A Compact Electrostatic Electron Multiplier of Continuous Dynode Type

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A simple and compact electron multiplier being composed of two parallel resistance strips and works only with an oblique electrostatic field applied between them is constructed, and the experimental results and discussions on the characteristics of the device are presented. The device would be useful unless the primary current varies over a wide range to ensure its linearity.

1. Introduction

A channel type electron multiplier proposed by Spindt et al.1 which is composed of two parallel resistance strips and works only with applied electrostatic field is quite attractive because of its simplicity and easiness to construct. The device, however, has the disadvantage that two strips should be placed very closely in the order of tenth in mm to make electrons collide successively and frequently with both surfaces to obtain sufficient multiplication, and this results in the difficulty to keep the electric field between them uniform.

The advanced device suggested by Hamisch 2) is a very ingenious one where the applied electrostatic field on a continuous dynode makes an oblique angle against the surface and lets electrons traverse the field jumping on. In this arrangement, the optimum over-all gain can be obtained by adjusting the inclination of equipotentials.

As for the materials of resistance strips or continuous dynodes, besides the requirements of proper resistivity and secondary electron yield, it is also desirable that the uniformity in surface quality and structure can readily be obtained. In this sense, the strips made by the reduction of lead rich glass in hydrogen atmosphere proposed by Siprikov et al.3) would often be better than those made by sputtering or evaporation processes.

In the present article, some experimental results and discussions are presented concerning to the characteristics of a channel type electron multiplier made from lead glass, where, in our experiment, the arrangement is made, in which two resistance strips are placed parallel and the inclination of equipotentials between them can be adjusted by changing the voltages applied, and thus enables one to obtain the optimum overall gain quite easily.

2. Experimental Device and Method

2.1 Preparation of Dynodes

The X-ray protection glass which contains about 65% lead was used as the bases of the resistance strips or

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Fig. 1. Schematic diagram of channel type secondary electron multiplier.

The device, here, is operated with the oblique equipotentials against dynode surfaces.

continuous dynodes. The polished strips of $30 \times 20 \times 2.0\text{mm}$ were treated following the reduction process suggested by Blodgett in a hydrogen furnace. The strips of the resistances of $2 - 3 \times 10^9$ ohms were used as sample dynodes. The resistances obtained were nearly ohmic and remained quite stable for a year in spite of about one hour per day exposure in atmosphere.

2.2. Device and Method

Figure 1 shows the scheme of the multiplier device made. $V_F$ is the voltage supply to the dynodes. The voltages between $A$ and $B$ ($V_{AB}$) and $A'$ and $B'$ ($V_{A'B'}$) are adjusted separately and thus the angle $\theta$ of equipotentials against dynode surfaces can be changed. P.C. shows an electrode to measure the primary current, and P.A. is an auxiliary dynode to accept primary current to be multiplied and is kept several tens to two hundred volts lower than $A'$ in potential. When the over-all gain is to be measured, the primary current read by P.C. is led directly into the gap of the multiplier strips. E.G. shows an electron gun to be used for an ordinary C.R.T., and all parts are set up in a glass bell jar and evacuated down to about $10^{-7}\text{Torr}$ by an oil diffusion pump. Currents are measured by a vibrating reed electrometer connected to S.C. which is kept 50 volts positive relative to the end of multiplier by a voltage supply $V_S$.

3. Experimental Results

To investigate the characteristics of the device, the relations between the dynode voltage $V_F$, the over-all gain $G$, the gap $d$ between the strips, the angle $\theta$ of equipotentials, and the injected primary current $I_p$ are measured taking...
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some variables as parameters.

3.1. Effect of $\theta$ on $G$

Primary current of $5 \times 10^{-13}$ A was led directly to the dynode gap of 1.5 mm and the over-all gain $G$ of the device was measured against the dynode potential $V_F$ taking the angle $\theta$ as a parameter. Figure 2 shows the results of the cases where $\theta = 0$ and $\tan \theta = 0.3$ which gives the optimum gain. The gain $G$ in the optimum case increases exponentially with the applied voltage $V_F$, while in the case where $\theta = 0$, it falls probably due to the too much wide gap to make electrons collide with the opposite dynode surfaces frequently.

3.2. Effect of $d$ on $G_m$

Figure 3 shows the characteristics of the optimum gain $G_m$ vs. $V_F$ with various gap widths, and it is found that the gap width is not essential in the present arrangement. The deviation of the gain for $d = 1.5$ mm will be discussed later.

3.3. $I_p$ and $G_m$

Figure 4 gives the characteristics

![Graph](image)

**Fig. 2.** Comparison between two multiplication conditions; one is under oblique equipotentials ($\tan \theta \approx 0.3$), the other is under perpendicular equipotentials ($\tan \theta \approx 0$). Gap width $d$ is 1.5 mm.
of $G_m$ vs. $V_F$ for various primary currents $I_p$ keeping the gap width 2.5mm.

The saturation of $G_m$ with increasing $V_F$ for $I_p = 1 \times 10^{-11}$ A may be due to the "saturation effect" as will be pointed out in 4-2. However, the decrease of $G_m$ with increasing $I_p$ cannot be interpreted by the saturation effect, because each curve obtained shows the exponential increase with $V_F$ except the case mentioned above.

