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HIGH SPEED GATED X-RAY IMAGERS*

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I. Abstract

Single and multi-frame gated x-ray images with time-resolution as fast as 150 psec are described. These systems are based on the gating of microchannel plates in a stripline configuration. The gating voltage comes from the avalanche breakdown of reverse biased p-n junction producing high power voltage pulses as short as 70 psec. Results from single and four frame x-ray cameras used on Nova are described.

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There has been much recent interest in gated x-ray cameras and spectrometers with gate times as short as 100 psec. In the ICF field, this time resolution is necessary to freeze implosions with velocities of 10^7 cm/s and resolutions of 10 μ m. There are two different techniques for gating, shuttering electro optic tubes and voltage gating of a proximity focussed device. Several schemes have been proposed for subnanosecond shuttering of electro-optical tubes.¹⁻³ Such approaches are attractive in that several frames can in principle, be achieved,² there is little problem from x rays that are transmitted through the cathode, and a uniform response can be obtained over a large photocathode area. However, these schemes are complex and to date have found little practical application.

Gating a proximity focused device is much simpler. A voltage pulse is applied across either photocathode-phosphor gap,⁴ or across a microchannel plate.⁵⁻⁶ There are several disadvantages to this approach: a fast, high voltage drive is required because a large detector area implies a high capacitance, it is inherently a single-frame device, straight through hard x rays can cause problems, and the response across a large sensitive area will be non-uniform due to the finite propagation velocity of the gating voltage wave. Until recently, fast high voltage pulses for the electrical gating could only be generated by photo-conductive switches with the concomitant complexity of a short pulse laser.⁶ However, the well known phenomenon of avalanche breakdown⁷ has now been developed so that high power electrical pulses as short as 70 psec can be produced by purely electronic drivers. These voltage pulses are applied to a strip transmission line with a microchannel plate

as the dielectric. The temporal and spatial resolution are described in Sec. II. Using a voltage doubling scheme sufficient voltage from four paralleled reverse biased diodes can be produced to gate four microchannel plates arranged in the four corners of a rectangle. The field uniformity and gain width variation of this configuration are described in Sec. II. For use on Nova, these microchannel plates are gated at different times and detect four gated images from an array of four pinholes. The system and its timing fiducial are described in Sec. III. Representative results from direct-drive implosions are described in Sec. IV.

II. The Four Channel Gated X-ray Detector

When a 1 keV, 1A p-n junction is reversed biased to a high voltage from a low impedance source, it can be made to avalanche breakdown. In previously reported work⁷ the fall time of the diode impedance was 0.5 nsec. By taking care to minimize inductances, we have been able to cut the voltage fall time to 70 psec.⁸ Moreover, by use of a pulse forming network, a pulse instead of step can be formed.^{3,5} These systems are pulse charged by 1 nsec rise time 3 keV pulser based on a microwave triode.³ The repetition rate is limited by the pulse charger and can be up to 1 kHz, with negligible jitter in the avalanche breakdown time of the pulse former.

A single diode can readily produce a 1.5 kV pulse into 50 Ω thereby switching 160 kW. A variety of pulse shapes can be produced by varying the pulse forming network as shown in Fig. 1. Rise times of 70 psec can be obtained, and the shortest pulse (not shown) can have a FWHM of 70 psec. To obtain x-ray gating, a 1/2 mm thick, 1/d=40 microchannel

plate is used as the dielectric of a planar microstrip transmission line, with the amplified electron cloud at the MCP output being accelerated onto a phosphor at +3kV. The phosphor is on a fiber optic faceplate with optical film in contact with the output of the faceplate.

We have standardized on 12 Ω microstrip transmission lines coated on the microchannel plate as they can be driven without mismatch by two 25 Ω coaxial lines in parallel, and the 7 mm width on the microchannel plate provides adequate detector area. A single diode can switch enough power to provide a pulse for one such line: to obtain four images, four 12 Ω lines are arranged in a rectangular pattern as shown in Fig. 2. To obtain sufficient switching power, four diodes are charged in parallel. By tuning the in-line inductance to each diode, the diodes can be made to avalanche simultaneously, all four pulses being combined before split again as shown in Fig. 2. This ensures that the relative timing of all four microchannel plates which is set by the difference in cable lengths stays fixed. The relative timing of a gating pulses onto the microchannel plate is measured by a sampling oscilloscope to an accuracy of 50 psec. The blocking capacitor shown in Fig. 2 allows a d.c. bias to be applied to the plate.

The x-ray images are aligned onto the open circuit end of the strip lines coated onto the microchannel plate to utilize the voltage doubling at an open circuit. This scheme has the advantage of effective pulse shortening for detector areas away from the open circuit, although the gain decreases away from the open circuit in an accurately calculable manner. For detector positions, displaced x away from the open circuit, the incoming and reflected voltage pulse add with a time difference

$\tau_d = 2x \sqrt{\epsilon_r}/c$ where ϵ_r is the relative permittivity of the transmission line, as illustrated in Fig. 3. Because the microchannel plate gain is a strong function of voltage, $\sim V^{11}$, once $t_d \sim \tau_{FHHM}$, the factor of two fall in the superposition of the two voltages causes a large decrease in the gain. For the ideal case of a square voltage pulse, there is a reduction in the gain width for $0 < x < \tau_{FHHM}$ as illustrated in Fig. 3. This is true if the electron transit time in the microchannel plate is small i.e., $t_d > 100$ psec.^{5,7} For our instrument on Nova, we have used a 300 ps FHHM voltage pulse which is well represented by a Gaussian giving a calculated gain profile of the gain as shown in Fig. 4. For this voltage profile, the gain narrowing illustrated for an ideal square voltage pulse in Fig. 3 does not occur.

