June 23, 1936. J. H. O. HARRIES 2,045,527

ELECTRON DISCHARGE TUBE

Original Filed Feb. 26, 1932 3 Sheets-Sheet 1

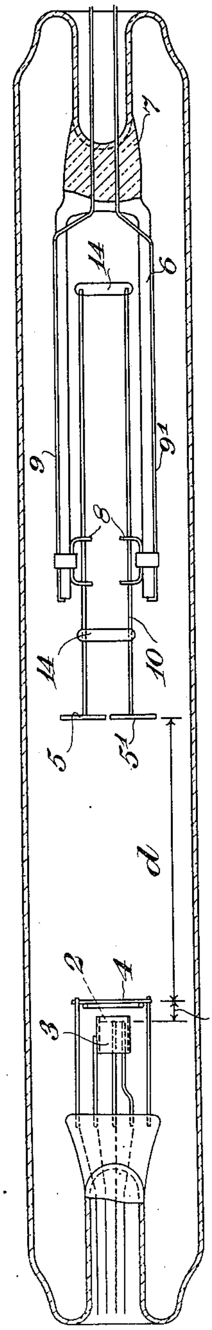

Fig.1.

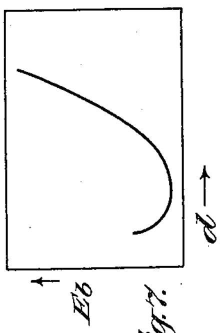

Fig.7.

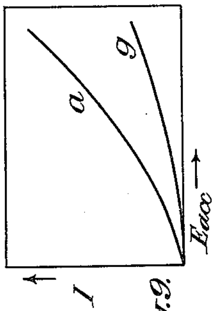

Fig.9.

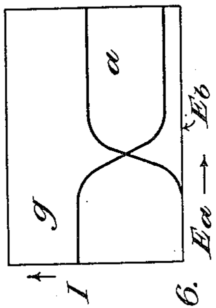

Fig.6.

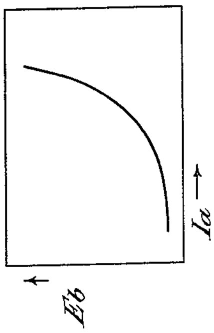

Fig.8.

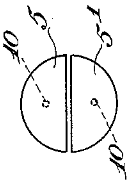

Fig.5

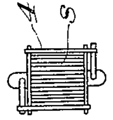

Fig.4.

Fig.3.

Fig.2.

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ELECTRON DISCHARGE TUBE

Original Filed Feb. 26, 1932 3 Sheets-Sheet 2

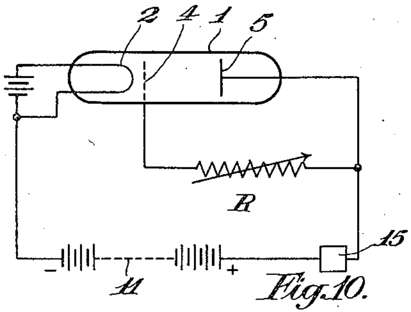

Fig.10.

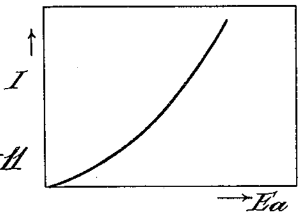

Fig.11

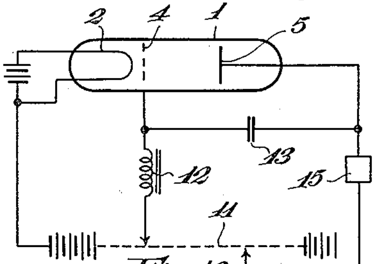

Fig.12.

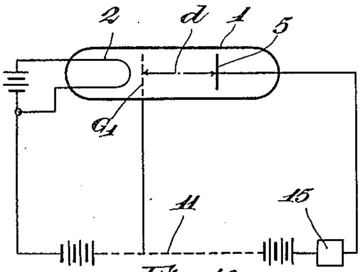

Fig.13.

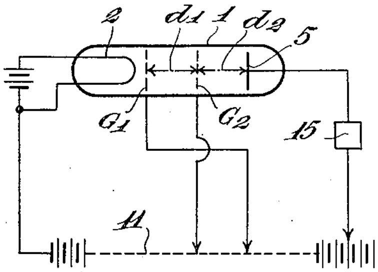

Fig.14.

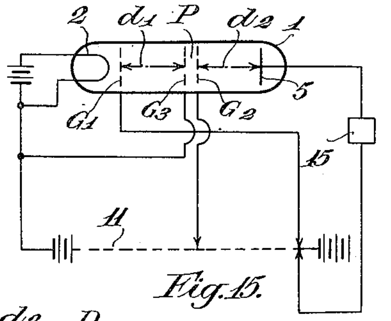

Fig.15.

