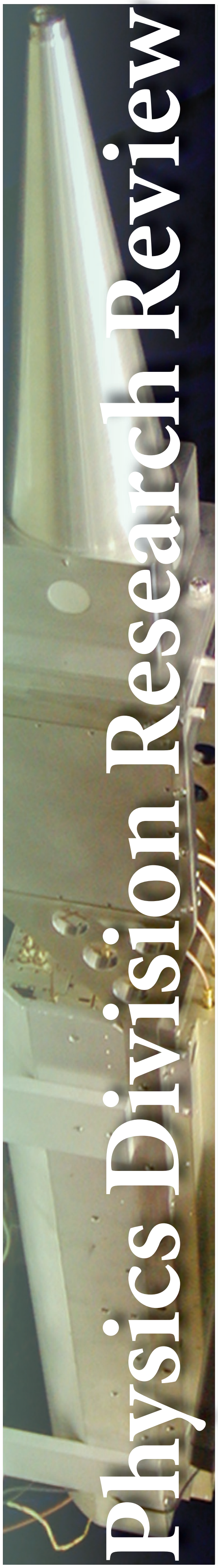

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A Large-Format Gated X-Ray Framing Camera

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Gated x-ray imaging cameras have been a principal time-resolved x-ray instrument for the national Inertial Confinement Fusion/Radiation Physics (ICF/RP) program for over a decade.[1] Typically, these instruments use micrometer-size pinhole arrays to focus x-rays onto an image plane with the maximum usable image size limited by the height of the microchannel-plate (MCP) electrical microstrip. Most of the instruments currently in use have microstrips on 40-mm channel plates; with 4 or 2 separate strips to provide more time coverage, the image fields are only 6 mm tall with a few up to 15 mm tall.[2] A 6-mm-tall strip used with 12× magnification only allows a 0.5-mm-tall object to be imaged. This configuration causes the image to completely fill the strip and does not allow for any instrument misalignments. What most experimenters regularly do to compensate for the small image field is to focus onto that field with a lower-magnification pinhole configuration. This technique works fine until the experimenter requires higher spatial resolution or would simply like to image larger objects while maintaining resolution. We have designed, built, and fielded a gated x-ray framing camera that uses the equivalent of more than four normal-sized channel plates to provide a larger image plane—the Large Format Camera (LFC). While the LFC does have increased parallax compared to smaller-format systems, this camera (Figure 1) enables researchers to fully image objects from 1 mm to 6 mm tall (12× to 2× magnification) with high spatial resolution, allows space on the imaging strip for slight misalignments, and provides greater temporal coverage.

Additionally, most gated instruments are constructed around standard 40-mm MCPs with 4 microstrips that can be gated independently. When acquired in a

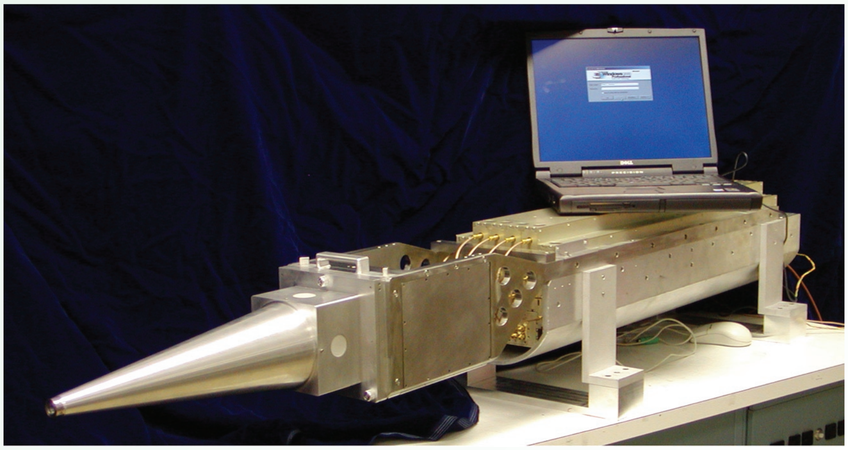

Figure 1. A photograph of Los Alamos National Laboratory's (LANL) large-format x-ray imaging camera with its laptop-computer control system.

