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J. P. BLEWETT

2,428,612

MAGNETRON

Filed May 9, 1942

Fig. 1.

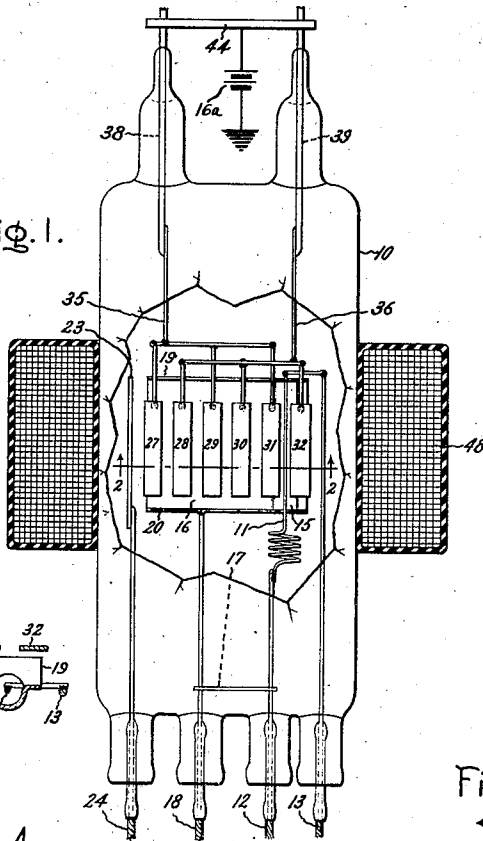


Fig. 2.

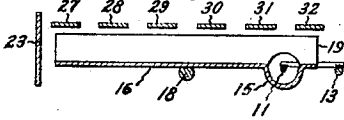


Fig. 4.

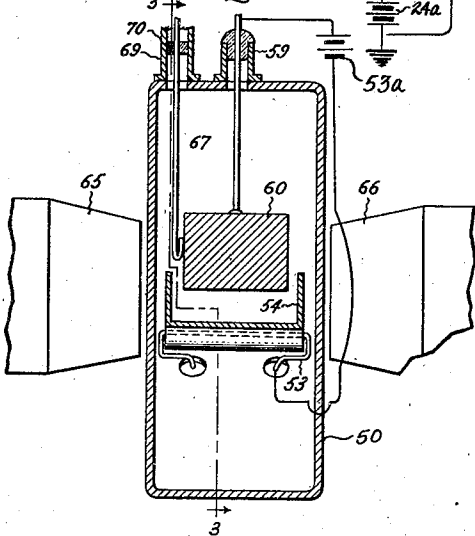
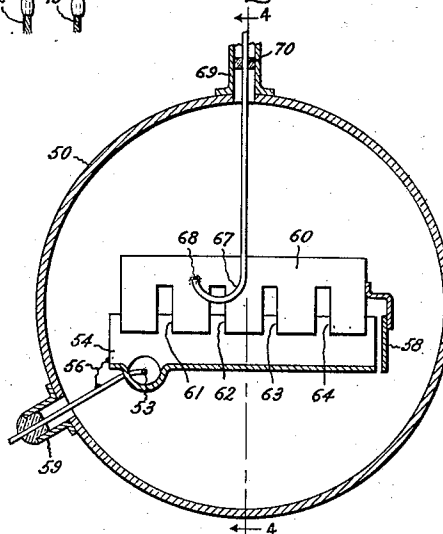


Fig. 3.



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UNITED STATES PATENT OFFICE

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MAGNETRON

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14 Claims. (Cl. 250—27.5)

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The present invention relates to improvements in high frequency electronic devices of the magnetron class.

One known form of magnetron comprises a plurality of anode elements grouped in a circular array about a common cathode, a magnetic field being provided of such character as to produce a rotating space charge in the region surrounding the cathode. In general, it has been found possible to increase the operating frequency of such arrangements by adding more and more anode elements, but this obviously leads to a complicated structural arrangement. Moreover, in certain types of magnetron the stability of multi-anode constructions is poor because of the fact that the number of possible modes of oscillation increases with the number of anodes.

