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ULTRAFAST X-RAY DIAGNOSTICS FOR LASER FUSION EXPERIMENTS*

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Abstract

Temporally, spectrally, and spatially resolved x-ray emission diagnostics are important tools in the study of the heating and compression of laser fusion targets by sub-nanosecond laser pulses. The use of the Livermore 15 psec resolution x-ray streak camera to make such measurements is reviewed. Temporal histories of spectrally resolved x-ray emission in the 1-10 keV range have been obtained. These data have served to further define the x-ray streak camera as a quantitative diagnostic tool and have also provided data relating to the absorption and compression phases of laser heating. The x-ray streak camera has been used in conjunction with a specially designed pinhole imaging system to temporally record images of laser compressed targets with a spatial resolution of approximately 6 μ m. Implosion characteristics are presented for experiments with glass microshell targets. The concept, development, and testing of an ultrafast framing camera for full two-dimensional time resolved imaging is discussed. A prototype camera, based on the image dissection-restoration concept, has achieved an approximately 200 psec frame period with a resolution of 50 μ m.

Introduction

The essential feature of the concept of laser induced fusion that is under study in a number of laboratories worldwide, is the compression and heating of matter to thermonuclear conditions. (1-4) X-ray measurements play an important role in the diagnostics of this process because of the high temperatures and densities created. The need for the development and application of new diagnostics techniques and instrumentation has been emphasized by the spatial and temporal time scales characteristic of laser fusion experiments. A present fusion experiment typically involves a fuel filled hollow glass microsphere target of roughly 100 μ m or less diameter, irradiated by an approximately 100 psec, terawatt pulse from a neodymium laser. As a result of this interaction, the target is heated and subsequently compressed to a fraction of its initial size. Time integrated x-ray spectral data has been obtained on compression experiments for some time(5). Figure 1 shows a time integrated x-ray spectrum obtained on a fusion target implosion experiment. Data such as this has played an important role in understanding preliminary implosion experiments by providing information on the thermal and non-thermal processes occurring in them. Measurement techniques capable of working in the x-ray intensity and spectral ranges shown in Figure 1 with temporal resolution on a picosecond scale and spatial resolution on a micrometer scale are required to obtain an adequate understanding of the phenomena under study.

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

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For the purpose of this paper, techniques capable of time resolution in the sub-nanosecond regime are being considered. Therefore, mechanical cameras are excluded from consideration as are devices using phosphors or fluors as x-ray converters. However, it should be noted that ongoing work with fluor compositions that provide very short time response is encouraging^(6,7) and that their use with devices analogous to those to be described below may provide viable alternatives for fast time resolution x-ray detection systems. Fast x-ray photodiodes have been developed and applied to laser-plasma experiments⁽⁸⁾. These devices provide a time resolution in the roughly 50-100 psec regime by employing an elaborate electronic sampling scheme to obtain the data signal. The main disadvantage of photodiodes, other than the time resolution limitation, is the lack of spatial resolution capability, short of using an array of such devices.

The ultrafast streak camera is the only comprehensive diagnostic tool presently available to study the temporal profiles of electromagnetic radiations in laser fusion experiments. Ultrafast, x-ray sensitive, image converter streak cameras, with picosecond scale time resolution, have been developed recently^(9,10). In addition to providing high time resolution, linear response, and a moderately long (≈ 1 nsec) recording time, the x-ray streak camera is sensitive and provides one dimension of spatial resolution. The concept of this diagnostic instrument will be briefly reviewed, and its quantitative application to laser fusion target experiments will be discussed. Specifically, x-ray spectral data, resolved to 15 psec are presented. These are the first observations of x-ray emission from laser irradiated targets with sufficient temporal resolutions to display features associated with the heating and compression phases. The observations provide previously unavailable data for the implosion time, and indirectly of the average implosion velocity. Temporally resolved x-ray spatial image data from laser fusion target experiments which provide more detail of the implosion process are presented. Finally, work toward the extensions of these concepts to true picosecond scale "framing" (two-dimensional imaging) x-ray photography will be discussed.

X-Ray Streak Camera

The x-ray streak camera⁽⁹⁾ used in our experiments is shown schematically in Figure 2. The time varying x-ray signal emitted by a laser irradiated target strikes the 100 Å thick, slit-shaped (0.1 mm x 12 mm) gold photocathode. The gold is evaporatively deposited on an 8 μ m thick beryllium substrate which serves as the vacuum window for the image converter tube. This detail is shown in the inset in Figure 2. Slow, secondary electrons are emitted by the transmission photocathode, accelerated, pass between a pair of deflection plates, and are imaged onto the output phosphor screen.

