FR 8600941

COMMISSARIAT A L'ENERGIE ATOMIQUE

CENTRE D'ETUDES NUCLEAIRES DE SACLAY
Service de Documentation
F91191 GIF SUR YVETTE CEDEX

CEA-CONF - - 8143

L4

X-RAY ACQUISITION AND ELECTRONIC DIGITAL READOUT BY CHARGE COUPLED DEVICES

CAVAILLER, C.; LAUNSPACH, J.; MENS, A.; SAUNEUF, R.
CEA DAM, Centre de Limeil

Communication présentée à : Conference on photo-electronic imaging
London (UK)
10-11 Sep 1985

X-RAY ACQUISITION AND ELECTRONIC DIGITAL READOUT BY CHARGE COUPLED DEVICES

C. Cavailler, J. Launspach, A. Mens, R. Sauneuf

Commissariat à l'Energie Atomique, Centre d'Etudes de Limeil-Valenton, B.P. 27, 94190 Villeneuve-Saint-Georges, France

INTRODUCTION

X-ray imaging adapted to laser-matter interaction experiments consists in recording plasma images from its X-ray emission ; these phenomena have between 100 ps and some nanoseconds duration.

When we only need spatial information on 1 - 10 keV X-ray emission, the most simple imaging device is the pinhole camera ; the two-dimensional image of the plasma is temporally integrated by an X-ray sensitive detector ; until now, X-ray film was used ; its operation was long and tedious so we replaced it by a television camera built around a charge coupled device (C.C.D.).

Investigation of the laser-driven plasma may require the formation and the detection of two-dimensional images formed by X-ray microscopes or spectrometers in the soft X-ray range (from about 50 eV to some keV). To reach that purpose, we have developped and tested two opto-electronic chains. The first one is built around a small image converter tube with a soft X-ray photocathode and P20 phosphor screen deposited on a fiber optic plate ; the electronic image appearing on the screen is read by a C.C.D. working in the visible spectral range .

The second one, designed to work below 100 eV is realized with a very thin phosphor screen deposited on the fiber optic input of a visible microchannel image intensifier ; the output image is then read by a C.C.D. in the same manner than previously.

X-ray detection in the 1-10 keV spectral range

Operating principle of the C.C.D. detector and the associated miniature camera

CCD's are sensitive within a spectral range of 0.3 to 1.1 µm. Below 0.3 µm, radiation is stopped by the superficial insulating material (SiO2) and by polycrystalline silicon electrodes. Since the energy of X photons is greater than 0.5 keV, they begin to penetrate the silicon substrate and create an electron-hole pair at 3.6 eV incident energy (1).

Our experience in the field of laser pulse detection (2) then in the field of streak camera automatic image reading (3) and in the field of diagnostics led us to choose the THOMSON-CSF* TH 7861 CDA or TH 7882 CDA matrix detectors for the detection of X-rays in a pinhole camera.

The C.C.D., TH 7861 CDA is a frame transfer component made of 288 lines of 384 pixels for each frame and measures 6.6 mm x 8.8 mm ; this detector is able to detect continuous or pulsed phenomena.

The C.C.D., TH 7882 CDA is a whole image component made of 576 lines of 384 pixels for each image and measures 13.2 mm x 8.8 mm ; having no memory area, it detects only pulsed phenomena.

Figure 1 shows the structure of a pinhole camera mounted with the C.C.D. detector under vacuum. The image of the plasma through the pinhole is recorded onto the C.C.D. with an adjustable magnification between b1/a and (b1 + b2) / a.

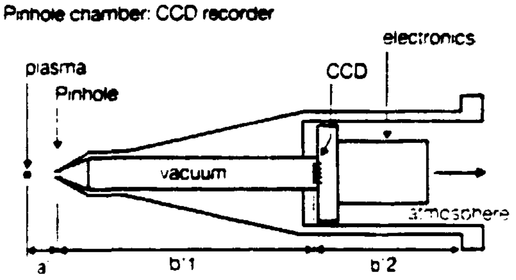


Figure 1 - Pinhole chamber, C.C.D. recorder

The television camera produced by THOMSON-CSF** is in three parts (fig. 2). The C.C.D. detector operating under vacuum in the chamber, is connected to the head of the miniature camera by means of the 29 pins vacuum proof connector of known design (1) and tested down to pressures of 10^{-7} Torr.