Alternatively, higher frequencies may be obtained with relatively fewer anodes by using more powerful magnetic fields, but the difficulty of obtaining such fields in any practical way places a distinct limitation upon this approach.

It is an object of the present invention to provide a magnetron construction by which even the highest frequencies may be obtained by the use of relatively few anodes and with a magnetic field of easily attainable strength. Broadly, the invention involves a distinct departure from established magnetron practice in that it employs a non-circular, preferably a planar arrangement of the anode elements. The considerations which establish the operability and advantages of such an arrangement will be set forth at a later point.

The features of the invention desired to be protected herein are pointed out in the appended claims. The invention itself may best be understood by reference to the following description taken in connection with the drawing in which Fig. 1 is a partially sectionalized view of a multi-anode magnetron embodying the invention; Fig. 2 is a section taken through the electrode structures of the device of Fig. 1 along the line 2—2; Fig. 3 represents a sectional view of an alternative embodiment of the invention; and Fig. 4 is a section taken on line 4—4 of Fig. 3.

The construction of Fig. 1 will be described first with reference to its structural aspects and subsequently with reference to the theoretical considerations which determine its operation.

The device shown comprises an evacuated, hermetically sealed glass envelope 10 containing within its interior a plurality of electrodes including an electron-emitting filament 11. This filament, which is adapted to be supplied with heating current by means of lead-in conductors 12 and 13, is located in a semi-cylindrical recess

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15 formed in a plate-like member 16. The member 16 is maintained at the same D. C. potential as the filament by a bridging conductor 17 which extends between the filament terminal 12 and a lead-in conductor 18 associated with the member. The member 16 is provided at its edges with flanges 19 and 20 having the function of preventing the escape of electrons which are released from the filament 11 and travel across the surface of the member. A collector 23, located at the left-hand extremity of the plate 16 and normally maintained at a positive potential by appropriate connections including for example a battery 24a between lead-in conductor 18 and lead-in conductor 24, receives the electrons after they have reached the end of the plate.

Supported above the plate 16, as viewed in Fig. 2, there is provided an array of parallel anode elements 27 to 32 which are arranged in a common plane and which are mutually spaced to provide gaps between their adjacent edges. The elements 27, 29 and 31 are connected to a common terminal wire 35 whereas the remaining elements 28, 30 and 32 are connected to a second terminal wire 36. Lead-in conductors 38 and 39 respectively associated with the terminal wires 35 and 36 are brought out through the extremity of the envelope 10 and are terminally short-circuited by a bridging conductor 44 having a function which will be described at a later point. The various anode elements are assumed to be maintained at a common positive potential with respect to the cathode plate 16 as by connection to an appropriate D. C. source 16a. A coil 48 which surrounds the tube 10 provides a magnetic field parallel to the filament 11 in the region between the cathode plate 16 and the anode elements 27 to 32.

It is found that under appropriate conditions, a device such as that of Fig. 1 may be made to produce high frequency oscillations analogous to those obtainable with split-anode magnetrons of conventional form. While I do not wish to be limited to a particular explanation of this result, the following is given as a tentative analysis which appears to fit the observed facts.

In connection with the operation of a multi-anode magnetron using a cathode of negligible radius (i. e. a single filament) the following approximate relationship has been determined by empirical means:

$$N\lambda H \geq 80,000 \quad (1)$$

Where N represents the number of interanode gaps, λ is the operating wave length and H is the strength of the magnetic field.

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From this relationship it will be seen that as the operating wave length decreases it is necessary, with a fixed number of gaps, to use greater and greater magnetic field strengths. It would appear possible to avoid the use of impracticably high magnetic fields by increasing the number of gaps; however, this obviously leads to a large and cumbersome construction and is objectionable for that reason.