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

The high electric field at the photocathode produced by the accelerating grid close behind it is necessary to provide the high temporal resolution by reducing the transit time dispersion as the electrons travel the length of the tube. A properly timed ramp voltage applied to the deflection plates sweeps the "slit" of electrons rapidly across the phosphor screen thereby converting the temporal x-ray intensity information (as carried by the photoelectron current) into a phosphor brightness versus position image. An avalanche transistor circuit (13) provides the deflection voltage with a trigger "litter" of less than 100 psec and provides a streak speed on the phosphor of 74 $\mu\text{m}/\text{psec}$. In order to avoid effects which would be deleterious to the resolution capability of the camera, and hence the time resolution, the streak tube is operated at as low current levels as possible and the image at the phosphor screen is correspondingly weak. The fiber-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. The spatial value has been determined by backscattering x-ray absorption metal wires. The temporal value is dependent upon the transit time dispersion of the electrons in the tube, and hence, upon the energy distribution of the emitted electrons. (14, 15) A result of detailed studies of the secondary electron emission spectra from our gold photocathode, as measured by Henke, et. al. (16) is shown in Figure 3. This distribution is essentially independent of photon energy over a measured range from 100 eV to 8 keV. The small electron energy spread of 4 eV FWHM gives a transit time dispersion value of approximately 13 psec for the electric field (3 kV/cm at the cathode) and geometry of the streak tube. Additional factors (14, 15) combine to result in an overall temporal resolution conservatively evaluated as 15 psec, as quoted above. In the x-ray case, as often reported by others (10, 11), the direct measurement of such short temporal resolution, in the Rayleigh sense, is difficult because of the long temporal tails generally present in the x-ray emissions. However, we do observe that experimentally observed fast rising x-ray signals presented in subsequent sections are consistent with the predicted target emission profiles (17) and the calculated temporal resolution.

Figure 3. Secondary electron emission spectrum from an x-ray irradiated (13.7 μm) gold photocathode. R. L. Henke, et. al., [Pp. 16]

Temporally Resolved X-Ray Spectral Measurements

In order to record spectrally and temporally resolved x-ray emission from laser irradiated targets (18, 19), a set of simple K-edge absorbers are placed over the streak camera slit as shown in Figure 4. In this way, the temporal history in an array of x-ray "energy bins" will be displayed in the streak data. Various filtering materials of aluminum, chromium, titanium, cobalt, zinc and yttrium are used; the x-absorption edges are indicated in Figure 4. Except for chlorine, the filters are high purity "metal" foils, typically 25 μm thick. The chlorine filter consists of commercially available polyvinylchloride (PVC) foils of thicknesses of 25 μm and titanium are 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 (20) and with the steeply falling x-ray emission spectrum, as typified in Figure 1. The higher energy channels are chosen so as to sample wider spectral ranges, thus compensating for the problems of rapidly declining emission spectrum and photocathode sensitivity. Typical spectral widths for other channels are 1.7 keV centered at 4.0 keV for titanium and 2.2 keV centered at 5.7 keV for cobalt. Lower energy x-ray emission has not been sufficiently intense to date to produce a detectable signal with the yttrium channel. Figure 6 is a streak record from a target compression experiment showing responses for all channels from aluminum to zinc. Although this particular record is heavily exposed and the entire range of the recording film is spanned, useful data is obtained in all channels.

Streak record photographic density contours obtained for the temporally and spectrally (but not spatially) resolved x-ray emission in another experiment are shown in Figure 7. The target was an 87 μm diameter, 0.7 μm wall thickness glass microshell target filled with a deuterium-tritium mixture at an initial density of 3 mg/cc. The target was irradiated from opposite sides by simultaneous 70 nsec (FWHM) pulses of 14.5 J and 13.8 J at the JANUS laser facility (21) and produced 4.6×10^{16} neutrons. Time integrated x-ray microscope photographs show that the target compressed with a change in radius by a factor of approximately six. From the data in Figure 7, film density versus time profiles are obtained for each channel. Characteristics of the recording film (N vs. log E) are then removed with a simple computer routine, thus converting the data to x-ray intensity versus time, on a channel by channel basis. Using measured yield data for the gold

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

Figure 5. Spectral response of the chlorine filter channel.

