Picosecond X-ray framing camera using gated MCP

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ABSTRACT

Multiframe images at a meander shape microstripline were gated sequentially by a single high voltage pulse. The meander microstripline was made by a fine mesh contacting the input surface of the MCP and the coated rear face of the MCP to reduce the ohmic losses. The dynamic gain characteristics of the MCP gated by picosecond pulse were simulated by Monte-Carlo method taking into account the effect of electron transit time dispersion. The measured spatial resolution of the framing camera is 20 lp/mm and exposure time is ~100 ps.

Keywords: framing camera, picosecond, ultrashort high voltage pulse, MCP

1. INTRODUCTION

Picosecond framing camera is one of the key diagnostic tools for laser produced plasma physics study because of its high temporal resolution and two dimensions spatial resolving ability. Such camera can be implemented by several different technical approaches. We have proposed an 'optical framing /electron shutting' method and obtained four framed imaged with 250 ps exposure time for each image(1,2). The technology of gating MCP in image intensifier with picosecond high voltage pulse for ultrahigh speed photography (3,4,5)has been developed in our group since 1987(6). The voltage pulse was generated by using GaAs photoswitch at that time and fed to a meander microstripline coated on the MCP to gate the imager. Although some preliminary results had been obtained with this scheme, the difficulty of controlling the voltage pulse shape makes it inconvenient for practical usage. In this paper, camera using avalanche diode to generate the gating pulse is described. To understand the MCP gating process deeply, Monte-Carlo simulation was done to investigate the dynamic gain characteristics of MCP, taken into account the effects of the electron transit time dispersion. Lot of effort has been made to reduce the ohmic losses of the 200 mm long microstripline on the MCP.

1. THEORETIC STUDY OF MCP GATED BY PICOSECOND PULSE

The configuration of the framing camera is shown in Fig. 1. It consists of a pinhole-array camera, a special proximity focused imager, an ultrashort high voltage pulse generator and the image record media(contacting film or CCD camera). When the framing camera is used to diagnose laser produced plasma, its pinhole-array produces many X-ray images of the plasma at the conducting strip of the microstripline laid on the MCP of the imager, these X-ray images are converted to electron images, then gated and intensified by the MCP one by one when the microstipline is fed with a very short high voltage pulse. The gated electron images are converted to optical images by the phosphor screen and then recorded by film.

The key specification of the framing camera is the exposure time of each images, which is mainly determined by the MCP and the voltage pulse. The exposure time is defined as the FWHM of MCP gain vs. time curve. It is obvious that the exposure time can be reduced by decrease the width of the electric pulse, but the peak gains also decrease due to the electron tranist time effects. It must be pointed out the peak gain is very important to get images with high extinction ratio, it must be high enough for the gated signal to overtake the background produced by the X-ray penetrating the MCP. High gain is also necessary for the film to get enough exposure.

The dynamic gain characteristics of MCP gated by picosecond pulse is very complicated because of the statistic feature of the electron multiplication process, which can hardly be studied quantitatively by analytic method. Three

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dimensional Monte-Carlo simulation was done here(7) which taking into the effects of electron transit time and its dispersion.

