500 FS STREAK CAMERA FOR UV-HARD X RAYS IN 1KHZ ACCUMULATING MODE WITH OPTICAL -JITTER FREE- SYNCHRONISATION

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Abstract

The development at the ESRF of a jitter-free, laser triggered Streak Camera has now yielded time resolution results as short as 460fs while operating in accumulating mode. The so-called jitter-free synchronisation between the laser light and the Streak Camera is performed through a GaAs photo-switch in a simple HV circuit that connects directly to the Streak tube’s deflection plates.

The novelty of this technique permits to obtain excellent dynamic range measurements in a shot-to-shot accumulation of ultra fast (laser stimulated) events at up to 1Khz without degrading the time resolution.

Important insight was obtained on the quality of this optical synchronisation and its dependence on the laser characteristics, the switch circuit, and the structure of the GaAs switch itself. This permitted to suppress the jitter causes and today the 500fs limitation is imposed by the streak tube’s intrinsic time resolution. This work was done by measuring (with Au or Pd photo-cathodes) the 3rd harmonic (i.e. 267nm) of a 100fs Ti:Saph laser.

Also important progress was made with the reliability of the photo-switch and problems of HV break-down and structural degradation have been completely resolved.

Since the principal use of this system at the ESRF is in ultra-fast X-ray diffraction experiments the exchangeable photo-cathode structure of this tube covers the entire UV-to-X-rays spectrum. The QE of various photo-cathode materials was measured in the 8-30KeV range.

1 MOTIVATION & INTRODUCTION

1.1 Ultra fast Pump-Probe X-ray experiments

A number of ultra-fast time-resolved X-ray scattering experiments can now benefit from both the ESRF unrivalled high brilliance X-ray source and state-of-the-art ultra-fast laser and detector technology. [1] In such an experiment a broad X-ray pulse (typ. 100picosec) probes the structure of the sample under study (e.g. a crystal) while an ultra-short (typ. 100femtosec) laser pulse (λ=200-1000nm by an OPA) triggers an ultra-fast reaction in it (see fig.1). The latter becomes apparent by a modification of the diffracted X-ray beam. An X-ray Streak Camera having this beam centered on its photo-cathode will measure the broad probe pulse while the ultra-fast modulation contained in it will be detectable within the time resolution limits of the Streak Camera.

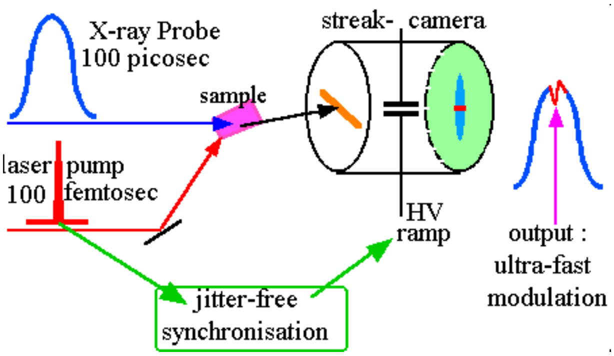


Fig.1 Pump-Probe experiment with Streak Camera optically synchronised

This intrinsic time resolution for X-rays has been measured independantly at the INRS with an ultra-fast 3KeV source and is estimated at below 700femtosec. [2]

1.2 Accumulation for High Dynamic range

However, in single-shot operation the dynamic range of the obtained data will be extremely limited as the intra-tube space charge effects only allow small input photon flux per shot to avoid the loss of the tube’s intrinsic time resolution. This is a general problem with all ultra-fast streak cameras.

The requirement for the above experiments of high quality data to discern relatively weak signals within it make operation in repetitive, accumulation mode imperative. However, the effective time resolution of the system in accumulation mode would be impaired unless the un-precision of the trigger synchronisation, or the so-called jitter, would be negilible compared to the tube’s time resolution.

2 JITTER-FREE SYNCHRONISATION THROUGH PHOTOSWITCH

The innovation in this system is to obtain this synchronisation optically between the Streak Tube and laser pump pulse by the use of a photo-conductive switch and to attain a truly jitter-free performance.