K-edge filters

Zn (9.7 keV)

Co (7.7 keV)

Ti (5.0 keV)

Cl (2.3 keV)

Al (1.0 keV)

Time →

Figure 6. Streak camera record of laser irradiated target showing responses for the aluminum through zinc x-ray filters.

Figure 7. Streak record photographic density contours from target compression experiment. (37 μ m diameter target)

Figure 8. Temporally and spectrally resolved x-ray emission from a laser compressed 97 μ m diameter target

photostats⁽²⁰⁾ these channels can then be quantitatively related to one another in relative intensity, as shown in Figure 8. Time integration of these temporal profiles gives an emission spectrum that is in good agreement with the 500 eV value determined by standard time integrated measurement techniques,⁽⁵⁾ (e.g. Figure 1).

The multi-hundred picosecond x-ray emission profiles shown here, lasting considerably longer than the incident laser pulse, are characteristic of the imploding targets we have studied. This is to be contrasted with the much shorter emission histories we observe upon irradiation of massive targets. The aluminum channel is not shown in Figure 8 because a folding of the emission spectrum, camera response and filter transmission characteristic shows that this particular channel has contributions from both high and low energy x-rays and can therefore not be used to represent the localized 1.6 keV spectrum. Both the zinc and yttrium channels

showed no discernible signal in this particular experiment. The chlorine and titanium channels were both recorded with two thicknesses, as described previously in the text; the thin and thick titanium channels basically follow each other, without saturation effects, but the thinner signal (thin channel) shows signs of resolution degradation in the final x-ray burst. This latter effect is likely due to excessive current in the streak tube, the cost one must pay for meeting the equally important demand of wide dynamic range. (23,24) A significant feature of Figure 9 is that the late time burst in the temporal signatures is not saturation limited but provides a profile of the x-ray emission throughout the record.

The measured x-ray temporal profiles presented in Figure 9 are interpreted in terms of general features of present day target irradiation experiments. These targets are of the "exploding pusher" type (25-29) in that they are rapidly and uniformly heated by a short, untailored optical pulse, as opposed to the relatively delayed compression planned for later experiments with longer pulses and "sausage" targets. In these exploding pusher experiments, laser energy is absorbed and heats the glass shell ("pusher") where significant hydrodynamic expansion takes place. Numerical simulations of this process (30,31) show that this rapid heating results in an extremely impulsive or a relatively short acceleration period, followed by a period in which the glass shell forces the contained fuel toward a relatively constant velocity, reaching a final stagnation near the target center, and finally a subsequent piston target disassembly. The general features of kilovolt x-ray emission from such a process in an experiment can be seen in Figure 10. In all three x-ray energy channels the emission is an emission pulse with shell heating, the plateau region in which laser heating and acceleration take place (finishing at the secondary peak which corresponds to stagnation near the target center), and the final pulse as the target disassembles (the center is observed). The final stagnation time can be estimated by subtracting the time from the onset of the laser pulse (estimated to be about 100 psec in Figure 9) to the implosion time (the time of the final pulse) of 100 psec. After a final target status as recorded by a time-resolved x-ray pinhole camera, an average implosion velocity of 2.5×10^6 cm/sec is deduced. This result is in good agreement with the numerical calculations of this target experiment (32). A significant spectral feature inherent in Figure 9 is the rapid decay of emission in the highest energy (5.3 keV) channel between the first peak and the final peak. This spectrally sensitive data is interpreted as experimental evidence of target disassembly during the period extending from early laser pulse to final stagnation. Figure 9 shows the final behavior at various times in the implosion process, as determined from the data of Figure 9. The earlier behavior referred to above is clearly evident in the slope of the 200 psec line in this plot.

This experiment employing an x-ray sensitive ultrafast streak camera to record quantitative, temporally and spectrally resolved x-ray data from laser compressed targets has now provided data with sufficient resolution to show pertinent features of target performance. From this data we are able to infer time-resolved temperatures, implosion times, and indirectly, implosion velocities for laser target experiments, data previously not available in such a direct and simple manner.

Time-Resolved One-Dimensional X-Ray Imaging

Results of the data described in the preceding section represent a major advance in our time-resolved x-ray diagnostic capabilities. X-ray streak camera data have been obtained which show significant temporal structure but which do not localize the spatial emission of the compressed fuel ("sausage"). Time-integrated x-ray pinhole cameras have the spatially resolved photographs required for target dissection (33). As pointed out in the introduction, it is necessary to be able to make x-ray measurements with sufficient temporal and spatial resolution to directly study the dynamics and compression of laser implosion targets.

