LLNL-CONF-556394

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May 8, 2012

19th Topical Conference High-Temperature Plasma Diagnostics
Monterey, CA, United States
May 6, 2012 through May 10, 2012

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X-ray Streak Camera Cathode Development and Timing Accuracy of the 4ω UV Fiducial System at the National Ignition Facility

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(Presented XXXXX; received XXXXX; accepted XXXXX; published online XXXXX)

The convergent ablator experiments at the National Ignition Facility (NIF) are designed to measure the peak velocity and remaining ablator mass of an indirectly driven imploding capsule. Such a measurement can be performed using an x-ray source to backlight the capsule and an x-ray streak camera to record the capsule as it implodes. The ultimate goal of this experiment is to achieve an accuracy of 2% in the velocity measurement, which translates to a ±2 ps temporal accuracy over any 300 ps interval for the streak camera. In order to achieve this, a 4-ω (263nm) temporal fiducial system has been implemented for the x-ray streak camera at NIF. Aluminum, Titanium, Gold and Silver photocathode materials have been tested. Aluminum showed the highest quantum efficiency, with five times more peak signal counts per fiducial pulse when compared to Gold. The fiducial pulse data was analyzed to determine the centroiding a statistical accuracy for incident laser pulse energies of 1 and 10 nJ, showing an accuracy of ±1.6 ps and ±0.7 ps respectively.

I. OVERVIEW

The convergent ablator experiments at the National Ignition Facility (NIF) [1] are designed to measure the peak velocity and remaining ablator mass of an indirectly driven imploding inertially confined fusion capsule. This objective is achieved by using the streaked x-ray radiography technique in order to provide a temporal record of the velocity of the imploding ablator shell. The experimental setup uses a streak camera to record a temporally resolved 1-dimensional radiograph of the capsule, providing a record of the velocity of the ablator as a function of time [2]. The peak shell implosion velocity is expected to reach 330 μm/ns at a radius of ~250 μm. In order to measure the ablator velocity to 2%, we require a timing accuracy of ± 2 ps over a 300 ps interval.

In order to satisfy this experimental requirement, a calibrated 263 nm 4ω fiducial pulse train system has been developed and implemented at the NIF. The pulse train is used to verify the temporal calibration of the streaked image. The total timing error of the final system is in part dependent on the signal to noise ratio of the individual fiducial pulses, which impacts the accuracy of identifying their centroids. Artifacts from non uniformities in the streak camera sweep ramp and error in offline measurements of the pulse to pulse separation of the 4ω fiducial pulse train also contribute uncertainty to the overall timing accuracy. This work focused on identifying a photocathode material that would provide a sufficient signal to noise ratio of the swept 4ω pulses and determining the minimum laser energy necessary (per pulse) to meet the ±2 ps temporal accuracy requirement.

II. EXPERIMENTAL SETUP

All measurements were performed with the NIF Diagnostic Instrument Manipulator (DIM) Imaging Streak Camera (DISC) and a prototype version of the 4ω fiducial laser system that has been installed at the NIF. The performance of various cathode materials was investigated by taking streaked 4 ω pulse images with two DISC cameras. The performance of both detectors was shown to be comparable to within 10 % [3].

The fiducial pulses are generated by using the NIF 1ω (1053nm) fiducial tap as the seed. The first harmonic is amplified in a fiber amplifier, and a pulse train is then created through a series of fiber splitters and delay fibers which are recombined into a single fiber. The pulse train is amplified and the 1ω pulse stack and two pump lasers are delivered via fiber to an airbox on the DIM. Further fiber amplification of the pulse stack occurs in the DIM after which it is launched into a free-space optical system that converts the 1ω to 2ω and then to 4ω via two nonlinear crystals. The resulting 4ω pulse train, with 45 ps pulse duration and ~300 ps pulse separation, is isolated from the other frequencies with a dichroic mirror and is launched into a large-core fiber for delivery to the photocathode. The UV fiducial pulses are delivered to the back side of the photocathode in reflection geometry, see Fig 1. The energy of the 4ω fiducial pulses was measured at the DISC input fiber with a Coherent pyroelectric energy detector [4].