The generation of the High Voltage Sweep Ramp on the Streak Camera’s deflection plates is directly triggered by the laser light on the photo-switch. Its transition to a conductive state is essentially instantaneous and for a perfectly stable ultra short laser pulse the triggering should be intrinsically free of jitter and drift.

Semi-insulating Gallium Arsenide is the preferred material because of the combination of high resistivity (>106ohm.cm) and high break-down field in the dark (>100KV/cm), together with high carrier mobility (>5000cm2/V.s).

The recently developed version is greatly improved in performance and reliability from the original design [3] through the optimisation of the electrode geometry, process and material properties. In particular, because of the short optical absorption depth (of order 1µm), it is necessary to process the GaAs surface in order to lower surface recombination velocities to values yielding photo-conduction decay times significantly longer than the sweep ramp duration. In conductive state the switch resistance of a few ohm is obtained with laser pulse energy of the order of 10µJ.

The GaAs switch is a chip of 10x15mm2 with interdigitated electrodes. The gap between the electrodes is 1.7mm and the voltage applied in the dark corresponds to a typical electric field of 20KV/cm.

3 CONFIGURATION FOR JITTER-FREE TESTS WITH UV LIGHT

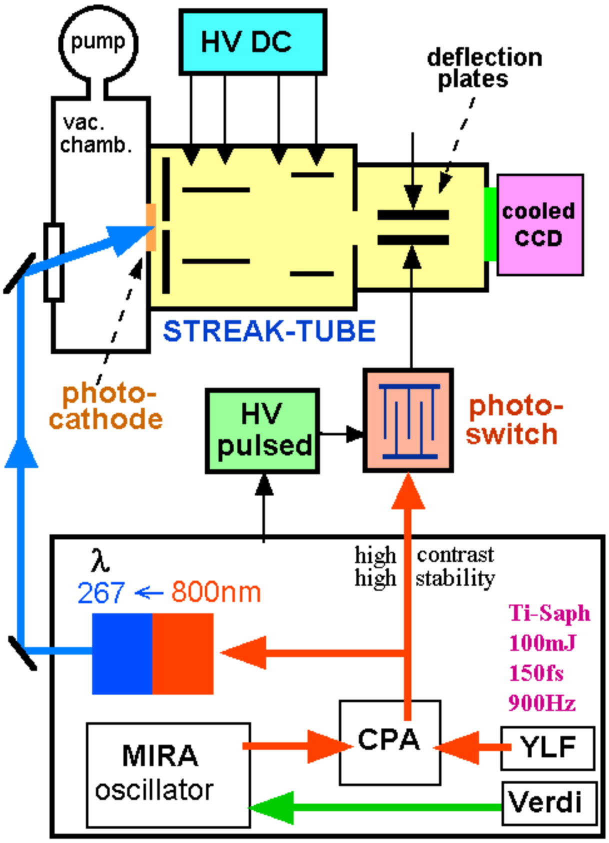


Fig2. Jitter-Free tests with 150fs UV light

The tests and measurements of the quality of the optical synchronisation can be done in an easy and straitforward manner by simply measuring the 100femtosec pulse from our laser with the streak camera system. The 3^{rd} harmonic (i.e. 267nm) is generated in a crystal set-up and is directed to the Gold or Palladium photo-cathodes used.

A laser beam at the fundamental wavelength is used to trigger the photo-switch. The adjustment of the timing between the UV (input light) and the IR (trigger light) is achieved by simple optical delay lines.

The characteristics of the IR trigger beam can be varied in a controlled and independent way. This permits to analyse the sensitivity of the optical synchronisation to these laser characteristics. In particular the effects of total pulse energy, pulse stability, pulse cleanliness or contrast, pulse duration, size and uniformity of laser spot on the photo-switch have been examined.

In this way the jitter-causes can be tracked down and an optimum working point for the system can be determined. The same configuration also permits to easily fine-tune the High Voltages on the streak tube for optimum focussing for different sweep speeds, and to verify the correct functioning of the subsystems like the HV supplies and the CCD camera.

