Numerical Simulation of Electron Amplification Process in Micro Channel Plate by Using Furman's Model

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Abstract— In measurement devices of very high-speed phenomena such as the framing camera and streak camera, the Micro Channel Plate (MCP) plays very important role for amplification of very small signals. It is necessary to understand the electron amplification process of the MCP for further improvement of these high-speed mesurement devices. This paper presents a numerical simulation method of the MCP based on the Monte Carlo calculation and Furman's secondary electron emission model. It is shown that electron amplification phenomena by the secondary emission in the MCP can be simulated.

Keywords— Micro Channel Plate (MCP), FDM, Monte Carlo Method, Furman's model, Lorentz equation of motion, Runge-Kutta method, Electrostatic field.

1. Introduction

For measurements of ultra high-speed phenomena of order of several hundred pico-second accompanying with light emission as in plasma processing, luminous phenomenon of semiconductor, beam physics, etc., the framing camera and streak camera have been frequently employed. One of core parts of such the high speed measurement devices is the Micro Channel Plate (MCP). In general, the light signals in such high speed phenomena are very weak intensity and it is necessary to be amplified for effective measurement. But the light signal itself can not be amplified directly. Then the MCP has important role of signal amplification in such high speed measurement devices. In the MCP, the light signal is once converted to electron beam density distribution and after that the signal is amplified as the form of electron beam by using the secondary electron emission phenomena. Accordingly in the case of ultra-high speed phenomena of order of several pico-second, linearity of amplification of signals may be lost in the secondary electron emission process. Then quantitative understanding of amplifying mechanism of the electron beam in the MCP is essential for design and development of such the ultra high speed measurement devices. To aim to analyze the cascading emission process in electron amplifier operation of the MCP, we present the Monte Carlo simulation code by using Furman's secondary electron emission model [1].

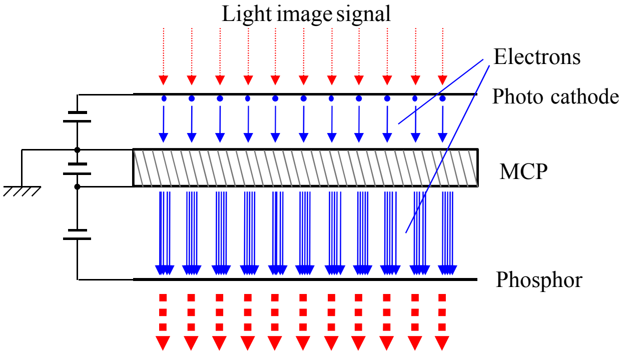

Fig. 1 Overview of framing camera system

2. MCP in framing camera

As an example of signal amplifications in the MCP, an overview of the framing camera system is shown in Fig.1. The light signal is assumed to come from upper direction. The incoming light is converted to electron beam density distribution depending on the original signal intensity at the photo cathode. The generated electrons at the photo cathode are accelerated toward to the MCP. The MCP is composed of dielectric material plate with over million inclined channels of about 10 μm diameter (Fig.2). When the electrons arrive at the MCP, most of electron get enter to the micro channels and hits to the inclined channel wall. As a result of this event, the secondary electrons are emitted at

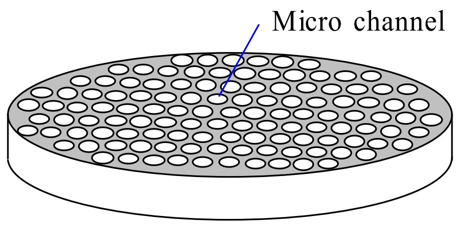

Fig. 2 Micro channel plate

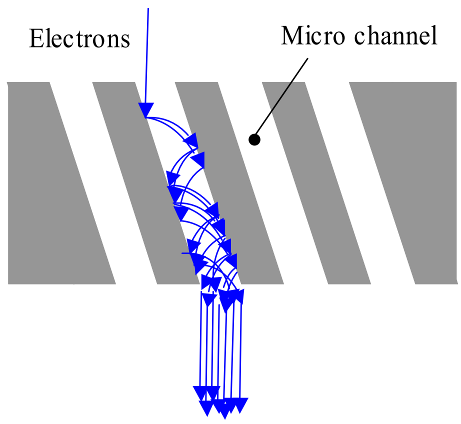

Fig. 3 Electron beam amplification in micro channel

this hitting point on the wall. The emitted 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). The amplified electron beam is 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. Then, inverse DC bias is applied ordinarily to the MCP to avoid passing of unnecessary signals. When measurement signal arrives on the MCP input surface, the shuttering pulse will be applied to the MCP electrode synchronizing with the incoming signal and begin the amplifier process in the MCP channel.