Four photocathode materials were evaluated for sensitivity to the 4ω fiducial: Aluminum, Gold, Silver and Titanium. The materials were evaporation deposited onto fused silica substrates. The performance of the metals was compared to that of a standard Au on Lexan photocathode, which consists of a 1000 Å Lexan substrate that is coated with 300 Å of Au. All test metals were deposited on a fused silica substrate and were 1000 Å thick. The performance of Al was further investigated by comparing the signal generated by a 120Å, 300Å and 500Å thick Al cathode to that of 1000Å. The cathode materials and thicknesses tested are listed in Table I.

III. DISCUSSION AND RESULTS

The work function of a metal is a rough indicator of the expected quantum efficiency of a photocathode for any incident photon energy. Here, the work function of a test photocathode had to be less than the incident photon energy of the UV fiducial pulses, i.e. 4.7 eV (263 nm). Data in Table I was used to narrow the photocathode selection to a few standard photocathode materials, Ti, Al and Ag. A standard Au photocathode was also used for comparison, for which low signal levels were expected due to the incident UV photon energy being 0.4 eV less that the work function. Although the work function is a useful guide to photocathode selection, the true quantum efficiency of a metal is much more complicated and a more accurate approximation is given by the three step model. This approach unites photo-excitation, transport to the surface and escape into vacuum into a single model [5]. The photoelectric yield from many metal photocathode materials have also been measured in the VUV region, showing the measured yield (at 263 nm) from Ag, Ti, Al and Au to be ~0.05, ~0.05, ~0.07 and ~0.025 electrons/incident photon respectively [6], but there is some discrepancy between theoretical predictions and within the published measured quantum efficiency values. The discrepancies have been attributed to the dependence of photoelectric yield on surface effects such as: cathode surface cleanliness, the presence of oxidation layers, cathode thicknesses, substrate materials and preparation methods. Because of the complexity of the photoemission process, this study measured the quantum efficiency of Al, Ti, Au and Ag directly. Care was taken to ensure that the test photo-cathodes were fabricated using vacuum evaporation deposition in a way that is identical to the standard DISC photo-cathodes. The effect of cathode thickness on the quantum efficiency was also studied.

The performance of each photocathode was evaluated by comparing the signal levels of swept fiducial pulses on the DISC camera. Data was analyzed in two ways; 1) the total number of counts was determined within a box region of interest around each fiducial pulse, and 2) for the same box region an average of pixels greater than 50% of peak signal was calculated. Results were averaged over a total of 70 pulses in order to account for any variation in pulse count levels that may be introduced by incident laser power instability. The sum of total counts analysis results are presented in Figure 2(a). Aluminum showed the highest quantum efficiency when compared to Au, Ag and Ti. The quantum efficiency of the Al also shows a dependence on the thickness of the photocathode film. The Al thin film absorption at 220 nm increases from 4 % to 68% as film thickness is increased from 40 to 500 Å [7]. Figure 2(b) shows the dependence of swept UV fiducial pulse signal on cathode thickness, indicating that a 500 Angstrom thick Al photocathode film is optimal for use in DISC.

Once Al had been identified as the optimum photocathode material, measurements of the signal to noise ratio of swept fiducial pulses was performed in order to determine the minimum necessary incident UV laser energy to satisfy the experimental timing accuracy of ±2ps. The fiducial pulses were approximated by a Gaussian and the statistical centroiding accuracy was determined with equation (1):

$$CentroidAccuracy = \sigma \Big/ SNR \Big/ \sqrt{\sqrt{2\pi}\,(\sigma) \big/ t} \quad (1)$$

where σ is the 1 sigma duration of the 4ω laser pulse (19.1 ps for 4ω pulses), *SNR* is the signal to noise ratio and *t* is the duration of a single resolution element which in DISC is 4-5 pixels wide corresponding to 4 ps in duration. Using this relation it was determined that in order to achieve a centroiding accuracy of ±2 ps the laser system must deliver at least 1 nJ/pulse, corresponding to a *SNR* of ~3 in a background subtracted image (see Figure 3). In this analysis, the minimum incident laser energy sets the total measured swept counts per UV pulse (i.e. the number of detected photo-electron events depends on the incident laser energy and the detection efficiency of the streak camera), which in turn directly impacts the measured signal to noise ratio and centroiding accuracy. The timing accuracy in this work was determined through the statistical analysis of the swept 4ω fiducial pulses. True timing accuracy error should also include the contributions from sweep ramp non-linearity of the instrument and the magnitude of the background that may be present during typical experiments at the National Ignition Facility.

