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UCRL - 75756

PREPRINT

Conf. 740915--1

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore, California

**HIGH SPEED RADIATION CAMERA USING A PTM RUBY LASER
AND HYDRATED ELECTRON ABSORPTION PHENOMENA**

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July 11, 1974

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This paper was prepared for presentation at the
Eleventh International Congress on High Speed Photography,
London, England, September 15-21, 1974.

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HIGH-SPEED RADIATION CAMERA USING A PTM RUBY LASER
AND HYDRATED ELECTRON ABSORPTION PHENOMENA*

APPAREIL PHOTOGRAPHIQUE DE RADIATION À HAUT VITESSE
UTILISANT UN LASER RUBIS DE MODE PTM ET DES
PHÉNOMÈNES D'ABSORPTION DES ÉLECTRONS HYDRATES

EINE SCHNELLSTRAHLKAMERA DIE EINEN PTM RUBIN
LASER UND HYDRATIERTE ELEKTRONENABSORPTION
PHÄNOMENE BENUTZT

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ABSTRACT

In an attempt to circumvent timing limitations imposed by scintillators and gated image intensifiers, we have developed a twelve-frame radiation camera incorporating a Pulse Transmission Mode (PTM) ruby laser and employing the transient absorption phenomena associated with the hydrated electron. An ionizing radiation pulse absorbed in an acidic aqueous cell generates an absorption pattern which is characteristic of the time-space pulse profile. A 2.5 ns laser pulse is split into 12 separate beams which sequentially strobe a radiation sensitive image cell and transfer 12 time samples of the changing absorption pattern to photographic film. Thus, the exposure time for this system is limited by the laser pulse width and the mean lifetime of the hydrated electron absorption centers.

With a 2.5 ns laser pulse and interframe times set at 3 ns, we have obtained high resolution photographs of a Febetron 705 pulsed electron beam interacting with aqueous solutions. Images obtained during the rise of the electron pulse indicate a sharp increase in the electron energy. Photographs obtained during the pulse decay indicate a large number of relatively lower energy electrons.

INTRODUCTION

High-speed radiation cameras typically employ fast scintillators and framing cameras constructed of electronically-shuttered image intensifier arrays (1,2). For such systems, the meaningful time resolution is limited by the 1.7 ns fluorescence lifetime of the scintillator material and by the gating potential of commercial image intensifiers (3,4). To avoid these limitations, we have developed a high-speed radiation camera which incorporates a ruby laser and makes use of the photo-absorption phenomena associated with the hydrated electron.

*This work was performed under the auspices of the U.S. Atomic Energy Commission.

Previous work has shown that the photo-absorption phenomena of the hydrated electron can be used as a sub-nanosecond pulse dosimetry mechanism (5-9). Acidic aqueous solutions can function as absorption mechanisms which convert rapidly-changing radiation patterns into corresponding optical absorption patterns. Separate, time-resolved, high-resolution images of these transient absorption patterns can be transferred to photographic film with short laser pulses. The effective exposure time for the transferred image is limited by the absorption center lifetime and the width of the sampling laser pulse. Since mode-locked laser pulses of less than 5 ps can be obtained (10), the potential time resolution for such a system should be about 20 ps. The potential time resolution for such a system is far superior to existing scintillator-type framing camera systems.

In order to investigate the technical difficulties and develop the technique associated with the radiation camera outlined above, we have built and operated a 12-frame camera. A frame exposure time of 2.5 ns is achieved with a Pulse Transmission Mode (PTM) ruby laser. An optical beam-splitter delay arrangement provides 12 frames with an interframe time of 3 ns (3×10^8 frames per second). With this radiation camera, we have obtained photographs of a 60 ns (FWHM) burst of high-energy electrons absorbed in an aqueous cell.

THEORY

$T(x, y, Z, t)$ defines optical transmission along the Z axis.