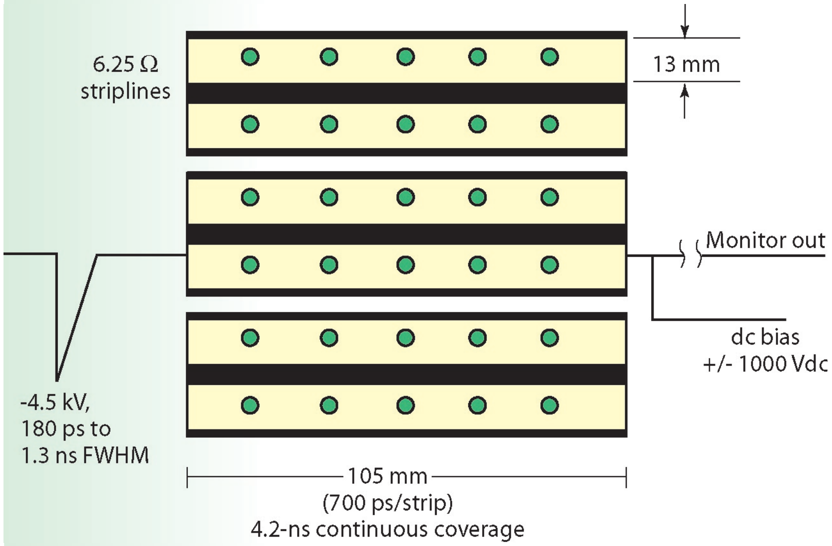

Figure 2. A front view of the gating process using three 105-mm × 35-mm microchannel plates.

"heel-to-toe" configuration, this type of instrument gives researchers a continuous data record up to 1 ns long. The temporal record is bounded both by the physical length of the microstrip and the propagation velocity of the electrical gating pulse. Researchers have worked around this instrumentation limitation by adding delay time between the individual microstrips and accepting the lost temporal information between the strip times.

For some experiments with a slower hydrodynamic evolution, the large interstrip timing technique is adequate and the missing data contains no useful information. But for fast-moving, long-duration (> 1 ns) plasma events, longer continuous-record lengths can be critical.[3] The small-format design limitations in present instrumentation and the need to prototype technology for the National Ignition Facility (NIF) instruments motivated the LANL ICF/RP program to fund the LFC.

The LFC design specifications are to provide

(1) a 13-mm-tall microstrip on the MCP, which provides a large field of view with equal or improved spatial resolution;

(2) six 105-mm-long microstrips, which enables a 4.2-ns continuous temporal record;

(3) compatibility with any ten-inch instrument manipulator (TIM) or diagnostic insertion manipulator (DIM) (i.e., the TIM and DIM are standard mechanisms used to insert instruments into ICF target chambers); and

(4) a prototype for the future gated x-ray detector for NIF.

Detailed Instrument Description and Specifications

As with conventional x-ray framing cameras, researchers can accomplish LFC imaging in many different ways. The standard pinhole imaging configuration for an LFC is also the simplest and least expensive.[1,4] Pinhole imaging uses small pinholes (typically 5 to 15 μm in diameter) made of materials with a high atomic number, high-Z materials, such as tantalum or tungsten. Other methods of imaging include the use of a Fresnel zone plate, a grazing incident mirror, and crystal imaging.[5,6,7]

Gating of the image is accomplished by launching a short-duration, high-voltage electrical pulse across a microstrip transmission line on an MCP. A photoelectron signal produced at the front surface

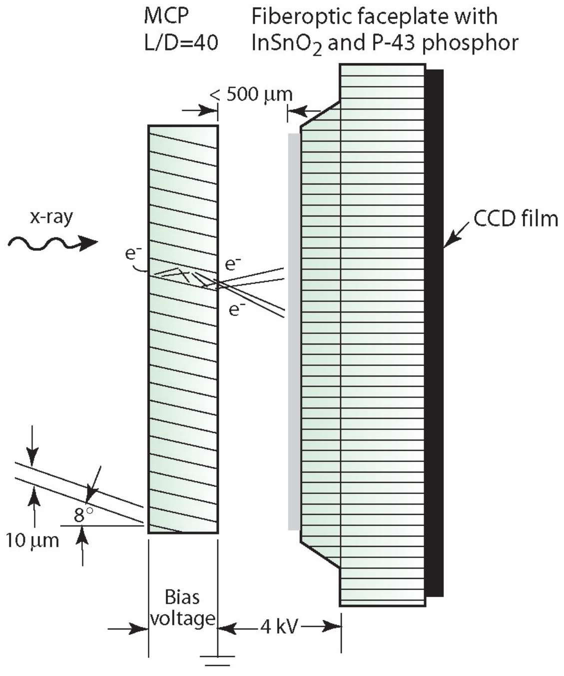

Figure 3. A side view of the microchannel plate and phosphor screen.

of the MCP photocathode is then exclusively amplified during the transit time of the voltage pulse across a given point on the microstrip (Figures 2 and 3). By varying the width of the electrical gate pulse, the corresponding optical gate or shutter time can be varied proportionately.[8] This gives researchers increased flexibility in balancing appropriate shutter times and exposures with a plasma-physics experiment.

