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Characterization of a picosecond gated optical intensifier

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The development of high speed imaging detectors is crucial for high-temperature plasma characterization and optimization. These detectors must perform within many strict parameters, such as precise timing, high spatial resolution, low noise, high gain, and fast gating. We present test results on a picosecond gated optical intensifier that aims to meet these requirements. The detector was developed by Kentech and is part of a packaged Sydor solution of 1-8 detectors, designed for use in plasma diagnostics. It has low jitter (SD 4 ps) and gate widths less than 80 ps. We use a pulsed laser to test the gate profile and the spatial resolution performance of the intensifier at different points within the gate. *Published by AIP Publishing.* https://doi.org/10.1063/1.5038813

I. INTRODUCTION

Image intensifier tubes, which were developed in the mid-20th century[1] primarily for night vision applications, have proven to be useful in scientific applications as well. Katz *et al.* have used a gated optical intensifier (GOI) to image scattered 3ω light refracted off plasma density gradients in order to better understand cross-beam energy transfer.[2] These GOIs have been implemented on Orion[3] and will soon be used on the Sandia Z machine as well.

In microchannel plate (MCP) intensifiers, the gain is generated through multiplication of the electrons off the photocathode as they travel through the pores of the MCP before hitting the phosphor, as shown in the inset of Fig. 1. Tunable gain factors over many orders of magnitude can be achieved.

The tube can be gated by modulating the applied voltage between the cathode and the MCP. While this is simple in principle, it is nontrivial to achieve a fast gate that does not distort the image. For proximity-focused tubes, which are capable of high resolution but particularly prone to this distortion, the resolution of the GOI during gating can be improved by introducing an axial magnetic field, which reduces the spreading of the electrons as they travel between the photocathode and the MCP. This study tests the imaging capabilities of the Kentech GOI head at the extremes of its gating speeds.

The GOI under test consists of an 18 mm MCP intensifier, with a S20 cathode on quartz input window and a P43 phosphor at the fiber-optic output. An axial magnetic field of 0.12 T at the cathode is applied by a pair of neodymium magnets.

II. GATE PROFILE MEASUREMENT

The setup is shown in Fig. 1. Light from a pulsed laser is incident on the GOI. The reticle is removed for the gate measurement so that the entire cathode is illuminated. The output of the intensifier is then imaged onto a CCD (Manta G-505B). The gate profile can be measured by varying the delay times of the laser pulse relative to the gate window and recording the total power incident on the CCD for each delay time. A computer controls the delay generator (SRS DG645) and stores the CCD images for analysis.

The resulting gate profiles are shown in Fig. 2. The psGOI has four modes—DC, slow gate (10 ns–10 μs), medium gate (250-5000 ps), and fast gate (80–120 ps), with discreet gate widths available within these windows. The DC and slow modes are useful for setup and alignment. Accurate measurement of the shortest gate times requires a clean and narrow pulse since the measured gate profile is a convolution of the laser pulse profile and the true gate profile.

For this preliminary study, we found that our laser had both a broad tail and a prominent second pulse. These features were observed on a streak camera, the results of which measurement are shown in Fig. 3 but can be clearly seen in Fig. 2 for the 250 ps gate window. Attempts to deconvolve the two did reduce the measured gate widths, as expected, but were too noisy to be more useful than that. Based on the test report from the manufacturer,[4] we believe the limiting factor in our profile measurements is the laser rather than the gate. In future work, we plan to use a cleaner pulse to verify the fast gate windows.

It is also important to note that the shape of the laser pulse has some influence on the results of subsequent measurements; this will be discussed in Secs. III–V.