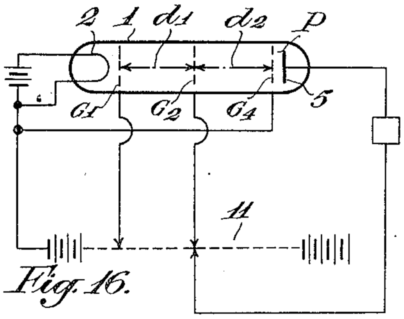

Fig.16.

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ELECTRON DISCHARGE TUBE

Original Filed Feb. 26, 1932 3 Sheets-Sheet 3

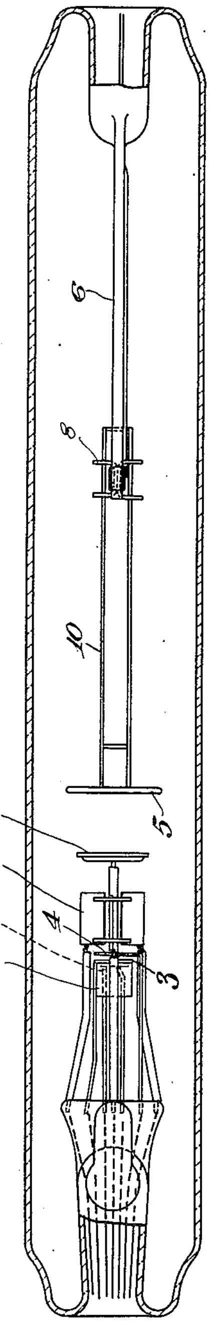

Fig. 17.

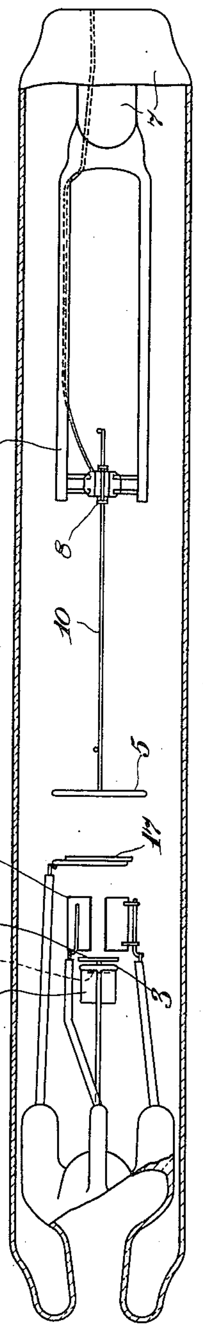

Fig. 16.

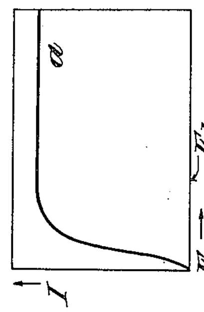

Fig. 25.

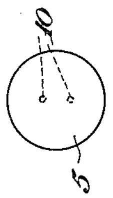

Fig. 24.

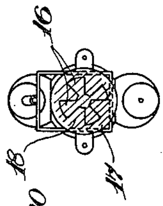

Fig. 23.

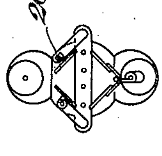

Fig. 22.

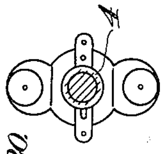

Fig. 21.

Fig. 20.

Fig. 19.

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ELECTRON DISCHARGE TUBE

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Original application February 26, 1932, Serial No. 595,339. Divided and this application March 18, 1933, Serial No. 661,512. In Great Britain March 10, 1931

13 Claims. (Cl. 250—27.5)

This invention relates to the production and control of electronic streams, particularly, though not exclusively, to discharge tubes where the current is varied in intensity by some means (for instance by deflecting the stream as in my British Patent No. 328,680) and these variations are employed to energize a load usually connected in the anode circuit of the tube.

In electric discharge vacuum tubes, streams of electrons the lengths of which are great in proportion to their cross section have the advantage that the capacities between electrodes can be greatly reduced, and the undesirable retrograde movement of secondary electrons from the anode is prevented. Furthermore, such streams of electrons can, in contradistinction to shorter streams, be deflected to a considerable degree and consequently can be used in tubes which are worked by deflection of the stream of electrons therein, for the purpose, for instance, of multiplying frequencies. (For this purpose, for example, a stream of electrons may be periodically moved by means of an alternating current over a perforated plate acting as the anode, so that a series of current impulses is produced in a closed output circuit connected to this plate.) Hitherto, however, the ratio between the voltage used to produce the space current, and the intensity of the current, in such streams of electrons which are long and small in cross section, has been so high that known apparatus worked by such streams of electrons have been unsuitable for practical use in incandescent cathode tubes and the like. Therefore, previous practice has been confined to the use of tubes with streams of electrons the lengths of which were comparatively short in proportion to their cross-sections, (and which were produced by voltages which were comparatively small in proportion to the intensity of the current), although such tubes exhibited disadvantageously high capacities between the electrodes a tendency towards the undesirable retrograde movement of secondary electrons, and the streams therein cannot be deflected to any useful extent.

