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The soft X-ray P 550 streak camera. Characteristics and applications

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Abstract

This paper presents the latest performances of our P 550 X soft X-ray camera for laser fusion applications. This instrument is sensitive to photon energies down to 100 eV and has the same spatio-temporal performances than standard X-ray streak cameras.

Introduction

Our high energy X-ray streak cameras[1] use sealed image converter tubes with a 25 µm thick beryllium vacuum window which additionally serves as a substrate for the 4000 Å gold photocathode.

This beryllium window transmits X-ray above 1.5 keV which is sufficient, for keV range X-ray diagnostics, to observe core compressions or to perform backlighting experiments. Since considerable emission from the high density, low temperature ablation region extends in sub-keV spectral region it is important to have access to this range.

The P 550 soft X-ray streak camera has been designed, built and tested to reach this purpose. Its spectral performances have been checked on CAMELIA experiment during mid 1981.

Description of the image converter tube (I.C.T.) and vacuum system

L.E.P.* has modified a standard P 500 X image converter tube which still works in the transmission mode (See Figure 1.) with a 500 Å gold photocathode deposited on a 8000 Å polystyrene substrate. This 15 x 2 mm removable photocathode is made at Limeil (some attempts are undertaken to reduce the C-H substrate thickness down to 5000 Å).

The replacement of the photocathode does not last more than one hour including vacuum operations.

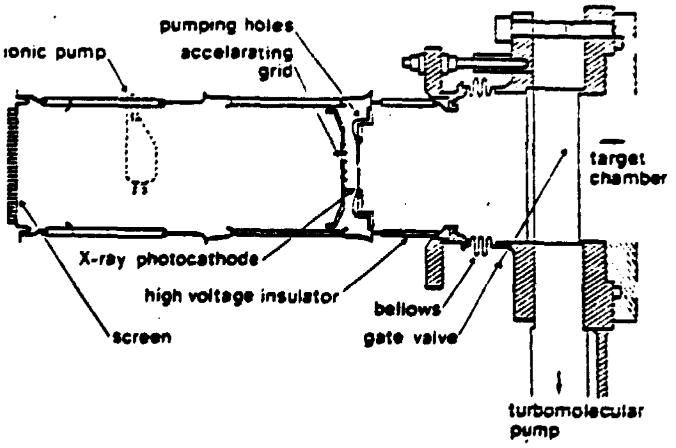

Figure 1. Schematic of P 550 X I.C.T.

The photoelectrons are accelerated to 2.5 keV by grid G_1, transmitted through a focusing field, accelerated up to 15 keV and then swept along a P 11 phosphor screen. The streaked image is amplified with a 40 mm microchannel-plate image intensifier.

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No beryllium photocathode substrate remains in the front end of the streak tube ; the very thin polystyrene foil is unable to maintain the pressure between atmosphere and vacuum required for the standard I.C.T. operation (10^{-6} torr). So, we have to operate the soft X-ray I.C.T. directly in the target chamber vacuum (See Figures 2 and 3.).

The tube's front end is isolated from the chamber by a pneumatic gate valve which includes a pumping pipe connected to a turbomolecular pump (See Figure 2.). So the I.C.T. is permanently pumped through this pneumatic gate (whatever the valve is opened or closed). The 120 $\ell.sec^{-1}$ turbomolecular pump provides 10^{-6} torr required in the photocathode region for the I.C.T. operation.

Two vacuum-gauges (one in the camera, one on experiment side) are coupled with the gate valve to assure the photocathode protection.

A few minutes before the laser shot the gate valve is opened setting the photocathode in the target chamber vacuum (10^{-5} torr).

