MEASUREMENT OF TEMPORAL RESOLUTION AND DETECTION EFFICIENCY OF X-RAY STREAK CAMERA BY SINGLE PHOTON IMAGES

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Abstract

In the third generation and the next generation synchrotron radiation light sources, the electron beam bunch length of ps∼sub-ps is expected to be achieved. An X-ray streak camera (X-SC) can directly measure the temporal width of X-ray synchrotron radiation pulse. The temporal resolution of X-SC depends on the initial velocity distribution of the photoelectrons from a photocathode which converts the X-ray photons to the photoelectrons. To measure the temporal resolution of the X-SC, we have observed 'single photon' streak camera images and measured the temporal spread of the images. We have also tried to evaluate the dependence of the temporal resolution and the detection efficiency on the thickness of the photocathode. For this purpose, we have developed a multi-array type CsI photocathode with 3 different thickness of the photocathodes. The experimental setups, and the results of the measurements of the temporal spread and the detection efficiency of the single photon events are presented.

INTRODUCTION

An X-ray streak camera (X-SC) can measure directly X-ray pulses whose lengthes are nano to pico seconds. In case of a single shot observation, the temporal resolution of the X-SC depends on an initial velocity distribution of photoelectrons at an X-ray incident photocathode and a space charge effect of the photoelectrons on the photocathode. A conversion process in which incident photons change to the photoelectrons at the photocathode creates primary electrons whose energy is ∼ keV because of the incident photon energy. On the other hand, secondary electrons which have typically the energy of several ten eV and the energy spread of several eV are also created. Because the secondary electrons contribute formation of the streak images, the initial velocity distribution of the secondary electrons affects the temporal resolution of the X-SC. The temporal spread due to the initial velocity distribution of the secondary electrons can be observed as a temporal spread of the streak image when single photon hits the photocathode. We have observed the temporal spread of the streak images of the single photon events by decreasing intensity of the incident photons up to single photon counting level. By changing the incident photon energy, we have observed the dependence of the temporal resolution of the X-SC on the photon energy. Because the secondary electrons which are created by multiple scattering process of the photoelectrons in the photocathode contribute the formation of the streak image, it is supposed that the detection efficiency and the temporal resolution depend on the thickness of the photocathode. To investigate this, we have developed a multi-array CsI photocathode which can set three different thickness of the photocathodes simultaneously and oserved the dependence of the temporal resolution and the detection efficiency on the thickness of the photocathode.

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EXPERIMENTAL SETUP

Figure 1 shows the block diagram and the timing setup of the single photon experiment. In the experiment, we have used a streak camera system (Hamamatsu, C5680-06) with a synchroscan unit(Hamamatsu, M5675) and dual sweeping unit (Hamamatsu, M5679). The RF signal (508.58MHz) of the SPring-8 storage ring is transferred from the RF station to the beamline station via optical cable, and the optical signal is converted to the electronic signal by O/E module. The timing signal of the synchroscan unit is generated by the frequency divider which generates 7th subharmonics of the RF frequency (72.65MHz). The timing signal is used for the input signal of the delay unit (Hamamatsu, C6878) which can adjust timing delay of the synchroscan unit. The reference signal from the synchroscan unit is used for the reference input of the delay unit.

The timing signal of the dual sweeping unit is generated by the frequency divider and the streak trigger unit (Hamamatsu, C4547). The streak trigger unit generates 9Hz repetition signal synchronized with the RF signal and the signal is used for the trigger of the digital delay pulse generator (Stanford Research Systems, DG535). The pulse generator generates 3 timing signals: (A)exposure trigger for CCD camera, (B)gate signal for image intensifier (I.I.) and (C)trigger signal for the dual sweeping unit. Because the CCD camera has internal delay (11μs) for the external trigger, the CCD trigger signal precedes in 11μs for both the I.I. gate trigger and the sweeping trigger. The fluorescent substance at the end of the streak tube is P43[1] for C5680-06; the 100%→10% decay time of the fluorescence is 1ms. Because of the decay time, it is necessary for identification of each single photon event on the fluorescent screen to provide timing gate shorter than 1ms for the photoelectrons which hit the screen. We have used the dual sweeping unit as a timing gate for the photoelectrons which hit the screen: we have operated the dual sweeping unit whose operation

