Two MCPs gated in cascade for picosecond framing photography

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ABSTRACT

It is shown in this paper that if two microchannel plates are used in chevron configuration and are gated one by one by ultrashort electric pulses, the exposure time can be reduced considerably compare to that of one MCP due to the superposition of the gain narrowing effects of the two stages gating. Another advantage of this method is that the signal to noise ratio can be improved because of the increase of gain and reduction of hard X-ray induced background.

1. INTRODUCTION

Picosecond X-ray framing camera is one of the key diagnostic tools for laser fusion and other laser-produced plasma researches, such camera technology has developed to the practical usable level during the last few years by using the MCP gating method[1~4] that provides high temporal and spatial resolution, large dynamic range and small image distortion. The exposure time of such camera is about 100 picosecond, limited by the electron transit time in the gated MCP which is typically 0.5 mm in thickness. The FWHM of electric pulse that is used for gating the MCP is ~300 picoseconds.

In principle the exposure time can be reduced 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[5], such cameras exhibit bad signal to noise ratio because of the background produced by the hard X-ray directly passing through the gated MCP[6].

In this paper gating two MCPs in cascade is proposed to improve the performance of framing camera, In the imager the two MCP are gated by the high voltages pulses respectively through the micro-strip lines lay on the them. The time delay of the second voltage pulse to the first one equals to the electron transit time in the first MCP. It will be shown analytically in section 2 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. The X-ray produced background is depressed because of the gating of the second MCP, hence the signal to noise ratio is improved. Numeric simulation in section 4 that based on the "energy proportionality hypothesis" confirmed this.

2. ANALYTICAL RESULTS

The principle of gating two MCPs in cascade is shown in figure 1. The first MCP is gated by electric pulse $V_1(t)$ and the second MCP is gated by electric pulse $V_2(t)$, while the time delay of $V_2(t)$ to $V_1(t)$ is Td. Both pulses are assumed to be Gaussian for simplicity, that is

$$V_1(t)=Vp_1*\exp(-(4*\log(2)*(t/Tn_1)^2) \qquad (1)$$

$$V_2(t)=Vp_2*\exp(-(4*\log(2)*(t/Tn_2)^2) \qquad (2)$$

where Vp_1 and Vp_2 are the peak amplitude, Tn_1 and Tn_2 are the FWHM of the pulses.

The gain of the two MCP gated by such pulses can be expressed respectively by

$$G_1(t)=Gp_1*V_1(t)^\gamma \qquad (3)$$

$$G_2(t)=Gp_2*V_2(t)^\gamma \qquad (4)$$

where Gp_1 and Gp_2 are peak gain and γ is a constant which represents the nonlinearity of the MCP gain. The FWHM of the $G_1(t)$ is shorter than the FWHM of $V_1(t)$ by a factor of $\sqrt{\gamma}$, so is $G_2(t)$ comparing to $V_2(t)$.

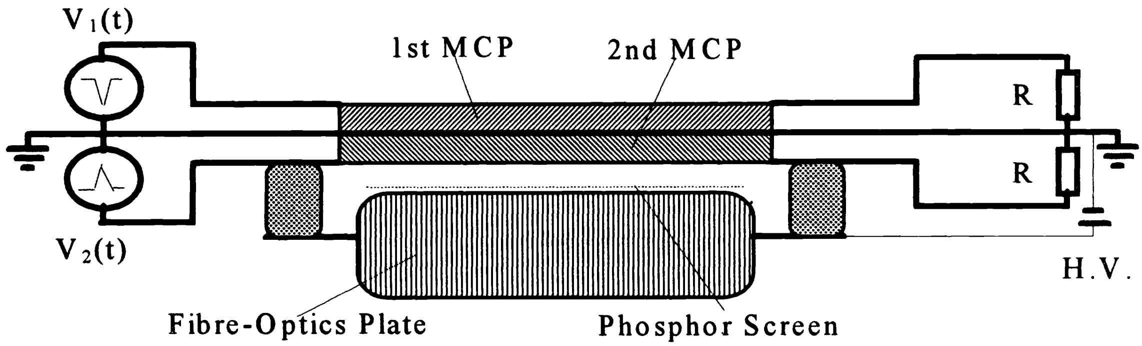

Fig.1 Principle of gating two MCPs in cascade

When the time delay of $V_2(t)$ to $V_1(t)$ equals to the transit time of the first MCP, the total gain of the two MCPs is