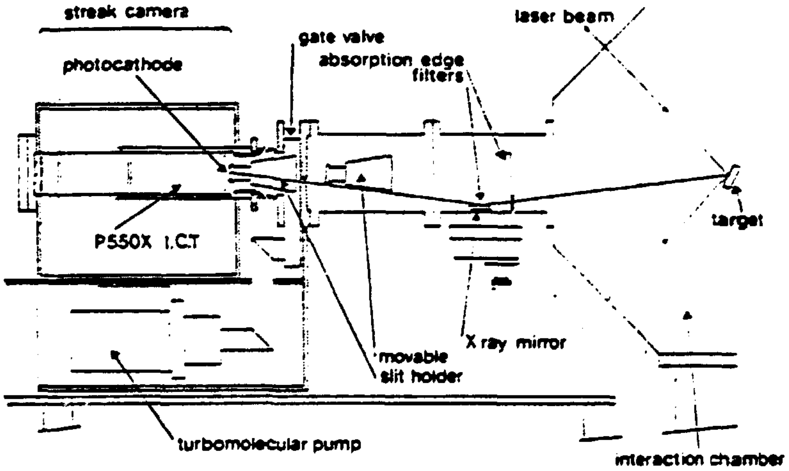

Figure 2. Schematic of soft X-ray system

A slit holder is then set in working position by a microprocessor which controls all the operations and security sequences.

X-ray emission is observed onto the streak camera through a glass mirror and appropriately matched absorption edge filters. This mirror is at equal distance from the X-ray source and camera slit.

Preliminary measurements have been undertaken to calibrate this streak camera.

Calibration results

Calibration work were performed as shown in Figure 4 with a laser plasma X-ray source. The KETJAK neodymium glass laser works with a mode locked YAG oscillator delivering a train of pulses (50 ps F.W.H.M.). The selected pulse is divided in 2 parts in a Michelson interferometer used as a delay line. This etalon is ajusted to provide the optimum temporal separation between the 2 generated pulses. Each one is amplified up to 5 joules and focused onto a tantalum slab target at normal incidence. For calibration purposes the P 550 X streak camera is positioned on the target chamber (forty five degrees to the incident laser beam).

The two X-ray pulses separated by 150 ps, are reflected on the glass mirror onto the streak camera slit.

Using this method the experimental results are the following :

- The spatial resolution varies from 3 $\ell p.mm^{-1}$ (temporal optimisation) to 6 - 8 $\ell p.mm^{-1}$ (spatial optimisation) for the maximum sweep speed at 2.5×10^9 cm s^{-1} (same performances than for sealed X-ray tubes).
- Sweep durations (20 ns, 10 ns, 5 ns, 2 ns) have been evaluated as well as sweep speed differential linearity (better than ± 10 % on the 4 cm length of the screen).

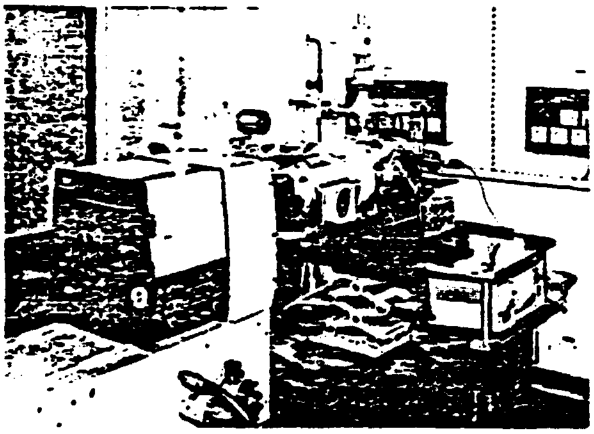

Figure 3. P 550 X streak camera

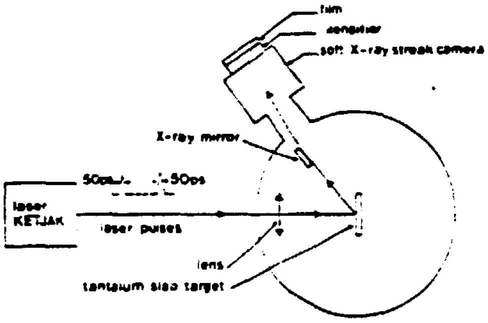

Figure 4. KETJAK target chamber

- Time response : 50 ps
  This temporal response to the incident X-ray source is strongly limited by the X-ray source pulse duration.
  The theoretical time response of such an I.C.T. has been already discussed previously[2].
  Two factors mainly limit the time resolution :
  . The transit time dispersion τ_1 resulting from the photoelectron's energy spread : $\Delta\varepsilon$ (eV) on the photocathode (for sub keV illuminations on gold photocathodes $\Delta\varepsilon$ has been evaluated at 3.8 eV value[3]).
  Since the X-ray streak camera works with an extraction field $E \approx 3000$ V/cm we have :

$$\tau_1 = 2.34 \times 10^{-8} \frac{\sqrt{\Delta\varepsilon}}{E} = 15 \text{ ps} \qquad (1)$$

