On the Build-up Mechanism of the Microwave Gas Breakdown

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It has been reported that the resolving power of the microwave counter is very high. In connection with this counter, the author has investigated the build-up mechanism of the microwave gas breakdown. But in the author's experiments, he has not been able to detect such pulses associated with eletron avalanche which, he expected, would occur as in the case of the d. c. gas breakdown. The author proposes a theory to explain this result.

INTRODUCTION

The breakdown mechanism of the direct current gas discharge has been investigated by Loeb[1], Meek[2], Raether[3], Fletcher[4] and many other authors[5], and especially S.Kojima[6] investigated this problem by applying the method of electronic counter, but as to the breakdown mechanism of the microwave gas discharge, its fundamental researches have scarcely been performed except for the investigation concerning its practical application to TR-tubes. The author has made experiment by the method of electronic counter to make clear the breakdown mechanism of the microwave gas discharge, but could not detect such pulses associated with electron avalanche which, he expected, would occur as in the d.c. gas breakdown. This result seems to suggest an essential feature of the breakdown mechanism of the microwave gas discharge, so the author proposes a theory to explain this result.

EXPERIMENT

In this experiment, the author used the same coaxial type cavity as reported in his previous papers[7][8][9] with the only difference that the center wire is electrostatically isolated from the outer cylider by glass beads in order to make it possible to use this cavity as a Geiger-Müller tube as well (Fig. 1).

Fig. 2 shows the block diagram of the arrangement of this experiment. The main amplifier is of the Model-100 type which is reported in "Electronics" by Elmore and Sands[10] and its gain about 100 db. The gas used was a mixture of 90 % argon and 10 % ethyl alcohol kept at various pressures from 4 to 70 mmHg.

First, the coaxial cavity was operated as an ordnary Geiger-Müller tube by applying a d.c. high potential between the outer and the central electrodes, and Fig. 3

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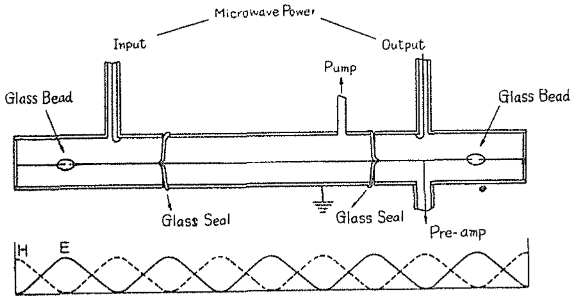

Fig. 1. Discharge tube used in this experiment. Two curves shown under this tube represent respectively the intensity distributions of electric (—) and magnetic (···) fields.

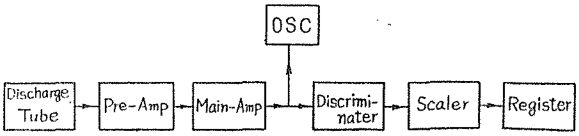

Fig. 2. Block diagram of the apparatus.

shows the threshold voltage versus gas pressure p. Next, we removed the high d.c. potential and fed microwave power into the cavity. The gas breakdown did not occur at lower powers, but as the power was increased, it suddenly occurred at a certain value of the power and at the same time the noise associated with this breakdown was found on the screen of the oscilloscope. But we could not detect any pulse arising from electron avalanche which might appear just before the breakdown

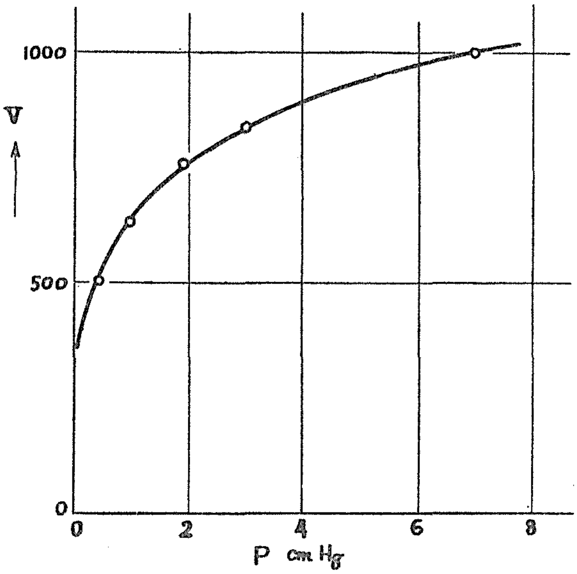

Fig. 3. The threshold voltage versus gas pressure p.

occurs, although in the d.c. gas breakdown such pulses were observed. Finally, it was found that the curve of Fig. 3 was not affected at all by superposing the mic-ro wave power on the d.c. high potential.

THEORY

Fletcher's theory[4] is typical among many theories on the mechanism of the d.c. gas breakdown. He has considered as follows: The average distance of an electron from the center of the electron avalanche is called the avalanche radius and is equal to $(6Dt)^{\frac{1}{2}}$, where D is the electron diffusion coefficient and t is the drift time. The electron avalanche moves from the cathode to the anode, becoming larger and larger and leaving the positive ions behind it. The breakdown occurs at the instant when the space charge field E becomes equal to the applied d.c. field E_l (Fig. 4). This is Fletcher's consideration.

