

# Ion Detection Using Continuous Dynode Electron Multipliers.

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## §1. Introduction.

In recent years, the use of channeltron electron multipliers for detection of charged and neutral particles has increased considerably. In particular, curved and spiral channel multipliers have been widely used to detect single particles because of their excellent characteristics of saturated electron gain<sup>(1)~(7)</sup>. Straight channel multipliers such as parallel plate multipliers are not suitable for the pulse counting since they give rise to an output pulse with a rather long risetime<sup>(8)</sup>. This long risetime is attributed to the ionization by electrons of the residual gas in the channel. The existence of the ion feedback is also very serious in another application where an output current proportional to the input current is desired.

The method proposed by Hamish<sup>(9)</sup> and adopted by Ezoe et al.<sup>(10)</sup> is quite attractive, in which an electrostatic field is applied obliquely against dynode surface. In this method, secondary electrons liberated from a dynode surface collide again with the same surface after describing a parabolic trajectory. Therefore, multiplication is carried out only on one of the two surfaces (electron-emitting surface). The opposite surface acts as a field provider (Fig. 1). This method will be termed *oblique-field method* in the following although it is not always an appropriate terminology.

The oblique-field method has following advantages; (1) the feedback effect is expected not to be serious, (2) relatively large dynode gap can be taken, and (3) theoretical calculation shows that the gain increases exponentially with increasing applied voltage as far as the saturation factors such as the ion feedback and the field distortion due to wall charging do not an effect.

In the present work, electron multipliers of parallel plate type which were operated according to the multiplication mode of the oblique-field method were used as an ion detector of a sector type mass spectrometer. The ion feedback effect was examined. Causes for unstability of the multiplier gain has also been discussed.

## §2. Gain characteristics of channeltron electron multipliers.

Gain calculations of channeltron electron multipliers have been made under the assumption that all of secondary electrons are liberated with a constant initial velocity normal to the surface. In the case of the ordinary method in which the equipotential lines are perpendicular to the channel, the gain  $G$  given by Novotskii et al. is

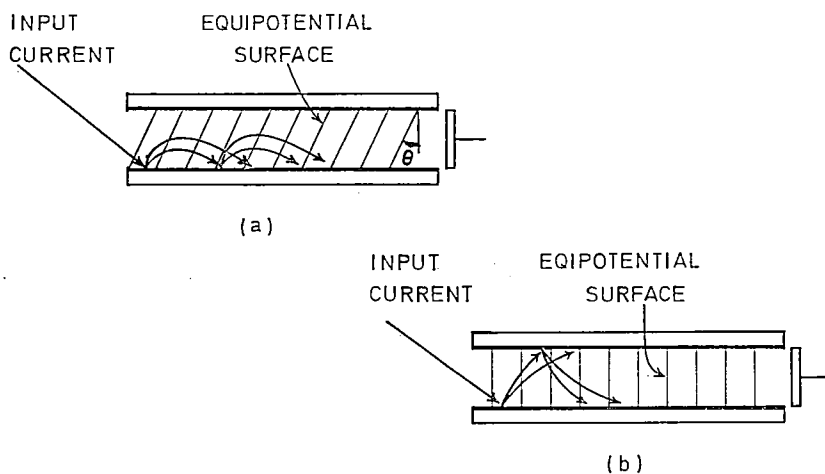


Fig. 1 Two types of electron-multiplication mode in parallel plate dynode electron multiplier; (a) the oblique-field method, (b) the ordinary method.

