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Subpicosecond X-ray Streak Camera

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ABSTRACT

We have designed and built an x-ray streak camera with subpicosecond time resolution. This camera attains its fast temporal resolution through a very strong extraction field, 100,000 V/cm, at the photocathode. It incorporates a narrow electron emission band photocathode that will also help the time resolution. The total time resolution has been calculated to be near 600 fs.

1. INTRODUCTION

With the advent of femtosecond lasers that produce millijoule type energy levels it has become possible to produce ultra-short x-ray emitting plasmas. In order to get a time histogram of these plasmas we need a camera that can resolve time scales shorter than a picosecond. Falcone et al. has succeeded in producing an x-ray streak camera with better than 2-ps resolution by reducing the extraction gap on a Kentech x-ray streak camera.[1] This increased the extraction field to near 35,000 V/cm. We are now working with the same principle to increase the extraction field to 100,000 V/cm. By using this high extraction field along with a narrow electron emission band photocathode we should be able to obtain better than 600-fs time resolution.

2. DESIGN AND TESTING

In order to optimize the time resolution of a streak tube we must look at the sources of dispersion in the streak camera that can degrade the temporal response. These sources of dispersion include some that we can control easily, such as transit time dispersion, others we cannot, such as static resolution and path length differences in the focusing region. The total time response of the streak camera can be related to most of these factors in quadrature in the following equation:

$$\Delta t = (\Delta t_{dc}^2 + (\Delta t_{pc} + \Delta t_{cf})^2 + \Delta t_{fo}^2 + \Delta t_{sc}^2)^{1/2} \quad (1)$$

where

$\Delta t_{dc} = \Delta x / v$, Δx is the dc resolution and v is the sweep speed, Δt_{cf} and Δt_{fo} are the time spread in the central field region and that due to flight path differences in the focusing region respectively.

$$\Delta t_{pc} = 3.37\text{e-}8 \; ((\Delta e)^{1/2} / E) \quad (2)$$

Δe is the energy spread of the photoelectrons, E is the extraction electric field strength. Δt_{sc} is that contribution to the total time response due to space charge effects.

Using a 100-µm slit on the front of the photocathode and a tube magnification of 1.2 we should be able to get DX = 120 µm. This coupled with an expected sweep speed of 4 ps/mm we expect to obtain Δt_{dc} = 480 fs. We are using a potassium iodide (KI) photocathode to obtain the minimum possible electron energy emission spread for x-ray photocathodes of 0.61 eV.[2] Using equation (2) above with an accelerating field of E – 100,000 v/cm we obtain an electron time spread of Δt_{pc} = 263 fs in the accelerating region. It was necessary to utilize a computer model to calculate both Δt_{cf} and Δt_{fo}. Assuming a potassium iodide photocathode we computed 30 fs and 65 fs respectively.

Space charge effects for this streak tube have not been calculated. If we operate this streak tube in the near single photon counting mode the space charge effects should be negligible. Using the values computed above and equation (1) we obtain a total tube time response of 566 fs.

3. EXPERIMENTAL WORK

The streak tube described above has been built as shown in figure 1 and is in the process of being tested in the lab. We have tested the tube on a 20-ps source in the unswept mode for focusing characteristics and voltage standoff capability. With an electric field of 100,000 V/cm at the photocathode and using a 100-μm entrance slit on the photocathode we get a best static resolution in the swept direction of 200 μm.

We currently have parallel plate deflection structures in the streak tube which have a 10 to 90 percent rise time of 700 ps as shown in the TDR trace in figure 2. The electrons are between the deflection plates much longer than the rise time of the deflection ramp. This has shown to be a very inefficient way of sweeping the electron beam. We have a pulse generator that can deliver more than ±3 kV in less than 100 ps with very low jitter (<10 ps). For our initial testing on a 100-fs source we will use this planar triode pulse generator or a high voltage silicon Austin switch. We are also looking into the possibility of using a meandering line traveling wave deflector. This should reduce the necessary sweep voltage by more than an order of magnitude.

4. FUTURE WORK

We plan on testing the time resolution of the streak camera system on a 100-fs laser source shortly. We will use a setup similar to that shown in figure 3. The two ultraviolet pulses will be used as timing fiducials and will be spaced about 10–20 ps apart in time. The laser entering the target chamber will be focused down upon a target to create a short-lived x-ray emitting plasma. The x-rays will be timed such that they arrive at the streak camera's photocathode in between the two ultraviolet pulses. We can measure the ultraviolet time response directly since that pulse width will be well known. Since the ultraviolet and x-ray electron distribution from the photocathode are not the same the x-ray time response will not be the same as the ultraviolet. The x-ray pulse width has never been measured temporally on this time scale so it cannot be assumed to be an impulse response to the system. The x-ray response should not be much worse than the ultraviolet excitation.

5. CONCLUSIONS

We have tested the streak camera on the 20-ps source in both the swept and unswept modes. We did not find any spurious electron emissions from the high electric fields at the photocathode as was postulated by some. We believe that we will achieve better than 600-fs time response when we test the camera on the 100-fs source early this fall.

