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UCRL -75923
PREPRINT

302-748915--1

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ULTRAFAST X-RAY STREAK CAMERA

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August 7, 1974

MASTER

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11th International Congress on High Speed Photography
London, England - September 16-20, 1974

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ULTRA FAST X-RAY STREAK CAMERA[†]
CAMERA À FENTE ULTRARAPIDE À RAYONS-X
ULTRASCHNELLE RONTGENSTRAHL SCHMIERKAMERA

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ABSTRACT

A unique ultrafast x-ray sensitive streak camera, with a time resolution of 50 psec, has been built and operated. A 100 Å thick gold photocathode on a beryllium vacuum window is used in a modified commercial image converter tube. The x-ray streak camera has been used in experiments to observe time resolved emission from laser-produced plasmas.

INTRODUCTION

The study of laser produced plasmas for fusion applications has emphasized the need for a sub-nanosecond resolution detection and recording system sensitive at x-ray wavelengths. Details of the x-ray emission characteristics with time resolution comparable to the plasma heating times will yield data that address the questions of the optical absorption, plasma heating and compression processes. Present interest is focused on sub-nanosecond optical irradiation of targets, and the concomitant x-ray emission. Unfortunately, nearly all observations of x-ray emission to date have been time integrated because of the absence of suitable time resolved x-ray detectors. Ultrafast streak cameras sensitive in the visible and near infra-red regions of the spectrum have been developed and successfully used in recent years (1-4), and the technique is now quite well known. We describe the development and use of a unique streak camera sensitive to photon energies in the 1 keV - 10 keV range with a time resolution of 50 picoseconds. A linear streak camera can not only provide high time resolution but has one dimension available over which spectrally or spatially imaged sources can be displayed.

[†] This work was performed under the auspices of the U. S. Atomic Energy Commission.

X-RAY STREAKING CAMERA

Photocathode

The x-ray sensitive photocathode is formed by depositing a layer of gold on an 8×10^{-3} mm thick beryllium window. Gold was chosen for the cathode material because it exhibits high quantum efficiency in the photon energy range of 1 keV - 10 keV (5). The cathode operates in the transmission mode. The beryllium which forms the streak tube vacuum window, has approximately 45% transmission for incident 1 keV photons. The gold thickness is chosen to be 100 Å based on electron yield measurements of 10% at 2.9 keV and 1% at 7.9 keV incident photon energy (5). Thicker gold films produce no higher electron yields due to the finite electron range in the material. Thinner gold films have lower photoelectron yields and do not offer a significant advantage for temporal resolution since the resolution is not limited by cathode transit time.

We have measured the energy distribution of emitted photoelectrons from gold by an electron spectroscopy technique (6). The measured distribution is approximated over most of the spectrum by a linearly decreasing function of energy out to a maximum electron energy equal to the incident photon energy. With 1 keV incident photon energy the rms electron energy spread is 240 eV for this distribution. The useful wavelength range is determined by the low energy cutoff of the beryllium window (~ 0.6 keV) and is controlled approximately at the high end (≥ 10 keV) by the decreasing quantum efficiency of gold.

X-Ray Streak Tube

The streak tube is a modification of a commercially available spherically focused image converter tube (RCA C73435)* into which the new cathode and a new extraction grid are incorporated. Figure 1 is a

Figure 1
Schematic of X-Ray Streak Tube

schematic diagram of the cathode-grid region of the tube. The gold coated beryllium window was attached with epoxy behind an aperture cut in a formed metal plate which replaces the glass front window of the commercial tube. The wire grid assembly in the original tube was replaced by a spherically shaped metal plate with an aperture in it directly behind the cathode. A voltage between this plate and the cathode provides an accelerating field for the photoelectrons.

* Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U. S. Atomic Energy Commission to the exclusion of others that may be suitable.

The remainder of the tube, including the plates which deflect the focused electrons and the phosphor screen, is unchanged and not included in Figure 1. Figure 2 is a photograph of one of the x-ray

streak tubes. The active cathode area of this tube is the 125 μm x 1.0 cm slit visible in the front plate. A tube with a circular 3.2 mm diameter cathode has also been built.