Figure 11 is a schematic diagram of the time-resolved x-ray pinhole camera developed to diagnose laser fusion target experiments at Livermore (30). An x-ray pinhole is used to image the target with its own x-ray emission, onto the slit of the streak camera. The one-dimensional image projected on the slit-shaped photocathode is streaked in time giving a space-time history of the target implosion. The imaging system must provide sufficient x-ray intensity in a spatially well-resolved, accurately alignable image at the photocathode.

Figure 9. Spectral behavior for various times for the laser heated and compressed target.

An x-ray pinhole is used in this present application because it combines ease of construction and large magnification with reasonable spatial resolution. X-ray pinhole cameras can provide spatial resolution in the micron range when properly designed with respect to geometrical and diffractive effects (34). In this work a 6 μ m diameter x-ray pinhole is used with an object distance of 1 cm and 50-times magnification.

Inspection of Figure 10 shows that a vertical displacement of one target radius from the optimum position renders the image tangential to the streak camera slit and therefore unphotographable. Considering that we are interested in 60 - 100 μ m diameter targets, and that these implode to a fraction of their initial radius,

Figure 10. Schematic diagram showing the laser irradiated target, a 50x pinhole camera, and a simplified representation of the x-ray streak camera. Note that a vertical target displacement of one radius from the ideal position renders the image tangential to the slit shaped cathode, and therefore undetectable.

severe requirements on alignment accuracy are imposed, typically of several microns. The difficulty that this generates resides in the fact that the x-ray pinholes are chosen to be near diffraction limited for 2 keV x-rays and a sufficiently intense alignment source does not exist at that wavelength. Instead we seek to use a convenient visible alignment technique employing a CW He-Ne laser at 6328 Å. For the given geometry and near optimum x-ray pinhole diameter, this factor of 1000 difference in wavelength causes severe diffraction and essentially renders the visible alignment scheme useless. A solution to this is to construct composite pinholes^(32,33) which appear small to x-ray wavelengths, but large to visible wavelengths. The use of x-ray absorbing, visibly transparent glass to construct such pinholes makes this technique possible. A conservative estimate⁽³⁰⁾ of the x-ray intensity requirements, by scaling from intensities recorded in the time resolved but non-imaged data discussed in the previous section, shows that the period of peak compression (peak x-ray emission in Figure 3) is easily recorded with the x-ray streak camera, a 6 μ m diameter pinhole, and a half-terawatt of laser power (characteristic of the JAWUS laser) irradiating a 50 μ m diameter glass shell target.

A typical composite pinhole is shown in Figure 11. Such a pinhole appears appropriately small at x-ray wavelengths to provide high resolution imaging but appears sufficiently large at visible wavelengths to allow convenient optical alignment. It is fabricated by first mounting a 12 μ m diameter thick gold foil on the end of a 16 gauge hypodermic needle, as seen in Figure 11 (a).

Figure 11. A typical composite pinhole is mounted on the end of a 16 gauge hypodermic needle, as shown in (a). A 125 micron diameter hole is mechanically drilled in a 12 micron thick gold foil, and then covered with a thin (5-10 micron thick) layer of x-ray absorbing, visibly transparent glass. A smaller (3-10 micron) x-ray pinhole is then laser drilled concentrically with the larger hole as shown in (b). A scanning electron microscope picture of the laser drilled hole is shown in (c). Composite pinholes have been formed with hot, tungsten phosphate and tantalum silicate glasses.

A 125 μm diameter hole is mechanically drilled in the gold foil and then the entire gold foil is covered, in this case, with a 9 μm thick disc of 66% by weight tungsten phosphate glass (34). This glass has an x-ray absorbance of 10^{-5} in the spectral region of interest, and a visible transmittance of 13%. In this case, a 2 μm diameter hole was then laser drilled concentrically with the larger 125 μm diameter hole, as shown in Figure 11 (b). A closeup view of the x-ray pinhole, taken with a scanning electron microscope, is shown in Figure 11 (c). Pinholes in the 2-10 μm diameter range have been constructed in the tungsten phosphate glass and also in 20 μm thick tantalum silicate glass. (35) The latter exhibits higher x-ray absorbance and higher visible transmittance than the tungsten glass, but has a higher melting point and is therefore more difficult to work with. Higher concentration lead glasses have not been used because lead has an α -edge at 7.46 keV and thus allows x-ray leakage, or insufficient absorbance in that spectral region. Tungsten and tantalum have their respective α -edges at 1.37 and 1.74 keV.