3.4. $I_p$ and Optimum Condition

Figure 5 shows the gain $G_m$ vs. $I_p$ characteristics keeping $V_F$ 4kV and
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d in 2.5mm. The circle marks indicate the gain where the angle $\theta$ is adjusted for every primary current to obtain the optimum gain, while others are the results for the angle $\theta$ which is set to attain the optimum gain at a certain primary current listed in the figure and those would be the cases where the device is used in practice. The gain changes remarkably with the current and this suggests the defect of the present device.

4. Discussions
4.1. Gain of Device
To evaluate the gain of the device theoretically, the ratio of secondary electron emission $\delta$ of a dynode used and the motion of electrons in the device must be known.

The characteristic of emission ratio $\delta$ of a dynode used against the accelerating voltage $E_p$ of primary electrons was measured and plotted in Fig.6. The result is represented fairly well as shown in the figure with the equation given by Novitskii et al.\textsuperscript{5)} as

$$\delta = \delta_{\text{max}} \frac{E_p}{E_{\text{max}}} \exp\left(1 - \frac{E_p}{E_{\text{max}}}\right), \quad (1)$$

where $E_{\text{max}}$ is the accelerating voltage of primary electrons which gives the measurement.
maximum secondary electron emission ratio $\delta_{\text{max}}$, and thus Eq. (1) can be applied to evaluate the gain of the device used.

Next step is to find out the trajectories of electrons among the resistance strips where equipotentials lie inclined against strip surfaces, but in the present analysis, it will be assumed that the field is uniform and there exist no space charge and saturation effect, and furthermore that every secondary electron is released perpendicularly from the dynode surface with initial kinetic energy of $eW$. In the present case where electrons emitted from dynode surface step over a strip as shown in Fig. 1, it will be readily derived that the energy which an electron acquires during its one step is given as

$$eE_p = 4eW \cot^2 \theta.$$  

Thus, the number of steps $n$ of an electron which traverses across the potential difference $V_F$ can be given as $n = V_F / E_p$, and hence the overall gain $G$ of the device will be $G = \delta^n$, and applying Eq. (1), it is

$$G = \left[ \delta_{\text{max}} \frac{E_p}{E_{\text{max}}} \right] \times \exp \left\{ 1 - \left( \frac{E_p}{E_{\text{max}}} \right) \right\} \frac{V_F}{E_F},$$  

(3)

where $E_p$ is given by Eq. (2) as a function of $\theta$. The angle $\theta$ which makes $G$ maximum is the angle which gives the $E_p$ that makes $G$ of Eq. (4) maximum. By the logarithmic differentiation of Eq. (4), we have

$$\left( \frac{1}{G} \right) \frac{dG}{dE_p} = \left( \frac{V_F}{E_F} \right) \log \left( \frac{E_{\text{max}}}{\delta_{\text{max}} \cdot E_p} \right),$$

and thus the maximum gain will be obtained by the condition that

$$E_p = E_{\text{max}} / \delta_{\text{max}}.$$  

(4)

Substituting Eq. (4) into Eq. (3), we have the maximum gain $G_m$ obtainable, that is,

$$G_m = \exp \left\{ \frac{1}{\delta_{\text{max}} - 1} \right\} \frac{V_F}{E_F}.$$  

(5)

This shows that $G_m$ depends only on $\delta_{\text{max}} / E_{\text{max}}$ of the dynode material used when the applied voltage is given and a dynode which has a large value of $(\delta_{\text{max}} - 1)/E_{\text{max}}$ is preferable to make the over-all gain large. The theoretical curve obtained by putting the measured value of $\delta_{\text{max}} = 2.2$ and $E_{\text{max}} = 480$ V in Eq. (5) is shown in Fig. 3.

4.2. Saturation and Feedback Effects

The saturation effect, which implies the saturation of the gain of a device when the output current increases comparably to the dynode current, is explained to be due to the space charge effect and the reduction of the potential gradient at the exit of a device caused by the loss of electrons flowing through the dynodes. In the present experiments, the effect was observed markedly as shown in Fig. 4, for instance, but no direct measurements were made to analyze the effect. The fringing field at the exit opening may cause the analysis to be too much complicated to do. However, it could be pointed out that since the final take-off point from which the output electrons jump out towards the outside collector
will retreat inside the strips as the reduction of the exit potential gradient grows and no effective acceleration can be performed, the effective solid angle for running out electrons from that point will decrease with increasing output current, and thus the saturation effect will be proceeded especially when the gap width between two strips is very narrow.

When gas molecules in the space between two strips are ionized by the secondary electrons possibly at the exit of a device, the produced positive ions will be accelerated towards inside and would have chances to emit secondary electrons from dynode surfaces which then will give false outputs. This is the feedback effect. It is, therefore, probable that in a device where the equipotentials between strips run perpendicularly to the strip surfaces and electric field lies parallel along the surfaces, the most of positive ions produced in the gap space would be accelerated to collide with the surfaces at the entrance of a device and thus the feedback effect would be rather remarkable. On the other hand, however, in the present device in which the electric field makes an oblique angle against strip surfaces, the positive ions produced at the exit would be accelerated to collide with a strip surface at the points near the exit, and hence, it would be expected that the feedback effect is insignificant.

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