An object of the present invention is the production of streams of electrons in which the ratio of the voltage to the intensity of the current is small, and the length in proportion to the cross-section is great, whereby the disadvantages of the two kinds of streams hereinbefore mentioned are avoided.

Examples of apparatus

The operation of the invention will now be described with reference to the accompanying drawings, wherein

Figure 1 shows a highly evacuated tube which will operate according to the invention;

Figures 2, 3, 4 and 5 are electrodes in such a tube;

Figures 6, 7, 8 and 9 are forms of characteristic curves obtainable with such a tube;

Figures 10 and 12 represent circuits which can be used with the tube;

Figure 11 is a form of curve obtainable with the circuit shown in Figure 10;

Figures 13, 14, 15 and 16 represent further circuits illustrating the combination of electrodes;

Figures 17 and 18 show sections at right angles of a tube suitable for use as a frequency multiplier as described in British Patent No. 328,680;

Figures 19, 20, 21, 22, 23 and 24 are electrodes in such a tube;

Figure 25 is a form of curve obtainable with such a tube.

Similar parts in different figures have the same reference marks.

The word "mesh" will be meant to include what is meant by a "grid" or "grating" when here applied to electrodes having apertures.

In Figure 1 the tube **1** is highly evacuated. The cathode **2**, Figure 2, which can conveniently consist of a flat pancake spiral, is heated in the usual way so as to emit electrons. A circular hood **3**, Figure 3, is arranged partly to enclose the cathode **2**, leaving it open towards an accelerating electrode **4**, Figure 4. Separate electrodes which may form a divided anode **5, 5'**, Figures 1 and 5, are mounted in the tube **1** in such a manner that the distance *d* from the accelerating electrode **4** may be adjusted. The glass rods **6** forming part of the pinch **7** at the end of the tube support two brackets **8** which are connected by means of the wires **9** and **9'** to the outside of the tube. The anode **5, 5'** is supported on two rods **10** connected by glass rods **14** which slide in holes in the brackets **8**. Thus the characteristics may be altered for design purposes as aforesaid. The brackets **8** and rods **10** are both of metal and the anode **5, 5'** is therefore in electrical connection with the outside of the tube. The distance *d* may then be adjusted by moving the tube and sliding the anode **5, 5'** to a different position. The accelerating electrode **4** consists of a mesh **6**, the spacing between the wires of the mesh being indicated by *s*.

This tube illustrates a simple form of apparatus made in accordance with the present invention and its operation will be described with reference to Figures 6, 7, 8 and 9 which are the characteristic curves of the apparatus. In Figure 1 the cathode 2 is assumed to produce a space charge and it is required that a substantial portion of the electrons therein be made to form a stream from the cathode 2 to the anode 5, 5′. Figure 6 shows the form of the curve connecting the anode voltage E_a and the anode current and the current to the accelerating grid 4. The curve *g* is that of the accelerating grid current and that marked *a* is the curve of the anode current. For purposes of explanation it will be assumed that the distance *d* is about 7 c.m., the voltage of the accelerating electrode 4 is about 200, and that the anode voltage is gradually increased from zero upwards as shown in Figure 6. It will be seen that the entire space current goes to the accelerating electrode when the anode voltage is below a certain point. When this point has been reached the anode current rises fairly suddenly to a saturated value, the grid current dropping by a proportional amount. Once this point has been passed the anode current and grid current are saturated and the grid current is only a small portion of the total. The anode voltage at which the anode current becomes saturated will be referred to as the "breakdown" voltage of the tube. It is indicated by E_b on the graph Figure 6. A typical value of the anode current density after "breakdown" may be between 10 and 15 m. a. per square c. m. of the cross section of the stream when *d* is 7 c.m. Whatever the anode and accelerating grid voltages which are employed the ratio between the accelerating grid and anode currents are substantially constant at all anode voltages over the "breakdown" value.

In Figure 7 the "breakdown" voltage E_b is plotted against the distance *d* in c. m. This will be referred to as the "resistance curve". It will be seen that E_b rises very rapidly with an increasing value of *d* (providing certain conditions as regards the electron velocities, etc. are fulfilled) but has a minimum. This point occurs when the anode is fairly close to the accelerating electrode. The rise in E_b for smaller values of *d* is due to secondary radiation from the anode reaching the accelerating electrode. This transfer of secondary radiation is small, and not unduly detrimental, where the rate of change of the distance curve is only slightly negative.