The visible alignment scheme used in conjunction with composite pinholes is shown in Figure 12.

Figure 12. Target alignment scheme employing a He-Ne laser, a focusing lens, and a set of Airy rings. Both the composite pinhole and the target are centered in the visible diffraction pattern.

A He-Ne laser, spatial filter, focusing lens and pellicle combine to provide the visible alignment beam. They are oriented so that the light appears to originate symmetrically from the center of the streak camera cathode. The pellicle is 50% reflective, 50% transmissive at 6328 Å, and 90% transmissive for x-rays of interest. The focal length of the lens is chosen to produce a focal region waist midway between pinhole and target. By appropriate clipping of the beam at the focusing lens, a set of diffraction rings modulates the waist pattern. The second dark ring is set approximately at 125 μm to allow accurate alignment of the large 125 μm hole of the composite pinhole. The x-ray pinhole is now centered in the optical alignment pattern within a concentricity error of 2 or 3 microns for the composite pinhole. The transmitted interference pattern, now somewhat affected by pinhole diffraction, propagates on to the target plane one centimeter away. The target is then moved to a central position in the ring pattern to insure the target diameter into the streak camera slit. With the cathode slit, pinhole, and target in alignment, the system is ready for target irradiation and compression experiments.

Results obtained during recent implosion experiments with the JANUS laser facility (21) are shown in Figures 13-15 for three nearly identical targets. These experiments involved the irradiation and compression of typically 68 micron diameter, 0.5 micron thick D₂ filled glass microshells. Using ellipsoidal focusing mirrors, the laser delivered approximately 0.45 TR in typically 70 nsec (FWHM) in these twosided irradiation experiments. X-ray imaging and filtering were obtained with a 6-micron diameter tantalum pinhole and a 125 micron thick beryllium filter, respectively. The space-time implosion diagrams presented in Figures 13-15 show isodensity film contours obtained directly from the respective streak camera records. Shaded blocks in the corner of each figure show the approximate space time resolutions of 6 μm and 13 psec.

The results presented in Figures 13 and 14 show two rather similar implosions, except that one is somewhat more symmetric (Figure 13), while the other shows more pronounced details of target acceleration. Both produced final implosion velocities of approximately 3.4×10^7 cm/sec, as seen in the illustrations. These final velocities are consistent with the indirect estimates obtained from the temporally resolved spectral data discussed earlier when proper account is taken of target mass and absorbed laser energy. In the third experiment, described by Figure 15, target irradiation was purposely blocked on one side so as to observe details of a single sided implosion experiment. This one-sided irradiation experiment is very interesting in that it shows hydrodynamic convergence toward the target center, and an asymmetric but two sided disassembly as the compressed core coasts for some distance beyond the target center.

Figure 16 shows spatial contours of the x-ray emission at several times for the data of Figure 14. At an early time the spatial profile shows two distinct emission regions corresponding to the oppositely directed sides of the imploding shell. At a later time, but before peak compression, the two regions grow significantly in intensity and begin to coalesce. At a still later time the two regions have merged into a single, stagnated core of peak x-ray intensity. Final target disassembly in the post-compression period is omitted for clarity.

Figure 13. Isodensity contours obtained from x-ray pinhole/streak record. The target had a wall thickness of 0.51 microns, a ρr fill of 1.32 mg/cc, and upon irradiation produced 1×10^5 neutrons. Two sided target irradiation consisted of 17.2J and 16.4J, 75 psec FWHM pulses.

Figure 14. Isodensity contours obtained directly from x-ray pinhole/streak record. The target had a wall thickness of 0.44 microns, a ρr fill of 1.67 mg/cc, and upon irradiation produced 1×10^5 neutrons. Two sided target irradiation consisted of 14.6J and 15.6J, 64 psec FWHM pulses.

Figure 15. Isodensity contours obtained directly from x-ray pinhole/streak record. The target had a wall thickness of 0.57 microns, a ρr fill of 1.82 mg/cc, and upon irradiation produced 2×10^5 neutrons. Single sided target irradiation consisted of a 16.9J pulse of approximately 70 psec FWHM.