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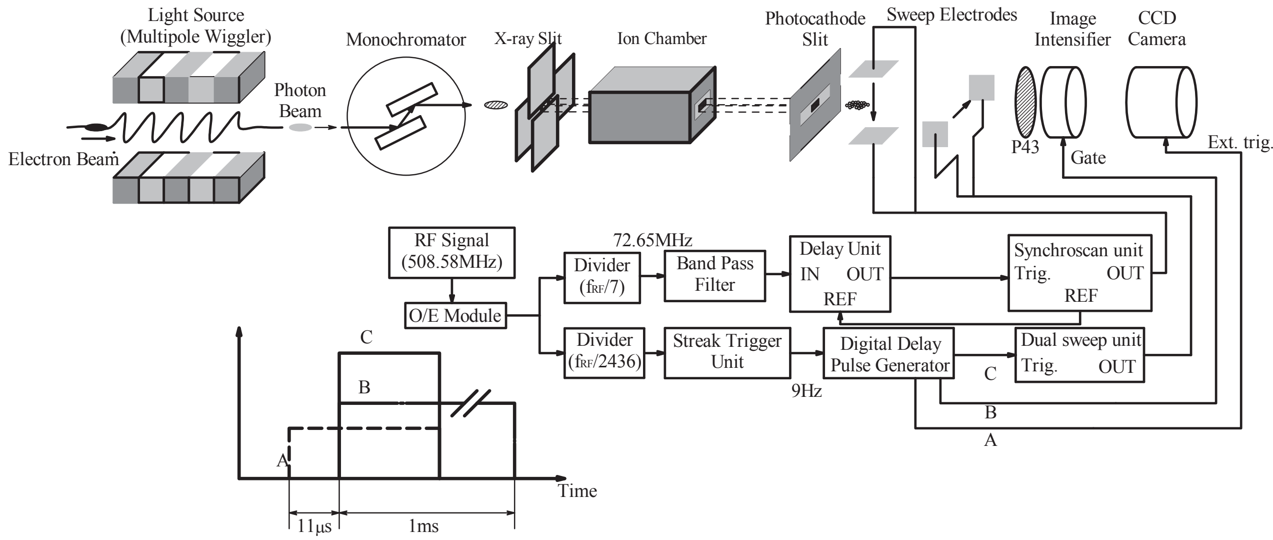

Figure 1: Setup of the experiment.

range is 100μs. To detect the single-photon events clearly, we have operated the I.I. as a gate trigger mode: the gate trigger mode can decrease dark signal from the micro channel plate inside the I.I.. We have settled the I.I. gate width of 1ms to collect the fluorescence from the screen sufficiently. The output window of the I.I. is also made of P43; therefore, we have set the exposure time of CCD camera to be 2ms.

The profile of the usual photocathode in X-SC is 200μm in vertical and 6mm in horizontal. In the experiment we put a 4 jaws X-ray slit made of Ta in front of X-SC. We shaped the spatial profile of X-ray by the slit so that the X-ray beam spot held the photocathode region. To measure the photon flux into the X-SC, between the slit and the X-SC we put an ion chamber which has Kapton sheeted input/output windows and is filled with pure nitrogen gas. We applied DC high voltage (1kV) inside the chamber and monitored ion current by an ultra high resistance meter (ADVANTEST, R8340).

OBSERVATION OF SINGLE PHOTON EVENTS

The experiments have been performed in the beam diagnostic beamline II (BL05SS)[2, 3, 4] in the SPring-8 storage ring. BL05SS has a multipole wiggler as a light source and a double crystal monochromator. We have adjusted the gap of the multipole wiggler and the bragg angle of the monochromator and injected the monochromatic X-ray into the X-SC. To identify individual single photon events, we have adjusted the beamline component to decrease sufficiently the photon flux into the X-SC. A typical streak image of the single photon in dual sweeping and single-shot operation is shown in Fig.2. A dot cluster inside the circle in the figure corresponds to the streak image due to the single photon event. The enlargement and the temporal profile of the dot cluster in the Fig. 2 is shown in Fig. 3. The dot cluster appears frequently when we adjust the beamline component to increase photon flux to the X-SC. We typically have got 10000 shots of the streak image in the same experimental condition, and picked up the single photon events from the series of the streak image data.