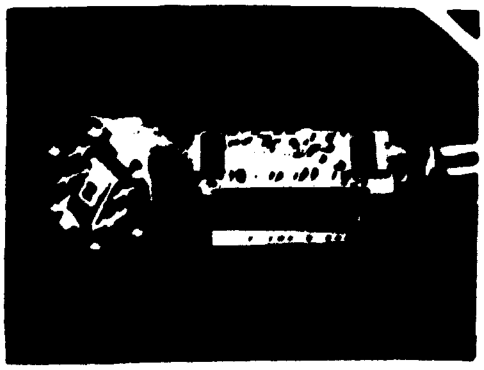


Figure 2 - Pinhole chamber, C.C.D. recorder

---

* THOMSON-CSF Boulogne DTE, 38 rue Vauthier B.P. 305, 92102 BOULOGNE, FRANCE

**THOMSON-CSF LER, avenue Belle Fontaine, 35510 Cesson Sévigné, RENNES, FRANCE

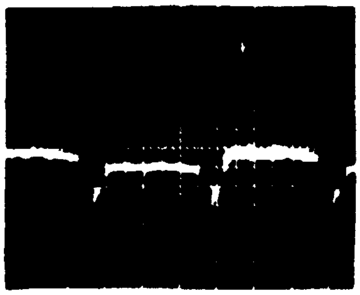
A miniature camera head, integrated in a tube of 44 mm outer diameter and 120 mm length is mounted in immediate proximitv on the other side (1 to 2 cm) of the C.C.D. and performs the shaping of the video signal as well as its amplification.

A control unit, located 1.5 m outside the pinhole camera contains the other electronic functions :

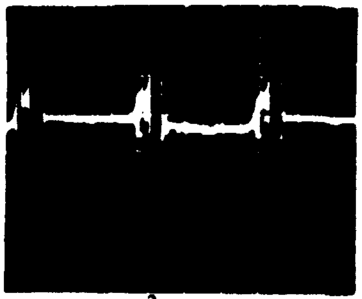
- power supplies
- logic signal generators (clock and synchronisations)
- signal processing (adaptation of the video signals to CCIR or whole image TV standards, triggering of the integration time by a - 4 ms external synchronisation signal, in order to observe single shot events, line and frame genlock for correct visualisaticn on a TV net work).

These electronic circuits have been optimized by THOMSON LER** in order to produce a very high dynamic range on the video signal. We have measured a dark noise of 0.5 mV peak to peak, for a saturation signal of 700 mV, so the signal to noise ratio is greater than 60 dB (peak to peak).

This parameter is very important for X-ray imaging. Measurements were carried out in order to know the falloff in performance of the C.C.D. working in vacuum. In fact no convection heat exchange occurs in vacuum, and any temperature rise may increase the dark current of this detector, and therefore decrease the value of the illumination dynamic range obtained. Experimentally, we noted no significant difference between the dark noise of the same C.C.D. operating at ambient temperature in air and in vacuum for integration times of 18.4 ms (CCIR TV standards). See figure 3.



Air ambient temperature



Primary Vacuum (10^{-2} Torr)

Figure 3 - Dark noise at air ambient temperature and after 15 minutes under vacuum

Consequently it is not necessary to cool a C.C.D working under these conditions and taking into account this point it is possible to simplify the construction of the camera.

The immediate processing of the images is performed by the image memory PC 200 developped by NUMELEC*** (ADC of 8 bits, 4 memories of 512 x 512 points, IEEE interface).

