Gated MCP framing camera with 60 ps exposure time

Chang Zenghu, Shan Bing, Liu Xiuqin, Liu Jinyuan,
Zhu Wunhua, Yang Hongru, Ren Youlai, Gong Meixia

State Key Laboratory of Transient Optics Technology,
Xi'an Institute of Optics and Precision Mechanics, Academia Sinica
Xi'an, Shaanxi, 710068, P. R. China

ABSTRACT

High voltage pulse of 140 ps in width and 2.7 kV was generated to gate the multiframe images on a meander shape microstripline on MCP. The measurement time range was extented to 1.1 ns while the exposure time of each image is 60 ps. The measured spatial resolution of the framing camera is 25 lp/mm. New method to reduce the exposure time down to 10 ps was simulated numerically.

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

1. INTRODUCTION

Picosecond framing camera[1,2] 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. The technology of gating MCP in image intensifier with picosecond high voltage pulse for ultrahigh speed photography.[3,4,5,6,7,8]has been developed worldwide during the last ten years. In this paper, we report the latest results of the MCP gated camera develoment in our group. To understand the MCP gating process deeply, numeric simulation was done to investigate the dynamic gain characteristics of MCP. It was shown by the simulation that if two microchannel plates are used in chevron configrution and are gated seperately, the exposure time can be reduced considerably compare to that of one MCP.

1. CONSTRUCTION OF THE CAMERA

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 microstripline 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 versus 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 transit 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. In the next section, camera based on gating one MCP is described. The exposure time of such camera is limited by the transit time of the electrons in the MCP, provided that the electric pulse can be generated short enough.

The dynamic gain characteristics of MCP gated by picosecond pulse is very complicated, which can hardly be studied quantitatively by analytic method. Numeric simulation results will be given in section 3. New method to reducing the exposure time was described also in that section.

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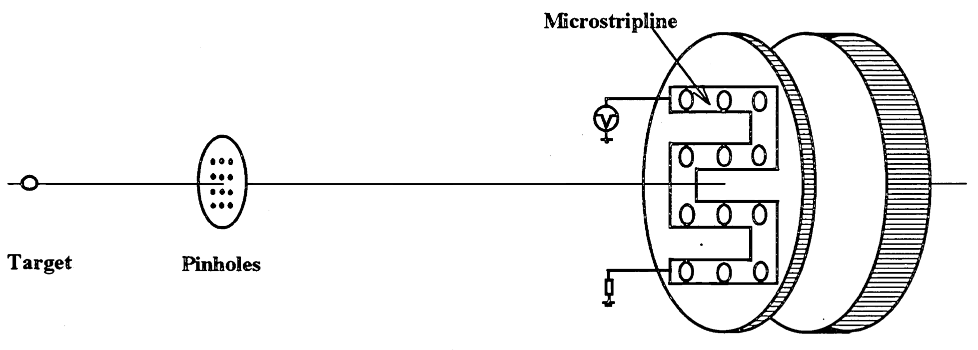


Fig.1 Schematic diagram of MCP gated picosecond framing camera

2. TECHNICAL IMPROVEMENTS

2.1 MCP imager

For most of the laser fusion researches, the laser pulses used are about 1 ns. It requires that the measurement time range of the framing camera is also about this value. To meet this demand a large MCP (ϕ56mm) was used in our camera. A 200 mm long microstrip line was fabricated on the MCP, making the time range 1.1ns. For such a long microstrip line, it is very important to reduce the ohmic losses. The resistance of the microstripline should be as small as possible to minimize pulse amplitude drop along the line. The resistance of the overall microstripline include the input and output impedance transformer is 0.7Ω. From the time domain reflectance results shown in Fig. 2, it is obvious that the change of impedance along the microstrip line is not significant. The output impedance of the pulse generator is 50 Ω , but the impedance of the microstripline that is 6mm in width is ~12 Ω, to minimize the signal reflection an exponential transformer was used between them, which can also be seen in Fig.2.

The thickness of the MCP is 0.5 mm and the microchannel diameter is 12.5 μm. The fiber-optic faceplate is coated with P20 phosphor screen. The static spatial resolution of the camera is 25 lp/mm (group N0. 25 of the testing chart in Fig. 3) when the phosphor screen is applied with 3 KV voltage.