  . τ_2 : equivalent time resolved element corresponding to the spatial image dimension μ of the slit on the screen or time required to sweep through the slit width μ

$$\tau_2 = \frac{\mu}{V} \qquad (2)$$

  with $\mu = 150$ μm and for the maximum sweep speed $V = 2.5 \times 10^9$ cm.s^{-1}

  $\tau_2 = 6$ ps

  For gaussian pulses and energy distribution, we can approximate the theoretical time response

$$\tau = (\tau_1^2 + \tau_2^2)^{\frac{1}{2}} \qquad (3)$$

  which numerically becomes

  $\tau = 17$ ps.

Application as a laser fusion experiments diagnostic

At C.E.L., implosion experiments are performed with CAMELIA[4,5] by using the eight-beams Nd-glass laser facility OCTAL[6].

P 550 X streak camera has been used on this experiment in order to obtain soft X-ray emission data.

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When the plasma emission is sufficient it is possible to obtain soft X-ray channels by associating absorption edge filters with grazing incidence X-ray mirror[7].

But in our case, soft X-ray emission from glass microballoon is too weak ; for that reason we have decided the following experimental arrangement to test this diagnostic system (See Figure 5.).

Channel 1 : X-rays are filtered by reflexion on the glass mirror
Channel 2 : Titanium (thickness 2 µm)
Channel 3 : Aluminum (thickness 10 µm)   } absorption edge filters
Channel 4 : Iron (thickness 1 µm)

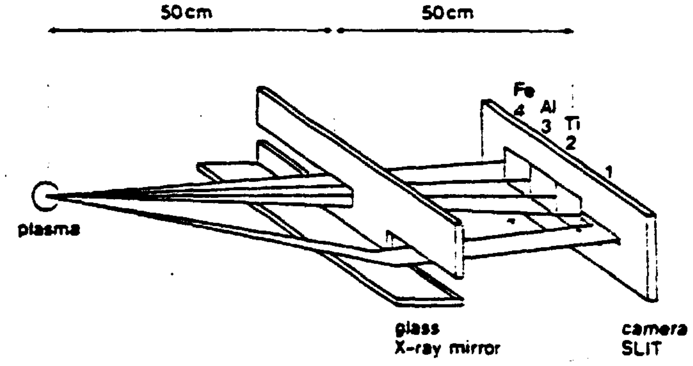
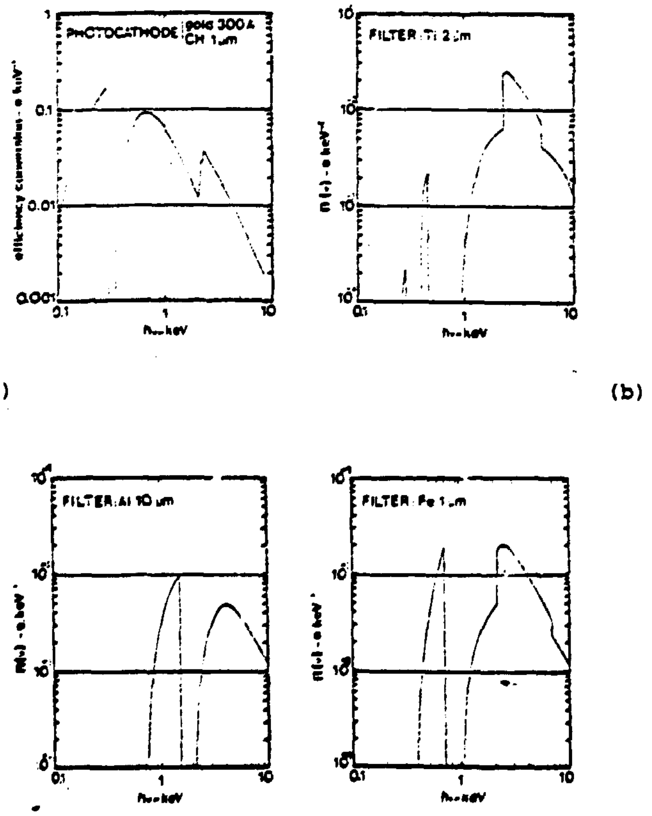


Figure 5. Four channels soft X-ray streak camera



(c)   Figure 6. Calculated spectral responses   (d)

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On Figure 6.a) the calculated[3] efficiency conversion of a 300 Å gold + 1 µm CH photocathode is plotted versus the energy range.