3. Simulation of electron amplification process

We here assume that the measurement signal is of order of nanosecond. This 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 $\mathbf{E}(\mathbf{x})$ can be regarded as static and there is 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 electrons are much smaller than the electric field produced by applied voltage on the MCP. In this case, the electric field is simply described by Laplace's equation,

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

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

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

The particle velocity easily reaches to relativistic region due to small electron mass, therefore the relativistic effects have to be included in the particle simulation.

The most complicated part of the MCP simulation is appropriate description of the secondary electron emission on the MCP channel surface. We here adopt Furman's secondary electron emission model which was developed for simulation of 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} (Fig.4). The 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 kinds of secondary electron emission currents 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 MCP channel surface material is not specified yet. To develop the MCP simulation code, the Furman's fitting parameters for the MCP channel material is identified compared with an experimental result [2] in this paper.

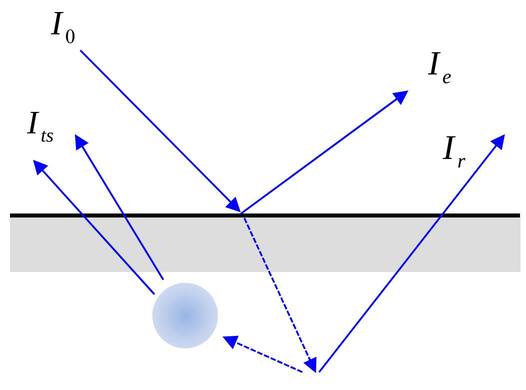

Fig. 4 Electron currents in Furman's model

4. Numerical simulation

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 for simplicity. The cross-section of uniform grid numerical model of the single channel MCP is shown in Fig.5(a). The diameter of the micro channel is 10 μm and the length of the micro channel is 460 μm. It is assumed that inside of the channel is vacuum, and relative permittivity of the MCP material is 6.0. Laplace's equation (1) is numerically solved by the FDM on this grid and the equation of motion (2) is integrated by 5th order Runge-Kutta (R-K) method combined with 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]. The figure 5(b) shows numerical example of electron amplification phenomena by repeating the secondary emission.

5. Conclusion

For quantitative understanding of electron amplification process in the MCP, numerical simulation code of the secondary electron emission phenomena is developed based on the FDM for electrostatic field and the R-K method combined with the Monte-Calso method for electron motion. For a further progress, we will quantatively compare the numerical simulation with experimental results of electron amplificaiton gain.

References

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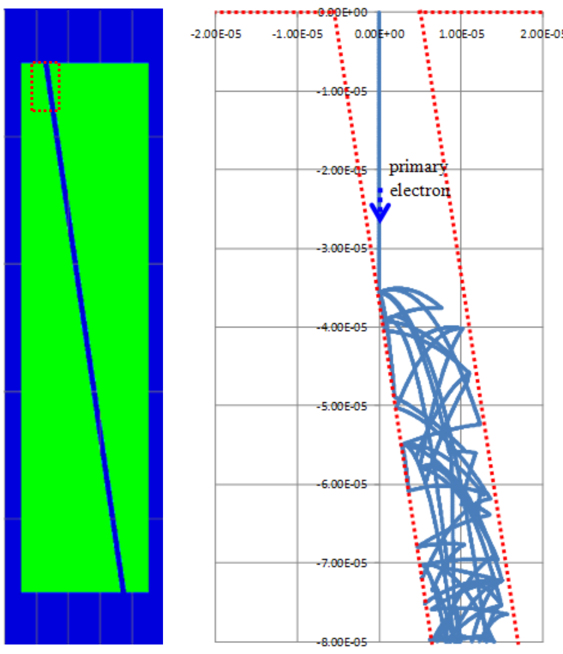

(a) numerical model (b) electron trajectories

Fig. 5 Numerical example of single channel model of MCP