$$G_{12}(t)=G_1(t)*G_2(t)$$

$$=Gp_{12}*\exp(-4*\log(2)*(t/Tm)^2) \qquad (5)$$

where $Vp_1=Vp_2=Vp$ and $Tn_1=Tn_2=Tn$. are assumed, and

$$Tm=Tn/\sqrt{(2\gamma)} \qquad (6)$$

$$Gp_{12}=Gp_1*Gp_2 \qquad (7)$$

that is, the FWHM of the total gain $G_{12}(t)$ is shorter than the FWHM of the electric pulses by a factor of $\sqrt{(2\gamma)}$. The FWHM of $G_{12}(t)$ is less than that of $G_1(t)$ by a factor of $\sqrt{2}$, which means that the exposure time of the two MCPs gated in cascade is shorter than that of one gated MCP. The total gain of the two MCP is higher than one gated MCP, if the gain of each MCP is larger than 1.

The above conclusions are valid when the electron transit time Ttr in both of the MCPs is much shorter than the width of the electric pulse Tn. The next two sections will simulate the gated MCPs when the transit time is comparable to the width of the electric pulse.

3.SIMULATION METHOD

Simulations based on "constant electron collision number" hypotheses have been done for single gated MCP[5,6]. Although this hypothesis can explain the gain versus DC voltage characteristics[7], 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 dynamic gain of a MCP, G(t), is calculated by

$$G(t)=\prod_{i=1}^{n} \delta_i \qquad (8)$$

where n is the stages of multiplication, δ_i is the secondary emission yield of each stage when $i>1$. Both n and δ_i are related to the arrive time of the incident photon t and the electric pulse $V_{mcp}(t)$ applied on the MCP.

i=1 represents the photoemision, and δ_1 is the quantum efficiency, which is related to the coating materiel of the MCP and the photon energy. In our simulation, We take $\delta_1=1$. The results can easily be converted to the case of $\delta_1=1$.

When i>1, we assume

$$\delta_i = (V_i / V_c)^k \qquad (9)$$

where V_c and k are constant of MCP.V_i is the energy of the primary electron, which is the key variable to be calculated in the simulation .

To simplify the simulation , we assume that both of MCPs are applied with Gaussian electric pulse , which are expressed by (1),(2) and is biased by a DC voltage V_d. We assume that the input surface of the first MCP is coated with Au photocathode and the photon energy of the incident X-ray is in the range of 0.1-10 keV . The normalized initial energy distribution of the photoelectron can be described by[8]

$$N(E_1)=6W*E_1/(E_1+W)^4 \qquad (10)$$

where E_1 is the photon energy, W=3.7.

When the photoelectron leaves the MCP wall at the time t_1 it is accelerated by the electric field and strikes the MCP wall at the time t_2,

$$t_2=t_1+D/\sqrt{(2E_1/m)} \qquad (11)$$

and with energy

$$V_2=0.5e^2/(mL^2)\left(\int_{t_1}^{t_2} (V_{mcp}(t)+Vd)dt\right)^2 \qquad (12)$$

where e and m are the charge and mass of electron respectively.

The origin of the space coordinate in the microchannel axis direction is taken at the input surface of the MCP. The photoelectron impacts the MCP wall at

$$Z_2=e/(mL)\int_{t_1}^{t_2}\int_{t_1}^{t} (V_{mcp}(t)+Vd)d\tau dt \qquad (13)$$

According to the energy proportionality hypothesis[7], the initial energy of the secondary electron is

$$E_2=V_2/(4\beta^2) \qquad (14)$$

where β is a MCP constant.

The time t_3, spatial place Z_3 and energy V_3 of the electrons when they strike the MCP wall can be calculated by the same method . The similar calculation are done until the elections arrive the output surface of the first MCP.

We assume that the second MCP contacts the first MCP face to faces, so the electrons enter the second MCP immediately after they leave the first MCP . The multiplication process of the electrons in the second MCP is simulated in the same way as in the first MCP.

4. SIMULATION RESULTS

The values of the MCP constants, β, Vc and k, are obtained by fitting the DC gain versus voltage curve of the MCP used in our framing camera. This curve was measured by using electron source and the acceleration voltage between the source and the MCP input surface was 800 volts . The initial energy of the secondary electrons produced by the electron from the source striking the MCP wall is calculated by a modification of (14) , that is

$$E_1=V_s/(4\beta^2)(1-\exp(V_1/V_s)) \qquad (15)$$

because the primary electron energy of this first striking is too large to use the energy proportionality[9] . V_s is other constant of MCP and the value is also determined by fitting the DC gain versus voltage curve of the MCP. The fitting results is shown in Fig 2.