In the streak image, not only the real single photon events but also dark events due to the dark current in the micro channel plate inside the I.I. are included. To separate the real and dark events, we have analyzed the intensity of the dots by making an intensity histogram. Figure 4 shows typical example of the intensity histogram when the photon energy is 10keV. Squares correspond to the histogram when the beam is in timing (occupied RF bucket timing) and circles correspond to that when the beam is out of timing (empty RF bucket timing). As seen in the figure, we can distinguish the real photon events and the dark events by applying an intensity threshold. In the analysis, we firstly have picked up all of the dots including not only the photon events but also the dark events, and next, we have made the intensity histogram of the picked dots such as Fig. 4, and define the intensity threshold not to pick up the dark events. After defining the threshold, we have picked up again the dots whose intensity is over the threshold, and have analyzed statistically averaged temporal structure of the single photon events.

Figure 5 shows the statistically averaged temporal profile of the single photon events for 10keV photons. In the analysis, we firstly analyzed the first order moment of the temporal profile for each dot cluster, and to get statistically averaged profile we have superimposed them to make the weighted center of each dot the same timing. We have fitted the temporal profile data with Lorenz distribution whose amplitude is treated as a free parameter and analyzed the FWHM for each X-ray energy data.

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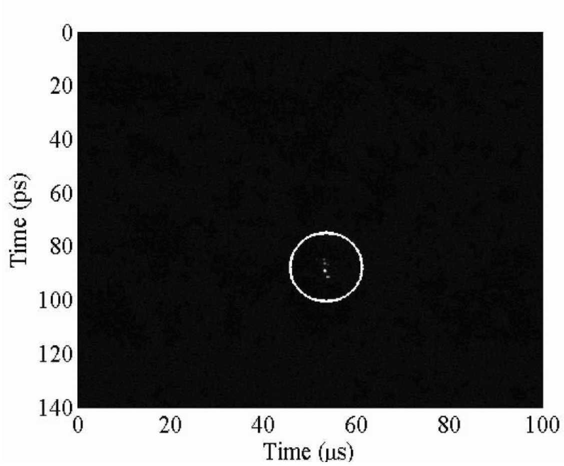

Figure 2: A streak image of the single photon event.

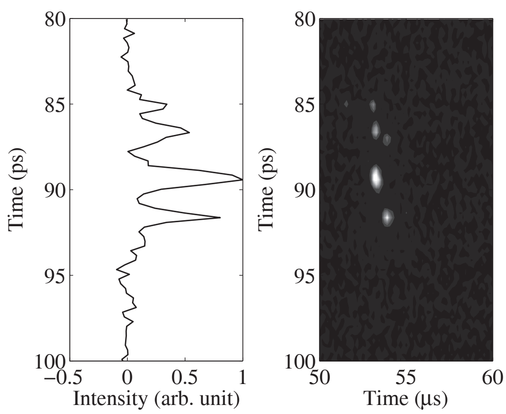

Figure 3: The enlargement and the temporal profile of the dot cluster in Fig. 2.

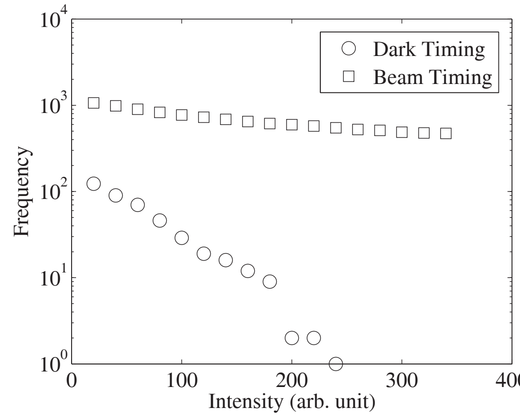

Figure 4: An intensity histogram of dots in the streak image in the single-photon experiment. Squares correspond to the data when the synchroscan timing is adjusted to filled RF bucket (beam timing). Circles corrsponds to the data in the same setup but in empty RF bucket timing (dark timing).