Since spatial and temporal modulation is achieved by passing an optical pulse through the cell, the optical transmission of the cell is related to the dose rate, i.e. $dR(x, y, z, t)/dt$, by the following approximation:

$$\int_0^Z \frac{dR(x, y, z, t)}{dt} dz \approx \frac{k_1 [H^+]}{k_0 \epsilon_\lambda} \{-\ln [T(x, y, Z, t)]\} \quad (1)$$

Here, k_0 is a yield constant, k_1 a rate constant, and ϵ_λ a molar extinction coefficient. The product $k_1 [H^+]$ is the reciprocal of the hydrated electron lifetime. If we define the mean dose rate along the z axis as $\hat{dR}(x, y, t)/dt$ where:

$$\frac{\hat{dR}(x, y, t)}{dt} = \frac{1}{Z} \int_0^Z \frac{d[R(x, y, z, t)]}{dt} dz \quad (2)$$

then the mean dose rate can be estimated from the image cell transmission via the following equation:

$$\frac{d[\hat{R}(x, y, t)]}{dt} = \frac{k_1 [H^+]}{k_0 \epsilon_\lambda} \{-\ln [T(x, y, Z, t)]\} \quad (3)$$

EXPERIMENTAL ARRANGEMENT

The experimental arrangement used to obtain time-resolved photographs of electron plasmas in water is shown in Figure 1. The optical arrangement consists of a PTM ruby laser, a beamsplitter

table with an expanding lens array, a collimating lens with an image cell, and a twelve camera recording system. High-energy electron bursts were generated with a Febetron 705.

The PTM laser active medium consisted of a 6.35 by 76.2 mm non-brewster ruby rod. The resonant cavity was composed of two flat dielectric mirrors separated by 37 cm. With this optical length, the generation of 2.5 ns pulses was possible.

Fig. 1. Experimental arrangement showing high speed radiation camera used to photograph electron plasmas in acidic solution.

The laser, coupling mirrors, collimator and optical delay section are assembled on a 1.22×2.44 m table. The optical delay assembly consists of 11 corner cube reflectors and 12 beam splitters mounted in 12 beam steering units. With this arrangement 12 different pulses separated by 3-ns intervals are obtained from a single laser pulse. These 12 pulses are directed into 12 separate paths which converge on the image cell. High energy electrons from the 705 Febetron enter the acidic solution through a 1.91 cm diameter tube protruding into the side of the cell. The tube is capped with 0.05 mm stainless steel. After traversing the image cell, each beam is then reflected by a mirror back through the cell and into its own camera.

RESULTS AND DISCUSSION

Figures 2, 3, and 4 are three sets of picture sequences taken at different times during three individual electron bursts. For all figures the image cell contained 0.4 molar HClO_4 . This acidic concentration provided a theoretical hydrated electron lifetime of about 0.1 ns. For all three sequences, images corresponding to frames d, f, and h were omitted.

Figure 2 is a sequence of nine time resolved images taken during the rise time of the electron output pulse. Since electron penetration is proportional to electron energy, these images provide time-resolved information concerning the energy of the electron beam. Frames a, b, and c indicate a very rapid increase in the electron beam energy.

Fig. 2. Sequence of nine time-resolved images taken during the rise time of a single electron pulse.

Fig. 3. Sequence of nine time-resolved images showing maximum electron penetration near the peak of current pulse.

Fig. 4. Sequence of time resolved photographs taken during decline of current pulse.

After frame i there is a sharp reduction in the electron energy. This decrease occurs about 27 ns after the start of the electron pulse.

The frame sequence shown in Figure 3 overlaps the sequence shown in Figure 2. From the images in Figure 3, frame c shows a maximum penetration of about 0.88 cm. This penetration corresponds to a beam energy of approximately 2 MeV. The time required for the pulse energy to reach the maximum is about 24 ns from the beginning of the electron pulse.

Figure 4 is a sequence of nine images which start 12 ns after frame l, as shown in Figure 3. This sequence starts well after the current peak and shows lower energy electrons which persist about 60 ns after the peak of the electron pulse.

Data obtained with the high-speed radiation camera are consistent with Febetron 705 performance data published by the Field Emission Corporation (11). Such agreement conclusively demonstrates the feasibility of the laser/hydrated electron system for obtaining nano-second images of intense radiation sources.

ACKNOWLEDGMENTS

The authors would like to express their appreciation to those people who have made significant contribution to the development of this camera. We are indebted to Robert A. Hansen for his mechanical support during the fabrication and evaluation of the PTM laser. Also, special thanks goes to Harold A. Gates, Jr. for his technical assistance during camera operation and refinement. The authors would further like to acknowledge the efforts of Darrel P. Hall and William C. O'Neal for their assistance in the design and procurement of camera components. The authors are also grateful to C. H. Dittmore and E. W. Hee for their assistance in processing the camera data.

Gerald W. Coutts would also like to thank Nathan Klein and Ronald A. Sassé of the Ballistics Research Laboratory for their helpful discussion concerning hydrated electron dosimetry.

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