Streak Camera System

Figure 3 is a schematic of the x-ray streak camera. A 3-stage electrostatic image intensifier (gain of 5×10^4) is lens coupled to the streak tube output and the recording film is in turn lens coupled to the intensifier output. The streak tube accelerating grid provides an electric field at the photocathode of 3000 V/cm. An optically triggered avalanche transistor circuit provides the voltage ramp for the streak tube deflection plates with very low trigger time jitter (7).

Figure 2
X-Ray Streak Tube

Figure 3
Schematic of X-Ray Streak Camera

Figure 4
Two Pulse Target Irradiation Scheme

OPERATION

An x-ray streak camera incorporating the tube with the circular cathode has been used in experiments to observe the emission from an iron target irradiated by a 1-J, 150-psec FWHM pulse from a neodymium laser. The incident optical pulse is measured with a 10-psec resolution optical streak camera with an S-1 photocathode (4). The streak speed of the x-ray camera, and an experimental indication of the time

resolution have been obtained by irradiating the iron target with two 0.5-J pulses separated by 300 psec with the scheme shown in Figure 4. The two pulses were focused to about 200 μm diameter spots on adjacent but non-overlapping areas on the iron slab target. The x-ray flux on the photocathode from this target spans roughly the 0.6 keV to 1.5 keV range; the average photon energy is about 1 keV (8). The photocathode was about 30 cm from the target. Figure 5 is a photograph showing the x-ray streak camera installed on a vacuum chamber in which the target was irradiated. The temporal history of the x-ray emission from the two plasmas separated in time by 300 psec was recorded with the x-ray streak camera depicted in Figure 3.

Figure 5
Target Irradiation Chamber

The laser pulse is incident from the upper right. The focusing lens and disc target are visible in the chamber.

Figure 6
X-Ray Streak Data for Two-Pulse Target Irradiation

RESULTS

Figure 6 is a microdensitometer trace of the x-ray streak record with the actual film record shown in the inset. The duration of the x-ray emission is comparable to the duration of the irradiating optical pulse. The measured separation of the streaks with the known 300 psec time separation yields a streak rate of 40 psec/mm on the film. This value is consistent with speeds obtained with our optical streak cameras using similar circuits.

A 0.3 mm aperture was used in front of the photocathode, as shown in Figure 3, to define the spatial resolution of the system. Together with the measured streak speed this yields a streak limited resolution of 12 psec. From the 240 ev rms electron energy spread and the 3000 V/cm accelerating field, the transit time dispersion is computed to be 49 psec. This is the result from a complete transit time dispersion equation which retains terms that are unnecessary in the usual optical approximation. Combined with the 12 psec streak limited resolution above, this results in an overall time resolution of 50 psec. The resolved separation of the pulses in Figure 6 provides experimental confirmation for this time resolution.

DISCUSSION

We have developed and operated a sub-nanosecond resolution x-ray sensitive streaking camera. With the low level of x-ray intensity in these experiments, very roughly estimated to be 10^{-8} J at the photocathode in the geometry used, and the relatively low effective optical gain of the camera system, the streak camera exposures on 2000 ASA film are low. An improved streak camera has been assembled. The new streak tube has a fiber optic output plate which is directly coupled to the fiber optic input of the image intensifier. This provides higher effective gain, and hence, sensitivity of the system. The photocathode on this improved camera is a 0.125 mm by 10 mm slit as shown in Figure 2. With the slit cathode it should be possible to couple the x-ray streak camera to imaging, dispersing, or filtering elements to obtain time resolved records of the corresponding distributions in a single experiment.

ACKNOWLEDGEMENTS

The authors wish to acknowledge valuable discussions with D. T. Attwood and R. Kalibjian, the work of T. G. Brown who modified the streak tubes, and E. L. Pierce for the operation of the laser and assistance with the target irradiations. All are with the Lawrence Livermore Laboratory.

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