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Imaging of laser-plasma x-ray emission with charge-injection devices

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This work details the method of obtaining time-integrated images of laser-plasma x-ray emission using charge-injection devices (CIDs), as has been demonstrated on the University of Rochester's 60-beam UV OMEGA laser facility [T. R. Boehly *et al.*, *Opt. Commun.* **133**, 495 (1997)]. The CID has an architecture similar to a charge-coupled device. The differences make them more resistant to radiation damage and, therefore, more appropriate for some application in laser-plasma x-ray imaging. CID-recorded images have been obtained with x-ray pinhole cameras, x-ray microscopes, x-ray spectrometers, and monochromatic x-ray imaging systems. Simultaneous images obtained on these systems with calibrated x-ray film have enabled determination of the absolute detection efficiency of the CIDs in the energy range from 2 to 8 keV. © 2001 American Institute of Physics. [DOI: 10.1063/1.1318257]

I. INTRODUCTION

X-ray imaging and x-ray spectroscopy are used in laser-plasma-generated physics research to diagnose conditions in laser targets. Examples of techniques used to image x-ray emission are pinhole cameras, Kirkpatrick-Baez (KB) microscopes, curved crystal optics, and Wölter microscopes.¹⁻³ All spectroscopic diagnostics also rely on spatial resolution to record an x-ray spectrum. Examples of spectroscopic techniques are Bragg crystal diffraction and grating diffraction. The simplest method of recording images is by time-integrated exposure of film, a common example being the calibrated Kodak direct exposure film (DEF).⁴ Alternatively, images can be recorded by a solid-state device that is either directly sensitive to x rays (photons absorbed in the device) or indirectly sensitive (photons absorbed in a phosphor coating, generating visible-range photons that are then absorbed in the device).

The detectors investigated in this work are known as charge-injection devices (CIDs), so named by the pixel architecture, and are used in the direct detection mode to record x-ray images. The instrumentation and methods used to interface CIDs to time-integrated x-ray diagnostics on the OMEGA UV laser facility⁵ are described in this work. Images were obtained with pinhole cameras, KB microscopes,² and a tunable monochromatic x-ray microscope.⁶

II. CHARGE-INJECTION DEVICES (CIDS)

The CID cameras used in this work are manufactured by CID Technologies, Inc., of Liverpool, NY.⁷ The model CID4150 is an 812×604 array having square pixels with

38.5 μm center-to-center spacing and overall array dimensions of 31.3×23.2 mm. Details of the pixel architecture can be found in the literature,⁸⁻¹¹ summarized here as follows: Each pixel contains two storage areas (pads). At the start of integration, voltage applied to both pads injects any stored charge into the substrate layer. Next, charge is accumulated under a negatively biased column storage pad until the bias is changed to transfer the stored charge to a row pad. The row pad is attached to a row preamplifier from which the signal is output and digitized. The CIDs used in this work were operated at room temperature and with no conversion phosphor coating on the detector surface (direct x-ray detection). A PC-based analog-to-digital converter with 16 bit resolution, operating at 500 kHz, accomplished the camera readout. The relatively high-speed readout was employed to minimize dark current in the uncooled detectors.

Figure 1 shows a CID camera in its housing and an epoxy-encased dental-imaging version,¹¹ for comparison, along side a film pack and film-pack positioner, illustrating the relative compactness of the CID camera. All signal amplification and switching electronics are contained in the CID camera. An overview of the installation on the OMEGA target chamber and surrounding structure is shown in Fig. 2. The DC power is supplied along with a clocking line and an integration trigger line. The common integration trigger supplies each camera in use with a preshot pulse to acquire a background image and an on-shot pulse to acquire an image on the laser target shot. The two images are subtracted to provide the final image. The single output line contains the unformatted video signal, which is sent to a PC-based analog-to-digital converter card. Up to two PCs are used to acquire six CID camera outputs per PC, on as many as 12 CID cameras for the currently planned system.

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FIG. 1. Picture of CID camera mounted on the end of a pinhole camera positioner. The CID camera replaces the film-pack holder (upper left) and film pack (lower left). The CID camera was designed to be compact, as evidenced by the dental-imaging version (lower right).

III. EXPERIMENTS

The CID cameras were used to obtain images of laser-plasma x-ray emission on OMEGA. Three different diagnostics were used as platforms for these tests: x-ray pinhole cameras and two different KB microscopes. One microscope was outfitted with a grating and used to obtain grating-dispersed images of target implosion cores.¹² The other microscope was outfitted with metal multilayer monochromators and used to obtain narrow-energy-band (monochromatic) x-ray images of target implosion cores.⁶

Figure 3 shows two images obtained with pinhole cameras located on opposite sides of the target chamber. The pinhole cameras have $11\text{ }\mu\text{m}$ pinholes and were located 170 mm from the target. The CIDs were located to provide images with a magnification of 4.0 ($\sim 10\text{ }\mu\text{m}/\text{pixel}$ at the target plane). The images are of x-ray emission from a 4-mm-diam, Au-coated plastic sphere. The OMEGA beams were surface focused onto the target using the standard OMEGA optics and distributed phase plates designed to produce Gaussian-like focal spots with a diameter of $\sim 900\text{ }\mu\text{m}$ (containing 95% of the energy). These produce x-ray spots with diameters of $\sim 600\text{ }\mu\text{m}$ [full width at half maximum (FWHM)]. The images are analyzed to determine the relative pointing of

FIG. 3. CID images taken from two opposing pinhole cameras on an OMEGA pointing shot.

each beam compared to the desired pointing (all beams pointed so as to converge at the target center, in the spherical-implosion-pointing mode). Typically, six or more film-based cameras are used to obtain like images, necessitating film loading, unloading, developing, drying, and finally digitizing. Although these processes are streamlined by using autofilm developers, quick drying, and video camera digitizing, the typical minimum processing time of ~ 40 min cannot compete with the several-minute time scale required to store and redisplay multiple digital image files.

