Sept. 17, 1968 D. GABOR ET AL 3,402,313

THERMIONIC GENERATOR HAVING AUXILIARY ANODES IN THE MAIN DISCHARGE SPACE

Filed May 10, 1965

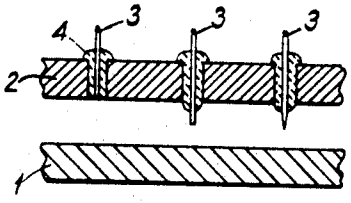


Fig. 1

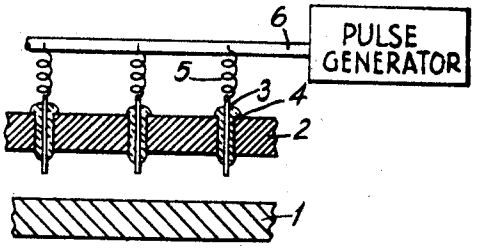


Fig. 2

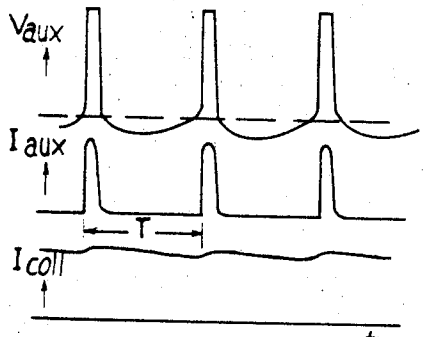


Fig. 3

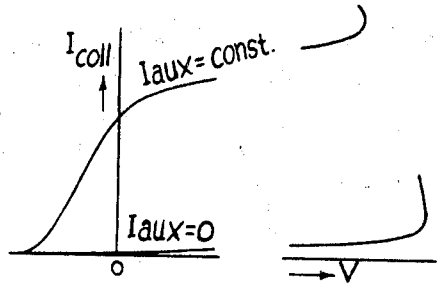


Fig. 4

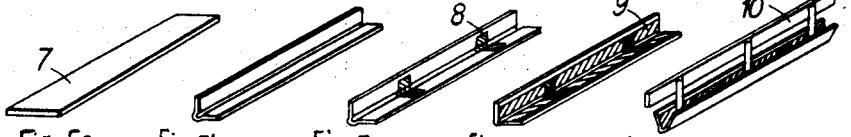


Fig. 5a Fig. 5b Fig. 5c Fig. 5d Fig. 5e

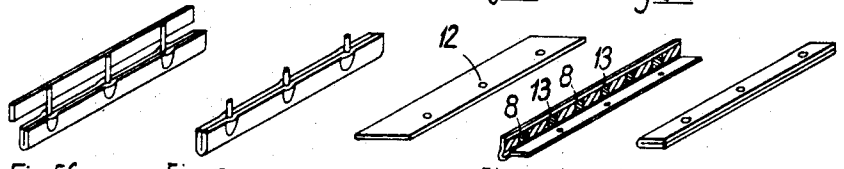


Fig. 5f Fig. 5g Fig. 6a Fig. 6b Fig. 6c

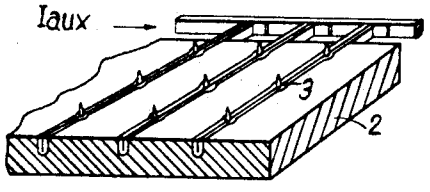


Fig. 7

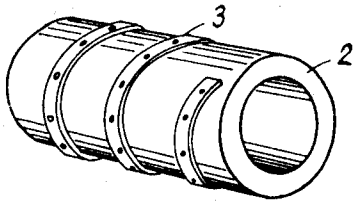


Fig. 8

United States Patent Office 3,402,313
Patented Sept. 17, 1968

3,402,313

THERMIONIC GENERATOR HAVING AUXILIARY ANODES IN THE MAIN DISCHARGE SPACE

Dennis Gabor, London, England, and John Anthony Nilson, Montreal, Quebec, Canada, assignors to National Research Development Corporation, London, England, a British corporation

Filed May 10, 1965, Ser. No. 454,319
Claims priority, application Great Britain, May 12, 1964, 19,806/64
4 Claims. (Cl. 313—306)

ABSTRACT OF THE DISCLOSURE

A thermionic generator having, in addition to a heated emitter and a collector, a plurality of auxiliary anodes in the emitter-collector space. The auxiliary anodes, which are carried by and insulated from the collector, provide a discharge to break down the electron space charge in the main discharge. Several methods of making combined collector and auxiliary anode structures are described. The auxiliary anodes are of very small area, and may terminate in sharp points. The discharge space may contain inert gases. The auxiliary anodes are preferably excited by pulses whose duration is considerably longer than the intervals between the pulses. The main discharge current can be controlled by varying the auxiliary anode current.