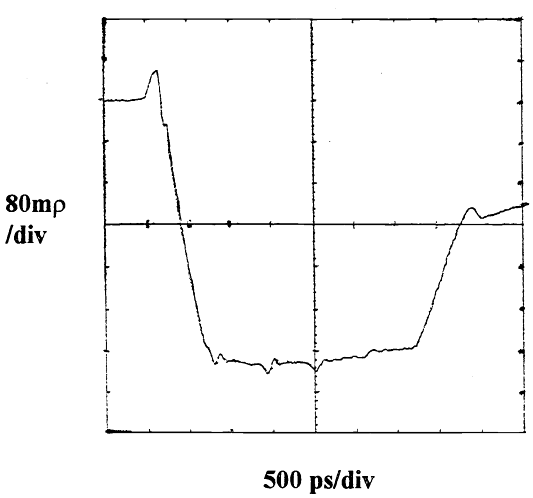


Fig. 2 The time domain reflectance of the imager

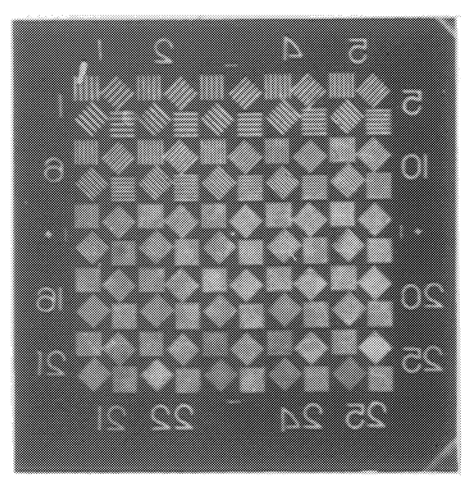
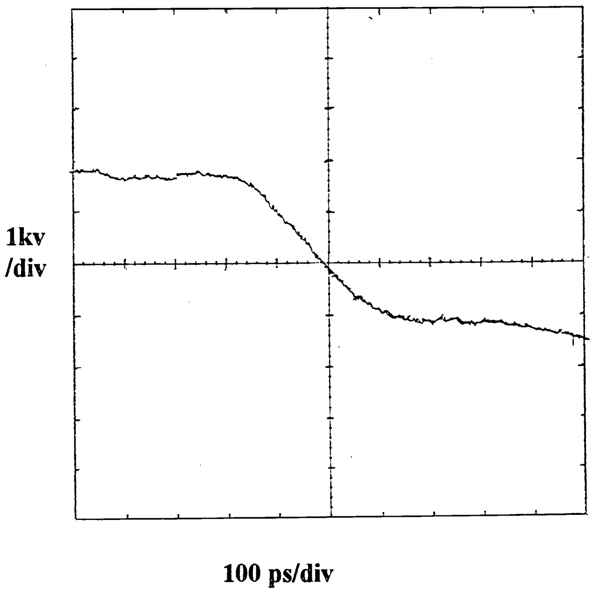


Fig. 3 Spatial resolution photograph

2.2 The electric pulse generator

The high voltage pulse used to gate the MCP was generated by a three stage circuit. By using avalanche transistors, the first stage produced a fast rise step pulse with 220 ps rise time [9]. The output of this stage is shown in Fig. 4. The amplitude of the step pulse is increased in the second stage by an avalanche diode while the fast rise time was preserved. The step pulse was transformed to a short pulse with 140 ps FWHM and 2.7 kv amplitude on the 50Ω load in the third stage by avalanche diodes[10]. The final output is shown in Fig. 5. Comparing with the two stage circuit that consists of the first and last stage of the above circuit, the insertion of second stage reduced the numbers of avalanche transistors in the first stage significantly, thus improved the reliability of the circuit. The jitter of the circuit is ±50 ps.