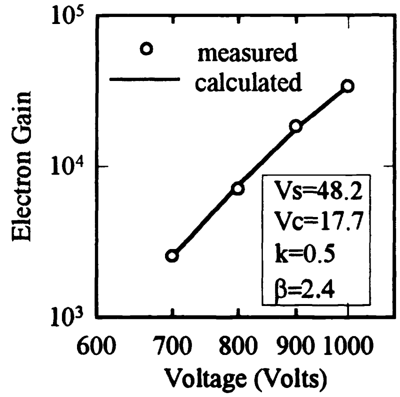

Fig. 2 Calculated MCP gain vs voltage(solid lines) and measured data (plotted points) at V_1=800 Volts for MCP of α=40 and ϕ=10

4.1. The dynamic gain of one gated MCP

A typical simulation result of dynamic gain, G(t), is shown in Fig.3. The numbers of electron colliding the MCP wall is shown in Fig. 4. It is clear in Fig.4 that the stage of multiplication is not a constant, but changes with time.

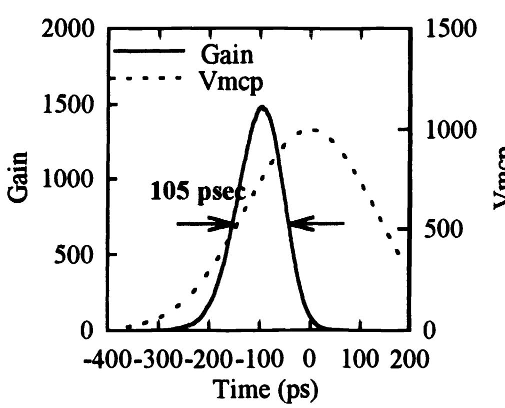

Fig. 3 The dynamic gain of the MCP gated by the voltage pulse whose FWHM is 300 ps

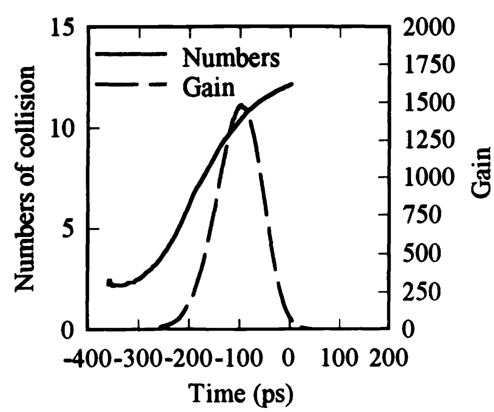

Fig. 4 Numbers of electron collision on the wall of the MCP gated by the voltage pulse of 300 ps

It is well known that the exposure time can be reduced by decrease the width of the electric pulse. This is shown in Fig. 5 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 6. 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 two 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.

4.2. Two MCP gated in cascade

Both two MCPs are assumed to be with L=0.25 mm and D=12.5 μm while the MCP constants Vc, k and β are the same as that in the section 4.1. Such thin MCPs are chosen because the transit time is shorter than that of thick MCP, hence shorter electric pulses can be used to get shorter exposure time. Fig.7 and 8 show some of results.

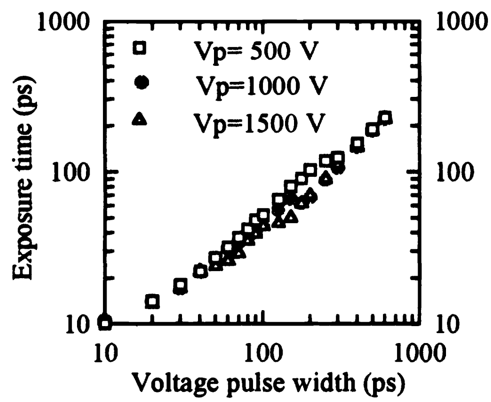

Fig. 5 Exposure time vs. the width of the voltage pulse whose peak amplitude is Vp.