This invention relates to thermionic generators and is more particularly concerned with controllable thermionic generators.

A thermionic generator is a device for the direct consion of heat into electrical power. It comprises an electron emitter which is heated to provide free electrons which flow to a colder electron collector spaced apart from the emitter and thereby maintain a potential difference between the emitter and collector. In a controllable thermionic generator an auxiliary discharge is provided which produces ions to break down the electron space charge in the main discharge.

In one kind of controllable thermionic generator an auxiliary anode is provided in a special discharge space which communicates with the main discharge space through foraminations in the collector electrode. Alternatively an auxiliary cathode may be provided to produce the auxiliary discharge.

In accordance with the invention a thermionic generator has a plurality of auxiliary anodes provided in the main discharge space, which auxiliary anodes provide an ionizing discharge.

In order that the auxiliary discharge shall enhance the main discharge it is desirable that the total area of the auxiliary anodes is as small a proportion as possible of the emitter area which they serve. The total area of the auxiliary anodes should not exceed $\frac{1}{1000}$ of the emitter area and preferably it should be less than this.

In a preferred arrangement the auxiliary anodes are energised with positive going pulses in which the "on-time" is sufficient to produce an ionizing discharge and the "off-time" is of considerably longer duration but is insufficient to allow an appreciable decrease in the main discharge current during the off-time. It has been found experimentally that in generators operating in atmospheres of argon, krypton or xenon the pulse repetition rate should be 5–10 kc. per cycle or higher and the duration of each pulse should be of the order of 1–5 microseconds.

In order to assist in the stabilisation of the discharge among the plurality of auxiliary anodes individual anodes resistors may be included in the current path to each auxiliary anode.

The invention will be better undesrtood with reference to the drawings accompanying this specification in which:

FIG. 1 is a schematic cross section of a thermionic generator embodying the invention, showing three different types of auxiliary anodes,

FIG. 2 shows one method of connection of the auxiliary anodes to a common terminal,

FIG. 3 is a diagram illustrating pulse operation,

FIG. 4 is a diagram of the electrical characteristics of a thermionic generator,

FIGS. *5a* to *5f* and *6a* to *6c* illustrate the stages in the manufacture of two different types of auxiliary anode systems,

FIG. 7 and FIG. 8 show alternative arrangements of electron collectors embodying the invention.

Referring now to FIG. 1 there is shown therein the essential elements of a thermionic generator comprising a heated emitter electrode **1** and spaced apart therefrom a collector electrode **2**. The two electrodes are contained in a vacuum tight envelope containing inert gases such as argon, krypton and xenon at 2 pressures of the order of 0.1–5 torr or mixtures of these gases with metal vapours. The collector electrode **2** may preferably comprise part of such a vacuum envelope and may be immersed in a coolant. The collector electrode **2** carries auxiliary anodes **3** which are insulated from electrode **2** by means of beads **4** of a suitable insulator such as an enamel. Wires **3** may be centered in the bores by means of beads or tubes of ceramic material, not shown. Wires **3** preferably consist of refractory materials such as tungsten, tantalum or molybdenum.

FIG. 1 shows three alternative arrangements of auxiliary anodes **3**. In the left-hand position electrode **3** and bead **4** are ground flush with the surface of collector electrode **2** so as to give the advantage of a very small and well defined area of auxiliary anode. In the centre position the wire **3** and bead **4** project a little into the discharge space. For instance if the gap between the emitter **1** and the collector **2** is 2 mm., which has been found to be an advantageous dimension in experiments, the wire may project to within 0.5–1.0 mm. from the emitter. This had the advantage that the anode drop region in which the ions are produced is about midway between the emitter and the collector, which favours the emitter in the distribution of ions, where ions are most needed. In the third type, the wire ends in a sharp point. This can be produced, e.g. by electrolytic etching of tungsten of molybdenum wires. It has the advantage of a more gradual development of the discharge, and a less sharply pronounced break down avalanche, which favours parallel operation of the auxiliary anodes. Experimentally it was found that 1–4 auxilary anodes per cm.^{2} emitter surface are convenient numbers.

