

Effects of Joule Heating on the Gain of Continuous Dynode Electron Multipliers

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§1. Introduction.

Since an idea of continuous channel electron multiplier was presented by Earnsworth in 1930, many multipliers using the idea have been reported^{(1)~(5)}. These can be divided into two groups, capillary type and parallel plate type. Recently, the capillary type has received practical application. The parallel plate type multipliers involve many problems to be solved. However, they are characterized by the property that one can easily prepare them with only evaporation technique.

The dynode of the parallel plate type multiplier has been produced mainly by evaporation of a substance having a suitable conductivity and a secondary emission yield larger than unity onto a glass plate. There is another way in which two layers are evaporated onto a glass plate, first a layer of high resistance providing a steady increasing potential along the plate, and then an oxidized metal layer as an electron emitter. Elements such as molybdenum, germanium and carbon have been generally used as a resistive substance, and oxidized metals such as Al_2O_3 and MgO have been used as an electron emitter.

Recently, Fiser has reported that multipliers which were stable for a long time were obtained by the use of only carbon as a film substance⁽⁶⁾. There is an example in which a uniform film is formed by deoxidation of a plate of flint glass in hydrogen gas surroundings⁽⁷⁾.

In continuous dynode electron multipliers, Joule heat is produced when a potential is applied between two ends of a multiplier. So far, there are few reports related to the problem how the characteristics of the multipliers are influenced by Joule heat. This problem is important for construction of the multipliers because the gain of multipliers is considerably influenced by the property of the secondary electron emission from the dynode surfaces.

In the present work, the secondary electron emission from the evaporated dynode films consisting of two layers of aluminium oxide and carbon has been experimentally studied. The increase in temperature of the films as a function of applied voltage and the secondary electron emission as a function of film temperature were examined. Their effects on the gain characteristics of continuous dynode electron multipliers are also discussed on the basis of the experimental results.

§2 Experimental

In order to estimate the temperature change of the film when a potential is applied, dynodes prepared for constructing continuous dynode electron multipliers were used. Method of producing the dynode is as follows. First, copper was evaporated on two ends of a glass plate cut into $15 \times 40 \times 1.8$ mm using a evaporation apparatus. This is for electrical contact to the dynode film. Then, carbon was evaporated with a electron-bombardment-type evaporator to a desired thickness. The resistance of the carbon film ranged from $50 \text{ M}\Omega$ to $500 \text{ M}\Omega$. Finally, aluminium was evaporated on the carbon film to an about 250 \AA thickness (Fig. 1). The evaporated aluminium is converted into aluminium oxide (Al_2O_3) when exposed to air. Glass plates were 45 cm away from the evaporator.

These dynodes were inserted in the center of a box made from stainless steel plate. The box was set in the belljar of the evaporation apparatus, which was evacuated to about 5×10^{-6} Torr with an evacuation system consisting of an oil diffusion pump and an oil rotary pump. After heat treatment up to about 300°C with heaters surrounding the box, measurements were made of the temperature dependence of the dynode resistance and of the relation between the applied voltage and the dynode current. The former was made in the method of changing the applied voltage so that the current was kept constant, and under such a small current condition that the temperature change of the film was negligible. In the latter, each experimental value was read about 30 minutes after from each set of the applied voltage so that equilibrium was reached. From the two kinds of measurement, the increase in temperature of films was estimated under the assumption that the increase is due to only Joule heating.

The determination of the secondary emission coefficient of the dynode film described above suffers complications as electron transport is not in general sufficient. So that samples with thicker carbon film were made to increase the conductivity of the film. The experimental apparatus used was similar to that of Fujii et al⁽⁶⁾. The measurement was made in the range of $20^\circ\text{C} \sim 80^\circ\text{C}$ with another vacuum equipment. Several band heaters were wound around the vacuum chamber to raise the temperature in the chamber. Each experimental value is an average of two values measured with increasing temperature and with decreasing temperature to avoid the confusion between the temperature-dependent change and the time-dependent change of the yield. Background during measurements was about 5×10^{-6} Torr. The primary ion current was around 5×10^{-10} A. The cross sectional area of the ion beam was 0.8 mm^2 .

§3 Results and discussion.

§3.1 Increase in temperature of the film due to Joule heating.

