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1.C Measuring Laser-Plasma X-Ray Emission Using Photodiode Arrays

Traditionally, in laser-fusion and laser-plasma research, film has been used in x-ray diagnostics to record the integrated x-ray flux. The advantages of film are its low cost and relative simplicity of use. Photodiode arrays (PDA's), although more complex, offer the advantages of nearly instantaneous results, high sensitivity, stability of response, and in principle are easy to calibrate. A PDA, manufactured by Hughes Aircraft in Carlsbad, CA, incorporated into a pinhole camera, has been used to image laser-plasma x rays. The readout electronics were developed at the Space Science Laboratory and experiments were performed on the University of Rochester's OMEGA target chamber.

X-ray imaging and x-ray spectroscopy are used in laser-fusion research to diagnose conditions in the targets. Examples of imaging diagnostics are pinhole cameras, Kirkpatrick-Baez microscopes, and Wolter microscopes. X-ray spectra can be obtained with various crystal or grating-dispersed spectrometers. The x-ray flux from these diagnostics can be recorded directly with film or by a solid-state imaging array such as a PDA, or a charged-coupled device (CCD). PDA's are more able to withstand the high instantaneous flux levels present in laser-fusion experiments and are therefore more appropriate for use in direct x-ray detection. X rays can also be recorded indirectly. Indirect detection is accomplished by allowing the x rays to impinge on a phosphor screen or a photocathode. If a phosphor alone is used, then visible-light photons are generated and subsequently detected. If a photocathode is used, then photoelectrons are generated. Photocathodes allow image-intensification techniques to be used. CCD's are often more appropriate for use in indirect imaging diagnostics since they have higher ultimate sensitivity because of their lower inherent noise.

If high spatial resolution is required, then direct detection of x rays is often necessary. This is a result of the limited resolution obtainable with phosphors or photocathodes (>100 μm is typical). In such a case, film or a solid-state array can spatially resolve the x-ray flux. The solid-state array, although considerably more complex and more expensive than film, offers the advantages of nearly instantaneous results, high sensitivity, and stability of response. Both PDA's and CCD's can be obtained with pixel sizes of ~20 μm and, therefore, comparable spatial resolution. If higher spatial resolution is needed, then film is still the only medium available since resolutions of better than 5 μm can be easily obtained with the finer-grained x-ray film.

A demonstration of the direct detection of x rays has been performed with a hybrid Hughes PDA-readout chip combination. The applicability of the photodiode arrays manufactured by EG&G Reticon is also examined.

Detector Sensitivity

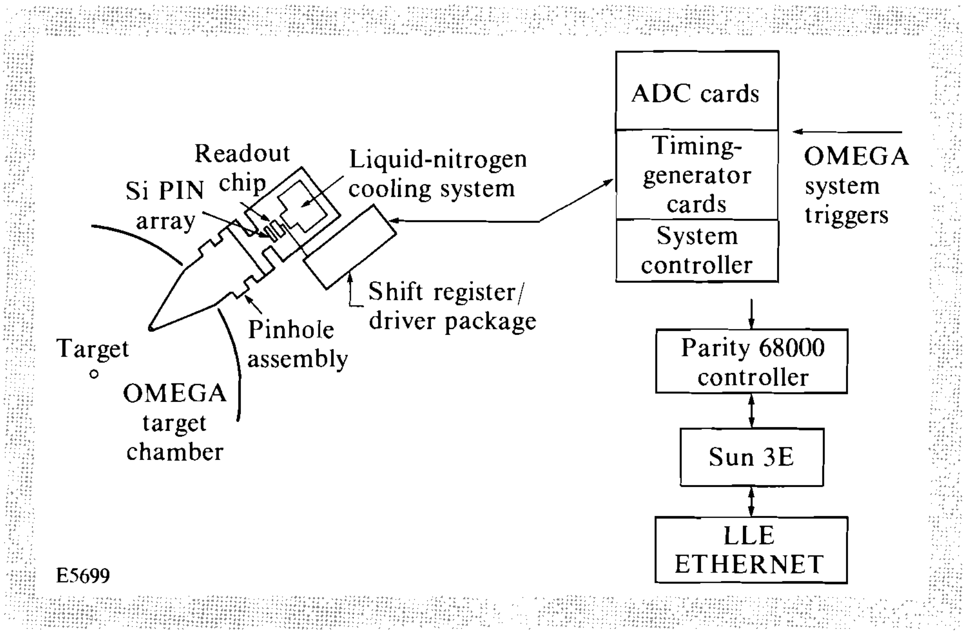
The photodiode array has a dynamic range limited at the lower end by the background noise and at the higher end by the well depth of the diode. The sources of noise in PDA's are thermal, readout, and pattern noise.[1] Both the thermal electron noise and the readout noise are functions of temperature and so can be minimized by cooling the array. Since they have been extensively characterized, the Reticon S series are used as a point of comparison. Allinson *et al.*[1] have shown that for the Reticon RL1024SF PDA, a practical lower limit to the total noise is 400 e^-. The well depth of the RL1024SF is 9×10^7 e^- yielding a theoretical dynamic range of 2×10^5 or 107 dB. As configured by EG&G Princeton Applied Research in the x-ray OMA III system, each photosite has a clear aperture of 25 μm × 2.0 mm and is covered with a 127-μm-thick Be light shield. The useful range of detectable x-ray flux levels can best be described by expressing the flux in units of energy-per-unit area. Since the energy per electron-hole pair in silicon is 3.7 eV, the well depth yields a maximum storable energy per readout of 3.3×10^8 eV or 5.3×10^{-4} ergs. Taken over the full aperture of the PDA this would yield a maximum detectable flux level of 1.1×10^{-1} ergs/cm^2. However, a narrower aperture could be used in front of the array to increase the maximum detectable flux level while the actual stored charge remained the same. As an example, a 25-µm aperture would allow detection of flux levels up to 8.5×10^1 ergs/cm^2. The minimum detectable flux level in the context of laser fusion (where all photons are counted simultaneously) is restricted to be approximately greater than 1 photon per pixel. At 8 keV and using the full aperture of the PDA, this corresponds to a flux of 2.6×10^{-5} ergs/cm^2. So, by choosing the aperture appropriately, flux levels from 2.6×10^{-5} to 8.5×10^1 ergs/cm^2 could be measured.

