Conf-760828--3

LA-UR-76-1458

TITLE: SUB-PICOSECOND X-RAY STREAK CAMERA DEVELOPMENT FOR LASER FUSION DIAGNOSTICS

AUTHOR(S): Albert J. Lieber, H. Dean Sutphin, Clinton B. Webb, and Arthur H. Williams

SUBMITTED TO: 12th International Congress on High-Speed Photography, Toronto, Canada, August 1-7, 1976.

los alamos scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

An Affirmative Action/Equal Opportunity Employer

Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

SUB-PICOSECOND X-RAY STREAK CAMERA DEVELOPMENT FOR LASER-FUSION DIAGNOSTICS*

Albert J. Lieber, H. Dean Sutphin, Clinton B. Webb, and Arthur H. Williams
University of California, Los Alamos Scientific Laboratory
Los Alamos, New Mexico 87545

Abstract

In laser-fusion interactions the effectiveness of coupling laser energy into target compression can be followed by obtaining spatial and temporal information on x-radiation emitted by the target. Microballoon targets now used require temporal resolution of better than a few picoseconds to track accurately target collapse and disassembly. Instabilities of two picoseconds or less are predicted for the process. Most streak cameras are based upon a sector-focused streak tube, which in the design limit is capable of only about 10 ps x-ray resolution. Therefore, a new tube, based upon the proximity-focused or wafer intensifier was developed as a laser-fusion diagnostic capable in the design limit of delivering truly sub-picosecond x-ray resolution. A new power supply was also developed to drive the streak tube. Together, a camera has resulted with true picosecond capability, small size, high sensitivity, broad dynamic range, high spatial resolution, and very low jitter. The system has proved 98% reliable in over 300 laser shots providing data on the collapse of microballoons when irradiated by a dual beam Nd:YAG laser. Theoretical predictions of 2.5 to 3 ps resolution are consistent with experimental data. A visible variant of the design now under construction is expected to give sub-picosecond resolution with advantages similar to the x-ray system.

Introduction

With the trend in laser fusion toward complex targets of the order of a few microns in diameter. temporal resolution of less than a few picoseconds is necessary to track accurately target assembly and disassembly. Instabilities predicted in this process are 2 ps or less. Almost all present streak cameras are based upon the RCA Type C-73435 shutter intensifier, which was designed over a score of years ago for use as a multiple fast rastering camera.[1] Modifications in this country and Europe have attempted to minimize the inherent weaknesses of the sector-focused or pinhole electron optics, image intensifier design.[2-4] The addition of an x-ray sensitive photocathode has resulted in a camera with 15 ps resolution and has already yielded data indicating the importance of this diagnostic to the understanding of laser fusion.[5] However, weaknesses generic to this basic type of intensifier preclude true picosecond and ultimately sub-picosecond x-ray resolution. Principal among these are pinhole electron optics causes resolution (spatial and temporal) to be a function of peak conductance and gain. Peak conduction must be limited to control electron defocusing due to space charge buildup at the pinhole. In ultra-fast streak applications an attempt is made to compensate for this loss of signal by the addition of a follow-on image intensifier. In the case of picosecond resolution such an initial loss in signal cannot be tolerated if high quality streaks, with good signal-to-noise ratios, are to be obtained for quantitative data reduction. To minimize photoelectron velocity dispersion effects on temporal resolution, a carefully engineered extraction grid is added to increase the photocathode field.[6] This geometry is not conducive to pulsing to obtain the ultimate extraction field and sensitivity. Finally, the overall length of the tube of 22 cm allows longitudinal velocity dispersion to reflect as an intolerable time dispersion for true picosecond and sub-picosecond operation. Employing another lens for velocity selection merely serves to lengthen the overall package still further, requiring higher selectivity, and reduced sensitivity.[7]

An investigation of another type of streak tube based upon the proximity-focused, or wafer intensifier, was undertaken by this laboratory several years ago for it was known that these tubes suffer from none of the above mentioned shortcomings.[8] For an instrument to be a viable laboratory diagnostic other merit factors than temporal resolution must be considered. Some factors included as design goals for the camera were: (1) Jitter. The complexity and cost of firing a large laser system demands obtaining a trace each time. (2) Size. The premium placed upon the experimental volume around the laser target demands a small vacuum compatible package, which can be placed in the chamber for maximum solid angle while not blocking the field of other diagnostics. The presently available commercial package of over 5 feet in length makes this impossible. (3) Sensitivity. Maximum transducer, or photocathode sensitivity, must be achieved and maintained. This can be traded for spatial resolution, energy resolution, or other gain-dependent functions later as the experiment may dictate. (4) Dynamic Range. A broad dynamic range independent of spatial and