The distance *d* may be set at this critical value (say 3 c. m.), and at this point the breakdown voltage wil be so low that it is possible to allow the anode voltage to become much less than the accelerating voltage without its going below the breakdown point and the anode current ceasing to be saturated. This is of particular importance when a load is connected in the anode circuit across which a considerable voltage drop is developed under working conditions. If the tube has a load impedance in the anode circuit, the current through which is to be varied in use, it will be realized that a considerable waste of power will occur if the anode voltage swing under working conditions has to be accommodated entirely above the accelerating voltage. This value of *d* when E_b is at a minimum will be referred to as the "critical anode distance".

In Figure 8 a typical graph between E_b and the anode current I_a for a given value of the distance *d* and the accelerating electrode voltage E_{acc} is shown. It will be seen to drop very rapidly for a certain range of values with a reduction in the anode current. It is also found that the shape of this graph is considerably affected by the efficacy of the focusing action of the electrodes, e. g. that of the hood 3 in Figure 1. I_a may be varied without altering E_{acc} by, for instance, varying the heating current to the cathode 2.

In Figure 9 the anode and accelerating grid currents are shown as functions of E_{acc}, with a constant value of *d* and with E_a greater than E_b, i. e. with the anode current in the saturated condition. The graphs are marked as in Figure 6. It should be noted that both are smooth and that the curve of their sum would be similar to that which one would expect to obtain if the accelerating electrode 4 in Figure 1 were a solid plate and did not pass any of the electrons on to the anode. If, however, the anode voltage falls below the breakdown point the graphs in Figure 9 will tend to cross.

Referring again to Figure 1, the accelerating electrode 4 is spaced by the distance *r* from the cathode. This distance is set to give the required space current at the voltage of the accelerating electrode to be used. The distance *s* between the wires in the mesh 6 is suitably arranged so that the apertures between the wires are not too small compared with the distance *r* in order to reduce the amount of current intercepted by the electrode 6. The distances *s* and *r* are a matter of compromise and are best determined by experiment in any given case. The wires forming the mesh 6 should be as thin as possible, and, when the tube is working above the break-down point in accordance with the present invention, the dissipation of anode current to these wires will not be excessive. In Figure 1, *r* may be about 2 mm. and *s* about 1 mm.

In a typical tube embodying the invention, the hood 3 will be of approximately one centimetre diameter with the cathode of slightly smaller area than the cross-sectional area of the hood and the accelerating electrode 4 will be approximately two centimetres square with 20 wires spaced apart at a distance of one millimeter and the anode 5 will be approximately three centimeters in diameter. The potential E_{acc} applied to the accelerating electrode 4 will be from 200 to 250 volts and the anode current will be 10 to 20 milli-amperes. In such a tube, the critical distance d_o will be from two to three centimetres.

It will be realized by those skilled in the art that, as is usual in electron discharge tubes, the best design for an actual tube for given purpose is best found by experiment, and that the exact form of the characteristics will vary considerably with the exact electrode assemblies used, although they will have characteristics broadly as shown. For this reason the design of a tube for a given purpose is best approached by means of a series of tests with movable electrode arrangements such as that shown in Figure 1. By this means the best compromise between the various quantities and the most satisfactory type of electrode to use will be easily ascertained. The value of various quantities quoted are thus only given for purposes of explanation and it is understood that they may be varied widely without departing from the scope of the invention. A trial tube can be constructed with movable electrodes to determine the best electrode assembly.

It will be seen that an essential characteristic of the tube illustrated in Figure 1 is that the differential impedance of the anode circuit is high. This is usually desirable. By interconnecting the anode **5** and, in this case, the accelerating grid **4** it is possible to reduce the impedance to a desired value.

In the following figures a load is represented by a numeral **15**.

Examples of transferred potentials

In Figure 10 the tube **1** is shown diagrammatically with the cathode **2**, accelerating electrode **4** and anode **5** represented therein. The distance *d* between the accelerating electrode **4** and the anode **5, 5′** is assumed to be large. The battery **11** is connected to the anode **5, 5′** in the usual manner to produce the anode current. Assuming that the tube is being employed as a relay or in other ways requiring that variations in the anode current are to operate a load impedance, this latter may be connected at **15** between the battery **11** and anode **5, 5′**. For instance, the anode **5, 5′** may be acting as the target electrode **7** in Figure 2 of my above mentioned British patent. The resistance R is connected between the anode **5, 5′** and accelerating electrode **4**. In accordance with the present invention the resistance R is of such a value that a considerable portion of the anode voltage is transferred to the accelerating grid **4** and therefore, if the anode voltage varies, the accelerating grid voltage varies proportionally. It will be seen by reference to Figures 6 and 9 that without the resistance R the change of anode current with anode voltage will be very small, but that a change of the accelerating grid voltage will produce a large change of anode current. It is of course assumed that the tube is working above the anode breakdown voltage. By suitably adjusting the value of the resistance R in Figure 10 the anode voltage variations which are thus transferred to the accelerating electrode may be made to cause a considerable change in the anode current, resulting in a large reduction in the anode differential resistance. The result will be an anode current characteristic of the form shown in Figure 11. The slope of this is quite large and because the breakdown voltage falls as Ia is reduced the curve is smooth and continuous from zero upwards. This arrangement is capable of a number of variations. For instance in Figure 12 the tube **1** has its anode **5** connected to the battery **11** through a load **15** as before. The accelerating electrode is connected to a tapping on the battery **11** through a choking coil **12**. Condenser **13** will transfer alternating potential variations of the anode to the accelerating grid without providing a path for the D. C. Thus the differential resistance of the tube in this circuit will be a function of frequency. Instead of the condenser **13** an A. C. network or tuned circuit may be substituted.