IV. CONCLUSIONS

The photoelectric yield at 263 nm was measured and compared for four photocathode materials, Ag, Ti, Al and Au. It was determined that a 500Å thick Al photocathode produced the brightest swept fiducial signal on the DISC streak camera, showing the highest relative quantum efficiency when used in the reflection geometry. The images of the swept UV fiducials were further analyzed to determine the minimum signal level needed to meet the Convergent Ablation experimental requirement of ±2 ps temporal accuracy.

IV. Acknowledgments

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. We would like to thank National Security Technologies and the Jupiter Laser Facility Fabrication Lab for providing the cathode samples used in this work. We would also like to note similar work done by P. Jaanimagi et. Al. [8]

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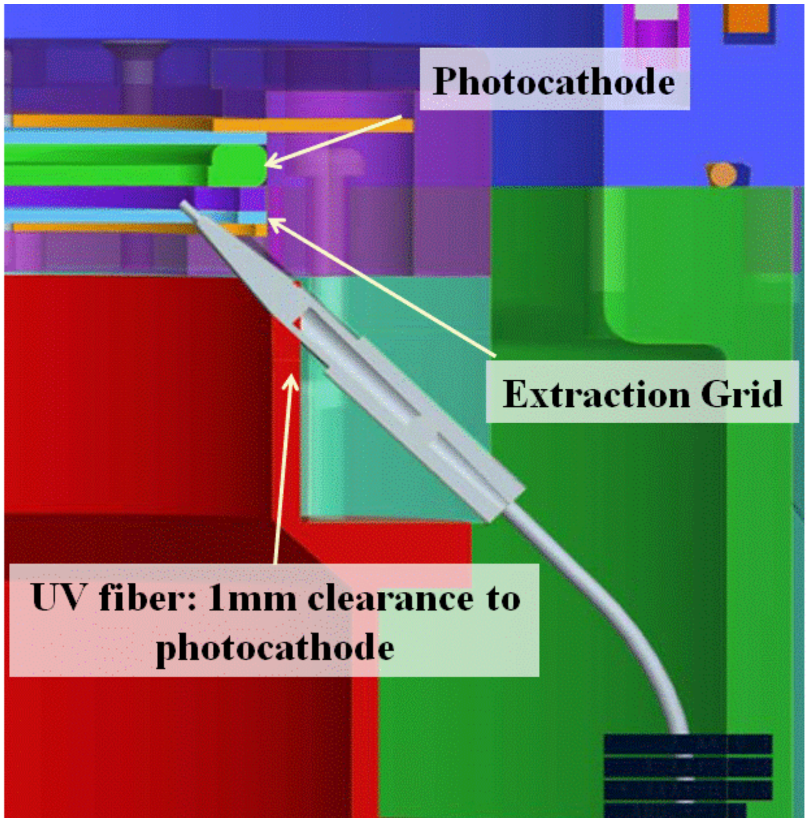

FIGURE 1: DISC 4 ω fiducial delivery setup. The fiber optic cable is shown on right; the UV pulses are delivered to the back side of the photocathode in reflection geometry. The resulting photoelectron signal is extracted from the photocathode and focused downstream onto the imaging system

Photocathode Material	Thickness Å	Substrate Material	Work Function (eV)
Au	250	Lexan	5.1
Al	120	300Å of Au on Fused Silica	4.28
Al	300	300Å of Au on Fused Silica	4.28
Al	500	300Å of Au on Fused Silica	4.28
Ag	1000	Fused Silica	4.26
Ti	1000	Fused Silica	4.33