It is well known that evaporated films of electric conductor have a very

high negative temperature coefficient of resistance in the same manner as semiconductor has⁽⁹⁾. The dynode current as a function of applied voltage would show some degree of nonlinearity, due to heating of the film and its negative temperature coefficient of resistance. In the present work, the departure from the linear characteristics was also evident.

The estimated values of the temperature change are shown in Fig. 2 for two different values of resistance. Because such values, of course, would differ with different conditions of heat treatment and vacuum evaporation, this analysis should not be used for quantitative prediction of multiplier behavior. It is apparent, however, that the increase in temperature is more remarkable for smaller values of resistance.

§ 3.2 *Temperature dependence of the secondary emission yield.*

Apart from changes of the yield at the melting point, Curie point and transition points, many authors have reported that they could not observe any influence of temperature on the secondary emission yield of metals⁽⁹⁾. In regard to metal compounds and their evaporated layers, however, experimental evidence available is rather limited. Only experimental evidence is that on oxide-coated cathode. Johnson's results show that the yield has a minimum as a function of temperature; as temperature T increases from 0°C there is an initial decrease of the yield, as T increase still more, the yield passes a minimum and increases again.⁽¹⁰⁾

The temperature dependence of the yield of the evaporated film obtained in this study is shown in Fig. 3 for three different cases of primary energy. This result indicates that the film has apparently a negative temperature dependence of the yield in the range of interest ($20^{\circ}\text{C} < T < 80^{\circ}\text{C}$). If the yield δ as a function of T is approximated by a simple analytical function

$$\delta = \delta_0(1 - \beta T)$$

the coefficient β is about 0.001 in this temperature range. In this formula, δ_0 is the yield at 0°C.

Aluminium oxide and simple compounds of the alkali and alkaline earth metals have a high secondary emission yield. The reason for this high yield has been explained in terms of the energy level model. According to this model, the unoccupied band in these compounds is at such a level that electrons are able to leave the substance without any additional energy. However, this model cannot explain the temperature dependence of the yield as observed in this study. An alternative explanation is in terms of the formation of an internal space charge in the layer. This charge can be removed or accumulated by a change in temperature, causing a change in the secondary emission yield. If it is valid, the secondary electron emission from films of the metal compounds having an electric conductor under them will be temperature-dependent.

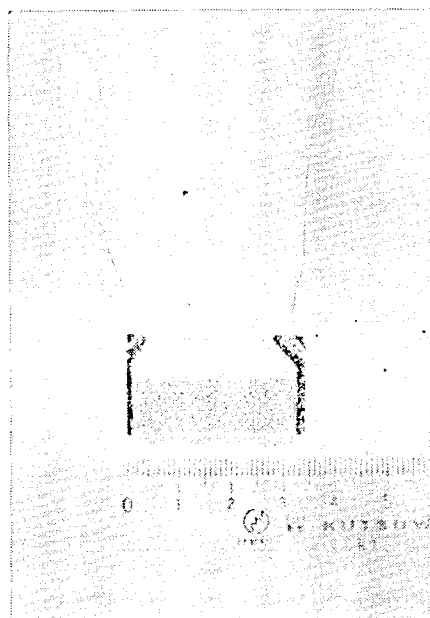


Fig.1 Photograph of the dynode.

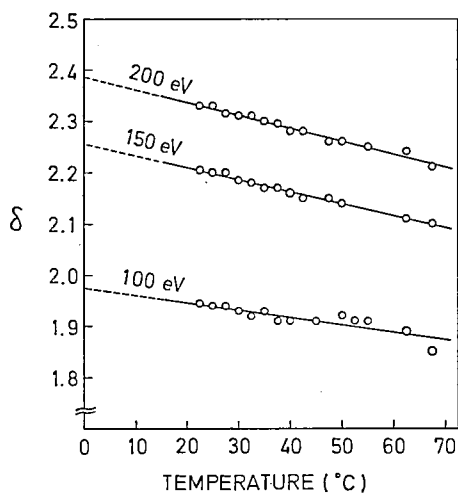


Fig.3 Temperature dependence of the secondary emission yield of the dynode film which is composed of carbon covered with thin layer of aluminium oxide.