Another example of CID-camera-obtained x-ray images is shown in Fig. 4. The CIDs were located behind the same pinhole cameras described above, but further away at a magnification of 8.0. The images are of the time-integrated x-ray emission from an imploded laser fusion target (in this case, a 3-atm- D_2 -filled, $20\text{-}\mu\text{m}$ -thick CH shell). Figure 4(a) was taken with minimum filtration in front of the CID sensor ($150\text{ }\mu\text{m}$ of Be, mostly in the pinhole camera itself), while Fig. 4(b) was taken with a CID on a pinhole camera on the opposite side of the target chamber and additional filtration of $50\text{ }\mu\text{m}$ of Al was used to limit the soft x-ray component of the image. Figure 4(a) clearly shows the target's outer-shell emission plus stalk emission (all of which occurs during target acceleration). Figure 4(b) shows only the harder x-ray emission that is confined to the high-density, high-temperature implosion core region.

FIG. 2. Schematic of the CID camera interface to an OMEGA x-ray diagnostic.

FIG. 4. CID images of a directly driven imploding OMEGA laser target (from opposing pinhole cameras): (a) soft x-ray image containing emission from the outer shell region, the stalk, and a saturated core region; (b) hard x-ray image containing only emission from the core.

FIG. 5. Pair of simultaneously recorded x-ray microscope images taken with (a) Kodak DEF film and (b) a CID camera. The image is an imploding OMEGA target with dispersion of the core emission by an x-ray transmission grating (evidenced by the features $\sim 30^\circ$ from the horizontal to the upper right and lower left). The horizontal and vertical streaks are due to small-angle specular scattering from the microscope mirrors.

Pairs of images, one on film and one with a CID on the same x-ray microscope, have been obtained on a series of target shots on OMEGA. The KB microscope was outfitted with a diffraction grating that yielded dispersed spectra of the implosion cores.¹² The magnification of the images is 20.3. Since the KB microscope is a four-mirror, four-image version with image views separated by 1.4° on the target chamber sphere, the images are nearly identical except for differences in the recording media. Figure 5 shows a pair of such images: (a) a film-recorded image (Kodak DEF) and (b) a CID-camera-recorded image. Both images are produced by the KB microscope, which has Ir-coated mirrors operating at grazing angles of 0.70° . Attenuation by $140\text{ }\mu\text{m}$ of Be is common to both, as is diffraction by the $0.2\text{-}\mu\text{m}$ -period transmission grating. The CID camera had an additional $25\text{ }\mu\text{m}$ of Be acting as a light shield and housing cover. Both images show nearly identical features. The main features captured by the grating-dispersed microscope (zeroth-order image of implosion and first-order diffracted image of the core) are seen in both images. Since the film and microscope have been absolutely calibrated, comparison of the film- and CID-recorded core spectra can be used to infer the absolute sensitivity of the CID pixels. Figure 6(a) shows such a comparison taken along the core spectrum and plotted as a function of photon energy. The CID pixel's inferred quantum efficiency dependence on energy is shown in Fig. 6(b). Although a precise model for the CID pixels has not been developed, the results of Janesick *et al.*¹³ for the case of a frontside-illuminated, thin-depletion-region charge-coupled device are shown for comparison in Fig. 6(b). This model should closely represent the CID sensitivity.

Finally, a pair of images taken with the KB microscope outfitted with metal multilayer monochromators is shown in Fig. 7. The imaging system has been previously described.⁴ WB_4C multilayers with a $2d$ spacing of $26.5\text{ }\text{\AA}$ were used, and the magnification of the images is 13.6. The monochromators were tuned so as to produce images of target emission centered on the Ar He-like β line ($3.683 \pm 0.011\text{ keV}$) and the Ar H-like β line ($3.935 \pm 0.012\text{ keV}$), where the indicated energy range is determined by the FWHMs of the monochromator diffraction peaks. The target was a 15 atm,

FIG. 6. Comparison of CID- and film-recorded spectra. (a) Lineouts through the two spectral features; (b) inferred CID quantum efficiency, derived from the calibrated constants of the microscope/grating/film system.

D_2 -filled, $25\text{-}\mu\text{m}$ -thick, 1-mm -diam CH shell containing 0.35% by atomic number of Ar gas as a dopant. The images show the enhanced line-plus-continuum emission from the implosion core region. The asymmetry of the core is ascribed to the lack of perfect direct-drive beam balance on this shot, aggravated by several lower-intensity beams being near each other on the target chamber sphere. The images show a clear core region whose size and morphology can be clearly measured.

IV. CONCLUSIONS

CID cameras have been used to obtain time-integrated x-ray images on a variety of imaging and spectroscopic diagnostics on the OMEGA laser facility's target chamber. Cross calibration of the CID camera with film shows that the CID pixels, when used in direct-detection mode (i.e., without a phosphor), have a useful energy range of better than 2–8 keV, with additional sensitivity to be expected, especially at

FIG. 7. Monochromatic images of an imploding OMEGA laser target taken with two CID cameras.

higher energies. Currently, all existing OMEGA time-integrated x-ray diagnostics are being outfitted with CID cameras as an optional recording medium.

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