The latter is a commercial device with 1242 X 1152 pixels of 22.5µm. It is in direct fiber-plate contact with the Phosphor screen and can be cooled to below –30C.

4 STREAK TUBE IMPROVEMENTS

4.1 *Streak Tube Characteristics*

The Streak tube used in the first stage of the project development is the Philips P860X/D1. With its so-called bilamellar electron optics, good spatial and temporal resolution are preserved with minimum space charge effects and electron transit time spread. The tube has a spatial resolution at the Phosphor screen of 40µm (fwhm).

The photo-cathode has a width of 10mm so one spatial domain of the detector is preserved and useable in experiments. The tube operates with 5 independent High Voltages : 15KV for the accelerating field of the photo-cathode, two focussing electrodes (around 6KV) and two quadrupole electrodes (around 500V).

4.2 *Improvements and New Tube*

The tube is open at the light input side which permits an easy exchange of the photo-cathode. This photo-cathode itself is a small 30x3mm circular pellet with a slit in its centre on which a foil is attached. This photo-cathode exchangeability makes it possible to use the material best suited to the photon energy of the experiment. The selection of the material can be governed by requirements on absolute sensitivity (QE) or time resolution (photo-electron energy spread).

The open input structure also allows to modify the distance between the photo-cathode and the accelerator slit and thus the acceleration field for the photo-electrons. This nominal distance is at 3mm but values as small as 2mm (i.e. 7.5KV/mm) have been tried with success after a complete re-design of the photo-cathode and its holder to assure a smooth and uniform field in order to minimise the risk of HV break-down. Also the Vacuum system was improved, a pressure of <3.10^{-7}Torr reduces the risk of HV breakdown or spurious emissions.

Increasing the strength of this acceleration field is of great importance as it limits time dispersion effects due to the energy spread of the emitted photo-electrons [4]

The deflection sensitivity of the above tube’s deflection plates being about 18µm/V meant that the photo-switch had to be strained with voltages as high as 4KV to attain a sweep speed of 200fs per pixel on the CCD camera. A new tube with modified deflection plates was designed, realised and successfully operated since. The sensitivity is increased to above 27µm/V.

5 SINGLE SWITCH CIRCUIT

An electric circuitry is needed to interconnect, the photo-switch, the HV supplies, and the sweep plates. An approach using 2 switches (1 per plate) was initially used but was unsatisfactory in terms of performance, reliability and practical use.

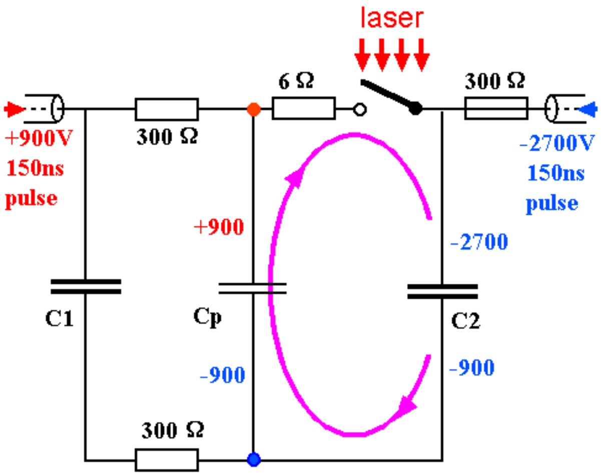


Fig.3 Single photo-switch circuit to 2 plates’ deflection yielding 125femtosec/pix (5.5ps/mm) sweep speed

A complete new design was realised that uses only one single switch to obtain a symmetric HV ramp on both plates (see Fig.3). The two capacitors C1 & C2 (100pF each) are arranged so that the deflection plates (represented by Cp=10pF) are symmetrically pre-charged (+U and –U) by a two HV pulses (amplitudes +U and –3U) of 150ns that are applied by commercial HV Pulsers through two 50Ω coaxial cables.