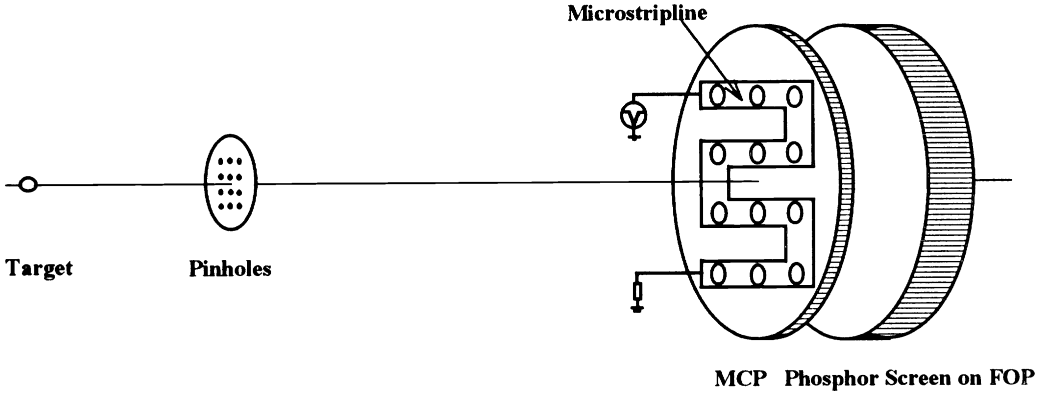


Fig.1 Schematic diagram of MCP gated picosecond framing camera

The simulation is for MCP with thickness (L) of 0.5 mm and microchannel diameter (D) of 12 mm, which assumes:

(a) that the secondary emission yield δ is related to the primary electron energy V_i and the incident angle θ, which can be described by modifying the expression given by (8), that is:

$\delta(V_i, \theta)=\delta_m(\theta)(\nu e^{1-\nu})^k$ (1)

where

$\delta_m(\theta)=\delta_m(0)(1+K_s\theta)$ (3)

and

$\nu=(V_i-V_o)/(V_m(\theta)-V_o)$ (4)

is the normalized energy, in which

$V_m(\theta)=V_m(\theta)(1+K_s\theta)$ (5)

$k=0.62$ for $\nu<1$ and $k=0.25$ for $\nu>1$.

The parameters in equation (1)~(5) take the following values: $\delta_m(0)=3$, $K_s=2.4\pi$, $V_o=3.4$ eV, $V_m(0)=245$ eV.

(b) that the secondary electron initial energy obeys Maxwellian distribution and the most probable energy is 1.4eV.

(c) that the secondary electron emitting angle obeys the Lambert distribution.

The simulation shows:

(a) The effects of transit time and its dispersion on the exposure time. The dynamic gain of MCP applied with a rectangular pulse is shown in Fig. 2. The amplitude of the pulse is 800 volts and the pulse width is 200 picosecond. Clearly the exposure time is much shorter that the electric pulse due to the transit time of the electron in the channel. The transit time dispersion influences the falling edge of the gain curve and enlarges the exposure time.

(b) The effects of electric pulse shape. The gain curves were calculated for rectangular, Gaussian and triangle pulses of 800 volts applied on MCP, which resulted in the exposure time of 35, 75 and 70 picosecond respectively. The corresponding peak gain is 1986, 400 and 160 respectively. This implies that rectangular pulse should be used to get short exposure time and high peak gain.

(c) The effects of electric pulse width. The exposure time and peak gain for triangle pulse of same amplitude (800 volts) but different width is shown in Fig. 3. It can be seen that that the exposure time does not decrease with the pulse width linearly. The drops of peak gain for very short gating pulse must be keep in mind for the camera design.

(d) The effects of MCP thickness (L) and applied voltage (V_{mcp}) on the electron transit time. The simulation shows that the most probable transit time $T \propto L^{1.54}/V_{mcp}^{1/1.29}$, which is different from the analytic result(9), that is, $T \propto L/V_{mcp}^{1/2}$.

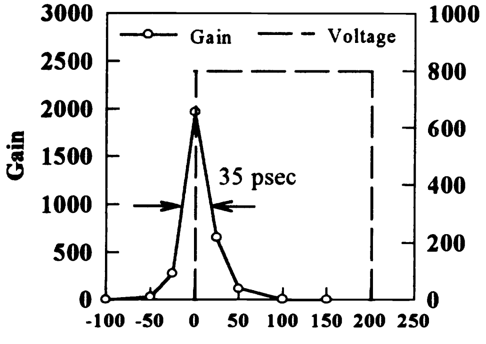


Fig. 2 The gain vs. time curve simulated by Monte-Carlo method

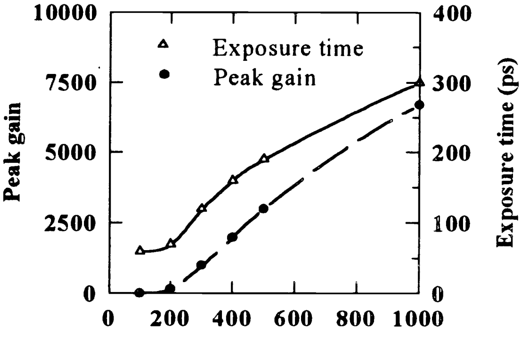


Fig. 3 The gain and exposure time simulated by taking into account the transit time dispersion

The details of the simulation work and some other results can be found in (7).