In a magnetron where the cathode is of dimensions which are not negligible, the cathode radius may be taken into account in determining the operation of the device in the following manner:

The absolute value of the angular velocity $\dot{\theta}$ (that is,

$$\frac{d\theta}{dt})$$

of electrons in a magnetron having a cathode of radius r_c is known to be

$$|\dot{\theta}| = \frac{eH}{2m} \left(1 - \frac{r_c^2}{r^2} \right) \quad (2)$$

(Cf. A. W. Hull, Phys. Rev. 18, 31 (1921))

where e and m are charge and mass of the electron

H =magnetic field

r_c =radius of cathode

r =radial co-ordinate of electron

So in the neighborhood of the anode

$$|\dot{\theta}| = \frac{eH}{2m} \left(1 - \frac{r_c^2}{r_a^2} \right) \quad (3)$$

where r_a =anode radius.

Now if there are N gaps, each gap subtends an angle

$$\frac{2\pi}{N}$$

at the axis and the transit time of an electron from one gap to the next is

$$t = \frac{2\pi/N}{|\dot{\theta}|} = \frac{2\pi/N}{\frac{eH}{2m} \left(1 - \frac{r_c^2}{r_a^2} \right)} = \text{approx.} \frac{7 \times 10^{-7}}{NH \left(1 - \frac{r_c^2}{r_a^2} \right)} \quad (4)$$

The condition for oscillation of this type of magnetron is that this transit time must be small compared with a period of the oscillation. Empirically, it is found that the transit time must be roughly a quarter, or less, of a period of the oscillation.

If T =one period of the oscillation,

$$= \frac{1}{f} = \frac{\lambda}{c}$$

where

f =frequency of oscillation

λ =wavelength

c =velocity of light,

we have

$$t \leq \frac{1}{4}T$$

or

$$\frac{7 \times 10^{-7}}{NH \left(1 - \frac{r_c^2}{r_a^2} \right)} \leq \frac{\lambda}{4c} \quad (5)$$

whence

$$N\lambda H \left(1 - \frac{r_c^2}{r_a^2} \right) = N\lambda H \left(\frac{r_a^2 - r_c^2}{r_a^2} \right) \geq \text{approx. } 80,000 \quad (6)$$

The above equation may be rewritten as follows:

$$N\lambda H \left[(r_a - r_c) \frac{(r_a + r_c)}{r_a^2} \right] \geq 80,000 \text{ (approx.)} \quad (7)$$

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Now let r_a and r_c become very large, approaching infinity, keeping $r_a - r_c$ equal to a fixed spacing d . Under these circumstances $r_a + r_c$ is equal approximately to $2r_a$, whence Equation 7 becomes

$$2N\lambda H \frac{(r_a - r_c)}{r_a} = 2N\lambda H \left(\frac{d}{r_a} \right) \geq 80,000 \text{ (approx.)} \quad (8)$$

If the distance from gap to gap is equal to w , we have

$$Nw = 2\pi r_a, \text{ or } N = \frac{2\pi r_a}{w} \quad (9)$$

Equation 8 now becomes

$$\frac{4\pi\lambda Hd}{w} \geq 80,000 \text{ (approx.)} \quad (10)$$

Whence

$$\frac{\lambda Hd}{w} \geq 6400 \text{ (approx.)} \quad (11)$$

This effectively defines the conditions of operation at a wavelength λ of a cylindrical magnetron of infinite radius with a spacing d between the anode and cathode elements and with a distance w between anode gaps.

Since the assumption of infinite radius effectively defines any particular section of the cylindrical structure in question as being essentially of planar character, it is reasonable to assume that any sub-assembly of several gaps might be expected to continue operation without substantial modification if it were abstracted from the complete system. In effect this is what is done in providing a construction such as that illustrated in Figs. 1 and 2 discussed above. That is to say, the anode and cathode structures illustrated may be considered to represent sections taken from a cylindrical magnetron of infinite radius, and tests made upon the pictured structure indicate that it operates in a manner consistent with this view.

In the operation of the device, the magnetic field established by the coil 48 is adjusted in strength to a value consistent with the requirements of Equation 11. It is the function of the filament 11 to provide a space charge in the region between the cathode plate 16 and the anode elements 27 to 32, which space charge is controlled in its motions by the joint action of the magnetic field and the unidirectional electric field maintained between the plate and the elements. As a consequence of the gyrations of the various electrons making up the space charge, alternating voltages are developed between adjacent anode elements. These voltages appear between the conductors 38 and 39, and, to assure a resonant condition of the anode assembly as a whole, the conductors are short circuited by the bridging member 44 at such a point as to cause the conductors to function as a quarter wave resonant transmission line. (The line is actually shorter than the quarter wave value due to the interelectrode capacity at its open end.)