The trigger pulse for the HV Pulsers comes from the laser timing and is arranged so that the IR laser arrives about 0.5µsec later on the switch. Upon this laser triggering the switch will form a short circuit between Cp, C2 and the 6Ω resistor (the 300Ω resistors de-couple the this fast loop from the surrounding part). Because C2 is a factor 10 bigger in capacity the charge transition between these two will result in an inversion of the polarity on the plates (Cp). This rapid inversion constitutes the HV ramp for the sweep plates, at the voltages indicated it is about 6V/ps, it is mainly determined by inevitable parasitic inductances in the circuitry (notably the intra-tube connections) and not by the series resistor of 6Ω which merely limits the post-sweep HV-ringing in the circuit.

The circuit is positioned very close to the tube and interconnected with a few cm long cables. It offers the advantages of excellent reliability and practical use (only one laser beam to be conditioned and aligned) while using only 2 HV pulsers (and no HV bias supplies). Moreover, their HV amplitude variations do not affect the streak image position on the Phosphor screen (when centred), this is of importance for our system operating in accumulation mode.

6 ANALYSIS & SUPPRESSION OF JITTER CAUSES

The 15KV supply to the photo-cathode has a stability of 50ppm, its contribution to timing jitter in the system is below 100femtosec. For the other static HV the stability is far less critical, and as said above, for the HV Pulsers in the switch circuit a stability of 10^{-3} is sufficient.

Several characteristics of the IR laser pulse were examined to precisely assess their influence on the quality of the optical synchronisation. The laser contrast, the laser amplitude stability, and the laser spot (size and uniformity) on the switch were found to be essential factors.

The 100fs laser pulse is preceded by laser energy that has two different origins : ASE built-up in the regenerative amplifier (CPA), and pre-pulses from leakage through the pockels cell. Although both can be minimised by careful alignment and timing arrangements their level remains prohibitively high since it causes a pre-triggering that is detrimental to both the reliability and jitter-free performance of the switch.

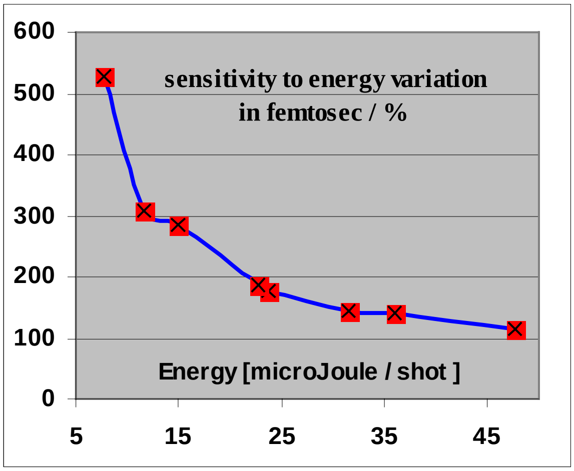
The needed contrast improvement was obtained through a saturable absorber that is formed by a RG850 filter in an adapted optics and cooling arrangement. The purity is now such that the energy in the 2ns preceding the laser pulse is less than 10^{-4} of the energy within the 100fs laser pulse. Any small fluctuations of this pre-pulse energy have only negligible effect on the optical synchronisation.

The effect of the laser amplitude stability was assessed by varying this amplitude in a controlled, independent, and calibrated way and measuring the corresponding time shift of the streak image. It was found that even when applying high energy levels to the photo-switch (>50µJ, i.e. driving the switch well into saturation level) the system would remain sensitive to small variations of the laser energy. This problem was tackled successfully by the optimisation of the GaAs switch geometry and structure, the adaptation of the circuit, and the improvement of the laser amplitude stability.

The latter was achieved by eliminating heat sources on the optical table and the application of beam path covers in the optical cavity, the compressor and the pump laser of the laser system in order to suppress the heat turbulence effects on beam pointing stability.

The single switch circuit as described above has only half the sensitivity to energy variations as the circuit that applies two photo-switches and bias voltages.