III. RESOLUTION MEASUREMENT

The limiting resolution of the intensifier is determined using the slant edge technique and verified using a resolution test target. A pulsed laser is incident on a transmissive target or sharp edge, which is then imaged onto the intensifier with lens L1 (HF25SA-1). The output of the intensifier is then imaged with a second identical lens L2 onto the CCD. The magnification of the system is measured using a microscope slide with

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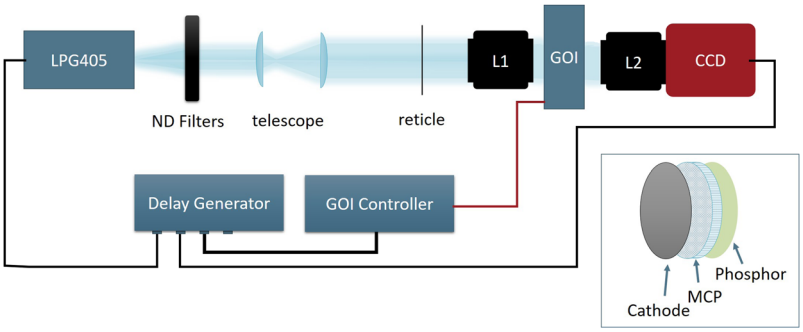

FIG. 1. A pulsed laser (Photek LPG 405) is used to characterize the imaging capabilities of the intensifier. A delay generator (SRS DG645) walks the pulse through the gate. A reticle is imaged onto the GOI with lens L1; the pattern on the GOI is then imaged onto the CCD with lens L2. Optics resolution was verified by removing the GOI. The inset outlines the components of a GOI: cathode, microchannel plate (MCP), and phosphor.

known markings at both the GOI location and the object, or reticle, location.

The limiting resolution of the optics is verified by removing the GOI and moving the CCD and L2 toward the target by a distance the thickness of the GOI. Measurement of representative points on the resolution test target, shown in Fig. 6, indicates that the contrast of the optics is sufficiently greater than the GOI so as not to be a limiting factor.

To measure the resolution of the GOI at particular gate times or gain settings, a slant edge technique is used to measure the modulation transfer function (MTF). The imaging target is a microscope slide with a piece of silver tape on it so that the resulting image is partly covered. The edge is angled (8°) relative to the orientation of the pixels to avoid pixelation artifacts. The raw image is shown in Fig. 4(a).

The standard (ISO 12233:2017[5]) analysis procedure is followed, using MatLab code written by Burns.[6] The raw data

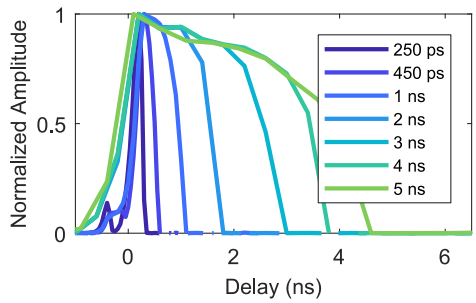

FIG. 2. The gate profiles are measured by adjusting the delay between the gate trigger and the laser and recording the total counts incident on the center region of the GOI. The time axis zero is somewhat arbitrary since the actual delay depends on additional cable and electronics delays.

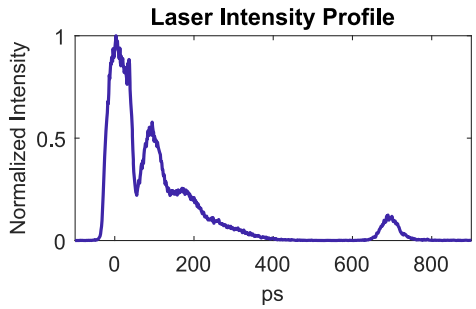

FIG. 3. The laser pulse profile, as measured on a Sydor ROSS streak camera, using a 2 ns ramp window. The quality of this pulse shape will be improved for future measurements.

(measured with known pixel sizes of 3.45 μm) are linearized, and the derivative of each row/column is taken, followed by the application of a Hamming filter. The edge position and angle is estimated and used to create a super-sampled edge-spread function, like the one shown in Fig. 4(b). The derivative of this gives the line-spread function, the Fourier transform of which produces the MTF.