It has been found experimentally, that though small anodes of any of the types described show a positive characteristic when immersed into a plasma already formed, they nevertheless do not always operate in parallel in a stable way if the plasma is produced by their own discharge. The reason is that the auxiliary anode which by some accident has struck first will produce a dense plasma only in its own neighbourhood, but it produces a voltage drop in the supply, such that the reduced voltage is insufficient for firing a second anode in a region where there is no dense plasma. This means that only a fraction of the cathode area will be well supplied with ions. This unstable behaviour is less pronounced if the auxiliary anode areas are very small or if they are sharply pointed. It can be entirely suppressed by connecting each auxiliary anode through a suitable resistor **5** to a common terminal **6**, as shown in FIG. 2. If for instance the current of one auxiliary anode is 10 ma., a series resistance of about 200 ohms for each is sufficient to stabilise the phenome-

non. The resistors can be dispensed with, however, if the electrodes 3 expose a sufficiently small area to the discharge space. As an example, stable operation in parallel has been achieved with electrodes as shown in the left position in FIG. 3 with wires of 0.1 mm. diameter, exposing an area of 0.0078 mm.^{2} to the discharge space at currents exceeding about 25 milliamperes per electrode, without any series resistance.

It is found, however, that even a fully stabilised plurality of auxiliary anodes gives only moderately good ratios of collector current to auxiliary current if the last mentioned are operated from a direct current source. The reason is that by a general principle governing all direct current discharges the voltage of the auxiliary anode relative to the emitter adjusts itself to a minimum value, at which the ionisation is just sufficient to maintain the discharge with the given current. In other words, the auxiliary current is maximised, while the collector current gets only a minimum of stray ions. This adverse behaviour can be overcome by transient operation; by applying a large voltage and current surge to the auxiliary anode and then breaking it off.

This operation is illustrated in FIG. 3. The auxiliary anodes are operated by pulse circuits known by themselves with short, sharp positive pulses, occupying only a small fraction of the cycle, while during the major part of the cycle the voltage is negative, so that the auxiliary currents, of say, 10–20 times their mean value, flow only during one-tenth or one-twentieth of the time. It has been found experimentally that the time T between two pulses can be anything below about 100 microseconds. With emitter-collector distance of the order 1–2 mm. the main current after a pulse is observed to remain almost constant for 50–200 microseconds, depending on the gas pressure, after which approximately exponential decay starts with a time constant of the order of 50–200 microseconds. If therefore the pulses with a frequency of the order of 10 kilocycles are themselves modulated with technical frequencies of 50–60 cycles, or even high frequencies up to about 1–2 kilocycles, the device according to the invention may be used to generate pulsed currents, which, by means well known in themselves, can be put together to produce alternating currents of rectangular or sinusoidal shape.

FIG. 4 is a diagram illustrating the collector current-collector voltage characteristics of a device according to the invention, at some constant mean auxiliary current and at zero auxiliary current. The device acts as a generator when the collector-emitter voltage V is negative. It is controllable up to a voltage at which an arc discharge sets in between the emitter and the collector. This is indicated in FIG. 4 by the backward curving branch of the characteristics. When the auxiliary anodes are not excited the arc will strike at about 12–20 volts in argon, at 8–12 volts in xenon, which gives a sufficient margin for operation with alternating current, in which the collector current must be suppressed during one phase of the cycle.

The collector current-collector voltage characteristics have similar shape whether the auxiliary anodes are energised with direct current or with pulses, but the auxiliary currents required for drawing a certain collector current may be ten times or more larger in D.C. operation than in pulse operation, while the auxiliary voltages required are less than doubled.

The realisations shown in FIGS. 1 and 2 have the disadvantage that when applied to directly cooled collectors, they require a high number of reliable metal-ceramic or metal-enamel vacuum-tight seals. The realisations shown in FIGS. 5–8 are free from this disadvantage, as the systems of auxiliary anodes are completely inside the vacuum space, and require only one terminal.

FIGS. 5*a*–5*g* show the stages of manufacture of one such system. In FIG. 5*a*, 7 is a strip of a metal, which as shown in FIG. 5*a*, is bent into the shape of an angle, with a rounded corner. This is then coated except in areas 8, shown in FIG. 5*c* with an insulating layer. One suitable method of insulation is fire-enamelling, another is spraying with a ceramic such as alumina by means of a plasma gun. If these methods are used, the areas 8 are scraped bare of the insulation. In the next operation, shown in FIG. 5*d*, the central part of the angle is coated with a resistive layer 9, preferably by vacuum evaporation of a nickel-chromium alloy. In the operation a metal tape 10 is prepared on which short lengths of refractory metal wires, e.g. of tungsten, molybdenum or tantalum are welded at right angles, and the ends of these are introduced into the angle, which is then clamped tight around the wires, preferably between jaws coated with an elastic material, such as rubber. The result is shown in FIG. 5*f*. In the next operation the tape is cut off, and the projecting wires are cut to the required length. In order to remove scratches which may have arisen during the clamping, the whole product with the exception of the wires may be re-insulated, e.g. by spraying. The projecting wires can be protected during this operation by a resist.