Various versions of GaAs switches have been tested to determine the most suitable based on the criteria of reliability, laser energy requirements, and in-sensitivity to laser amplitude variations.



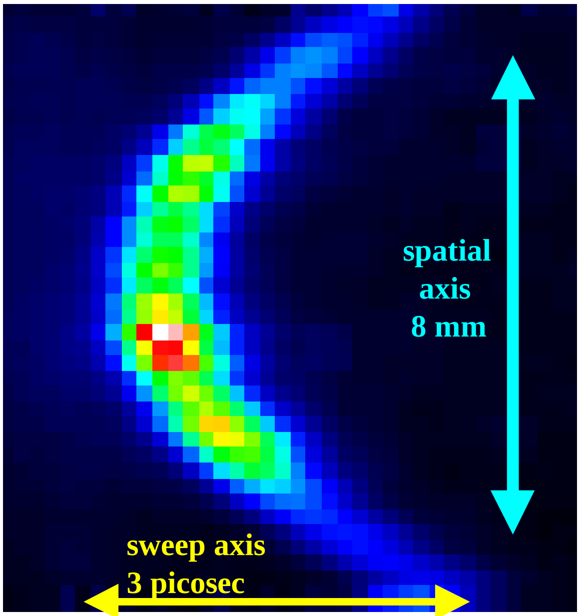
As is shown in the above graph this sensitivity is dependant on the laser energy and is below 150fs per percent energy variation at laser energy above 25µJ.

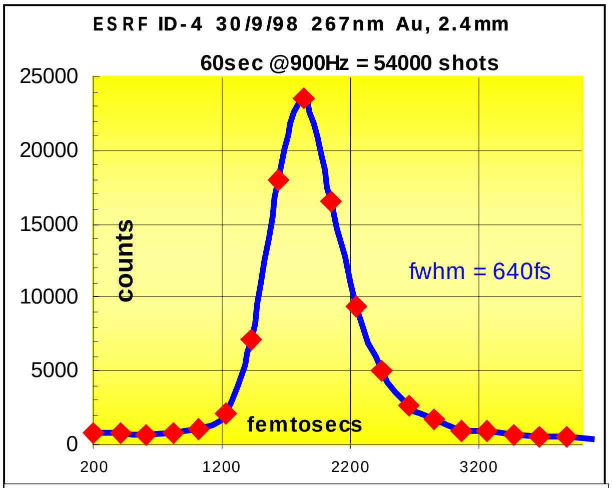
With the laser improvements a short-term stability of 0.25% is now achieved which means that its jitter contribution to the total effective time resolution of the system is below 100fs (fwhm).

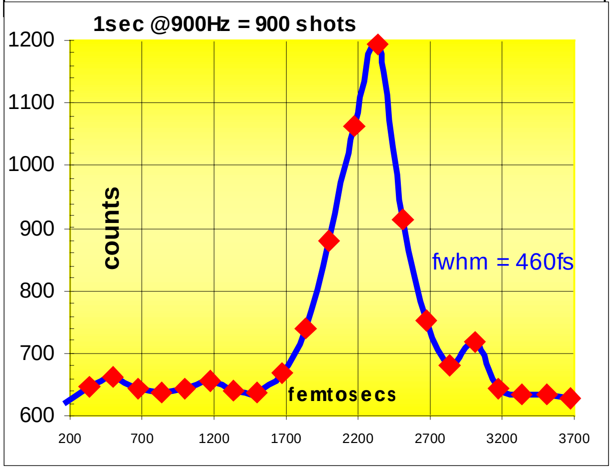
For the correct and reliable operation two separate diffusers make that the projected IR spot on the switch surface covers the full active area and has a high degree of uniformity to avoid local stress.

7 RESULTS

In the picture of the streak image shown here above the time axis is horizontally while the vertically the spatial width of the photo-cathode is represented. The curvature in the image is the explained by the relative time delay of the photo-electrons from the edges of the photo-cathode with respect to those emitted from the centre. Note the high quality of the image and the absence of noise. The time profile in the 2 graphs here above is taken over one single pixel of such a picture.