Figures 6.b)c)d) show the relative calculated spectral responses R(ν) of the same photocathode through the corresponding absorption edge filter.

In Figure 6.b) we can notice for Ti a 2.2-5 keV spectral range.

In Figure 6.c) we have for Aℓ a 1-1.5 keV and 2.2-10 keV spectral range.

In Figure 6.d) we have for Fe 0.5-0.7 keV and 2.2-7 keV spectral range.

We can notice that with the mirror, we would have had the opportunity to get thinner spectral bandwidths (high frequency cut-off of this mirror).

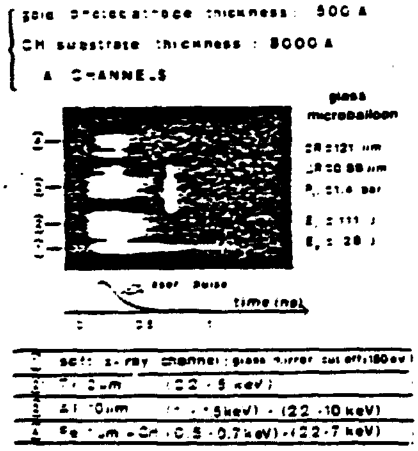

Figure 7. Temporal responses of a glass microballoon

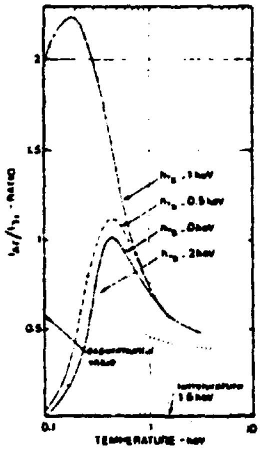

Figure 8. $I_{A\ell}/I_{Ti}$ ratio versus temperature

Figure 7 shows typical temporal responses of an imploded glass microballoon X-ray emission (laser pulsewidth was 200 ps).

For channel 1 the spectral bandwidth is given by the mirror position (calculated cut off $h\nu_c \sim 150$ eV). The duration of the corresponding soft X-ray signal is longer than durations in channels 2,3,4. This result may give us an information on the temperature decay time.

Moreover with a greater number of channels, we could calculate the plasma emission spectrum $S(\nu,t)$.

As an exemple we can determine the temperature of plasma with the recorded signals on channels 2 and 3 (Aℓ and Ti).

If we suppose that, at t, $S(\nu,t)$ is constant from o to νs $[S(\nu,t) = S_0]$ and then decays according to an exponential law

$$S(\nu,t) = S_0 e^{-\frac{h(\nu-\nu s)}{kT}} \text{ for } \nu > \nu_S.$$

We can calculate the theoretical $\frac{I_{A\ell}}{I_{Ti}}$ value versus ν_S.

Figure 8 shows theses theoretical values.

$\frac{I_{A\ell}}{I_{Ti}}$ ratio is plotted versus temperature ; $h\nu_S$ is considered as a parameter ($h\nu_S = 0$, 0.5 , 1.2 keV).

Experimental values of $I_{A\ell}$ and I_{Ti} are measured at the time of the laser pulse peak for the shot presented on Figure 7. The experimental ratio is therefore : 0.56. Comparison with theoretical curves allows us to evaluate a temperature value of 1.6 keV. Moreover, we can remark that this value is independant of the spectral shape under 1 keV making our previous spectrum assumption a posteriori justified.

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Conclusions

As a conclusion it is possible to say that we have developped an instrument, sensitive down to 100 eV, presenting a good spatio-temporal performance and a very reliable vacuum system.

This camera is a very important tool for spectral analysis of soft X-ray plasma emission.

Acknowledgments

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