In a system as described in FIG. 5 the current to the auxiliary anodes is carried by the U-shaped metal trough, which makes contact with the resistor layer only at the patches 8. The wires in turn make contact with this strip midway between two patches 8, so that they are supplied with current from both sides, and the resistance in series with each wire is one-quarter of the resistance between two patches 8. The resistance required for stabilisation depends on the area which is exposed to the discharge. If this area is made very small, of the order of one-hundredth of a square millimetre, stable parallel operation becomes possible without stabilising series resistances. In this case the design can be simplified. Instead of coating the inside of the angle-strip with a resistive material, a zone can be left bare, so that the wires make direct contact with the strip. Alternatively, the U-shaped strip is completely coated with an insulator, and the tape 10 is inserted into it, with the wires pointing outwards, and it is this tape 10 which serves as the common conductor for the auxiliary anodes. For added safety, it is preferable to coat this tape too with an insulator, leaving only the projecting part of the wires bare.

FIGS. 6*a*–6*c* show another variety of an auxiliary anode system, in which the auxiliary anodes are not wires but metallic patches behind a perforated insulator. In FIG. 6*a* the metal strip is perforated with fine holes 12. This is then treated as before (FIG. 6*b*), but with the exception that the resistive layer is deposited on one side of the angle only. Also it is preferable to apply a deposit of refractory metal or small metal plates 13 opposite to the holes, lest the resistive layer might be destroyed by the discharge through the holes. FIG. 6*c* shows the finished product. The whole surface is insulated except the metal patches which are exposed through the perforations.

FIGS. 7 and 8 show the application of these auxiliary anode systems to the collectors 2. In FIG. 7 the auxiliary anode strips are inserted into slots, and their ends are connected to a common lead to the terminal. All leads must be carefully coated with an insulator, because any bare patch could attract the discharge away from the small spikes. This can be done by coating with a ceramic cement paste, but also by making all leads of tantalum and anodising the assembled system until every patch of bare metal is covered up by an insulating layer.

The perforated strips whose making was explained in FIG. 6 can be laid flat on the collector, and tied down for instance by metal strips welded across them in a sufficient number of places. In the example shown in FIG. 8 the whole strip is wound in a helix around the tubular collector 2, which carries the coolant.

We claim:

1. A thermionic generator comprising an electron emitter and a collector electrode spaced apart from each

other to define a discharge space between them, a plurality of auxiliary anodes provided in said discharge space, and pulse generator means for applying to said auxiliary anodes positive pulses separated by negative potentials of duration insufficient to allow appreciable decay between said positive pulses of current between said emitter and collector electrodes.

2. The generator as claimed in claim 1 in which the pulse generator means is adapted to amplitude modulate the positive pulses to produce corresponding modulation of the main discharge current.

3. A thermionic generator comprising an electron emitter and collector electrode spaced apart from each other to define a discharge space between them, a plurality of metallic strips folded double along their lengths and coated at least over their external surfaces with an insulating layer and secured to the collector electrode, and a plurality of short wires held between the two halves of the strips, which wires project into said discharge space and form auxiliary anodes.

4. A thermionic generator comprising an electron emitter and collector electrode spaced apart from each other to define a discharge space between them, a plurality of metallic strips folded double along the direction of their lengths and coated over both their internal and external surfaces with layers of insulating material except

for a series of small uncoated areas spaced apart along the internal surfaces, a layer of resistive material coating the internal surfaces of said strips, and a plurality of short wires held between the two halves of the strips generally midway between said small areas so as to make electrical contact with said strips through said resistive layers and said small areas, said strips being secured to said collector electrode so as to allow said short wires to project into said discharge space and form auxiliary anodes therein.

References Cited

UNITED STATES PATENTS

2,239,694	4/1941	Bennett	313—351 X
2,607,016	8/1952	Kennebeck	313—351 X
2,959,704	11/1960	Snell et al.	313—351 X
3,021,472	2/1962	Hernquist	313—230
3,112,863	12/1963	Brubaker et al.	313—217
3,238,395	3/1966	Sense	313—310
2,697,800	12/1954	Roberts	313—351 X

FOREIGN PATENTS

29,854	7/1959	Germany.

JOHN W. HUCKERT, *Primary Examiner.*

A. J. JAMES, *Assistant Examiner.*