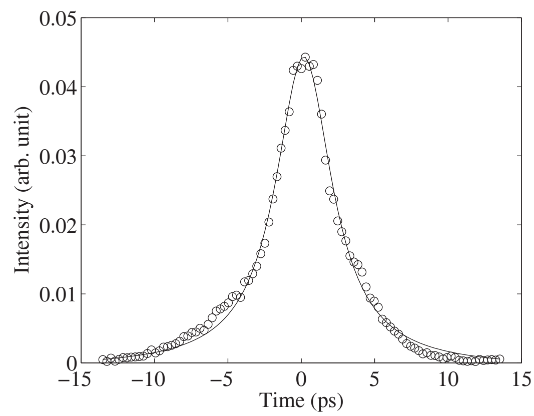

Figure 5: Statistically averaged temporal profile of the single photon(10keV) events. Circles correpond to the experimental result and a curve corresponds to a fitting result.

EXPERIMENTS WITH MULTI-ARRAY PHOTOCATHODE

In the X-SC, secondary electrons created by multiple scattering in the photocathode contribute the formation of the streak image, therefore, it is supposed that the detection efficiency and the temporal resolution depend on the thickness of the photocathode. To investigate this, we have developed a multi-array CsI photocathode which can set three different thickness of photocathodes simultaneously. Figure 6 shows a picture of the multi-array photocathode disk. At the center of the cathode disk, there are 3 different thickness of the CsI membranes. Figure 7 shows a focus image when we set the multi-array CsI photocathode disk. The size of each photocathode is 1.3mm in horizontal and 200μm in vertical. According to Henke et al.[5], the escape length of the CsI is 250nm; so we have prepared 50, 300 and 1000nm thickness of the photocathode membranes.

To remove/mount the photocathode disk in the X-SC, we have also improved a photocathode adapter in the X-SC. Due to the adapter, we can easily remove/mount the photocathode disk.

In the experiment, we have adjusted the X-ray slit so that the X-ray beam spot held a proper photocathode and observed the single photon spread in various photon energies. Figure 8 summarizes the temporal spread of the single photon events for 5.3∼30keV region for 3 different photocathode thicknesses. As seen in the figure, the single photon spread distributes around 4∼5 ps (FWHM) and the energy dependence of the spread cannot be seen clearly in this experiment. The dependence of the photon spread on the photocathode thickness cannot be seen clearly, either.

Figure 9 summarizes yields of the single photon events in different thicknesses of the photocathode. As seen in the figure, the yield has clear dependence on the photon energy: in the energy region of 5.3 to 5.8keV, the yields increase rapidly and beyond the peak the yields decrease slowly. Such energy dependence is caused by the absorption edge energy of the photocathode material; Cs and I. Figure 10 shows the numerical calculation[6] of dependence of the X-ray transmission on the photon energy for

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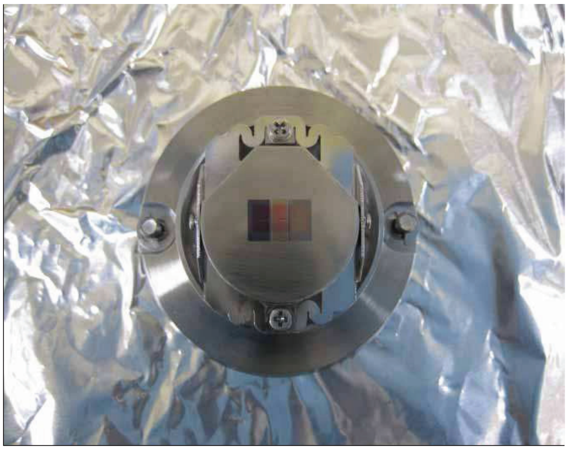

Figure 6: A picture of the multi-array photocathode disk. At the center of the cathode disk, there are 3 different thickness of CsI photocathode membrane: from left to right, 50, 300 and 1000nm.

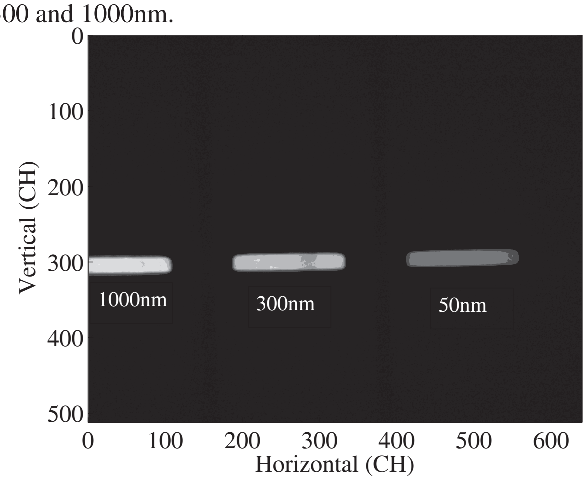

Figure 7: A focus image of the multi-array CsI photocathode.