Explanatory theory of discoveries and invention

The explanation of the phenomena illustrated in Figures 6–12 may be regarded as follows:—

To the best of my knowledge the sudden breakdown of the anode circuit resistance from very high values to very low ones has not been previously demonstrated in practice in the manner shown in Figure 6. It may be shown from the theory of electron discharges ("Conduction of Electricity through Gases", J. J. Thomson, pp. 373, 3rd edition, 1928) that if all the electrons in a stream are of substantially the same velocity the only values which the space current can take up from a cathode to an anode will be either zero or a saturated state when all the electrons leaving the cathode reach the anode. This is because the electrons present at low or zero anode voltage will produce a space charge, equivalent to a definite negative potential gradient in the space between the accelerating electrode and anode and no current will pass unless the initial velocity of the electrons, is sufficient for them to overcome this opposing gradient. The current will therefore be either saturated or zero in value.

In Figure 1 the electrons passing into the space between the accelerating electrode **4** and the anode **5** will be given a velocity dependent on the voltage of the accelerating electrode **4**. Therefore all the electrons may be considered as having substantially the same velocity, and the above mentioned negative potential gradient will be formed in the space between the accelerating electrode and the anode. From the considerations above mentioned it would be expected that, at other than small values of *d*, on raising the anode potential, no anode current would flow until a certain critical point was reached when the resistance of the tube would suddenly break down and the current would reach a saturated value. In practice the effect of varying values of the initial velocity and of diffusion are not entirely negligible and therefore a small anode current would be expected before this breakdown value of anode voltage was reached, and for the same reason the breakdown would not be as sudden as the former considerations would indicate. As the potential gradient of the anode will decrease inversely with *d*, the value of the breakdown voltage might be expected to increase with *d*. Further, if the initial velocity of the electrons was sufficiently high it might be expected to overcome the negative gradient, even though the voltage on the anode was very small, or even negative with respect to that of the accelerating electrode and therefore tending to decelerate the electrons. In other words one would expect the breakdown to occur in the tube illustrated in Figure 1 before the anode potential reached that of the accelerating electrode if *d* is not too large. These expectations agree with the phenomena actually found in practice and shown in the curves of Figures 6 and 7. Further, as the anode space current from the filament is reduced the negative gradient will become less and the breakdown voltage be correspondingly reduced for a given accelerating grid voltage. Varying the potential of the electrode **4** would obviously vary the anode current. This is corroborated by the graphs in Figures 8 and 9.

The phenomena illustrated in Figure 7 may be explained in greater detail as follows. When the distance *d* is very small (say 1 c. m.) in the tube shown in Figure 1, the secondary radiation from the anode when E_{acc} is between 100 and 300 volts will be sufficient to cause a large drop in the value of the anode current when the anode voltage is below that of the accelerating electrode **4**. Hence at this distance the "anode breakdown voltage" at which the anode current becomes saturated does not occur until the anode voltage is greater than the accelerating voltage. If, however, the anode is placed a little further from the accelerating electrode **4** (say at 3 c. m.), this distance will be too great for secondary radiation which is produced to travel back to the accelerating electrode **4**. Then the anode current will rise to a saturated value, and at an anode voltage very much less than that of the accelerating electrode. This corresponds to the lowest point of the curve in Figure 7. If the distance d is increased to say 4 or 5 c. m. the secondary radiation will still have no effect on the result, but, in accordance with the considerations already outlined, the breakdown anode voltage of the tube will be comparatively high. This corresponds to the right-hand part of the curve in Figure 7.

The distance d to the anode or the output electrode in the tube has therefore a definite optimum value and this fact is very important for the operation of the tube.