Table I. List of the photocathode materials tested in this study, along with their thicknesses and substrate materials and work functions [9]

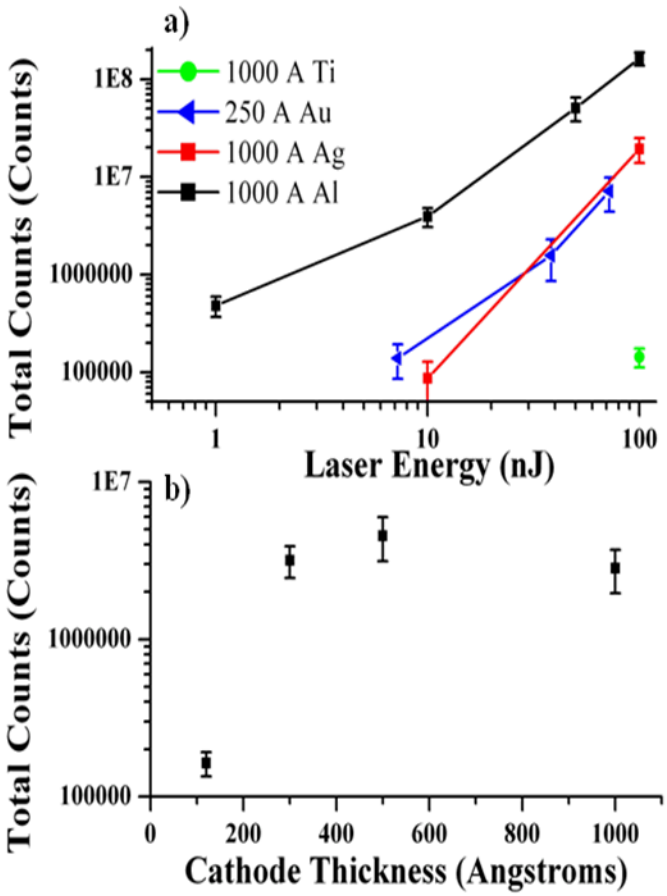

FIG. 2. a) Total counts measured in a swept UV fiducial pulse as a function of incident laser energy for an Al, Ti, Ag and Au photocathode. b) Counts vs Al cathode thickness

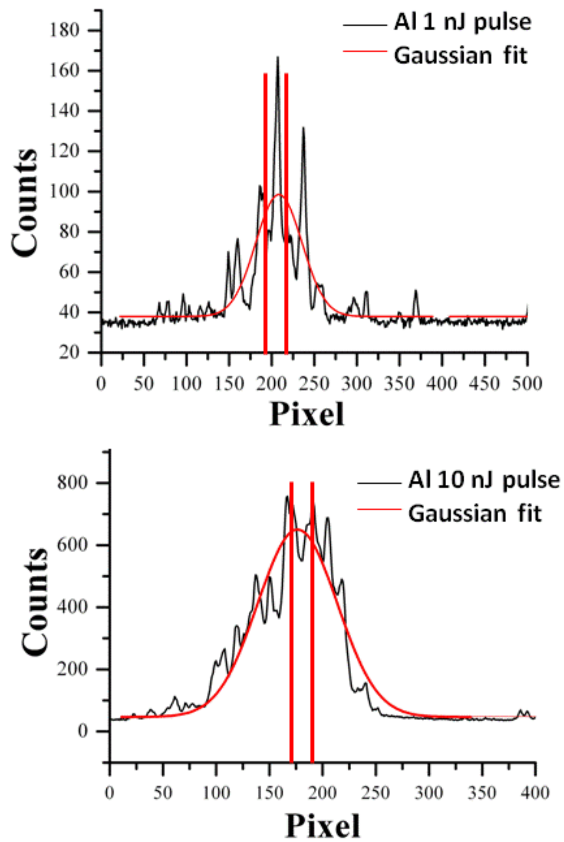

Figure 3: Representative lineout plot of a swept 1 and 10 nJ pulse shape. The data are fitted with a Gaussian pulse shape and the vertical bars represent a 20 pixel statistical region of interest.