Numerical Analysis of the Amplification Process of the Micro Channel Plate (MCP) in the Framing Camera

Y. Ito*, H.Kawaguchi**, E. Gjonaj***, T. Weiland***
*Yuge National College for Maritime Technology
Shimo-yuge 1000, Ochi-gun, Ehime, 794-2593, JAPAN
E-mail : y.ito@info.yuge.ac.jp
**Muroran Institute of Technology, ***Technische Universitaet Darrmstadt

Abstract — For higher speed X-ray measurements by using the framing camera, it is necessary to investigate electron amplification process of the micro channel plate (MCP) in order to understand the shuttering characteristic. This paper presents a numerical simulation method of the MCP based on the Monte Carlo calculation and the Furman's secondary electron emission model. It is shown that experimental result of electron gain characteristic in the MCP can be obtained by the simulation code.

I. INTRODUCTION

For the measurement of the ultra high-speed phenomena accompanying with light emission as in plasma processing, luminous phenomenon of semiconductor, beam physics, the framing camera has been frequently employed. The core part of the framing camera is the Micro Channel Plate (MCP) which is the electron amplifier device. Especially in the case of the highest-speed measurement of X-ray, the shuttering pulse of the framing camera is imposed on the micro-strip line laid over the MCP, therefore amplifier operation of the MCP sensitively affects to the shuttering characteristic. Accordingly quantitative understanding of amplifying mechanism of the MCP is essential for such the high-speed measurements. To aim to analyze the cascading emission process of the secondary electrons in electron amplifier operation of the MCP, we develop the Monte Carlo simulation code by using the Furman's secondary electron emission model [1].

II. FRAMING CAMERA SYSTEM

Overview of the framing camera system is shown in Fig.1. The X-ray signal is assumed to come from top to downward and most of the X-ray signal will enter to the MCP channel (Fig.2). When the X-ray hits to MCP channel wall, the secondary electrons are induced from the wall. The induced electrons are accelerated by imposed voltage between top and down surface of the MCP, and the secondary electron emission will repeats many times during all the electrons pass though the channel (Fig.3). Inverse DC bias is applied ordinarily to the micro-strip line laid over the MCP to avoid passing of unnecessary signals. When measurement signal arrives on the MCP input surface, the shuttering pulse will applied to the MCP electrode synchronizing with the incoming signal and begin the amplifier process in the MCP channel. The amplified electrons are extracted from the other side of the MCP, and re-converted to the light signal on the phosphor. And finally the amplified light signal will be captured by the CCD camera.

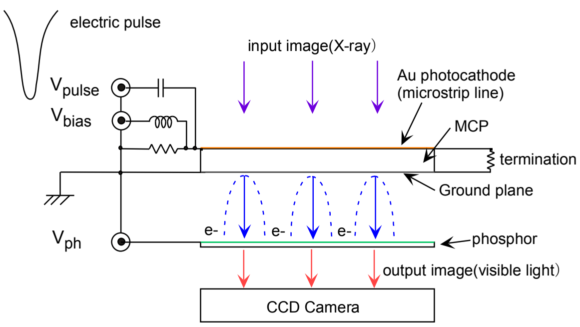

Fig. 1 Overview of framing camera system

It is easily predicted that this MCP amplification process will strongly affects to the shuttering characteristic and may break shuttering synchronization all over measurement surface of order of centimeter when very high-speed signal of order of pico-second will be tried to be measured by the framing camera. This paper presents numerical simulation of electron amplification phenomena in the MCP by using the Furman's secondary electron emission model to aim to quantitatively understanding of the MCP operation for such the very high-speed measurement by the framing camera.

III. MCP SIMULATION CODE BASED ON FURMAN'S MODEL

A. Formulation for em fields and particle motion

Here, we assume that the measurement signal is of order of nanosecond as the first step of the MCP simulation. This

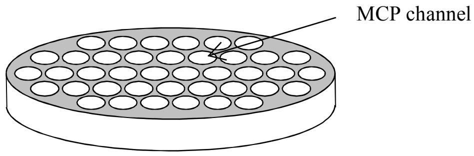

Fig. 2 Overview of MCP

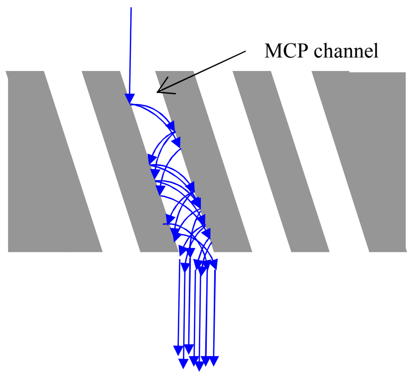

Fig. 3 Electron amplification process in MCP channel

time range corresponds to several meters wavelength which is much larger than the thickness of the MCP, of order of 100 micrometers. Accordingly the electric field $\mathbf{E}(\mathbf{x})$ is can be regarded as static field and no magnetic field. In addition, the number of electrons inside the MCP channel is at most several millions. This means that space charge effects caused by the secondary emitted electrons are much smaller than electric field due to applied electrode voltage. In this case, the electric field is simply described by the Laplace equation,

$$\nabla(\varepsilon\nabla\phi(\mathbf{x}))=0,\ \mathbf{E}(\mathbf{x})=-\nabla\phi(\mathbf{x}) \tag{1}$$

