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X-ray characterization of the Icarus ultrafast x-ray imager

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ABSTRACT

Ultrafast x-ray imagers developed at Sandia National Laboratories are a transformative diagnostic tool in inertial confinement fusion and high energy density physics experiments. The nanosecond time scales on which these devices operate are a regime with little precedent, and applicable characterization procedures are still developing. This paper presents pulsed x-ray characterization of the Icarus imager under a variety of illumination levels and timing modes. Results are presented for linearity of response, absolute sensitivity, variation of response with gate width, and image quality.

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I. INTRODUCTION

Experiments in inertial confinement fusion (ICF) and high-energy-density physics (HEDP) involve rapidly changing signals of interest, where interesting physics occurs at the nanosecond time scale or faster.[1–4] The experimental objects typically emit x rays and other energetic radiation, or x-ray backlighting may be used as a probe. Imaging x-ray detectors are required to utilize these radiation signals to full effect. Due to the challenging environments of ICF and HEPD facilities, time-integrated imagers such as an x-ray film or an image plate are common. Although they are immune to failure sources such as electronic noise, data quality can suffer when the signal accumulated over an entire experiment is overlaid. For example, ICF target self-emission at stagnation usually eliminates all contrast in at least part of the target area so that no other features in that area can be observed. Inferences of time-dependent behavior can thus be quite challenging or impossible to make. Time-resolved diagnostics exist, but the disadvantages can be significant. Streak cameras image in only one spatial dimension,[5] and gated microchannel plates (MCPs) cast multiple images on different lines of sight and have a limited dynamic range.[6] Both can be difficult to calibrate and operate.

The fast-gated Hybrid Complementary Metal Oxide Semiconductor (hCMOS) technology developed at Sandia National Laboratories offers a transformative diagnostic tool that can simultaneously provide two-dimensional imaging and temporal information on ICF-relevant time scales.[7,8] These compact devices do not require high voltage, perform two-dimensional direct x-ray imaging, and provide multiple frames along an identical line of sight. Framing cameras built around hCMOS detectors have been employed as diagnostics at the Z machine, NIF,[9–11] and Omega.[12]

The latest generation of hCMOS sensors, named Icarus, provides an on-device storage of four frames, 0.5×10^6 pixels, 5×10^5 e^- nominal full well, and gate times down to ~1.5 ns.[13] The temporal response of Icarus imagers has been previously characterized using laser light[11,14] and x rays.[15] However, the imaging performance and capacity for quantitative measurements are largely unexplored.

In this paper, we present the pulsed x-ray characterization of an Icarus sensor. Probe conditions span approximately 2.5 orders of magnitude of the x-ray illumination flux as well as multiple camera configurations, which allow us to investigate non-ideal qualities of the sensor arising from the fast time scales on which it operates. We describe the linearity of response and measure the absolute sensitivity of Icarus. We also examine the saturation behavior and the effect of a protection circuit. Finally, we analyze several metrics for the image quality, including response across a sharp edge, background variation, spatial uniformity, and noise characteristics.

II. EXPERIMENTAL SETUP

The x-ray measurements were conducted at Sandia National Laboratories in the Z-Beamlet/Z-Petawatt Target Bay. The Chaco

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