Figure 16. Spatial profiles showing the implosion of B-410 at various times. This data is obtained by examining various iso-temporal planes in Fig. 14. Emission from opposite sides of the imploding shell are observed to coalesce and finally form an intense stagnation region near the target center.

Figure 17 shows x-ray temporal profiles for the target center, and for a position 20 microns off center. Note that the latter position displays a two humped behavior as peak radiation passes that radial position once during implosion and once during disassembly. Note that a properly weighted sum of the two temporal profiles in Figure 17 could be used effectively to reconstruct the unimodal profiles in Figure 8. Further analysis of these results is underway, particularly with respect to removal of recording film (0 vs. ion C) characteristics.

Time Resolved Two-Dimensional X-Ray Imaging

The application of the x-ray streak camera pinhole combination to the study of laser fusion target experiments has provided direct, quantitative measurement of implosion dynamics. The step to full two-dimensional, time resolved x-ray imaging on a picosecond time scale, "ultrafast framing", will provide even more detailed diagnostics of the dynamics and symmetry of the implosion process. To meet this need, an ultrafast framing

Figure 17. Temporal profiles of x-ray emission from the target center and from a position 20 microns to one side. The latter shows a double humped behavior as intense x-ray emission passes this radial position once during implosion and once during post-compression disassembly. This data is obtained by examining iso-spatial planes in Figure 14.

camera system, capable of applications in optical or x-ray spectral regions, is under development^{13a}. A schematic diagram of the concept for a three frame camera, capable of sub-100 nsec frame periods, is shown in Figure 10. The tube consists of a dissector section and a restorer section. The framing concept is based on line-dissections of an electron image through a slit aperture and subsequent restoration into a spatially resolved image. The dissector section is similar to a conventional streak camera tube except for the replacement of the phosphor screen by the slit aperture plate at the image plane. The restorer section consists of a set of compensator plates for each slit, an electron lens, restorer deflection plates and the output phosphor screen. Image inversion and compensator plate action are not shown for simplicity in Figure 10. The time varying image is incident from the left onto the photocathode; the resulting electron image is accelerated, focused, and swept at high speed across the dissector plate. The electron signal emerging from each slit is now effectively like the signal from the cathode of a streak camera. Application of a suitably scaled and synchronized voltage signal to the restorer plates in the following section of the tube simply focuses and unfolds the signal to project the reconstructed images displaced spatially as a function of time. In this design there is a monotonic time shift through each image the magnitude of which will be determined by the image size, deflection speed, and dissector aperture size.

Figure 10. Principles of operation for the framing camera tube.

A prototype model of the framing camera tube has been built and tested. The dissector section is a modification of a standard image converter tube and a specially designed restorer section was fabricated. The tube has been operated with a thermionic cathode covered by a shadow mask to provide a spatial pattern for imaging and resolution evaluation. Figure 19a shows the shadow mask pattern. The time resolution in each line element of the dissected image is determined by the electron transit time dispersion, the slit height (which is made equal to the electron image resolution) and the streak speed. In present testing with the prototype, using our avalanche transistor circuits¹³ for the dissection and restoration deflection voltages, a frame period of approximately 200 psec with a temporal resolution in the line element of about 15 nsec and an image spatial resolution of 50 μ m has been achieved. Photographs of the reconstructed image are shown in Figure 12b for a 0.5 μ sec frame and in Figure 19c for a 200 psec frame. Continued development of this technique toward application to x-ray and optical imaging applications in laser fusion experiments will provide an important

Figure 1(a). Molybdenum shadow-mask for thermionic cathode.

Figure 1(b). A 0.5 usec framed image.

Figure 1(c). A 220 usec framed image.

new diagnostic capability.

Summary

The application of an ultrafast x-ray streak camera to obtain temporally resolved data on laser fusion experiments at Livermore have been discussed. The use of the x-ray streak camera has been advanced to the state of a quantitative diagnostic technique which is providing basic new data on laser fusion compression experiments. Results of spectrally and spatially resolved x-ray data, resolved to 10 picosec, which have provided data on the implosion process have been presented. The extension of the technique via the development of the ultrafast framing camera has been introduced. This technique will provide temporally resolved information when used in conjunction with devices providing spectral resolution and with high resolution grazing incidence x-ray microscopes or x-ray nichols for imaging studies.

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NOTES

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