A measurement of gain uniformity was made by exposing all four microchannel plates to a 150 psec x-ray flash from laser produced gold plasmon on Nova. With 250 psec interframe spacings, only frame 3 was gated on during the pulse, with a gain uniformity with length as shown in Fig. 4. As can be seen, there is good agreement with the above simple calculation. The effect on a image which is not larger in the direction parallel to the strip line is small: effectively the gain falls to zero in ~ 15 mm for our 300 psec gating pulse. As the width of the channel plate is 7 mm, there is $\sim 40\%$ edge to edge gain variation in a square image: for implosion work, the compressed core is usually much smaller. If this gain variation were considered too detrimental, it could be removed by flaring out the width of the line at its open circuit end.

The spatial resolution of a proximity focussed microchannel plate device is usually set by the electron spreading between the output of the channel plate and the phosphor. For our system, we have measured the resolution with an opaque resolution grid with variable spacing in contact with a microchannel plate. The film density was converted to exposure and a contrast transfer function computed that is shown in Fig. 5. Even at 10 l/mm, the contrast is still 40%. Measurements with a finer resolution grid shows that features with 30 μ m scale lengths can still be discerned visually.

The absolute sensitivity of the microchannel plate system was also measured by a calibrated electron-beam x-ray source. At a microchannel plate gain of 900 V, an x-ray exposure of 0.3×10^8 photons/cm² was sufficient to produce an optical density of 1 at RAR2484 film in contact with the phosphor, with photon noise of $\pm 20\%$.

III. The Four Frame Gated X-ray Imager on Nova

For use on Nova, four composite x ray pinholes image the x-ray emitting plasma onto the four gated areas of the channel plate, as shown in Fig. 6. Because of the large radius of the Nova target chamber, the system has to be run in on a rail system through a vacuum airlock. The pulse forming modules are close (~ 20 cm) to the gated areas to prevent pulse degradation in the cable run. The 1 nsec rise time pulse driver is placed outside of the vacuum chamber with a long cable run.

There is no measurable jitter in the avalanche pulse forming scheme, yet there are long term timing changes due to variations in the trigger pulse of the driver pulse. We monitor the shot to shot variation in the

timing of the gating with respect to the laser pulse, by displaying the fiducial laser pulse and the voltage pulse on a fast oscilloscope, as shown in Fig. 7. Once the timing has been established with a short flash of x rays, subsequent variations in the gating timing can be measured with an accuracy of 100 psec.

IV. Results from Experiments on Nova

The four channel gated x-ray imager (GXI) is in routine use on Nova. It has been used for single and multi-beam shots in high neutron and EMP environments. The most interesting pictures come from direct-drive implosions, where about 20 kJ of 0.35 μm laser light is incident on D-T filled 1 mm x 2.4 μm wall glass shells. The Nova system is not designed to optimize these implosions and these rather poor implosions are used primarily to calibrate because of their extremely large neutron detectors. One such implosion for which the thermonuclear yield was 1×10^{13} neutrons is shown in Fig. 8. The five beams on the right hand side of the image were timed to arrive 200 psec early and this side of the ball can clearly be seen imploding faster on the frame at 0.5 nsec.

The core of these direct-drive implosions is non-uniform as can be seen on the 1 nsec frame, but Nova is mostly used for indirectly-driven implosions. Two shots in which the drive was tuned for maximum symmetry are shown in Fig. 9. For these implosions, a uniform core with a high degree of uniformity is evident.

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FIGURE CAPTIONS

1. Pulse shapes that can be produced by various passive pulse forming networks from a p-n junction.
2. Arrangement of the four-gated detectors. The voltage pulse propagates along each microstrip line and double at the open circuit end.
3. Microchannel plate gain and gain width as a function of distance x away from the open circuit end.
4. Calculated and measured gain as a function of distance from the open circuit end of the transmission line.
5. Measured contrast transfer function.
6. Schematic of four-frame gated x-ray pinhole camera.
7. The pulse timing monitoring system.
8. Direct-drive implosion with one array of beams arriving early.
9. Image from an indirectly driven implosion.

contrast transfer fu...

An x-ray framing camera is used to measure symmetry of self-emission from imploded capsules

**Shape of the emission region is
matched by LASNEX calculations and can be
experimentally optimized**

Pole high drive

**Symmetric implosion within
resolution of experiment**

Four frame gated x-ray image of direct drive implosion

$t = 0.25 \text{ nsec}$

$t = 0.75 \text{ nsec}$

$t = 0.5 \text{ nsec}$

$t = 1.0 \text{ nsec}$

Four frame gated x-ray imager showing asymmetric implosion
(east beams early by 200 psec)