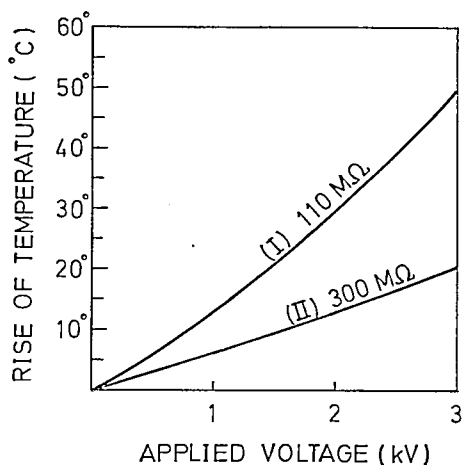


Fig.2 Estimated temperature change of dynode film for two values of dynode resistance.

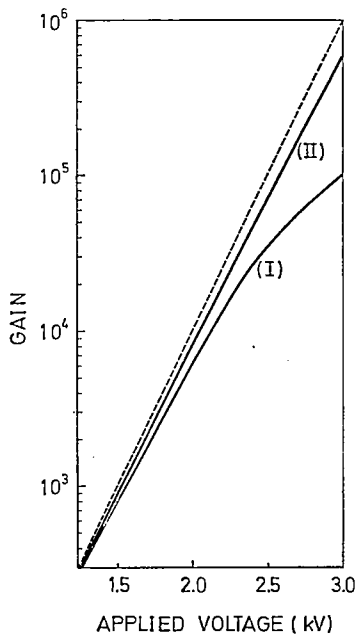


Fig.4 Departure from the exponential gain characteristics caused by increase in film temperature, calculated from curves (I) and (II) in Fig.2.

§ 3.3 The effect of increase in temperature of the film on multiplier gain.

The gain G of channeltron electron multipliers can be derived as a function of several parameters under a few assumptions;

$$G=f(V_a, \delta_{\max}, V_{\max}, W, \alpha, \dots\dots\dots)$$

where V_a is the applied voltage, V_{\max} is the electron accelerating voltage corresponding to a maximum yield δ_{\max} , α is the ratio of the dynode length and the dynode gap, and W is the work function of the surface. In addition, in the method proposed by Hamish in which an electric field applied obliquely against dynode surface, the angle between the dynode surface and the electric force is included as a parameter.

Now, we can consider the effect of the increase in temperature of the film due to Joule heating on multiplier gain. Taking into account that βT is very small compared to unity, we obtain the gain

$$G=\delta_0^n \{1-\beta T(V_a)\}^n = \delta_0^n \{1-n\beta T(V)\}$$

where n is the step number of electrons, and $T(V_a)$ means that T is a function of V_a . The term δ_0^n in this relation corresponds to the function $f(V_a\dots)$ given above. The term $(1-n\beta T)$ is the correction term due to the temperature change. This relation indicates that the gain of the multipliers having a layer of aluminium oxide (perhaps, of some of other metal compounds) as an electron emitter would show a departure from the exponential gain characteristics, even if other saturation factors do not show an effect. Fig. 4 shows the saturation effect which was deduced from curves (I) and (II) in Fig. 2 on the assumption that n is 10 at applied voltage of 1.5kV, and is proportional to the applied voltage. It is also assumed that the gain increases exponentially as a function of V_a in the absence of saturation factors. It seems that there are a few evidences showing this effect in the literature⁽⁴⁾⁽¹¹⁾.

§ 4 Conclusion.

It has been known that the saturation of gain in channeltron electron multipliers is caused by space charge and/or field distortion due to wall charging. The present work shows that in the multipliers whose electron-emitting surface consists of aluminium oxide, the increase in temperature further promotes the saturation. This suggests that multipliers which have an oxidized metal layer as an electron emitter may have similar effect. A higher dynode resistance has to be used to avoid the effect, although the upper limit is set by the field distortion.

In order to examine whether the characteristics of continuous dynode electron multipliers with layer of only one kind of material are affected by the temperature change of the layer or not, the author carried out the investigation of the secondary electron emission from evaporated carbon layers as well as aluminium oxide. An accurate conclusion was not obtained because of a complication

which made the results uncertain and irreproducible. It seems that the electron emission from carbon film is largely dependent on evaporating conditions, heat treatment, vacuum circumstances, baking etc.

References

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