Amplification or gain of the signal in the MCP scales strongly with the applied pulsed voltage to a large power ($G \sim V^9$).[2] The impedance, Z, of the microstrip on the MCP decreases with increasing height by the following equation:

$$\frac{w}{h} = \frac{2}{\pi}\left[(d-1) - \ln(2d-1)\right] + \frac{\varepsilon - 1}{\pi\varepsilon} \times \left[\ln(d-1) + 0.293 - \frac{0.517}{\varepsilon}\right],$$

where

$$d = \frac{59.95\pi^2}{Z\sqrt{\varepsilon}},$$

and where w is the height of the strip, h is the dielectric thickness, and ε is the effective dielectric constant.[9] The six 13-mm-tall (6.25 ohms), 105-mm-long microstrips require a custom impedance-matching circuit to drive the microstrip from a 50-ohm characteristic impedance. To date, the LFC incorporates a direct-impedance mismatch on the input side of the MCP. Although this is not the most voltage-efficient system, it was recognized as a high-fidelity alternative for propagation frequencies of interest. The output side of the MCP has been carefully designed to provide a path for MCP bias and to minimize reflections that could potentially double expose the image. Much of the impedance-matching network-development work tested (and eventually implemented) on this camera is directly applicable to the NIF gated x-ray instruments.

The MCPs[10] and six tapers require a special housing or module in which to be enclosed (Figure 4). This module is designed to mechanically capture the MCPs to an exacting tolerance (±0.001 in.) with respect to each other and the fiberoptic faceplate. To accomplish this, a nonconductive, high-tensile-strength web supports both sides of the MCPs. This web is then retained in a stainless-steel structure that also serves as the ground plane and supports the vacuum electrical feedthroughs. The 112.5-mm^2 fiber-optic faceplate[11] is a composite of thousands of 6-μm-diam fiber optics compressed together in a coherent array. The fiber array is coated on one side with an indium tin oxide[12,13] conductive layer and then overcoated with a green P-43 phosphor to match the charge-coupled device (CCD) sensitivity. As the amplified electrons stream out the back of the MCP array, they collide with the P-43 phosphor emitting visible photons to be collected with a CCD camera[14] or Kodak 2210 film.

The Kentech electronics designed to run this module are also very specialized.[15] The electronics unit provides computer control of the 6 MCP gate pulses and positive and negative direct current (dc) voltages to operate MCP and phosphor bias. Each of the 6 gate pulses can be biased independently, and a trigger-delay circuit enables timing control of each microstrip. Additionally, the high-voltage pulsers, used to gate the MCPs, can be pulse-width adjusted from 200 ps to 1300 ps. To determine the pulser voltage (V_{pulser}) required to drive a 6.25-ohm strip (R_{mcp}), the following equation is used:

$$V_{mcp} = V_{pulser}\Gamma_t = V_{pulser}\left[1 - \frac{R_{pulser} - R_{mcp}}{R_{pulser} + R_{mcp}}\right],$$

where Γ_t is the voltage transmission coefficient.[9]

The Kentech unit controls and monitors all electrical functions via an RS232 connection to a laptop-control computer. This Kentech unit will be very similar to the NIF gated x-ray detector system, and the software for that system is being prototyped on the LFC.

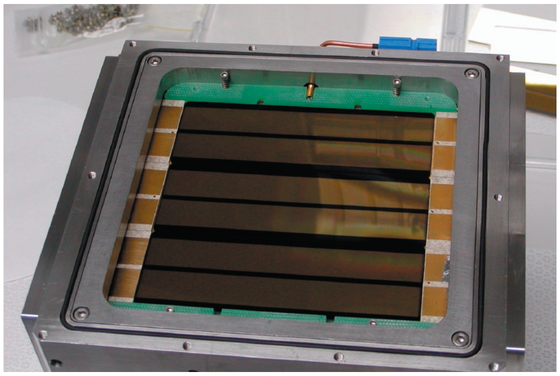

Figure 4. The LFC microchannel plate module containing three 105-mm × 35-mm microchannel plates.

Conclusion

The LFC is a new LANL x-ray imaging instrument designed to image large NIF-scale ICF/RP objects with a long, continuous temporal history, while maintaining equivalent spatial resolution relative to previous and current small-format instruments. The LFC camera has a 105-mm^2 active area with six 13-mm-tall striplines and a P-43 phosphor overcoat; it is then interfaced to a CCD camera. The electrical gate is variable from 200 ps to 1300 ps and is capable of continuous temporal records of 4.2 ns. This camera is also used to test and evaluate new technologies that will be applied to future NIF x-ray imagers.

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