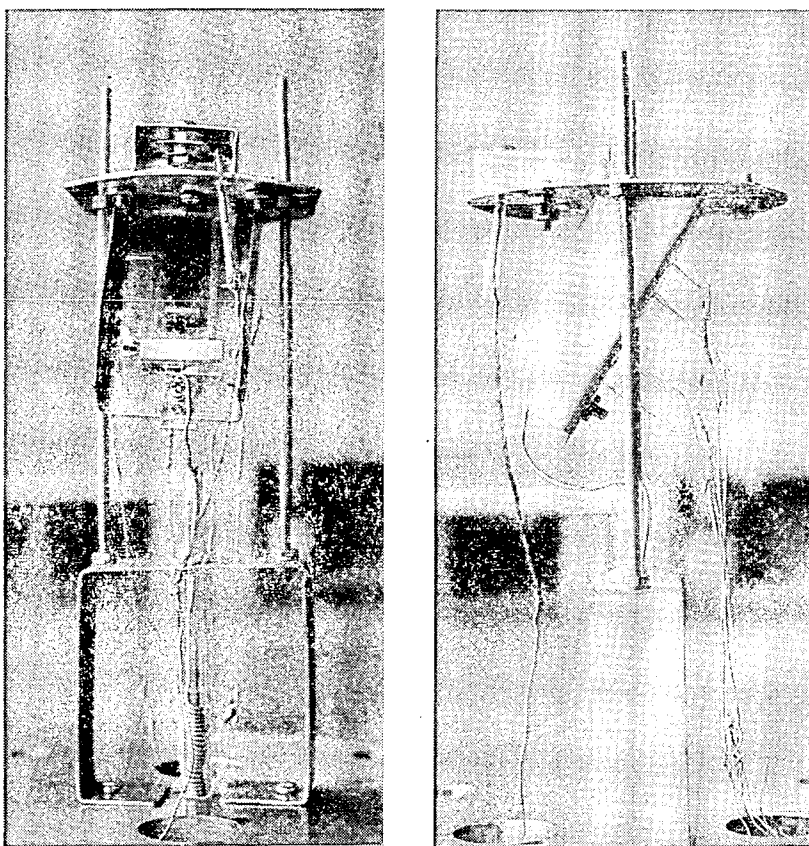


Fig. 2 Photographs of the ion collector in a mass spectrometer. The multiplier prepared is mounted as an ion detector.

$$G = \left( \frac{\delta_{\max} V_a^2}{4 V_{\max} W \alpha^2} \right) 4 W \alpha^2 / V_a \cdot \exp \left( \frac{4 W \alpha^2}{V_a} - \frac{V_a}{V_{\max}} \right) \quad (1)$$

where  $V_a$  is the applied voltage,  $\delta_{\max}$  is the maximum yield,  $V_{\max}$  is the accelerating voltage of primary electrons at which the maximum yield occurs,  $\alpha$  is the ratio of the dynode length to the dynode gap, and  $W$  is the work function of the surface. It is easy to show that there is a potential  $V_a$  which maximizes the gain as a function of  $V_a$ . On the other hand, the gain in the oblique-field method is<sup>40</sup>

$$G = \left\{ \frac{4 W \delta_{\max} \cot^2 \theta}{V_{\max}} \cdot \exp \left( 1 - \frac{4 W \cot^2 \theta}{V_{\max}} \right) \right\} V_a \tan^2 \theta / 4 W \quad (2)$$

where  $\theta$  is the angle between the electric field and the surface\*. In this relation, the applied voltage  $V_a$  is contained only in the index term. This shows that the gain increases exponentially with increasing applied voltage as far as the saturation effect does not appear. Moreover, the gain expressed by Eq. (2) is independent on the parameter  $\alpha$ , indicating that one can take the dynode gap wider than that in the ordinary method.

### § 3. Experimental.

Dynodes were produced by evaporation of a resistive substance (carbon) and a compound with large electron emission yield (aluminium oxide) onto glass plates ( $20 \times 40 \times 1.8$  mm).

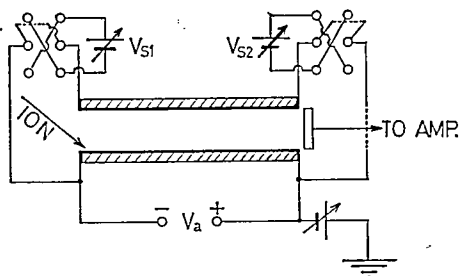
Copper was evaporated on both ends of the glass plate for electric contact, 1 mm width on one end and 3 mm width on the other end. Incident ions were directed to the electrode of 3 mm width. On the glass plate, carbon and then aluminium were evaporated. The latter is converted into aluminium oxide by air exposure. Values of the dynode resistance were between  $50 M\Omega$  and  $300 M\Omega$ . After heat treatment up to temperatures around  $300^\circ C$  in vacuum for half-hour periods, two plates were mounted parallel with a spacing of 2~3 mm. The multiplier produced was mounted in a sector type mass spectrometer as an ion detector (Fig. 2). The electric circuit for the multiplier is shown in Fig. 3. All measurements in this work were carried out by the use of  $He^+$  ions from a Nier-type ion source accelerated to a kinetic energy of 1.3 keV, and in a vacuum of  $5 \times 10^{-6}$  Torr except for the pressure dependence of gain. The output end of the multiplier was set at a small negative potential with respect to the ground. The input end was operated at a high negative potential  $V_a$ . Therefore, the ions strike the copper electrode of the input end with a total energy of 1.3 keV plus an energy nearly equal to  $eV_a$ .