CsI membrane whose thickness is 300nm. As seen in the figure, the transmission has a valley around 5keV: Cs and I have L-edge absorption energy in the region 4.5∼6keV[7]. In the absorption energy region, the quantum efficiency is larger; that introduces the increase in the yields in the energy region.

As seen in the Fig. 9, the yield becomes better when the thickness of the photocathode is larger in this experiment. As seen in Fig. 8, the temporal resolution have little dependence on the thickness; therefore, 1000nm thickness is better in this experimental condition. It is supposed that there is an optimum thickness to realize better yield and temporal resolution.

SUMMARY

In this article, We have tried to measure temporal resolution of the X-ray streak camera by observing temporal spread of the single photon events. Because the single photon event has the shortest duration in principle, it is possible

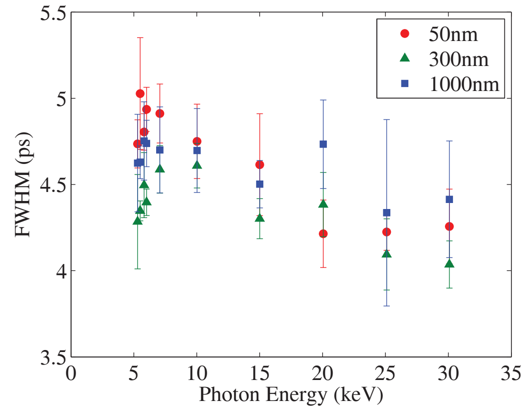

Figure 8: Temporal spread of the single photon events for 3 different thickness of photocathode.

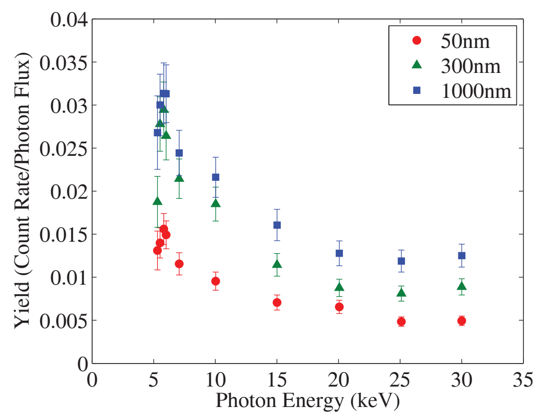

Figure 9: Yield of the single photon events for 3 different thickness of photocathode.

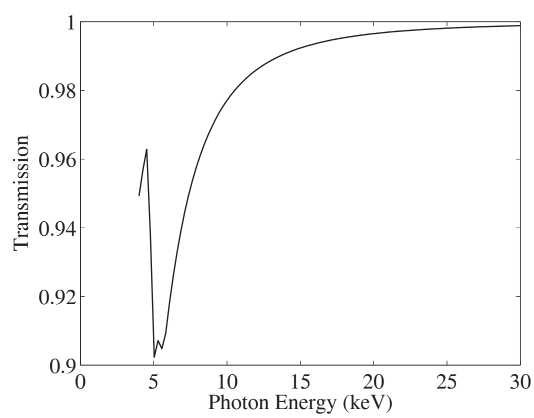

Figure 10: The dependence of the transmission on the photon energy for CsI 300nm membrane[6].

to measure precisely the temporal resolution of the streak camera. Because the measurement has been performed with the single shot observation mode, we can measure the temporal resolution without timing jitter. The single photon also has the smallest intensity, so the space charge effect on the photocathode can be minimized.

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We have measured the dependence of the temporal resolution on the photon energy and the thickness of the photocathode. To investigate this, we have developed the multi-array photocathode disk which can mount different 3 thickness of the photocathode membranes simultaneously. In our experiment, we have concluded that the temporal resolution of our streak camera system is 4∼5ps (FWHM). The resolution doesn't have clear dependence on the photon energy and the thickness of the photocathode. The yield, on the other hand, has clear energy dependence because of the absorption edge energy of the photocathode materials. In this experiment, the photocathode of 1000nm thickness has better yield than other thinner ones. It is supposed that there is an optimum thickness to realize better yield and temporal resolution. Investigation for better condition of the photocathode is a future plan.

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