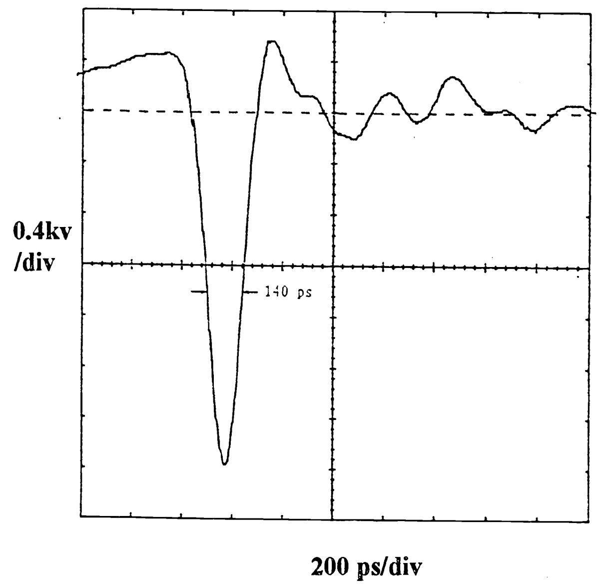


Fig. 4 Step pulse generated by avalanche transistors

Fig. 5 The electric pulse for gating MCP

2.3 Exposure time

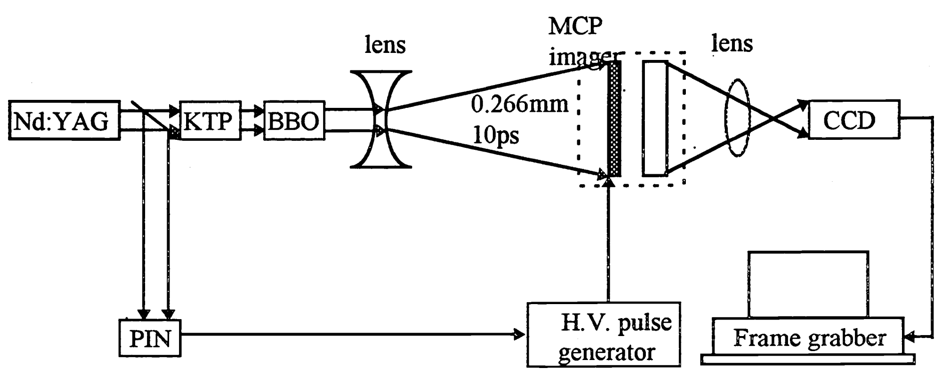


Fig. 6 Exposure time measurement system

The measurement system layout is schematically shown in Fig. 6. 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 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 0.18 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. 7 is the gain curve obtained by this measurement, which gives 58 picoseconds exposure time. In this measurement, the gate pulse used is 210 ps while the MCP was biased with 150 volts DC reverse voltage.

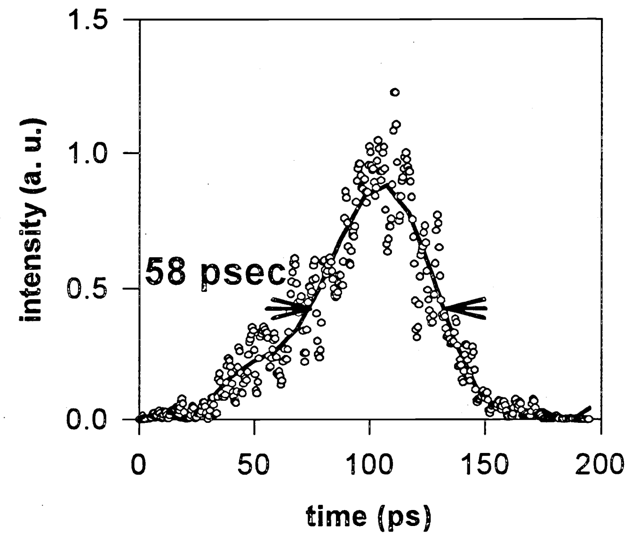


Fig. 7 The measured exposure time of the camera

3. MODELING RESULTS

For the camera described above, the exposure time can be reduced in principle by using shorter electric pulse to gate the MCP, but the gain of the camera will decrease drastically when the width of the electric pulse is less than the transit time of the electron in the MCP which is ~250 picoseconds for a 0.5 mm MCP. Although gating thin MCP (0.2 mm in thickness) that has shorter electron transit time can reduce the exposure time to 35 picosecond[10], such cameras exhibit low signal to noise ratio because of the background produced by the hard X-ray directly passing through the gated MCP[11].

Gating two MCPs in cascade was proposed to improve the performance of framing camera[12,13]. In the imager the two MCPs are gated by the high voltages pulses respectively through the micro-strip lines lay on the them, as shown in Fig. 8. It was shown analytically that the gain narrowing effects of the two MCPs is stronger than that of one MCP and the exposure time of is shorten by a factor of $\sqrt{2}$ by using two gated MCPs[13]. The X-ray produced background is depressed because of the gating of the second MCP, hence the signal to noise ratio is improved.