*Work performed under the auspices of the U. S. Energy Research and Development Administration.

temporal resolution is a necessity due to wide variations in x-ray yields from shot-to-shot on even the same type of target, and (5) Cost, Complexity, and Reliability. These factors are important not only to the laser-fusion community, but also if usage of the instrument is to expand to other disciplines.

Design

We feel the quest for a camera meeting the merit factors outlined above has culminated in our camera the Pico-X.[9] A schematic for the streak tube is shown in Figure 1. Starting with the discovery that some microchannel plates make excellent passive parallel-bore collimators each interface of the tube had to be intensively studied for maximum system response.[10,11]

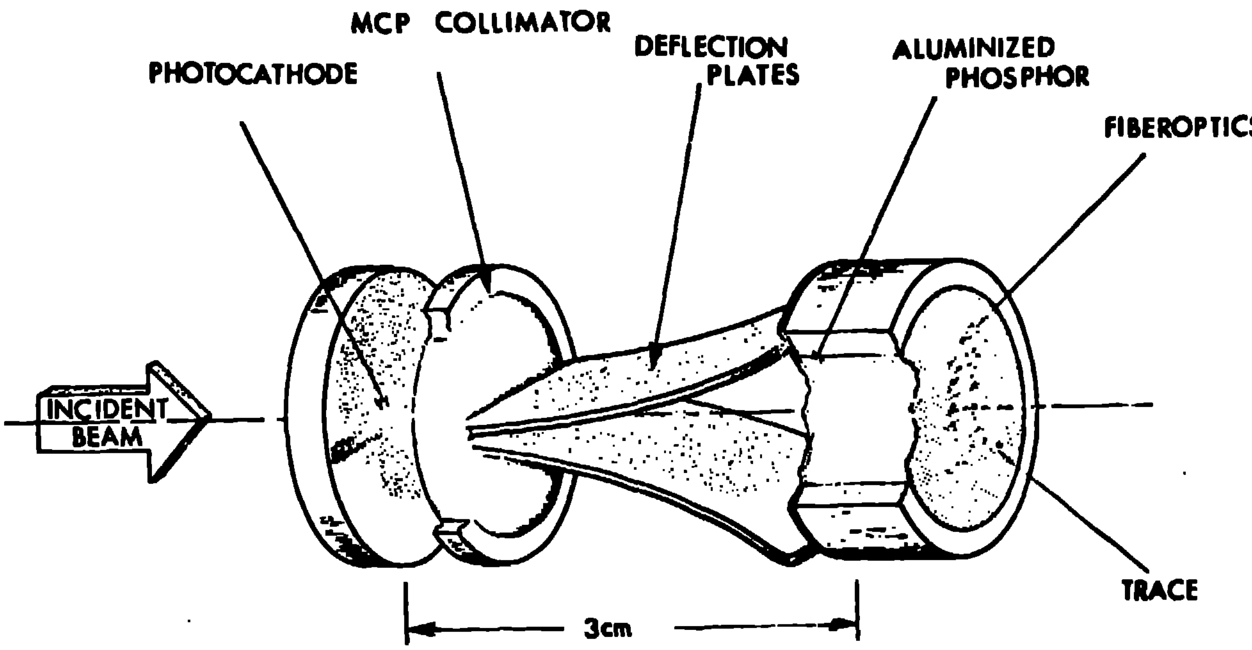

Fig. 1. Schematic proximity-focused streak tube.

The proximity-focused intensifier depends upon intense electric fields to map photoelectrons to phosphor, making it ideally suited to minimize photoelectron velocity dispersion effects at the same time. Peak extraction fields that can be generated between the polished parallel plates of the photocathode region far exceed those that can be generated by grid structures thereby yielding the highest possible photocathode extraction and sensitivity. Using a microchannel plate for transverse-photoelectron velocity control minimizes overall tube length eliminating the need for addition electron lenses.