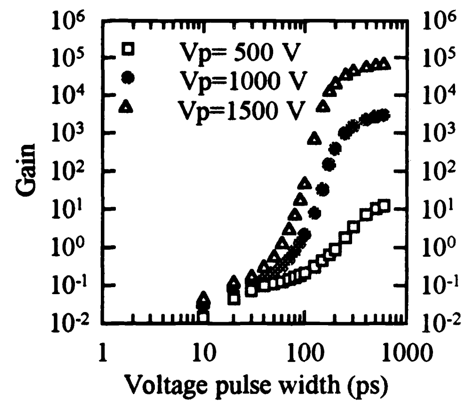

Fig. 6 Peak gain vs. the width of the voltage pulse whose peak amplitude is Vp

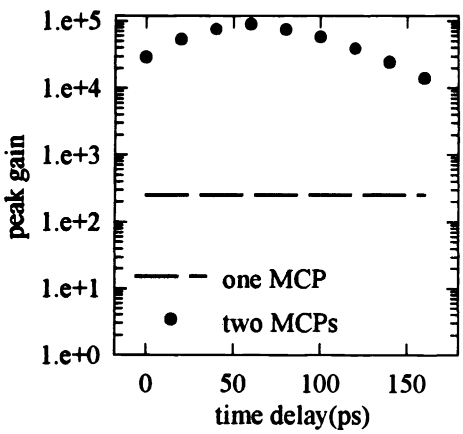

Fig. 7(a) The peak gain vs. the time delay for MCPs gated by 150 ps pulses

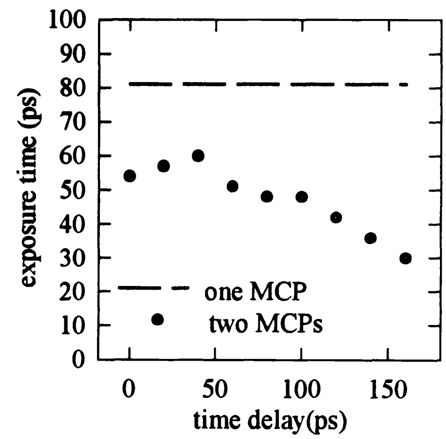

Fig. 7(b) The exposure time vs. the time delay for MCPs gated by 150 ps pulses

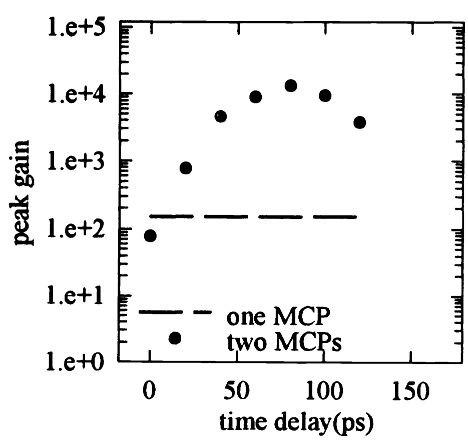

Fig. 8(a) The peak gain vs. the time delay for MCPs gated by 75 ps pulses

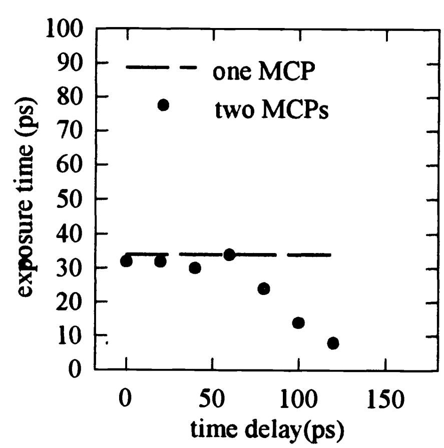

Fig. 8(b) The exposure time vs. the time delay for MCPs gated by 75 ps pulses

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 $\sqrt{2}$ 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. Fig. 9 shows the comparison of the dynamic gain curve of the two MCPs gated in cascade with that the single gated MCP. The FWHM of the electric pulse is 100 picosecond.

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 the can arrives 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.

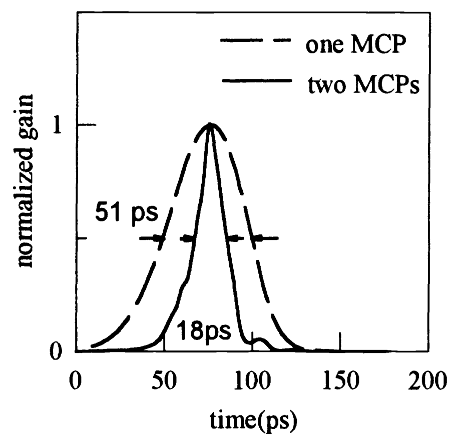

Fig. 9 Comparison of the exposure time of one MCP with two MCPs gated by 100 ps pulses

5. CONCLUSION

Two MCPs gated in cascade was proposed to replace the single gated MCP for picosecond framing photography. It keeps the advantages of the proximity focused tube, i.e., negligible image distortion, high dynamic spatial resolution and large dynamic rang. Compare to the single gated MCP camera, the two gated MCP can offer:

(1) shorter exposure time
(2) higher gain
(3) better signal to noise ratio

6. REFERENCES

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