This MTF method is also used to bring the target into focus; as can be seen from Fig. 5, the resolution measured is highly dependent on the position of the edge in the focal plane. Since this is not something easily seen by eye, this method provides a powerful focusing tool.

The validity of this method was independently verified using a resolution test target. Figure 6 shows contrast measurements taken manually, along with a measured MTF. The slight disagreement may be due to a small magnification or focal plane change between the two measurements but is not significant enough for concern.

A primary goal of this study was to measure the MTF at different points in time during the gate window and to quantify the imaging quality at the extremes of the gate. One challenge encountered was the trailing profile of the laser (discussed in Sec. II), which prevented precise images of the gate edge. Another consideration was the low intensity of the images at the gate window extremes. It has recently been noted that the error in the MTF measurement grows with decreasing edge contrast, particularly in the presence of noise.[7] For this reason, images with edge contrast below 20% were discarded.

The edge slant MTF method was used to evaluate the resolution of the intensifier at various points within each of the gate windows. The results of two representative gate window modes are shown in Fig. 7. The time axis in (a) and (c) corresponds to gate delay time so that the start of the gate window is on the right and the end is on the left.

One consistent feature noted is a slight improvement in resolution toward the tail end of the gate window. This can be seen in Fig. 7(b), where the darker blue curves indicate a higher resolution by as much as 10% contrast at 10 lp/mm. One explanation is that at the end of the gate, the electric field has reached its maximum and stabilized. This could be the case if the electric field strength is the dominant factor for the focusing of the electrodes on the MCP.

However, if the magnetic field is the dominant factor, this effect could be due to the transit time changing to be closer to or further from the Larmor period. The presence of a strong magnetic field, such that the transit time is much less than

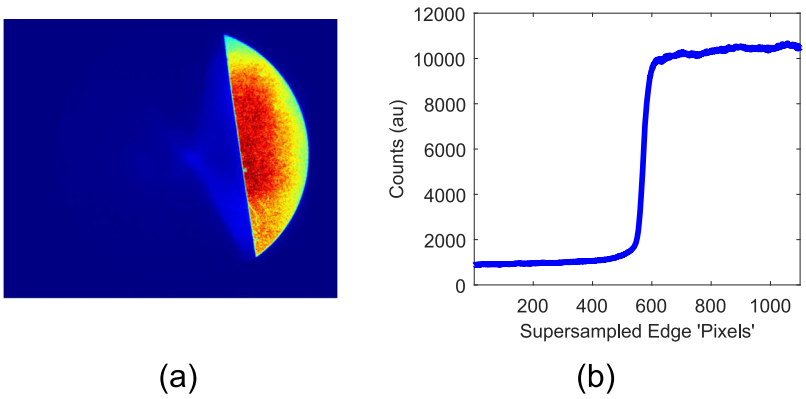

FIG. 4. (a) Raw CCD image of the slant edge. The edge angle is 8°. (b) Sample of a super-sampled edge spread function generated from the raw data in (a). The Fourier transform of this gives the frequency response of the imaging system, or the MTF.

the Larmor period, results in good focus. However, the single loop focusing regime, where the transit time equals the Larmor period, can also produce optimal focusing. It is possible that when the electric field is comparatively weak at the beginning or end of the gate pulse, this second regime comes into play. The expected symmetry on the other side of the gate window may be washed out by the trailing laser profile; future measurements with a narrower and more symmetric pulse are planned to further investigate this behavior.