A computerized study was made to ensure the maximum deflection sensitivity for minimum plate length.[12] The effectiveness of this study in generating an efficient short set of pulses is reflected in Figure 2. Our tube is compared with a standard RCA C 73435 visible streak tube. A striking feature of the tube is the overall length is 3 cm from photocathode to phosphor. This results in a very small, vacuum-compatible package which fits into our scattering chamber.

The limit on deflection ability defines the tube's record length. This, in turn, places stringent requirements on trigger jitter if the merit factor of a trace per shot is to be realized. Therefore, a new trigger had to be developed to power the tube. The trigger and pulse system contains a laser-triggered gap which uses a thin dielectric in the interelec-

Fig. 2. Size comparison of proximity-focused tube prototype with visible RCA C-73435

trode space. The gap has shown less than ~ 20 ps jitter and proved 98% reliable in over 300 shots. The present Pico-X uses a direct 35 mm film cassette readout. Automatic remote controlled film advance and gap arming are incorporated to speed data acquisition.

Experimental Results

Although our measurements of the collimation ability of specially constructed microchannel plates showed scattering to be minimal, the ultimate test remained to image through the tube itself. Figure 3 shows a deflected image of a 100-μm-wide slit object formed by the Pico-X from x-rays generated by a 1 J Nd:YAG pulse on a 150-μm-diameter-nickel ball. The image formed is consistent in width with that predicted for the microchannel plate collimator. Curvature of the image is due to fringing in the deflection region for the slit is wider than the deflection plates.

Once the static resolution for the tube was established (static and dynamic resolution are the same for this type of tube) a measure of the sweep velocity was needed. This was determined by irradiating a 150-μm-diameter nickel sphere with two 1 J Nd:YAG beams. For these tests an image intensifier was added to provide a gain of approximately 200X. The film used had an ASA rating of 125. The intensifier could have been eliminated entirely by using a higher speed film. Figure 4 shows a calibration test. A 50-μm-vertical slit was used to separate the interactions on the sphere. The beams were first brought into coincidence and then optically displaced in time to provide the calibration. It may be seen that the inverse sweep velocity for the Pico-X is 10 ps/mm. Slower rates are available and have proved useful in establishing timing. The statistical quality of the streaks allows quantitative densitometry of the traces.

It is of historical note that one of the main reasons we built the Pico-X was to determine how long x-rays lingered after termination of irradiation. This information was vital before a backlighting fast-framing system could be implemented as proposed at the 11th International Fast Framing Conference.[13] From Figure 4 it is evident that x-rays generated in a 0.8 to 6 keV window lasts well past the 73 ps laser pulse.

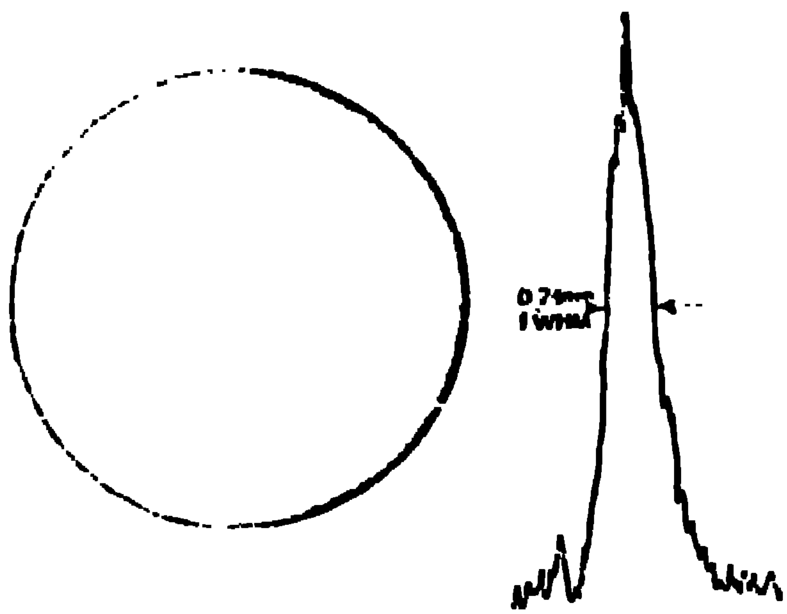

Fig. 3. Static x-ray resolution test. Static and dynamic resolution are the same in this type of tube.