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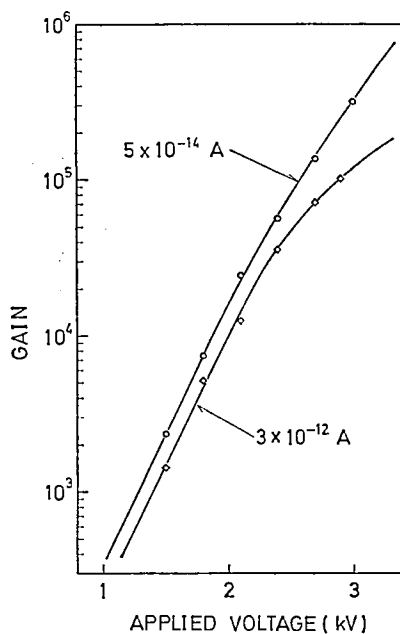
\* Strictly speaking, the initial kinetic energy of produced secondary electrons is neglected in this calculation. If it is taken into account, the gain  $G$  will be

$$G = \left\{ \frac{\delta_{\max} W (4 \cot^2 \theta + 1)}{V_{\max}} \cdot \exp \left( 1 - \frac{W (4 \cot^2 \theta + 1)}{V_{\max}} \right) \right\} V_a \tan^2 \theta / 4 W$$

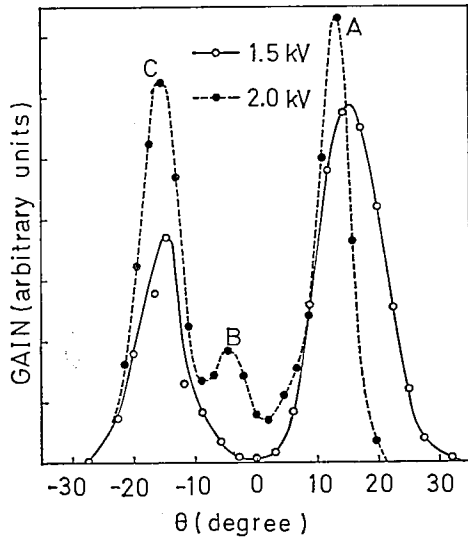
where  $eW$  is the mean initial kinetic energy of secondary electrons. However, the optimum value of  $\theta$  is around  $17^\circ$ , and it can be easily shown that the kinetic energy is negligible for such values.



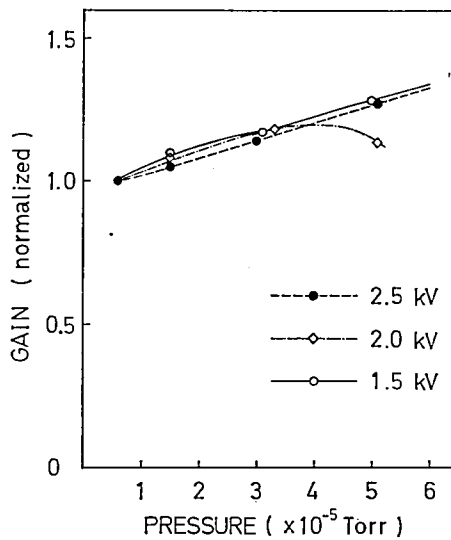
**Fig. 3** Circuit for the continuous dynode electron multiplier.



**Fig. 4** Gain as a function of the applied voltage for two different values of incident ion current.



**Fig. 5** Variation of gain with  $\theta$ . Different curves correspond to different values of applied voltage. Three peaks are denoted by A, B and C.



**Fig. 6** Pressure dependence of gain. Different curves are for different values of applied voltage. These are normalized to 100 at a pressure of  $5 \times 10^{-6}$  Torr.

#### § 4. Results and discussion.

Fig. 4 shows the gain characteristics of the multiplier as a function of  $V_a$ . Two different curves correspond to different values of primary ion current. A departure from the exponential gain characteristics is evident. This can be interpreted in terms of the saturation effect caused by space charge and field distortion due to wall charging. Moreover, there is a possibility that the change in the film temperature plays an important role<sup>(4)</sup>. In order to demonstrate that the multiplier operates practically according to the present multiplication mode, the change in gain with  $\theta$  was examined. Fig. 5 shows two curves corresponding to different values of applied voltage obtained with a typical specimen. It is clear from the curves that the multiplication is done according to this mode. Peak A and C correspond to the multiplication according to the present mode, and peak B to the ordinary mode. This is further confirmed from the fact that the optimum values of  $V_{s1}$  and  $V_{s2}$  in Fig. 3 are proportional to the applied voltage. No peak corresponding to B can be found in the curve of 1.5kV. This may be because of ununiformity of the dynode film.

It is shown in Fig. 5 that the angle  $\theta$  where the gain takes its maximum is about  $17^\circ$ . In the present method, some of ions produced in the channel can collide with the opposite surface. Their kinetic energy at the surface will be in proportion to the applied voltage. For example, when the dynode gap, the length of multiplier and the applied voltage are 2mm, 40mm and 2kV, respectively, the ions produced near the electron-emitting surface will get energy of about 330eV. This value is sufficient to produce a second generation of secondary electrons at the opposite surface. From this point of view, the ion feedback phenomenon is expected to be present even in the multiplication mode following Hamish's principle.