The arrangement described has the double advantage of structural simplicity and of freedom from the runaway characteristic which many cylindrical magnetrons exhibit. The first-named advantage is a consequence of the use of a relatively small number of electrode parts, simply arranged, and the latter follows largely from the particular cathode construction adopted. More specifically on the latter point, it is to be noted that since the electron source (i. e. the filament 11) is located near the one end of the electrode assembly it is not subject to appreciable reverse bombardment by the emitted electrons as they

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move in spiral or circular paths under the influence of the magnetic field. Accordingly, no excessive and uncontrolled heating of the cathode due to this cause is possible and a relatively constant emission of electrons can be maintained. Since the cathode part 16 is not inherently emissive, the impingement of reversed electrons on this part has little or no effect on the total electron emission.

An alternative embodiment of the invention is represented in Fig. 3 in which the operating elements are shown as enclosed within a cylindrical metal (e. g. copper) container 50. The cathode structure is similar to that described in connection with Fig. 1 and includes a flanged plate 54 and an emissive (e. g. tungsten) filament 53 located in a semi-cylindrical recess in the plate, the filament and plate being connected as indicated at 56 in Fig. 4. (Alternatively, the cathode structure may comprise an arrangement in which the entire surface of the plate 54 is activated and maintained at an emissive temperature, the filament 53 being omitted in this case. However, this sacrifices to some extent the stability in operation by which the previously described construction is characterized.) A collector 58 for the electrons emitted by the cathode is provided at one end of the cathode structure, being connected to an anode system described in the following. A series of eyelet lead-in seals 59 are provided for the purpose of supplying potential to the various electrode elements.

The anode structure is formed of a unitary rectangular block 60 of conductive metal such as copper and is provided at the edge which faces the cathode with a series of mutually displaced slots 61 to 64. These serve the double function of dividing the structure into a series of independent anode elements and of providing space-resonant cavities between adjacent elements. These cavities, which are defined by the opposed metallic surfaces of the anode elements, may be regarded as quarter wave resonant transmission line sections having voltage loops at their respective openings. Accordingly, if appropriate excitation is assumed, high frequency alternating voltages may be developed between the adjacent anode elements. The various resonant systems thus provided are inherently coupled to one another so that their action is mutually reinforced.

In order to obtain resonance effects of the desired character, electrons are supplied to the space between the cathode plate 54 and the anode structure by the emissive filament 53, and a unidirectional potential is impressed between the cathode and anode structures by a suitable source 53a. A magnetic field in a direction parallel to the gaps 61 to 64 is produced by a magnetic system having opposed poles 65 and 66, as indicated in Fig. 4. As in the construction of Fig. 1, the gyrations of the electrons in proximity to the various anode elements excite the elements in the manner characteristic of magnetron operation.

In order to take power from the apparatus, use can be made of a coupling loop 67 which is terminally connected to the anode structure as indicated at 68 and which is brought out through the wall of the container 50 through a conductive tube indicated at 69. A glass bead 70 sealed into the tube 69 preserves the vacuum within the container.

A particular advantage of a non-circular anode structure employed in the manner illustrated in Fig. 3 consists in the fact that the small number of anode elements employed inherently requires

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a correspondingly small number of coupled resonant systems. This limits the number of possible modes of oscillation of the apparatus as a whole and minimizes the tendency of the apparatus to transfer from one mode to another in sporadic fashion.

While the planar construction of the anode structure which has been described in the foregoing possesses obvious advantages from the standpoint of simplicity, it will be understood that a perfectly planar arrangement is not essential; that is to say, some curvature of the anode system in either direction may be tolerated. In a broad sense, the invention includes arrangements which comprise an incompletely circular array of mutually spaced anode elements lying upon a locus having a radius between a finite value which is large in relation to the dimensions of the individual elements, and infinity, the latter limit being included. The non-circular aspect of the anode construction may be described in another way by saying that with respect to an axis lying at the center of curvature of the common locus of the various anode elements of the entire anode array subtends an angle materially less than 360° and preferably less than 180°.