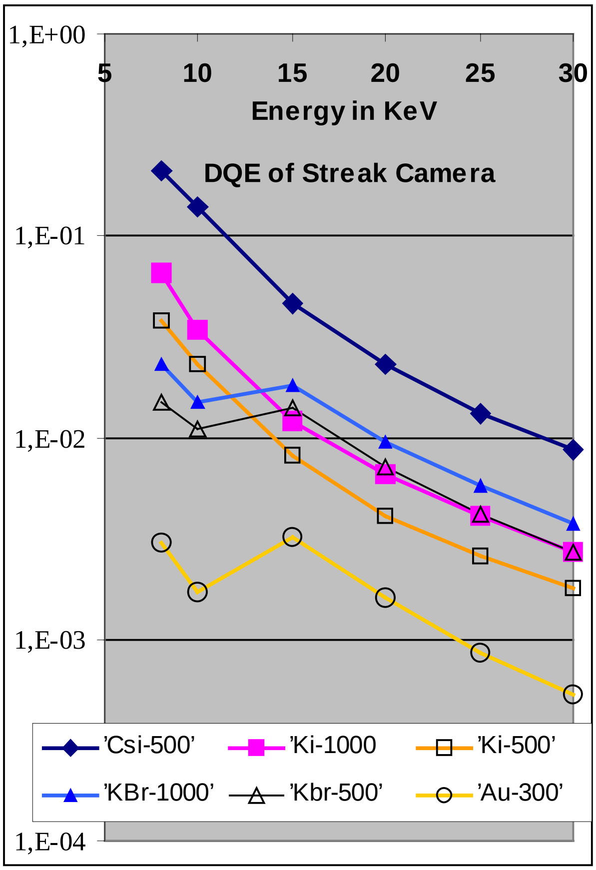


The performance of the system, i.e. the total effective time resolution, is shown for accumulation times of 1second and 1minute (i.e. integrating respectively 900 and 54000 shots). This was with the first version of the streak tube, with UV on Au photo-cathode and a 15KV/2.4mm acceleration field.

With an optical synchronisation of this quality it is the intrinsic time resolution of the streak tube that now dominates the effective time resolution of the system. Identical results were obtained with the new streak tube but no improvements were obtained so far by increasing the acceleration field further or other modifications of the accelerator slit.

8 X-RAY QE MEASUREMENTS

A total of 10 photo-cathodes have been measured for their QE in the system for X-ray energies in the 8-30KeV range. The streak camera is in static mode (not sweeping) and the QE value of the whole system (i.e. photo-cathode, tube, CCD camera) is determined by measuring the total number of counts (on the CCD) and to divide it by the number of photons that hit the active area of the photo-cathode. The latter is determined independently by a calibrated slit, foil pin-diode and picoAmp meter.



The results show a clear decrease of QE with increasing energy. The CsI has by far the highest QE, a factor >3 more than the KI and KBr, materials which are believed to be give better time resolution thanks to smaller energy spread of emitted photo-electrons.

The thickness of 100nm in comparison to 50nm yields a gain of about 40%. However, a decrease of QE during a time period of only a few hours was observed on the KI photo-cathodes together with a change of colour. The long term behaviour of these materials is to be assessed more precisely in another measurement campaign.

9 CONCLUSION , FUTURE TESTS

Our streak camera system has now attained time-resolution of the order of 500fs in accumulation mode thanks to the successful application of the optical synchronisation by means of GaAs photo-switches to a femtosec laser. The system works reliably and the optimum performance can be reproduced for easy routine operation. This was demonstrated for UV light and Gold photo-cathode.

The next test foreseen in July 1999 is to measure this time-resolution for hard X-rays by a so-called surface disordering experiment that produces the ultra-fast modulation in the broad X-ray pulse from the ESRF source.

10 ACKNOWLEDGEMENTS

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We also would like to thank M.Wulff and A.Souvorov for the support in design and carry-out of tests and experiments with X-rays on the ID-9 and D5 beam lines.

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