3. EXPERIMENTAL RESULTS

3.1 MCP imager and electric pulse generator

It is shown in the above simulation that in order to get exposure time less than 100 picosecond the electric pulse should be shorter than 300 picoseconds. To meet this demand the response time of the microstripline on MCP must be better than 300 picoseconds. The resistance of the micrstripline should be as small as possible to minimize pulse amplitude drop along the line. In our imager, the meander shape infinity-ground microstripline was made by a mesh strip contacting the input surface of the MCP and the conducting metal layer on rear face. The resistance of the overall microstripline include the input and output impedances transformer is 0.7Ω. The response time of the transmission line was obtained by feeding in a very short pulse (50 ps) and measured the broadened output pulse that was 115 ps as shown in Fig. 4.

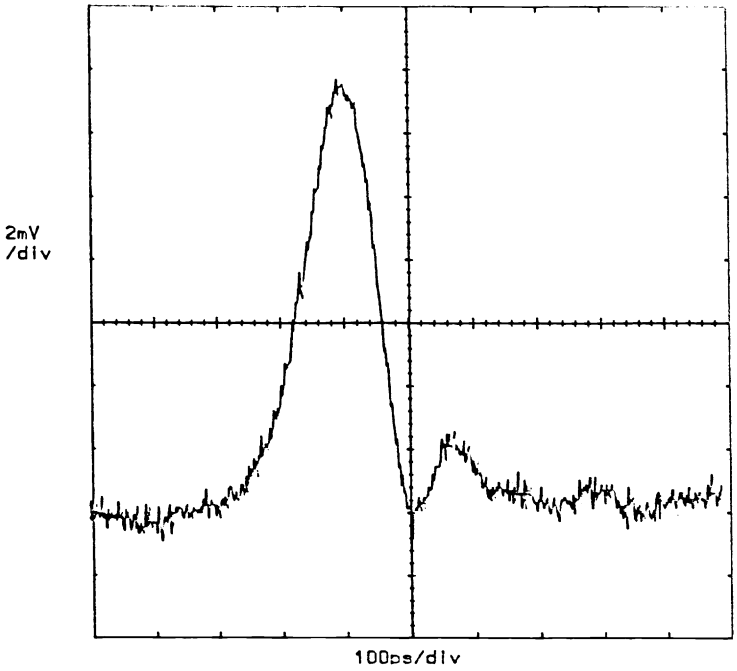
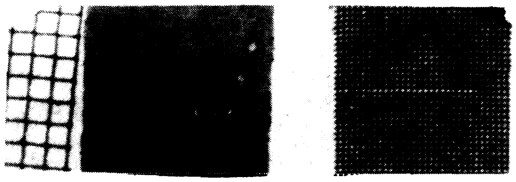


Fig. 4 The temporal responce of of the transmmision line

To extend the temporal range from the first to the last images, a large MCP (ϕ56mm) was used. The thickness of the MCP is 0.5mm and the microchannel diameter is 12.5 μm. The fiber-optic faceplate is coated with P20 phosphor screen. The image is recorded in a film contacting the faceplate. The static spatial resolution of the camera is 20 lp/mm (Fig. 5) when the phosphor screen is applied with 3 KV voltage. The MTF of the image was calculated as shown in Fig. 6.

The picosecond high voltage pulse, Fig. 7, is generated by an avalanche diode circuit that is driven by a high voltage step pulse. The output impedance of the pulse generator is 50 Ω, but the impedance of the microstripline is ~12 Ω, to minimize the signal reflection a taper transformer was used between them.