While the invention has been described by reference to particular embodiments, it will be understood that numerous modifications may be made by those skilled in the art without departing from the invention. I therefore aim in the appended claims to cover all such equivalent variations as come within the true spirit and scope of the foregoing disclosure.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. An electron discharge device having an envelope enclosing a resonant anode structure comprising an array of generally parallel anode elements and resonant means interconnecting selected elements, said elements being mounted in a common locus and mutually spaced providing gaps between each other, said array having a radius of curvature between a finite value which is large in relation to the dimensions of said elements and infinity and subtending at the center of curvature of its locus an angle of substantially less than 180°, conductive means of extended area mounted in opposed substantially parallel relation with respect to said array, means for maintaining said anode elements at a positive unidirectional electric potential with respect to said conductive means for maintaining therebetween a unidirectional electric field substantially normal to said array, means for supplying an electronic space charge to the space between said anode elements and said conductive means, and means for producing a magnetic field parallel to the said gaps whereby said anode structure may be set into high frequency resonance as a consequence of the magnetically controlled gyrations of the electrons traversing said space.

2. An electron discharge device having an envelope enclosing a series of anodes mutually spaced providing gaps between each other, each anode having a surface lying at least approximately in a planar locus common to the corresponding surfaces of the other anodes, a conductive body of relatively extended area mounted in opposed substantially parallel relation with respect to said anode surfaces and adapted to be maintained at a negative potential with respect thereto whereby a unidirectional electric field substantially normal to said locus may be maintained between said anodes and said body,

means for introducing electrons into the space between said body and said anodes, means for producing a magnetic field in the said space parallel to the said gaps, and resonant means interconnecting selected anodes to permit alternating voltages of high frequency to be developed between them.

3. A magnetron device having an envelope enclosing a non-circular array of anodes which are mutually spaced providing parallel gaps between them, each of said anodes having a surface lying in a substantially planar locus common to the corresponding surfaces of the remaining anodes, a cathode structure including conductive means of extended area mounted in opposed substantially parallel relation with respect to said array and means for supplying electrons to the space between said conductive means and said anodes, means for maintaining said anodes at a positive unidirectional electric potential with respect to said conductive means for maintaining therebetween a unidirectional electric field substantially normal to said locus, means for producing a magnetic field in the space between said anodes and said cathode structure and parallel to the said gaps whereby said array of anodes may be set into high frequency resonance as a result of the magnetically controlled motion of electrons traversing said space, and resonant means interconnecting selected anodes to facilitate the production between them of alternating voltages of high frequency.

4. An electron discharge device having an envelope enclosing a generally planar conductive body, an array of mutually spaced anodes mounted in opposed substantially parallel relation to said body, said anodes defining gaps between each other, means for supplying electrons to the space between said body and said anodes, means for maintaining said anodes at a positive unidirectional electric potential with respect to said body for maintaining therebetween a unidirectional electric field substantially normal to said array, means for producing a magnetic field in said space and parallel to the said gaps whereby said anodes may be set into high frequency resonance as a result of the magnetically controlled motion of electrons traversing said space, and resonant circuit means interconnecting said anodes to permit alternating voltages of high frequency to be developed between them as a result of the motion of the said electrons.

5. An electron discharge device having an envelope enclosing a generally planar conductive body, an array of mutually spaced planar anodes mounted in opposed substantially parallel relation to said conductive body and adapted to be maintained at a positive average potential with respect thereto whereby a unidirectional electric field substantially normal to said body and said array may be maintained therebetween, said anodes defining a plurality of parallel gaps between each other, means for producing a magnetic field generally parallel to said gaps in the space between said anodes and said conductive body, means for supplying electrons to the said space, and resonant means interconnecting the said anodes to permit alternating voltages of high frequency to be developed between them as a result of the motion of electrons traversing said space.