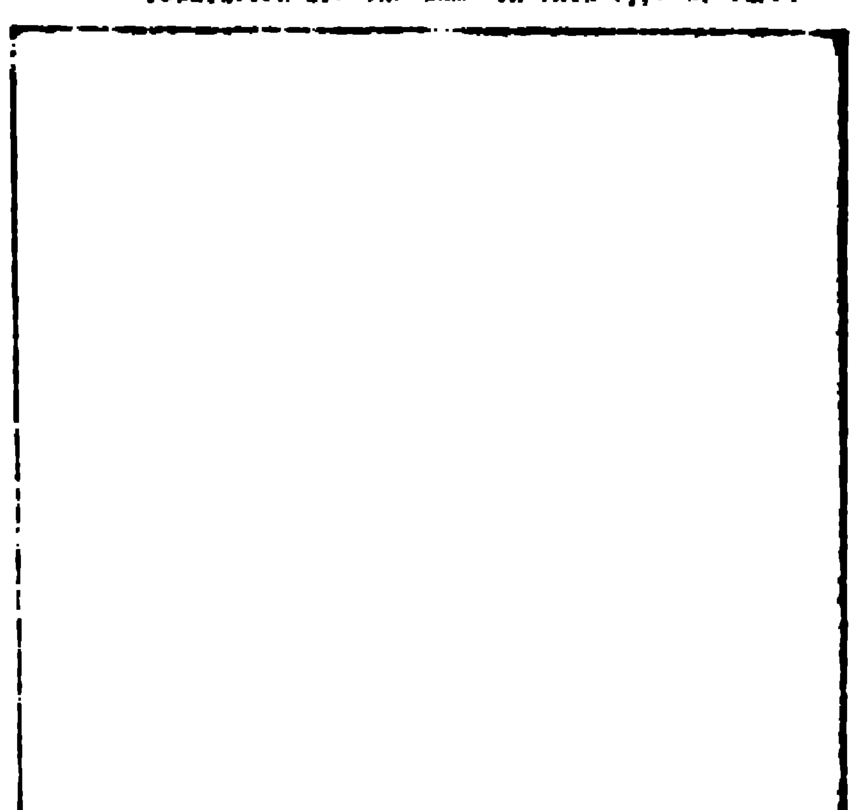

Fig. 4. Sweep calibration for Pico-X. v^{-1} = 10 ps/mm.

We are confronted with the problem of how to test x-ray resolution of 2.5 to 3 ps theoretically predicted for the prototype. In the absence of an x-ray pulse train of duration and separation comparable to the predicted resolution, we confine ourselves to the admittedly circular logic of using features generated in laser-fusion reactions themselves to demonstrate the experimental resolution. Figure 5 shows the compression of a 50-μm-diameter hollow glass microballoon when irradiated diametrically by two 1 J Nd:YAG laser pulses of 70 ps duration. For this test a slit of 25 μm width was used. A conventional x-ray pinhole photograph of the interaction is also shown in the figure. It is apparent from the photo that the glass experienced cold collapse followed by compression, expansion, and recompression. Thus, we were fortunate enough to "catch" an instability of 3 ps or less which serves to verify the theoretical predictions.

Using a better microchannel plate collimator it should be possible to obtain 0.6 ps resolution assuming an 8 eV spread in photoelectrons. A visible variant of the design is under construction and is expected to yield equally impressive advances over the old tube.

