acad. Nauk SSSR 108, 218 (1956). V. V. Korobkin, A. A. Malyutin, and M. Ya. Schelev, J. Photog. Sci. 17, 179 (1969).
11. J. T. Larsen, private communication.
12. J. L. Gaines and R. A. Hansen, Lawrence Livermore Laboratory report UCRL-77821 (to be published).
13. J. F. Holzrichter and D. R. Speck, J. Appl. Phys. 47, 2459 (1976).
14. F. Seward, J. Dent, M. Boyle, L. Koppel, T. Harper, P. Stoering, and A. Toor, Rev. Sci. Inst. 47, 464 (1976). M. Boyle, private communication.
15. M. Ya. Schelev, M. C. Richardson, and A. J. Alcock, Rev. Sci. Insts. 43, 1819 (1972). D. J. Bradley, B. Liddy, W. Sibbett and W. E. Sleat, Appl. Phys. Lett. 20, 219 (1972).
16. G. H. Dahlbacka, and J. Nuckolls, Bull. Am. Phys. Soc II 19, 950 (1974); Lawrence Livermore Report UCRL-75885.
17. G. S. Fraley and R. J. Mason, Phys. Rev. Lett. 35, 520 (1975).
18. J. T. Larsen, Bull. Am. Phys. Soc. II 20, 1267 (1975); Lawrence Livermore Laboratory Report UCRL-77040.
19. J. F. Holzrichter, H. G. Ahlstrom, D. R. Speck, E. K. Storm, J. E. Swain, L. W. Coleman, C. D. Hendricks, H. N. Kornblum, F. D. Seward, V. W. Slivinsky, Y. L. Pan, G. B. Zimmerman, J. H. Nuckolls, Accepted for publication in Plasma Physics.