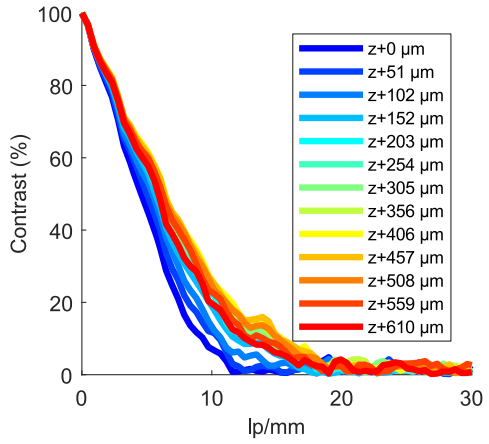

FIG. 5. The slant edge MTF method can be used to find the focus to be used for evaluating the imaging system, capturing the contrast on levels not visible by eye. From this figure, it is evident that a micrometer position around 457 μm places the target in focus.

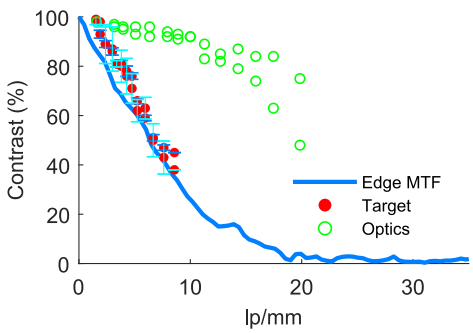

FIG. 6. The validity of the slant edge method is verified independently using a resolution target (NBS 1963A). The results show reasonable agreement. The contrast of the optics without the GOI was also measured and plotted for comparison.

IV. IMAGE UNIFORMITY

One of the challenges of fast gating on image intensifiers is the fast and uniform propagation of the gate pulse across the photocathode. A slow propagation of the pulse will be visible at the start and end of the gate, both in irising as the outer edges turn on or off before the center, and in distortion, as the field lines change. The Kentech electronics have been specifically designed to minimize these effects.

In a conventional gating scheme, the gate signal propagation is set by the cathode and microchannel plate,[8] giving hundreds of picoseconds turn-on time on an 18 mm tube. The GOI under study uses a capacitive coupling scheme,[8] which is limited by the speed of light in the quartz window and the driving electronics, corresponding to a gate turn-on time of 30-50 ps. Observation of this effect, often known as irising, is limited at these time scales by the temporal profile of the laser making

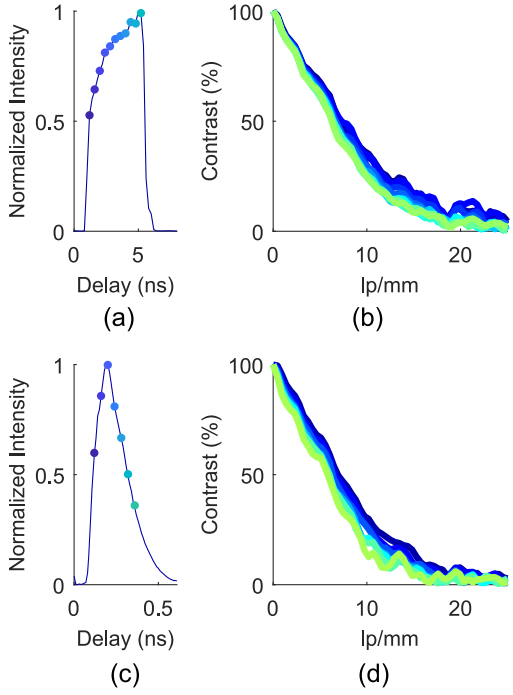

FIG. 7. Images are taken at successive delay points during each gate window and the slant edge MTF method applied. Shown are representative images of the 5 ns gate profile (a) and contrast (b), and the 80 ps gate profile (c) and contrast (d). In (a) and (c), the horizontal axis is gate pulse delay, so gate time goes from the right to the left.