Calibration of the C.C.D. detector and associated camera on an X-ray source :

The C.C.D. must be illuminated by an X-ray source as far as possible monochromatic. The schematic of the experiment is given on fig.4 : a standard X-ray tube, with a chromium anode is operating at different voltages between 10 and 17 kV. In the vacuum chamber the radiation is emitted through a 500 μm thick beryllium window.

The resultant spectrum includes :
- a continuous background between 10 and 17 keV
- characteristic chromium lines (Kα : 5.41 keV and Kβ : 5.95 keV)

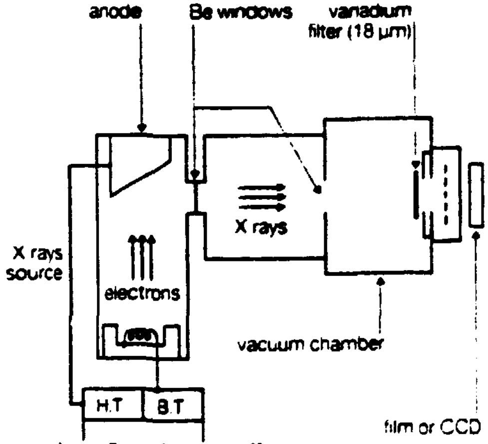


Figure 4 - Continuous X-ray source

With a vanadium foil of 18 μm thick used as a K-edge filter at 5.46 keV we have obtained a nearly monochromatic source at 5.4 keV with 80 % of energy in the Kα chromium line. The first measurents have been done with this experimental assembly (4) on a small THOMSON-CSF C.C.D. detector, TH 7851 CDA (previous reference THX 31135). A sensitivity S1 of 1.1×10^8 photons.$cm^{-2}.V^{-1}$ has been measured in these conditions at 5.41 keV in some detectors. This value has been confirmed by comparison with KODAK SB2 X-ray film response at 5.4 keV.

The C.C.D. detector, and then the KODAK SB2 film, are placed on the same X-ray source ; integration time of the C.C.D. is electronic (18.4 ms) ; the film integration time is produced by a mechanical shutter (measured value 40 ms). The level V of the C.C.D. video signal is then compared with the darkening of the film corresponding to an optical density d. Figure 5 shows the calibration curve of the SB2 film at 5 keV the optical density has been obtained by an external calibration source and plotted in relation to the number of photons.cm^{-2} irradiating the film.

We have measured in that case, an average [illegible] sensitivity S_2 of 7.5×10^7 photons.$cm^{-2}.V^{-1}$ (5.4 keV)

This value is roughly of the same order, to these obtained by the first method. Using these measurements (fig. 5), we can calculate

***NUMELEC, 1 place de la Gare, La Verriere, B.P. 38, 78320 LE MESNIL SAINT-DENIS, FRANCE the following characteristics of C.C.D. THX 31135 :

- detectability 1.5×10^{5} photons$\cdot$cm^{-2}
- saturation 5×10^{7} photons$\cdot$cm^{-2}
- dynamic range 300

The C.C.D. is therefore 10 times more sensitive that KODAK SB2 film at 5.4 keV

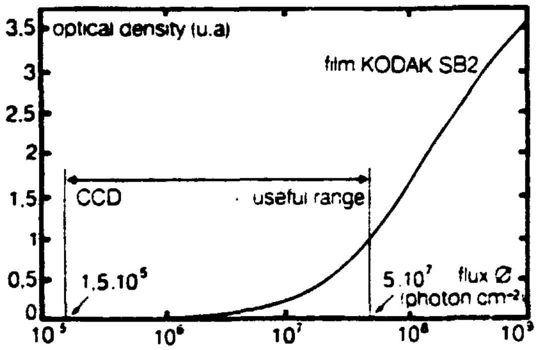


Figure 5 - Test curve of KODAK SB2 film

These measurements are in good agreement to those obtained by L. Koppel (5) on the SID 51232 from RCA and J.C. Gauthier (1) on the same THOMSON-CSF C.C.D.