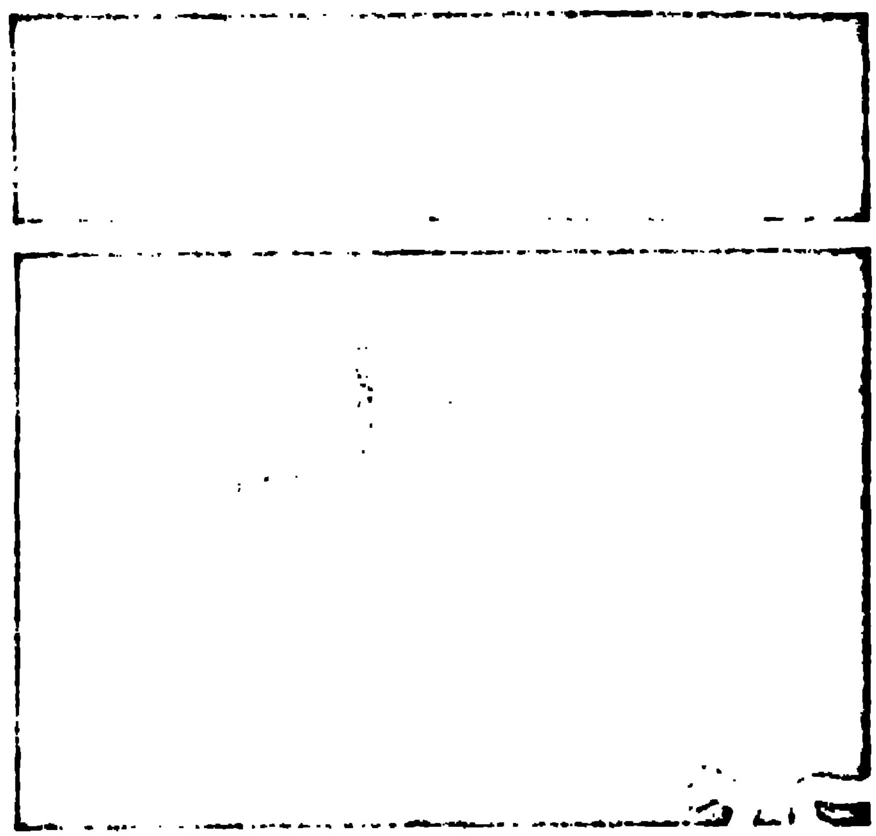

Fig. 5. Instability in compression of 50-μm-diameter microballoon.

References

1. R. Engstrom and R. Fitts, SPIE 42 (Aug. 1973).
2. M. Y. Schelev, M. C. Richardson, and A. J. Alcock, "Operation of a Grid-Shuttered Image Converter Tube in the Picosecond Region," Review of Scientific Instruments 43, 12 (Dec. 1972).
3. M. C. Richardson, "Investigation of the Characteristics of a Mode-Locked Nd:Glass Laser with the Aid of a Picosecond Streak Camera," IEEE Journal of Quantum Electronics, QE-9, 7 (July 1973).
4. D. Bradley and G. New, IEEE 62 (1974).
5. C. F. McConaghy and L. W. Coleman, "Picosecond X-Ray Streak Camera," Applied Physics Letter 25, 5 (Sept. 1974).

6. E. Zavoiskii and S. Franchenko, Transl. from Dokl. Akad. Nauk. SSSR 108 (May-June 1956) pp. 218-221.
7. G. Clement, C. Loty, and J. P. Roux, "The Design of a New Electron Optics for a Picosecond Streak Camera," Proc. of the 11th International Congress on High-Speed Photography, London, England, Chapman and Hall (Sept. 1974) pp. 131-135.
8. A. J. Lieber, Review of Scientific Instruments 43, 1 (1972).
9. ERDA Patents Pending, Pico-X Patent Waivers Applied for by General Engineering Applied Research Incorporated, 260 Sheridan Avenue, #414, Palo Alto, California 94306.
10. A. J. Lieber, R. F. Benjamin, H. D. Sutphin, and C. B. Webb, "Investigation of Microchannel Plates as Parallel-Bore Electron Collimators for use in a Proximity-Focused Ultra-Fast Streak Tube," Nucl. Instrum. Methods 127 (1975) pp. 87-92.
11. C. B. Webb, A. J. Lieber, H. D. Sutphin, and R. F. Benjamin, "Investigation of Microchannel Plates as Parallel-Bore Collimators for Electron Pulses," Rev. Sci. Instrum. 47, 1 (Jan. 1976) pp. 149-150.
12. S. J. Gitomer and C. K. Krishnan, "Numerical Simulation of Direct Energy Conversion," IEEE Plasma Science PS-2, 277 (1974).
13. A. J. Lieber, R. F. Benjamin, H. D. Sutphin, and G. H. McCall, "Applications of Ultra-Fast High-Resolution Gated-Image Intensifiers to Laser-Fusion Studies," 11th International conference on High-Speed Photography, SPIE (1974) pp. 144-149.