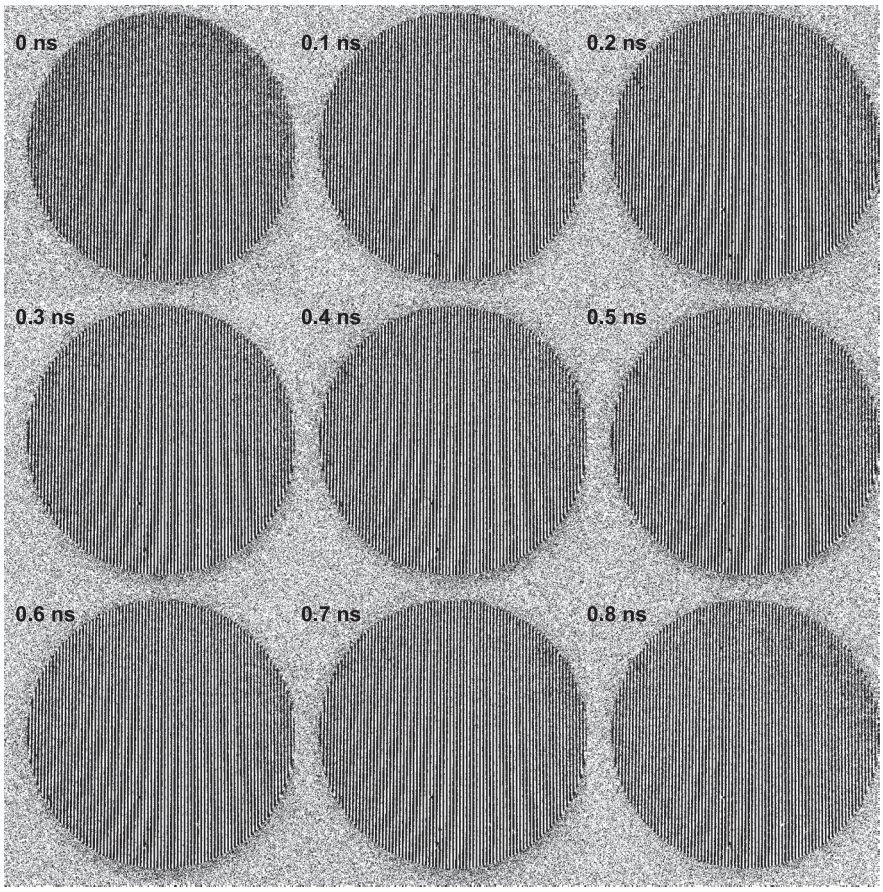

FIG. 8. Images taken with a Ronchi ruling at 100 ps intervals during a 1 ns gate. Even at the edge of the gate, there is no noticeable distortion of the lines. The images have been flatfielded and normalized to make this easier to see.

the measurement. For this preliminary study, the laser pulse limits our study to observation of "slow" irising, that is, effects on the scale of hundreds of picoseconds. Since this effect can still be significant at such time scales, we took images at different times within the gate. No irising was detectable in our images. In future study, we plan to use a clean 30 ps pulse to test the limiting speed of the gating.

To reveal any possible image distortion due to gating effects, a Ronchi ruling was imaged at times within the gate. Representative data from the 1 ns gate is shown in Fig. 8. The images have been normalized and divided by images without the ruling. Close examination reveals straight lines even at the start and end of the gate.

V. DISCUSSION

A setup has been developed to characterize the picosecond GOI developed by Kentech. These GOIs, which are packaged by Sydor Technologies with CCDs and software, are soon to be fielded on the Z Machine at the Sandia National Lab. The ongoing tests being performed aim to support the experiments by the users, as well as to provide more rigorous characterization of the devices for future use.

The preliminary results of this study indicate that the slant edge MTF method is a good one for characterizing the image quality of a GOI. Images taken at the extreme edges of the gate windows do not exhibit any irising or distortions. These are important factors for many experiments. Further testing with a cleaner laser pulse is needed to measure the true gate profile at higher speeds. Future work will also include measurement of luminous gain and characterization of the noise. We anticipate that these picosecond GOIs will be useful to a broad range of applications requiring narrow timing windows and low light levels.

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