This critical distance depends also upon the amount and nature of the secondary radiation produced. The effects of secondary radiation have been investigated by various writers (for instance Hull and Williams in the "Physical Review" Vol. 27, pp. 432, 1926, and Farnsworth in the "Physical Review" Vol. 20, pp. 358, 1922; Vol. 25, pp. 41, 1925, and Vol. 27, pp. 413, 1926) and the amount and nature of it is related to the velocity of the primary electrons and to the material and configuration of the electrodes from which it is produced. I have found that it is not always possible to obtain the critical distance effect if the velocities of impact of the primary electrons are substantially above a certain value at the surfaces of the electrodes in question for a given size of tube. For instance, in Figure 1, if the voltage of the accelerating electrode 4 (and therefore the velocity of the primary electrons) is too high the amount and velocities of the secondary radiation from the anode will be so great that it will travel back to the accelerating electrode 4 and prevent the anode from being given a lower potential than that of the accelerating electrode without losing the saturated condition. In general, accelerating voltages of several hundred volts may be used successfully in tubes of sizes such as that shown in Figure 1 without detriment to the existence of a critical anode distance.

When large voltages must be employed in order to produce a sufficiently great current and output power in the stream of electrons from the source of electrons in the discharge tube the primary electrons must be retarded by the use of electrodes having a comparatively low potential which are inserted in the length of the stream before it reaches the anode or other electrode.

A considerable variety of combinations of electrodes are available for any given purpose, examples of which are given below.

In accordance with the invention a further accelerating electrode may be placed between the anode and first accelerating electrode. Preferably this is placed at such a distance from the first accelerating electrode that at working potentials of both the current is just above the breakdown point; and the anode is placed at the critical distance from the second accelerating electrode. By the use of additional accelerating electrodes in this manner the length of the stream may be increased without increasing the voltage required to produce it.

As a result of my invention, discharge tubes can be provided, other things being equal with a much greater distance between the anode and accelerating electrode having, therefore, the following advantages:

(1) Avoidance of negative differential resistance characteristic because the comparatively low velocity electrons forming the bulk of secondary radiation cannot cross the increased length of gap, while the passage of desired primary electrons to the anode is substantially unaffected.

(2) Reduced inter-electrode capacity, thereby tending to render the operation of the apparatus independent of frequency.

(3) The anode potential may be reduced below that of the accelerating electrode to a substantial extent without reaching the anode break-down voltage below which the anode current ceases to be saturated, thus enabling an increased output of undistorted power to be obtained in conjunction with the other advantages of the use of a stream of comparatively great length in proportion to its cross-section. Experiment has shown that my invention enables the passage of saturated anode current in the anode circuit to take place at a lower anode voltage than is possible with other known expedients.

(4) The production of deflectable streams—particularly useful in frequency multipliers.

The advantages of the present invention set out in items 1 and 3 are because the increased potential gradient or dip will prevent electrons having a low velocity from passing across the space while allowing the passage of the electrons of high velocity. Secondary radiation consists almost entirely of low velocity electrons and will be stopped; whereas, as previously explained, the primary electrons travelling from the accelerating electrode are all of substantially the same velocity and are of a higher velocity than the secondary radiation to which their impact on the anode gives rise. This is illustrated in connection with the tube illustrated in Figure 1 by the minimum value of the curve in Figure 7 and is due to the fact that the two electrodes in question may be separated by such a distance that the velocity of the secondary electrons emitted from the anode is not sufficient for them to travel back to the preceding electrode. In addition, if the negative dip is sufficiently great, it is able to prevent an appreciable amount of secondary radiation from the accelerating electrode from traveling to the anode in addition to prevent it travelling in the opposite direction. In both cases, however, the passage of the high velocity primary electrons will be unaffected. These results can only be obtained when an anode is spaced from the accelerating electrode at or about the critical distance.

The valve according to Figure 13 shows only one accelerating electrode G1 separated from the anode 5 by the critical distance d, as in Figure 1.

Figures 14–16 show several possibilities for positioning and arranging the electrodes. The accelerating or retarding grid electrodes in the path of the electrons are designated respectively by G_1, G_2, etc. The distance between these electrodes are d_1, d_2, etc. It is obvious that the source 11 of voltage is not necessarily tapped at the points shown in the figures under all operating conditions. Sometimes it may be desirable to make the voltage difference across one part of the distance between the cathode and anode equal to zero, and in this case two or more voltages can be made equal to the critical anode distance in Figures 13, 14 and 15.

Figure 14 shows a valve similar to that in Figure 13 but with the difference that the distance between the anode and the first accelerating electrode G_1 is greater, and that an additional accelerating electrode G_2 is provided in the path of the stream. The distance d_1 may be selected so that the electrode G_2 is operated at a voltage just above the break-down voltage E_b of the spacing d. That means that the electrode G_2 is situated at the greatest possible distance from G_1 (at the given voltages of the electrodes) at which the current remains saturated. The distance between G_2 and the anode 5 may be the critical anode distance.

As shown, the electrode G_2 has a lower voltage than G_1 and therefore works as a decelerating electrode.

The valve according to the invention may also possess an electrode which is at or about the cathode potential and is arranged between G_1 and G_2 in Figure 14. The negative potential gradient may be generated partially by such an electrode of low potential, and partially by the space charge.