5 lp/mm 20 lp/mm 10 lp/mm

Fig. 5 Spatial resolution photography

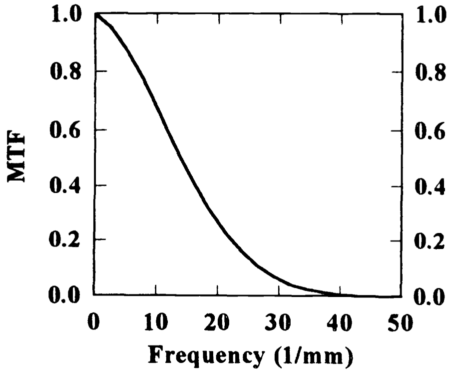


Fig. 6 Calculated MTF of the MCP imager

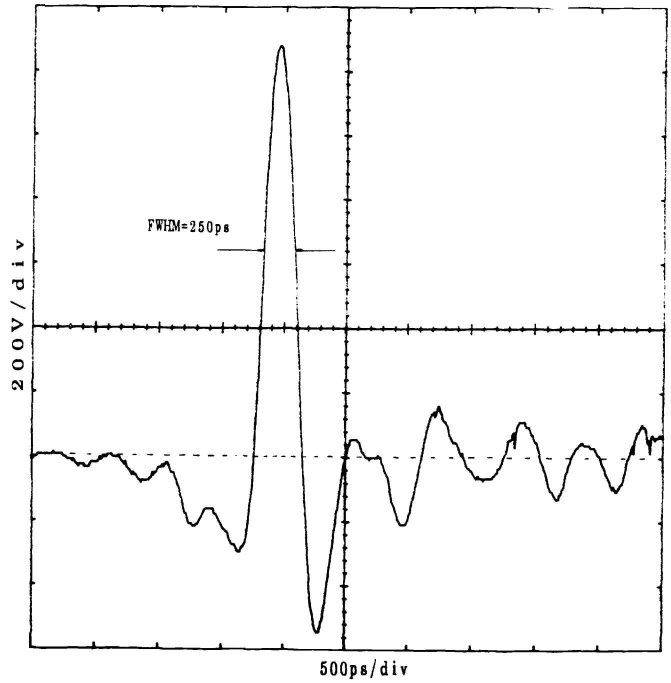


Fig. 7 The electric pulse for gating MCP

3.2 Exposure time measurement

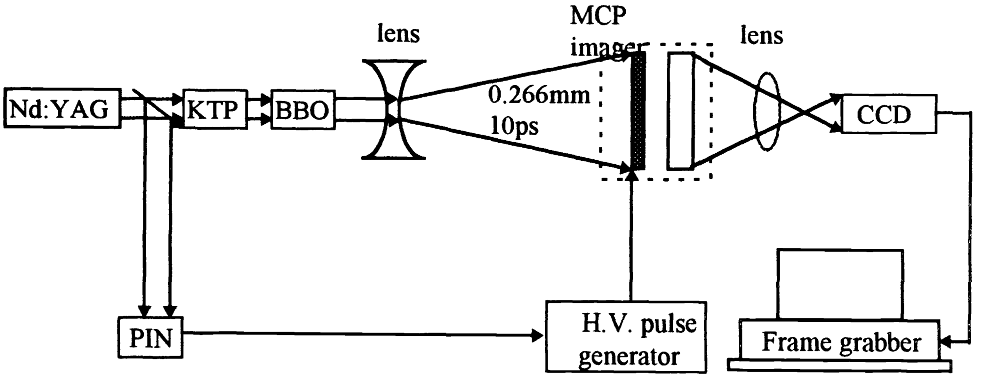


Fig. 8 Exposure time measurement system

The measurement system layout is schematically shown in Fig. 8. The laser pulse produced by a CPM Nd:YAG laser was amplified and frequency quadrupled. The uv pulse that is ~10 picosecond was spatially expanded and irradiated on the MCP. The output of image was taken by a CCD camera frame grabber. First, the MCP was applied with DC voltage, all microstripline covered range produced output. Then the imager was gated by an electric pulse, in this case, only part of the range that had voltage at the time of laser pulse arriving had light output. The gain versus time curve can be obtained from the light intensity distribution along the signal traveling direction on the microstripline, provided that the propagation velocity is known. The propagation velocity is 0.153 mm/ps, which was measured by time domain reflection method. To eliminate the effect of the nonuniformity of the laser light, the gated image was normalized by the image in DC mode. Fig. 9 is the gain curve obtained by this measurement, which gives 120 picoseconds exposure time. The best results we have got is 100 picoseconds.

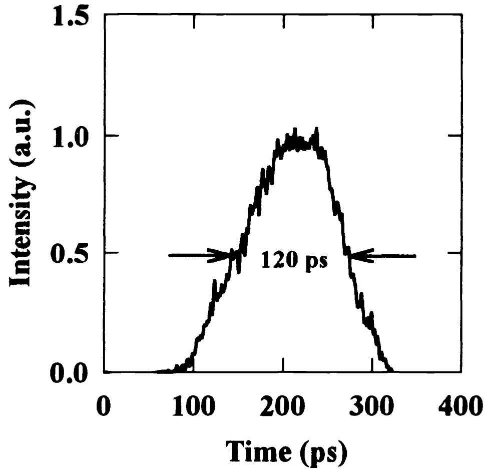


Fig. 9 Measured exposure time of the framing camera

3.3 Application