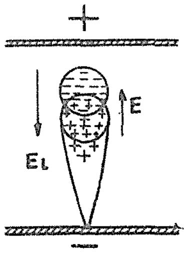

Fig. 4. Space charge distribution of the avalanche.

Furthermore, the electron avalanches are statistically formed and Wijsman[11] has studied in detail the formation of electron avalanche and derived the following equation:

$$P(n,d) \cong (1/\bar{n}) \exp(-n/\bar{n}), \qquad (1)$$

where $P(n,d)$ is the probability that a given electron which starts from the cathode grows to an avalanche of n electrons at a distance d from the cathode and $\bar{n}$ is the expectation value of n. S.Kojima and K.Kato[6] have justified this equation by the experiment in the d.c. gas breakdown at low pressure.

Then, what happens in the microwave gas breakdown? In the microwave gas breakdown, the drift current, which is oscillatory in this case, is not capable of transporting electrons in the discharge tnbe, and therefore the electron losses to the walls are caused only by diffusion[12][13]. But it seems to the author that during the build-up process the wall effects can be neglected because the electron avalanche is considered to exist, if any, in a very limited region as compared with the discharge space.

In connection with this problem of wall effect, L.M. Hartman[14] has treated the case in which the microwave gas breakdown takes place in an infinite medium by assuming that the electron removal is mainly due to the recombination of electrons with positive ions and the diffusion losses are zero, and concluded that the electron density increases and thus the breakdown ocurs at a certain field strength of microwave. As he has treated with the energy distribution function which he derived, he has not been so successful in clarifying the build-up process of the breakdown.

Herlin and Brown[15] have developed the diffusion theory of microwave gas breakdown. They started from the following continuity equation:

$$\partial n_-/\partial t = \nu n_- + D\nabla^2 n_-, \tag{2}$$

where n_- is the electron concentration and ν is the net production rate of elect-rons, i.e. the difference between the ionization rate per electron and the attachment rate to neutral molecules per electron. They obtained from Eq. (2),

$$\psi = \psi_0(x,y,z) \exp\,(-t/\tau), \tag{3}$$

where $\psi = Dn_-$. The boundary conditions that ψ is zero on the walls result in a set of characteristic values $1/\tau_a$ for $1/\tau$ and also a corresponding set of orthogonal functions ψ_a. The back ground electron density at the instant the microwave field is applied, may be expanded in a series of functions ψ_a. Each term therafter rises or decays, depending on whether τ_a is negative or positive. This consideration by Herlin and Brown suggests to the author that there may exist the electron avalanche in the microwave breakdown also.

Furthermore, Herlin and McCarthy[16] have reported that there is the formative time lag in the microwave counter. This also seems to support the above suggestion.

Then, why were pulses not observed in our experiment, notwithstanding that there may exist electron avalanche in the microwave breakdown?

To answer this question, we will reconsider Eq. (2) for the microwave, breakdown following Fletcher's treament of the d.c. gas breakdown. Fletcher has considered the following equation for the electron avalanche:

$$\partial n_-/\partial t = \alpha v n_- + D\nabla^2 n_- + v\,(\partial n_-/\partial z), \tag{4}$$

where α is the first Townsend coefficient and v is the drift velocity of electrons by the applied d.c. field. By comparison, (2) may be obtained from (4) by setting $\nu = \alpha v$ and dropping the last term of Eq. (4) which means the drift motion of electrons. Following Fletcher's method, the exact solution of Eq. (2) is derived:

$$n_- = (4\pi Dt)^{-\frac{3}{2}} \exp\left(-\frac{r^2}{4Dt} + \nu t\right). \tag{5}$$

The continuity equation of positive ions is given, because of the smallness of their diffusion coefficient, as follows:

$$dn_+/dt = \nu n_-, \tag{6}$$

where n_+ is the concentration of positive ions. Using (5), Eq. (6) gives the following solution :

$$n_+ = \nu \int_0^t (4\pi Dt')^{-\frac{3}{2}} \exp\left(-\frac{r^2}{4Dt'} + \nu t'\right) dt'. \tag{7}$$

This integral cannot be evaluated in terms of well-known functions, but its behavior necessary for us can be seen from this equation.

Eqs. (5) and (7) show that the spatial distribution of both the electrons and the positive ions are spherical and the average radii of their respective spheres from their common fixed center are the same value $(6Dt)^{\frac{1}{2}}$, as seen from the simple consideration. Also, we are considering the case in which electrons have not yet reached the walls though they diffuse, so the total numbers of the electrons and the positive ions must bee the same.

Thus, we conclude that some electrons of the background produced by some sources can become a nucleus of a pair of electron and positive ion avalanches. These avalanches expand uniformly in all directions at the same rate, and moreover the total numbers of both particles existing in one pair are the same. Such avalanches apparantly can not induce any current in the outer electric circuit.

Thus we can explain our explerimental result that we could not detect the pulses associated with the electron avalanche.

In conclusion, the author wishes to express his sincere gratitude to Professors K.Honda and S.Kojima for their helpful discussions and also to thank Professor I. Takahashi for his suggestion and encouragement to this work.

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