If in Figure 14 an electrode at or approximately at the potential of the cathode is added between G_1 and G_2, it will tend to increase the negative potential gradient in the neighborhood of the adjacent electrodes. Experiment shows that it has a further and a favorable effect in increasing the electrostatic screening between the anode and G_1. A valve arranged in this way is shown in Figure 15.

Figure 16 shows an arrangement similar to that of Figure 15, but an electrode G_4 which is wholly or approximately at cathode potential, is located between G_2 and the anode 5. It assists the production of the negative potential gradient or voltage drop between G_2 and the anode 5, which is produced partly by the electrode G_4 and partly by the space charge, as described. The subject-matter of the invention is in this way combined with suppressor electrodes.

It is pointed out that the critical distance effect will not be produced between two electrodes (e. g. G_2 and the anode 5) unless the velocity of the electrons entering the space therebetween has a sufficiently high and approximately single value; thus the positioning and mesh of G_4 in Figure 16 must not be such as to produce such a very low velocity by increasing the negative potential gradient to too great a degree.

Record modulator

The application of the present invention to a frequency multiplier tube will now be described with reference to Figures 17 and 18.

In addition to the filament 2, Figure 19, focussing hood 3, Figure 20, and first accelerating electrode 24, illustrated in the longitudinal view in Figure 21, the tube also contains an additional accelerating electrode 16, a record 17 and a target anode 5, Figure 24. The record 17 is supported from the side of the tube and consists of a metal disc having slots therein in accordance with my said co-pending application. The slots therein are each covered by a mesh 18 in accordance with the present invention. Certain electrostatic means for deflecting the jet in accordance with the prior patent are shown by the plates 20, Figure 22, and are interposed between the second accelerating electrode 14 and the record 17.

In accordance with the present invention the distance between the two electrodes 14 and 16 is such that the current between them is above the breakdown point and is saturated. The same conditions hold between the second accelerating electrode and the record 17. The anode is placed at the critical anode distance previously referred to. The stream of electrons is influenced by said deflecting means 20 and the position of impact with the record 17 caused to travel over the slots. According to its position in respect to the apertures in the record 17, more or less of the stream will reach the anode. The anode 5 is connected to an output circuit. Due to the fact that the anode is at the critical distance the voltage variations across this load will not prevent the tube from working entirely in a saturated condition despite the load being such as to reduce the anode voltage very much below that of the other accelerating electrodes.

In Figure 25 a typical curve between the anode current of a tube such as that shown in Figures 17 and 18 and the anode voltage is shown. The voltage of the accelerating electrodes is assumed to be very much higher than E_b in this case. Anode current has been measured with the stream passing through one of the apertures in the record 18, Figure 23. A similar graph having a lower maximum value will be produced when part of the stream is cut off by the record.

By secondary radiation or the like referred to in this specification is meant both reflected and emitted secondary electrons.

According to the invention the grid, accelerating or decelerating, electrodes as mentioned heretofore are formed so as to intercept as little of the electron stream as possible. To do this they are in the shape of a mesh or grid. The sizes of the apertures in the electrodes are not made too large and there are preferably more than one aperture. For example, for the satisfactory operation of the tube illustrated in Figure 1, an electrode of the kind shown in Figure 4 is necessary. An important part of my invention is in the fact that I have shown that such mesh electrodes may be made to give satisfactory results in the production of streams of electrons which are of the "jet" type, i. e. are of comparatively great length in comparison with their cross sections. Previously it appears to have been thought essential in endeavors to produce such "jets" to employ electron "guns" or the like of, for instance, tubular, and similar formations. They intercept almost all the space current, or only produce a very small space current, and therefore, make the anode current too small to be of use.

The characteristics of means employed to transfer potential variations from one part of a stream to another as in Figures 10 and 12, may also be arranged to change the characteristics of the said variations when transferred (e. g. change the phase, amplitude and/or wave form thereof). The characteristics of the said means may be a function of other factors, e. g. the frequency of the variations. The potential variations when transferred to different parts of the length of stream may have relatively different characteristics. Therefore, by means of the present invention the differential resistance may be given a series of values including vector forms and complex values which may be dependent on variables which are changeable over a very wide range.

The potential variations across a stream or portion thereof may be transferred to sources of potential in other parts of the stream by suitable electrical circuits, e. g. potentiometer devices, reactive networks, inductive coupling, relaying devices, or the like. Or, if an output circuit is used in conjunction with the tube, potentials may be tapped off thereacross for this purpose. For example, if this coupling circuit is inductive and the potentials transferred to the unsaturated part of the stream are tapped off therefrom, a phase difference may exist between the original potential changes and those transferred and if potentials of another phase are applied from the load to another electrode also acting on an unsaturated part of the stream, the current phase will depend on the resultant of all three phases, i. e. the differential resistance will possess a phase angle. If the frequency is varied the phase angles will change, hence the phase angle of the differential resistance will change also.