We are now calibrating the two others THOMSON-CSF C.C.D. (TH 7861 and TH 7862) having a similar structure on the same source; their sensitivities should be improved by a factor 2 to 4 because of the high quality of the electronics; some other measurements will be done around 2 keV by using an X-ray source with a tungsten anode.

C.C.D destruction study in conjunction with irradiation

X-ray photons can destroy the crystalline network of the silicon under certain condition. The deterioration which we observed resulted in increased noise, which eventually made the device unuseable.

We carried out measurements which showed that at 5.4 keV :

- for a normal X-ray dose corresponding to 4×10^{7} photons/cm^{2} (half saturation flux), lifetime of a C.C.D. is several tens of minutes.
- for a dose corresponding to 10 times the saturation flux (5×10^{8} photons/cm^{2}) the C.C.D. is destroyed in a few tens of seconds.

These measurements show that, if a detector is used normally, the number of images which can be recorded in the pulsed mode (duration of between 100 ps to a few nanoseconds for laser-matter interaction experiments) is almost unlimited. These measurements have not been made for the harder X-rays (a few tens of keV).

Finally, it should be noted that C.C.D. s are quite insensitive to electromagnetic disturbance generated during the laser shot.

Experimental results recorded during laser-matter interaction experiments using a pinhole X-ray camera

The pinhole X-ray camera and the associated automatic image read chain which we have just described were first used on the ASTARTE installation, associated with laser KETJAK. The main features of this installation have already been described (6).

Figure 7 shows the image of plasmas obtained with C.C.D. camera during a two-beam shot (twice 3 joules at 50 ps) on a copper wire of 250 μm diameter. A simultaneous recording was made on a film in a second pinhole chamber to confirm the measurements made with the C.C.D.

This camera is now operational and has been installed as part of the HELIOTROPE experiment (8 laser beams of 100 J 800 ps 0.35 μm enabling immediate use of the images in the 1-10 keV X-ray spectral range.

X-rays detection in the 50 eV - some keV spectral range

A large amount of soft X-rays are emitted in laser-matter interaction experiments ; so plasma investigations require special instrumentation to assume the detection of two-dimensional images obtained by X-ray microscopes ar spectrometers in this soft X-ray region

Figure 7 - KETJAK dual beam laser C.C.D. readout of the plasma

We have seen that C.C.D. are not sensitive under 1 keV. So we have developped two opto-electronic chains to investigate that spectral range.
The first one is built around a small image converter tube.

Soft X-rays image converter tube and electronic digital readout

Principle

Its is derived from an electrostatically focused diode-inverter tube which is made by RTC**** and works in infrared region. For our needs, such a tube has been modified as follows (fig. 8) :

- in order to collect more light, the outer glass window is replaced by an optic fiber plate on which is deposited the phosphor screen;

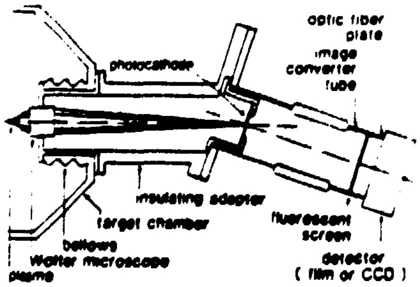


Figure 8 - Schematic of the soft X-ray image converter tube

**** RTC, 130 avenue Ledru-Rollin,75540 PARIS CEDEX 11, FRANCE

- the input glass window is replaced by a mechanical device which holds a soft X-ray photocathode (a very thin Au or CsI layer on a plastic foil as transparent as possible) that photocathode is entirely under vacuum ;
- a vacuum flange with an elastomer O-ring is added to the front part to allow pumping of the tube and good X-ray transmission.

An insulating adaptor connects the tube to the microscope so that the photocathode is in the image plane. The tube axis makes a slight angle with the microscope axis to prevent unabsorbed X-rays from illuminating the electronic image zone on the screen.

The photocathode is grounded and a voltage of + 10 kV is put on the screen. The external face of the optic fiber plate is metallized and grounded in order to protect detectors using C.C.D.