Two films commonly used for detecting laser-plasma x rays are Kodak 2495 and Kodak DEF. These have been characterized for their response to x rays by Henke.[2,3] DEF is the more sensitive over the range from 1 to 10 keV. Goodman *et al.*[4] have compared the sensitivity of the OMA III PDA system to DEF. They find that the PDA has a useful dynamic range seven times greater than DEF film and has greatly superior low-flux performance.

Experiments

Experiments were carried out with a pinhole camera attached to the OMEGA laser target chamber. The detector was a Si photodiode array of 256 × 256 pixels, 30 µm on a side, with a 300-µm-thick depletion layer. The diode was indium-bump bonded to a Hughes readout device[5] and the signal measured with custom, double-correlated, sample-and-hold electronics.[6] Figure 50.20 shows a schematic of the arrangement used for these experiments. The detector was in its own vacuum housing, separated from the OMEGA chamber by a thin Be window (100 µm thick). A gate valve was placed between the detector housing and the OMEGA chamber so that the detector could be installed and removed while the OMEGA target chamber was under vacuum. A 10-µm-diam pinhole laser drilled into a 25-µm-thick tantalum foil was used to image the x-ray emission. The pinhole array was placed at a distance of 19.0 cm from the target while the detector was placed at a distance of 95.0 cm from the pinhole array yielding a magnification of 5.0.

Fig. 50.20
Schematic of the x-ray pinhole camera system as deployed on the OMEGA target chamber.



Timing of the detector readout was accomplished by sending a trigger signal to the readout electronics 45 ms before the laser shot. The readout cycle consisted of four full-frame readouts. The laser shot occurred during the second frame readout. Since the duration of the subsequent x-ray emission was short (~1 ns), the frame was effectively recorded during the time of one pixel readout. Consequently, the image was recorded in the last part of frame 2 and the first part of frame 3. Frames 1 and 4 sampled the before and after shot background. The final background-corrected image was produced by adding frames 2 and 3 and subtracting frames 1 and 4. The before and after background frames were examined for differences caused by incomplete recovery by the detector. No significant differences were seen.

Figure 50.21(a) shows an image obtained on a target shot where the beams were all surface focused. The target was an 800-μm-diam polystyrene sphere with a 1-μm-gold overcoat. [The purpose of this target shot was to verify OMEGA beam targeting before beginning uniform or overlapping beam illumination of smaller (~250-μm-diam) targets.[7]] Figure 50.21(b) shows an x-ray image of the target taken by the nearest film-recording pinhole camera. This camera was located directly below the PDA detector on the target-chamber sphere. The x-ray emission regions produced by the focused OMEGA beams (beam spots) appear rotated downward on the PDA image relative to their locations on the film-recorded image. Note also that during the time of these experiments one beam was transported to the target through an auxiliary focus lens. The x-ray spot from this beam appears along the equator of the film-recorded image at the right side [Fig. 50.21(b)]. This same spot appears ~45° clockwise from the apparent equator and near the limb of the target image [Fig. 50.21(a)]. The beam spot at the top of the PDA image shows an apparent break in the emission. This is a result of the emission being partially obscured by the stalk. This is not seen on the film-recorded image since no beam spots seen from that view are obscured by the stalk. The relative size of the beam spots appears larger than the size of those seen with the film because of the much higher sensitivity of the PDA, enabling the weaker emission from the edges of the beam spots to be detected by the PDA but not by the film. The centers of the PDA image appear uniform because the x-ray emission creates a saturated signal. [The Hughes array has a much lower well depth (10^6 e$^-$) than that of the Reticon PDA previously discussed.]

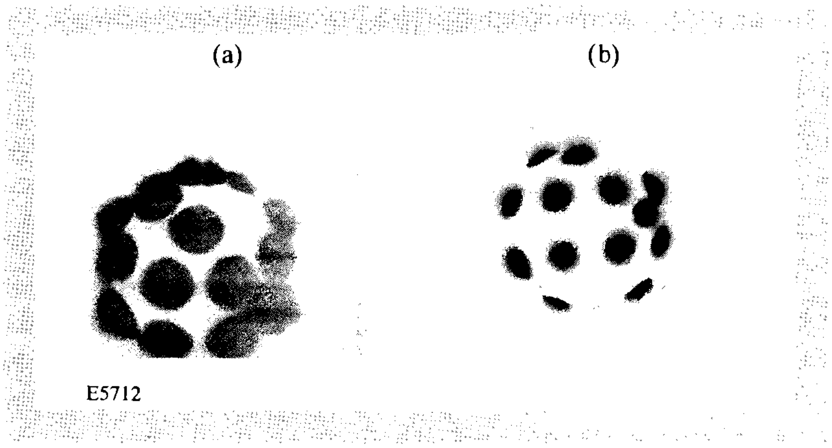


Fig. 50.21
X-ray images of an OMEGA pointing shot: (a) from the PDA-recording pinhole camera; (b) from a film-recording pinhole camera.