The pressure dependence of the gain obtained from peak A is shown in Fig. 6. Different curves correspond to different values of applied voltage. The curves are normalized to 100 at a pressure of  $5 \times 10^{-6}$  Torr. Although some ion feedback is still evident, the present method can reduce the effect to a considerable extent<sup>(4)</sup>. Since electron multipliers are generally used under a nearly constant pressure, the pressure dependence as shown in this study would not be serious. If the dynode surface of opposite side is replaced by a surface with small electron emission yield, the feedback effect will be further reduced.

One of the problem which is undesirable in practical application is a decreasing of gain during operation. Likely mechanisms to explain this behavior are as follows; (1) degassing of adsorbed gases on the dynode surface, (2) pump oil contamination, (3) surface damage during operation, and (4) decomposition of the compound.

In this work, the decrease was observed as well. However, there was a somewhat rapid rate of decrease within a several tens of minutes after having

the potential applied. After that, a very slow rate of decrease followed. The decomposition of the compound seems not to be important, because a thin film of evaporated aluminium can be oxidized easily even in the atmospheric surroundings around  $5 \times 10^{-6}$  Torr.

The rapidly decreasing was present not only when the multipliers produced were for the first time used, but every time these were used repeatedly. When the potential was applied for a long time before ions were permitted, the phenomenon was inconspicuous. This may be strongly related to the electron emission mechanism from the two-layered film in which a conductor is covered with an insulator or a semiconductor. The temperature rise of the layer by Joule heating and electron bombardment can remove the positive charge, which is considered to be a reason for high secondary emission of some kinds of compound, left behind by the emission of the secondary electrons<sup>12</sup>. This results in the decrease of electron emission yield.

The phenomenon of secondary electron emission from thin layers is of interest from not only a practical but also a physical point of view. There are a few theoretical explanations for the secondary electron emission. However, no theory has yet been found which satisfactorily covers all the observed phenomena. Further development of the theory is expected.

## § 5. Conclusion.

It has been found that the oblique-field method provides a way of solving the problem of the ion feedback effect in continuous dynode electron multipliers. This method has a disadvantage that the voltage  $V_{s1}$  and  $V_{s2}$  have to be changed with changing the applied voltage. If two dynodes are mounted so as to look sideways at the copper electrode of the opposite side each other, this procedure will be eliminated.

In the present study, two-layered film consisting of two layers of carbon and aluminium oxide was used. Aluminium oxide was used as an electron emitter because of its high secondary emission. This seems suitable to obtain high gain with relatively low applied voltages. It is desirable to use as large values of dynode resistance as possible because the secondary electron emission from this kind of films is largely dependent on temperature.

Evaporated carbon films seem to be unstable to temperature changes if they are not heat-treated at a high temperature ( $>1000^\circ\text{C}$ ). In the present study, however, the heat treatment was limited because of the electric contact consisting of copper and an adhesive.

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### References.

- (1) C. N. Burrous, A. J. Lieber, and V. T. Zaviantseff : Rev. Sci. Instrum., 38 (1967) 1477.
- (2) N. N. Lewis, L. S. Van Loon, and T. A. Mayer : Rev. Sci. Instrum., 39 (1968) 1386.
- (3) E. Yellin, L. I. Yin, and I. Adler : Rev. Sci. Instrum., 41 (1970) 18.
- (4) W. G. Wolber and B. D. Klettke : Rev. Sci. Instrum., 41 (1970) 724.
- (5) R. A. Heppner and D. P. Donnelly : Rev. Sci. Instrum., 41 (1970) 1513.
- (6) J. E. Lester : Rev. Sci. Instrum., 41 (1970) 1513.
- (7) G. R. Carruthers : Rev. Sci. Instrum., 41 (1970) 1882.
- (8) C. S. Evans : Rev. Sci. Instrum., 36 (1965) 375.
- (9) H. Hamish : Zets. angew. Phys., 14 (1962) 1962.
- (10) H. Ezoe : A. Koyama, and I. Nishi, Mass Spectroscopy (Japan), 18, No.3, (1970) 1161
- (11) T. Nagata : Reseach Bull. Meisei Univ. (Physical Science and Engeneering), No.9 (1973).
- (12) H. Bruining : *Physics and Application of Secondary Electron Emissin* (Pergamon, London, 1954) p88
- (13) M. Kanayama, T. Konno, and S. Kiyono : Rev. Sci. Instrum., 40 (1969) 129.