Tests with a continuous X-ray source

The ICT and its adaptator are mounted on the test chamber described in figure 4, as the ICT is also sensible to X-ray of 5.4 keV we have determined its resolution by putting a 75 um gold resolution chart in front of the photocathode.
The visible output image was then recorded on a 55 PN polaroid film (fig. 9).

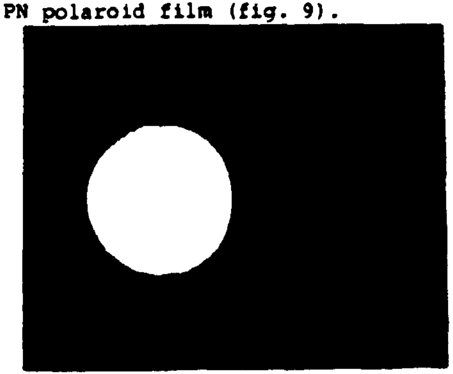


Figure 9 - Spatial resolution test of the ICT (grid period 75 um)

We can see two parts on that image. The very luminous small diameter spot corresponds to the direct X-rays which are not absorbed by the photocathode. The other spot is the electronic image of the grid and we can notice the absence of distorsion though the photocathode is plane instead of being spherical. But the small difference of shape may explain the defocusing of the image center. So we have to find a better position of the photocathode to achieve a good resolution over the whole field and we expect a 5 to 10 lp/mm resolution.

Tests on an interaction chamber

As the resolution is far better than that of the testing microscope (4 lp/mm on the image) we have put the ICT on the microscope holding device (fig. 10) ; the electronic image appearing on the screen is read by a C.C.D. working in the visible spectral range (3). The electronic video signal is then sent to the image memory PC 200 and processed in a Pericolor 1000 in real time.

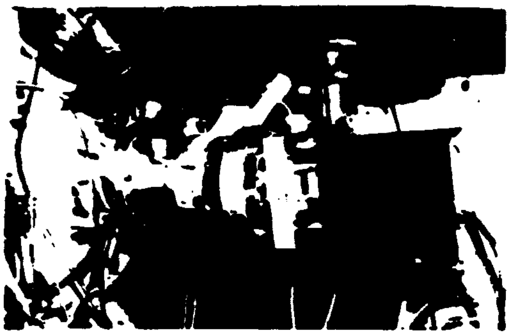


Figure 10 - Photograph of the whole apparatus mounted on the interaction chamber

Figure 11 shows the image of the soft X-ray source given by the microscope and recorded by the automatic readout.

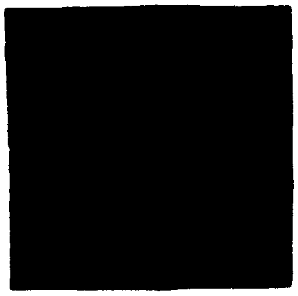


Figure 11 - Image of the X-ray source given by the microscope and recorded by the automatic readout

The second device consists in a very thin phosphor screen deposited on the fiber optic input of an image intensifier ; this phosphor $(Gd\,S\,O_2)$ is made by THOMSON-CSF DTE, two layers of 1 um are made by the absorption method on the fiber optic input of a RTC P454 image intensifier.

P454 is a double proximity focused intensifier with a microchannel plate and a P20 phosphor screen on a fiber optic plate. The electronic digital readout is the same than previously.

This device should be sensitive below 100 eV. The first X-ray image recorded on a continuous X-ray source with a polaroid 57 PN film is presented in figure 12.

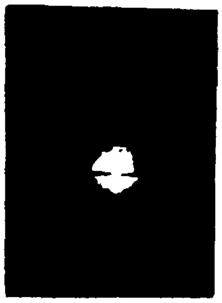


Figure 12 - Image of a soft X-ray source given by a phosphor/image intensifier

After preliminary tests this device will be associated to a soft X-ray spectrometer working under 100 eV range.