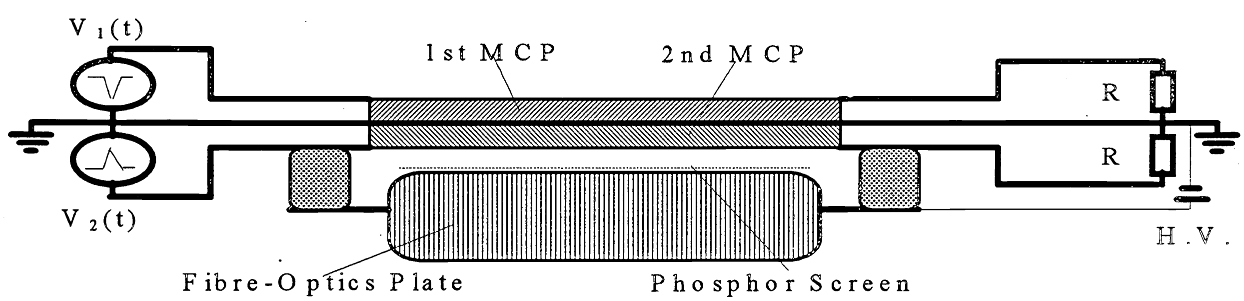


Fig. 8 Principle of gating two MCPs in cascade

3.1 Simulation algorithm

Simulations based on "constant electron collision number" hypotheses have been done for single gated MCP[10,11]. Although this hypothesis can explain the gain versus DC voltage characteristics[14], there is no evidence that it is valid for MCP gated by picosecond pulse. However, such hypothesis can be derived from the "energy proportionality hypothesis" when the MCP is applied with DC voltage. Therefor the simulations here start directly from the "energy proportionality hypothesis". The details of the algorithm was described in [13].

3.2 Simulation results

3.2.1 The dynamic gain of one gated MCP

It is well known that the exposure time can be reduced by decrease the width of the electric pulse, which is shown in Fig. 9 by our simulation. It should be kept in mind that the peak gain of the MCP also decrease with the electric pulse width, as shown in Fig 10. To compensate the gain, another MCP operated in DC mode can be placed behind the first MCP. But if the peak gain of the first MCP is too low , the numbers of electrons exit the first MCP can be comparable to the numbers of X-ray photons penetrating through the first MCP, in this case, the signal to noise ratio can be very low.

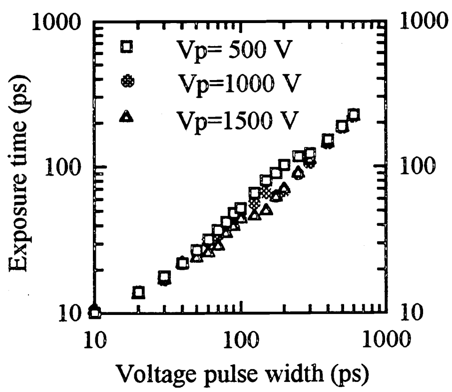


Fig. 9 Exposure time vs. the width of the voltage pulse whose peak amplitude is Vp.

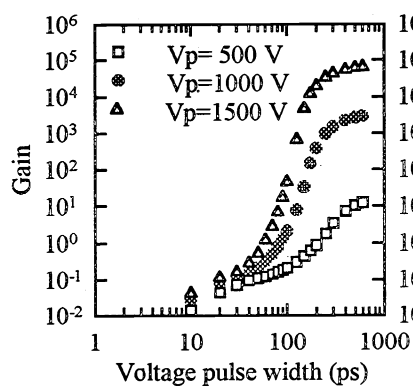


Fig. 10 Peak gain vs. the width of the voltage pulse whose peak amplitude is Vp

3.2.2 Two MCP gated in cascade

Both two MCPs are assumed to be with the same parameters. Fig.11 to 12 show some of results.

It can be seen from the figures that the time delay between the two electric pulses obviously affects the exposure time and the peak gain. There exists an optimum value of the time delay with which the peak gain is the highest.

It can also be seen that the exposure time of the two gated MCP decreases with the increase of the delay time and is about 1 to 4 times shorter than that of one MCP, provided that the electric pulses width and amplitude are the same. The peak gain of the two MCPs is two to three orders of magnitude higher than that of one MCP.