6. ACKNOWLEDGMENTS

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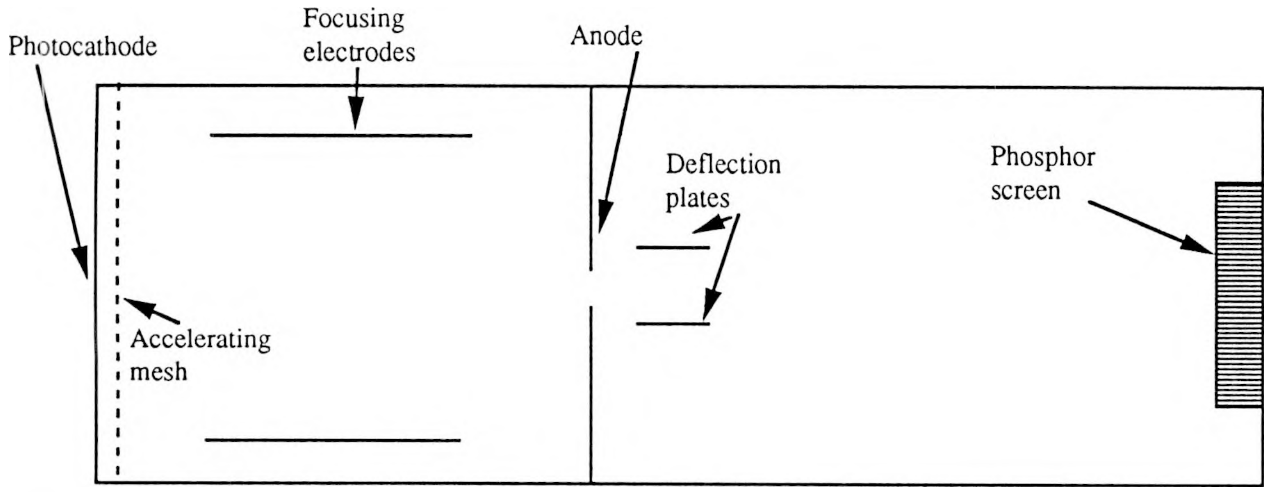

Figure 1. Schematic of the streak tube that has been built. The electric field strength between the photocathode and the accelerating mesh is 100,000 v/cm

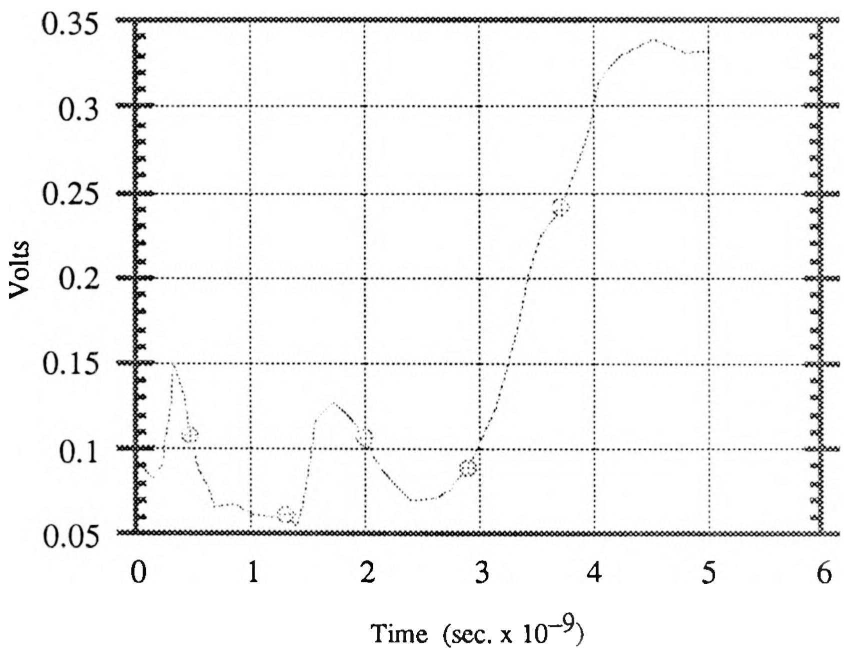

Figure 2. TDR trace of the deflection plates shows a slow 700 ps, 10 - 90% rise time.

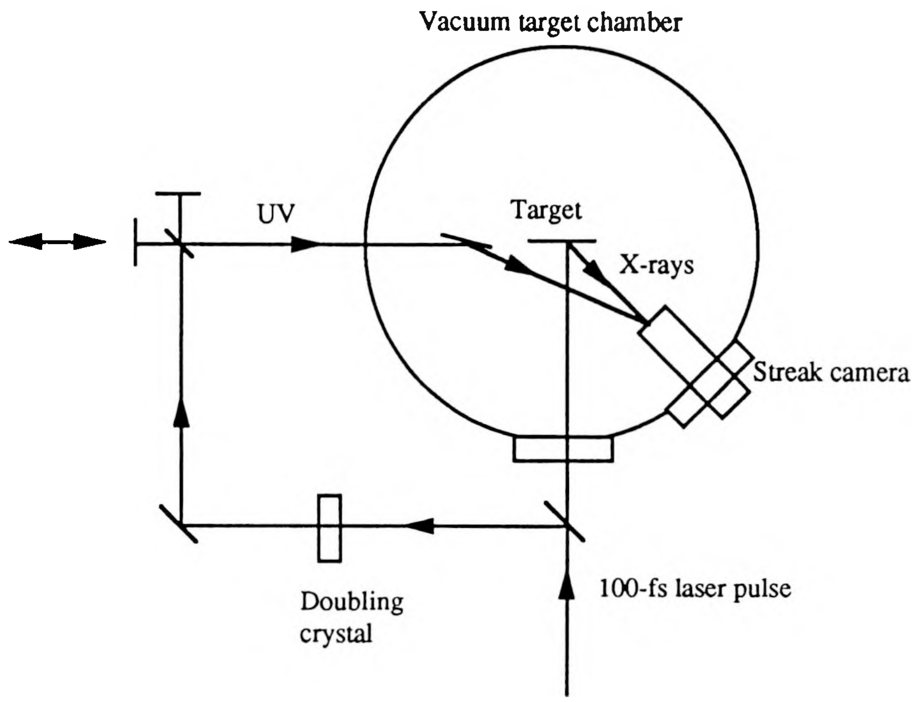

Figure 3. Experimental setup to determine the UV and x-ray time response of the streak camera.