The camera has been used in "SHENG GUANG-12#" high power laser system to take pictures of the laser produces plasma. The magnification of the pinholes camera is 10 and the diameter of the pinholes is ~10 μm. Up to 12 frames image can be taken for each shot, which is limited the pinhole numbers and the image size. Fig. 10 is one of the photograph that vividly shows the evolution of plasma at the laser entrance hole of a hollow target, while the laser energy injected to this entrance hole is ~1kJ. Some of the images were not entirely shown due to the alignment error of the pinhole-array. The experiments revealed that the camera has high sensitivity, large dynamic range and good stability.

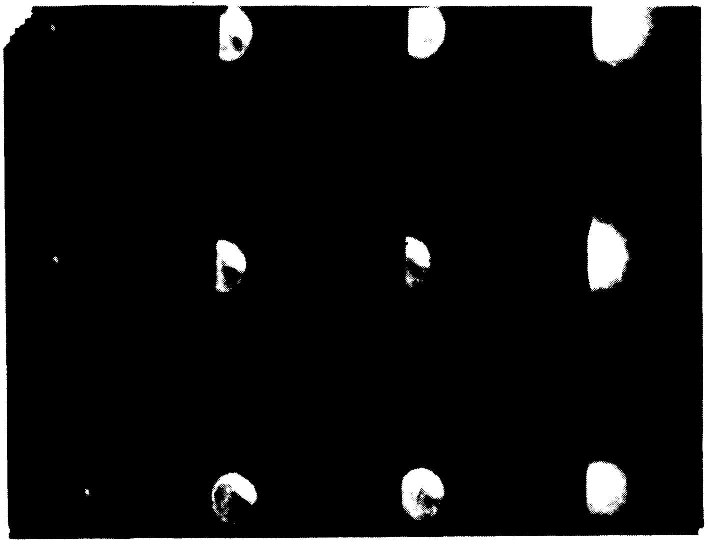


Fig. 10 Framing photograph of the laser produced plasma

4. CONCLUSION

The dynamic gain characteristics of MCP gated by electric pulse whose duration is comparable with the transit time were simulated by Monte-Carlo method, so that the effects of transit time and its dispersion were taken into account. The effect of pulse shape was also been investigated.

The ohmic losses of the meander shape microstripline on MCP and the reflection losses between the pulse generator and the MCP were reduced, which resulted in a MCP imager with very fast response time. Such imager was gated by electric pulse generated by avalanche diode and the exposure time reached 100 picosecond.

5. ACKNOWLEDGMENT

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6. REFERENCES

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