6. An electron discharge device having an envelope enclosing an anode structure having a generally planar surface and provided with a series of mutually spaced slots in said surface

dividing the structure into separate anode elements, each of said slots forming a resonant system interconnecting two adjacent anode elements, a cathode structure including a generally planar member mounted in opposed substantially parallel relation to said planar surface of said anode structure and means for providing electrons in proximity to the said anode elements, means for maintaining said anode structure at a positive unidirectional electric potential with respect to said member for maintaining therebetween a unidirectional electric field substantially normal to said planar surface and said member, and means for producing a magnetic field parallel to said slots in the space between said anode and cathode structures whereby said anode structure may be set into high frequency resonance as a consequence of the resultant motion of electrons traversing said space.

7. An electron discharge device having an envelope enclosing an anode structure comprising a generally planar array of generally parallel anode elements, said elements being mutually spaced and providing space resonant cavities between each other, said array subtending at the center of curvature of its locus an angle of substantially less than 180° , means for providing an electronic space charge in proximity to the said anode elements and in energy exchanging relation with the said cavities, generally planar conductive means having an extended area and mounted in opposed substantially parallel relation with respect to said array, means for maintaining said anode elements at a positive unidirectional electric potential with respect to said conductive means for maintaining therebetween a unidirectional electric field substantially normal to said array, and means for producing a magnetic field parallel to the said anode elements whereby said anode structure may be set into high frequency resonance as a consequence of the motion of the electrons composing the said space charge.

8. An electron discharge device having an envelope enclosing a resonant anode structure comprising an array of generally parallel anode elements and resonant means interconnecting selected elements, said elements being mounted in a common locus and mutually spaced providing gaps between each other, said array having a radius of curvature between a finite value which is large in relation to the dimensions of said elements and infinity and subtending at the center of curvature of its locus an angle of substantially less than 180° , conductive means of extended area mounted in opposed substantially parallel relation with respect to said array, means connected to said anode elements for maintaining said anode elements at a positive unidirectional electric potential with respect to said conductive means for maintaining therebetween a unidirectional electric field substantially normal to said array, cathode means mounted adjacent one end of said array for supplying an electronic space charge to the space between said anode elements and said conductive means, magnetic means positioned adjacent said array for producing a magnetic field parallel to the said gaps whereby said anode structure may be set into high frequency resonance as a consequence of the magnetically controlled gyrations of the electrons traversing said space, and electrode means mounted adjacent the other end of said array adapted to be maintained at a positive potential with respect to said conductive means for collecting electrons traversing said space.

9. An electron discharge device having an envelope enclosing a series of anodes mutually spaced providing gaps between each other, each anode having a surface lying at least approximately in a planar locus common to the corresponding surfaces of the other anodes, a conductive body of relatively extended area mounted in opposed substantially parallel relation with respect to said anode surfaces and adapted to be maintained at a negative potential with respect thereto whereby a unidirectional electric field substantially normal to said locus may be maintained between said anodes and said body, cathode means mounted adjacent one end of said series for introducing electrons into the space between said body and said anodes, magnetic means positioned adjacent said series for producing a magnetic field in the said space parallel to the said gaps, resonant means interconnecting selected anodes to permit alternating voltages of high frequency to be developed between them, and electrode means mounted adjacent the other end of said series adapted to be maintained at a positive potential with respect to said body for collecting electrons traversing said space.

10. A magnetron device having an envelope enclosing a non-circular array of anodes which are mutually spaced providing parallel gaps between them, each of said anodes having a surface lying in a substantially planar locus common to the corresponding surfaces of the remaining anodes, a cathode structure including conductive means of extended area mounted in opposed substantially parallel relation with respect to said array and means adjacent one end of said array for supplying electrons to the space between said conductive means and said anodes, means connected to said anodes for maintaining said anodes at a positive unidirectional electric potential with respect to said conductive means for maintaining therebetween a unidirectional electric field substantially normal to said locus, means mounted adjacent said array for producing a magnetic field in the space between said anodes and said cathode structure and parallel to the said gaps whereby said array of anodes may be set into high frequency resonance as a result of the magnetically controlled motion of electrons traversing said space, resonant means interconnecting selected anodes to facilitate the production between them of alternating voltages of high frequency, and means mounted adjacent the other end of said array adapted to be maintained at a positive potential with respect to said conductive means for collecting electrons traversing said space.