On the other hand, the charged particle equation of motion under the static electric field is as follows,

$$\frac{d\mathbf{p}(t)}{dt}=e\mathbf{E}(\mathbf{x}(t)),\ \mathbf{p}(t)=\frac{m\mathbf{v}(t)}{\sqrt{1-\left(\frac{v(t)}{c}\right)^2}}. \tag{2}$$

The particle velocity easily reaches to relativistic region due to small electron mass, therefore the relativistic formulation (2) is essential in this particle simulation.

B. *Furman's secondary electron emission model*

The most complicated part of the MCP simulation is appropriate description of the secondary electron emission on the MCP channel surface. We here adopt the Furman's secondary electron emission model which was developed for electron cloud effects in particle accelerator science [1].

In Furman's model, three kinds of secondary electron emissions for the incident electron beam current I_0 are assumed, the backscattered elastic electron beam current I_e, the rediffused electron beam current I_r and the true-secondary electron beam current I_{ts}. The actual number of the secondary emitted electrons, emitted electron energy and momentum are calculated by using the Monte Carlo simulation depending on individual generation probability of each currents. The biggest advantages of this model are treatment of more than two secondary electron emissions and exact conservation of electron energy and generation probabilities. On the other hand, there exist many fitting parameters depending on emission surface material in Furman's model. Especially the fitting parameters for reduced lead grass which is the MCP channel surface material was not yet specified. To develop the MCP simulation code, the Furman's fitting parameter for the MCP channel material is identified comparing with an experimental result [2] in this paper.

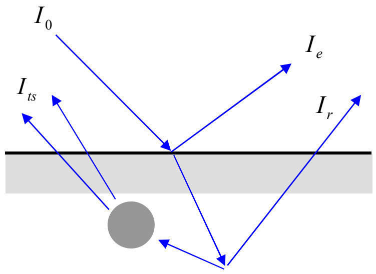

Fig. 4 Furman's secondary electron emission model

IV. NUMERICAL EXAMPLE

Although the actual MCP consists of about 1000 x 1000 micro channels with honeycomb arrays (Fig.2), we use here single channel model to compare with the experimental result [2]. The cross-section of uniform grid numerical model of the single channel MCP is shown in Fig.5. The diameter of the micro channel is 10 µm and the length of the micro channel is 460 µm. Inside of the channel is a vacuum, and relative permittivity of the MCP material is 6.0. The Laplace equation (1) is numerically solved by the FDM on this grid and the equation of motion (2) is integrated by 5th order Runge-Kutta method employing Furman's model for the secondary electron emission. Especially the rediffused electron beam current I_r is not included in this simulation since this current I_r is not considered in Ref.[2].

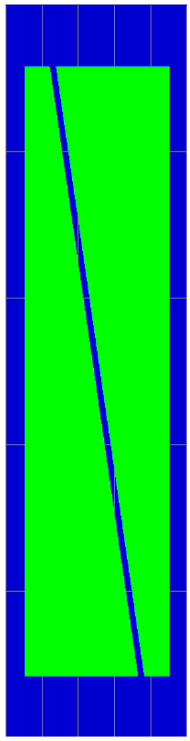

Fig. 5 Single channel MCP

The figure 6 shows amplified electron gain curves against the MCP voltage as the comparison of Ref. [2], CST Particle Studio simulation and presented simulation. To appropriately set the Furman parameters, the gain curve can be obtained.

V. CONCLUSION

To aim to higher speed measurement of the framing camera, a numerical simulation method of the MCP for quantitative understanding of electron amplification process has been presented in this paper. For a further progress, we will investigate the pulse mode operation to understand the shuttering characteristics of the framing camera.

VI. REFERENCES

[1] M.A.Furman, M.T.F.Pivi, "Probabilistic Model for the Simulation of Secondary Electron Emission," SLAC-PUB-9912, pp.1-19 , 2003.

[2] M.Wu, C.A.Kruschwitz, D.V.Morgen, J.Morgen, "Monte Calro Simulation of Micro Channel Plate Detector I. Stady-state Voltage Bias Results," Rev.Sci.Instrum., Vol.79,073104, 2008.

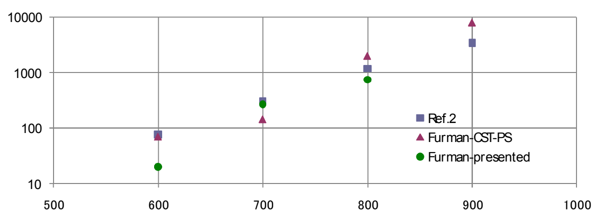

Fig. 6 Electron gain for MCP voltage