The x-ray photons that penetrate through the first MCP will produce photoelectrons at the input surface of the second MCP. Since the second MCP is gated by picosecond pulse, these "noise" electrons are gated and only part of them can arrive the phosphor screen. In this way, the background of the image is depressed, hence improve the signal to noise ratio. The shortest exposure time is determined by the gain and signal to noise ratio required by application.

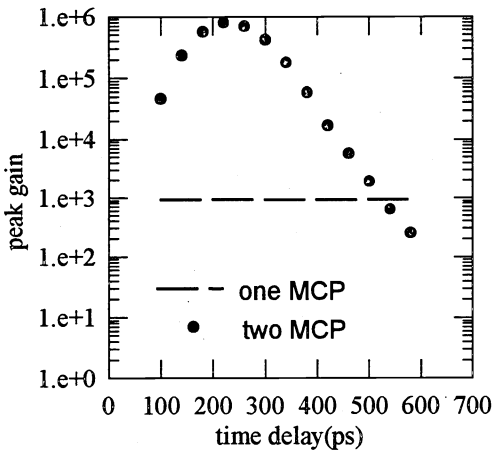


Fig.11(a) The peak gain vs time delay for MCPs (L=0.5mm, D=12.5μm) gated by 250ps pulses

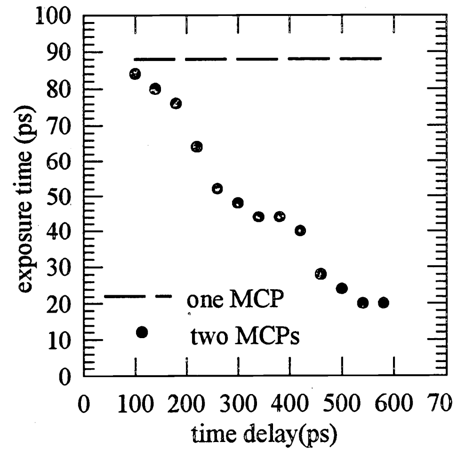


Fig.11(b) The exposure time vs time delay for MCPs (L=0.5mm, D=12.5μm) gated by 250ps pulses

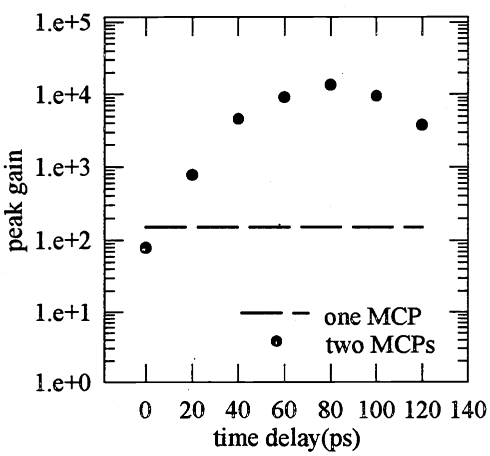


Fig.12(a) The peak gain vs time delay for MCPs (L=0.25mm, D=12.5μm) gated by 75ps pulses

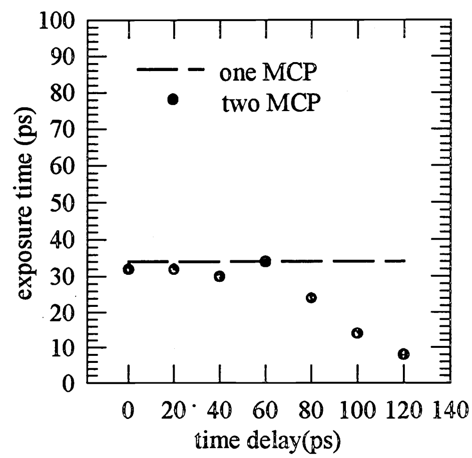


Fig.12(b) The exposure time vs time delay for MCPs L=0.25mm, D=12.5μm) gated by 75ps pulses

4. CONCLUSION

By using large MCP and long microstrop line, measurement time range of 1.1ns was realized. For thick (0.5mm) MCP, 58 ps exposure time was obtained. To reduce the exposure time further, two MCPs gated in cascade was simulated.

5. ACKNOWLEDGMENT

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6. REFERENCES

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