11. An electron discharge device having an envelope enclosing a generally planar conductive body, an array of mutually spaced anodes mounted in opposed substantially parallel relation to said body, said anodes defining gaps between each other, means adjacent said body and adjacent one end of said array for supplying electrons to the space between said body and said anodes, means connected to said anodes for maintaining said anodes at a positive unidirectional electric potential with respect to said body for maintaining therebetween a unidirectional electric field substantially normal to said array, means mounted adjacent said array for producing a magnetic field in said space and parallel to the said gaps whereby said anodes may be set into high frequency resonance as a result of the magnetically controlled motion of electrons traversing said space, resonant circuit means interconnect-

ing said anodes to permit alternating voltages of high frequency to be developed between them as a result of the motion of the said electrons, and means mounted adjacent the other end of said array adapted to be maintained at a positive potential with respect to said body for collecting electrons traversing said space.

12. An electron discharge device having an envelope enclosing a generally planar conductive body, an array of mutually spaced planar anodes mounted in opposed substantially parallel relation to said conductive body and adapted to be maintained at a positive average potential with respect thereto whereby a unidirectional electric field substantially normal to said body and said array may be maintained therebetween, said anodes defining a plurality of parallel gaps between each other, means adjacent said array for producing a magnetic field generally parallel to said gaps in the space between said anodes and said conductive body, means adjacent one end of said array for supplying electrons to the said space, resonant means interconnecting the said anodes to permit alternating voltages of high frequency to be developed between them as a result of the motion of electrons traversing said space, and means mounted adjacent the other end of said array adapted to be maintained at a positive potential with respect to said body for collecting electrons traversing said space.

13. An electron discharge device having an envelope enclosing an anode structure having a generally planar surface and provided with a series of mutually spaced slots in said surface dividing the structure into separate anode elements, each of said slots forming a resonant system interconnecting two adjacent anode elements, a cathode structure including a generally planar member mounted in opposed substantially parallel relation to said planar surface of said anode structure and means mounted adjacent one end of said structure for providing electrons in proximity to the said anode elements, means connected to said structure for maintaining said anode structure at a positive unidirectional electric potential with respect to said member for maintaining therebetween a unidirectional electric field substantially normal to said planar surface and said member, means mounted adjacent said structure for producing a magnetic field parallel to said slots in the space between said anode and cathode structures whereby said anode structure may be set into high frequency resonance as a consequence of the resultant motion of electrons traversing said space, and means mounted adjacent the other end of said structure adapted to be maintained at a positive potential with respect to said cathode structure for collecting electrons traversing said space.

14. An electron discharge device having an envelope enclosing an anode structure comprising a generally planar array of generally parallel anode elements, said elements being mutually spaced and providing space resonant cavities between each other, said array subtending at the center of curvature of its locus an angle of substantially less than 180° , means mounted adjacent one end of said array for providing an electronic space charge in proximity to the said anode elements and in energy exchanging relation with the said cavities, generally planar conductive means having an extended area and mounted in opposed substantially parallel relation with respect to said array, means connected to said anode elements for maintaining said anode elements at a positive

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unidirectional electric potential with respect to said conductive means for maintaining therebetween a unidirectional electric field substantially normal to said array, means adjacent said array for producing a magnetic field parallel to the said anode elements whereby said anode structure may be set into high frequency resonance as a consequence of the motion of the electrons composing the said space charge, and means mounted adjacent the other end of said array adapted to be maintained at a positive potential with respect to said conductive means for collecting electrons traversing the space between said anode structure and said conductive means.

JOHN P. BLEWETT.

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Disclaimer

2,428,612.—*John P. Blewett*, Scotia, N. Y. MAGNETRON. Patent dated Oct. 7, 1947. Disclaimer filed Aug. 23, 1951, by the assignee, *General Electric Company*.

Hereby enters this disclaimer to claim 6 of said patent.
[*Official Gazette November 20, 1951.*]