Electrostatic screening devices, e. g. metal grids, may be interposed between the electrodes in the tube if required.

The term "auxiliary" electrode and "anode" in this specification and the appended claims are intended to refer to any two electrodes having positions respectively at the beginning and end of a portion of an electron stream; and not only to the last two electrodes at the end of the electron stream. The term "auxiliary electrode" includes both accelerating and decelerating electrodes.

The "critical distance" referred to in this specification and appended claims may be defined as the distance between the anode and an auxiliary electrode at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode; when the distance is shorter than this value secondary radiation, when produced at the anode, tends to pass to the auxiliary electrode (when the anode potential is less than that of the auxiliary electrode) tending to produce a negative resistance characteristic; when the distance is longer than this value then there is a range of anode voltages from zero upwards over which substantially no anode current tends to be produced and immediately above this range, the anode current rises abruptly to a saturation value.

It is pointed out that though the critical distance is distinguished from shorter distances by its effect in preventing the passage of secondary radiation (which passes at shorter distances), my invention is not limited to the use of electrodes of material which produce secondary electrons copiously. The operation of the invention does not depend upon producing secondary radiation, but in obtaining the desired ratio between voltage and current intensity by the arrangement which renders feasible, for practical use in incandescent tubes and the like, electron streams which are long and small in cross-section.

It is to be understood that various methods of discharge tube control above described are merely by way of illustrating the invention and that the invention is not limited thereto, but is limited only by the scope of the appended claims.

This application is a division from my application Serial No. 595,339, filed on February 26th, 1932.

Having now described my invention, what I claim as new and desire to secure by Letters Patent is:—

1. An electron discharge device having an anode, a cathode and an auxiliary electrode therebetween, the auxiliary electrode and the anode being spaced apart by a distance at least equal to about the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode.

2. An electron discharge device comprising an anode, a cathode and a plurality of auxiliary electrodes therebetween, the auxiliary electrode nearest the anode being spaced therefrom by a distance at least equal to about the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode.

3. An electron discharge device having an anode, a cathode and an auxiliary electrode therebetween, said auxiliary electrode and anode being spaced apart by a distance approximately equal to the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode.

4. An electron discharge device comprising an anode, a cathode and a plurality of auxiliary electrodes therebetween, the auxiliary electrode nearest the anode being spaced therefrom by a distance approximately equal to the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode.

5. An electron discharge device having an anode, a cathode and an auxiliary electrode therebetween, the auxiliary electrode and the anode being spaced apart by a distance at least equal to about the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode, and electron focusing means between said cathode and anode.

6. An electron discharge device having an anode, a cathode and an auxiliary electrode therebetween, the auxiliary electrode and the anode being spaced apart by a distance at least equal to about the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode, and means for applying deflecting forces to the electron stream between said auxiliary electrode and said anode.

7. An electron discharge device having an anode, a cathode and an auxiliary electrode therebetween, the auxiliary electrode and the anode being spaced apart by a distance at least equal to about the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the

neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode, means for applying deflecting forces to the electron stream between said auxiliary electrode and said anode, and an additional electrode arranged to intercept the electron stream after deflection, said additional electrode having open spaces covered by a mesh.

8. An electron discharge device according to claim 5 wherein the distance between the auxiliary electrode and the anode is approximately equal to said critical distance.

9. An electron discharge device according to claim 6 wherein the distance between the auxiliary electrode and the anode is approximately equal to said critical distance.

10. An electron discharge device according to claim 7 wherein the distance between the auxiliary electrode and the anode is approximately equal to said critical distance.

11. An electron discharge device having an anode, a cathode and at least one auxiliary electrode therebetween, the auxiliary electrode nearest the anode being spaced therefrom by a distance not less than the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum whereby any secondary electrons radiated by said anode are prevented from reaching said auxiliary electrode even though the voltage applied to said anode is less than the voltage applied to said auxiliary electrode.

12. An electron discharge device according to claim 11, wherein the auxiliary electrode nearest the anode is spaced therefrom by a distance approximately equal to said critical distance.

13. An electron discharge device having an anode, a cathode and an auxiliary electrode therebetween, the auxiliary electrode and the anode being spaced apart by a distance greater than the critical distance at which the anode breakdown voltage at which the anode current becomes substantially saturated is in the neighborhood of the minimum and the intensity of the electron stream is substantially at zero for a considerable part of the range of the potential difference between said cathode and anode up to the potential difference at which the electron stream is substantially saturated.

JOHN HENRY OWEN HARRIES.

CERTIFICATE OF CORRECTION.

Patent No. 2,045,527.

June 23, 1936.

JOHN HENRY OWEN HARRIES.

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 2, first column, line 40, for the word "resistance" read distance; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 22nd day of September, A. D. 1936.

Henry Van Arsdale
Acting Commissioner of Patents.

(Seal)