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X-RAY AND VISIBLE LIGHT

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SUB-PICOSECOND PROXIMITY-FOCUSED STREAK CAMERA FOR X-RAY AND VISIBLE LIGHT*

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Abstract

Laser-fusion requires diagnostics of high-density, high-temperature plasmas on the picosecond time scale. To this end a proximity-focused streak camera has been under development. An x-ray version of this device has been constructed and tested using x-rays generated by irradiating microballoon targets with a two-beam Nd:glass laser. Results indicate the prototype to be of high sensitivity with temporal resolution of 2.5 to 3 ps. Later production cameras based upon this design are expected to give sub-picosecond temporal resolution for both x-ray and visible light. The camera is simple, compact, rugged and vacuum compatible. It has proved 98% reliable in over 350 laser shots. Applications to other disciplines are being studied and will be discussed.

Introduction

The trend in laser fusion has been toward complex targets of the order of a few tens of microns in diameter. Due to the duration of instabilities predicted for such small targets, x-ray streak camera resolution of less than 2 ps is necessary to track accurately target assembly and disassembly. In spite of claims of picosecond x-ray resolution (and now even femtosecond visible resolution) almost all present streak cameras are based upon a common ancestor--the RCA C-73435 shutter intensifier, which in the design limit can yield only 10 to 15 ps x-ray resolution.⁽¹⁾ Even with this resolution it has already been demonstrated⁽²⁾ that the x-ray streak camera is a very necessary diagnostic for understanding laser fusion. Modifications in this country and Europe have attempted to minimize the inherent weaknesses of the basic tube design but at the expense of other important parameters.⁽³⁻⁵⁾ A principal weakness, generic to this type of intensifier is its pinhole electron optics causes spatial and temporal resolution to be a function of peak tube conduction and gain. Peak conduction must be limited to control electron defocusing due to space charge at the pinhole. Although static resolution is of the order of 20 lp/mm, for fast streaking or high conductance the resolution drops below 5 lp/mm. Thus, the dynamic range of the tube is also limited. In fast streak applications, an attempt is made to amplify and regain signal through the addition of an expensive follow-on image intensifier. In the case of true picosecond operation, such an initial signal loss cannot be tolerated if streaks of high statistical quality are to be obtained which are suitable for quantitative analysis. In addition, to minimize photoelectron velocity dispersion effects and to provide a high extraction efficiency, a carefully engineered grid structure is added to increase the photocathode field.⁽⁶⁾ Because this geometry is not conducive to fast pulsing, the ultimate extraction field and sensitivity cannot be obtained. Finally, the 22 cm overall tube length allows longitudinal velocity dispersion of the photoelectrons to reflect as a significant temporal dispersion for true picosecond and sub-picosecond x-ray operation. Employing another lens for velocity selection merely serves to increase this length, thereby requiring even higher selectivity and reduced tube 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. Present cumbersome packages are over five feet in length making this difficult. (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 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.

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Design

We feel the quest for a camera meeting the merit factors outline 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 has 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 additional electron lenses.

A computerized study was made to ensure the maximum deflection sensitivity for minimum overall tube length⁽¹²⁾ This has resulted in the overall length of the Pico-X streak tube of only 3 cm from photocathode to phosphor, and a compact vacuum housing for the entire camera that can be placed within the scattering chamber. A typical commercial package for the instrument is shown in Figure 2. The package contains, not only the streak camera and film cassette, but all high voltage supplies as well. The entire package is less than 14 inches in length.

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 interelectrode space. The gap has shown less than ± 20 ps jitter as may be seen in Figure 3. It has proved over 98% reliable in over 350 shots. The present camera uses a direct 35 mm film cassette readout. Automatic remote film advance and gap arming are incorporated to speed data acquisition.

Fig. 2. Comparison of prototype with RCA C 73435 visible streak tube.

Fig. 3. Sequence of five shots showing trigger jitter of Pico-X. Record length is 180 ps.

Experimental Results

Although our measurements of the collimation ability of specially constructed micro-channel plates showed scattering to be minimal, the ultimate test remained to image through the tube itself. Figure 4 shows a deflected image of a 160- 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.

Fig. 4. Static x-ray resolution test. Static and dynamic resolution are the same in this type of tube.

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 5 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 5 it is evident that x-rays generated in a 0.8 to 6 keV window linger well past the 70 ps laser pulse.

We are confronted with the problem of how to test the 2.7 ps theoretical x-ray resolution for the camera prototype. In the absence of an x-ray pulse train of duration and separation comparable to this resolution we confine ourselves to the admittedly circular logic of using features generated by the laser fusion compressions themselves to demonstrate the resolution. Figure 6 shows a typical rather cold compression of a 50- μm -diameter hollow empty glass microballoon embedded in a 200- μm aluminum disk. The target is irradiated diametrically by two 1 J Nd:YAG laser pulses of 70 ps duration. The high background in the figure is due to bad tube vacuum and not indicative of typical operation. The corresponding pinhole photograph is shown above the streak camera picture. It can be seen a compression of the order of 25 to 30 ps has taken place. Figure 7 shows a streak made under similar circumstances. It is apparent from the streak that the glass balloon experienced a cold collapse a moderate

Fig. 5. Sweep calibration for Pico-X. $V^{-1} = 10$ ps/mm.

Fig. 6. Typical 50- μ m-diameter glass microballoon compression streak. Record length on the streak is 180 ps.

Fig. 7. Instability in compression of glass microballoon.

compression, expansion and recompression. Thus, we were fortunate enough to "catch" an instability of 3 ps or less which serves to verify the theoretical prediction.

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

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