Nov. 14, 1967 I. B. BOTT 3,353,053

RADIATION GENERATOR OPERATING IN THE MILLIMETER AND SUBMILLIMETER WAVELENGTH RANGE

Filed March 25, 1964 4 Sheets-Sheet 1

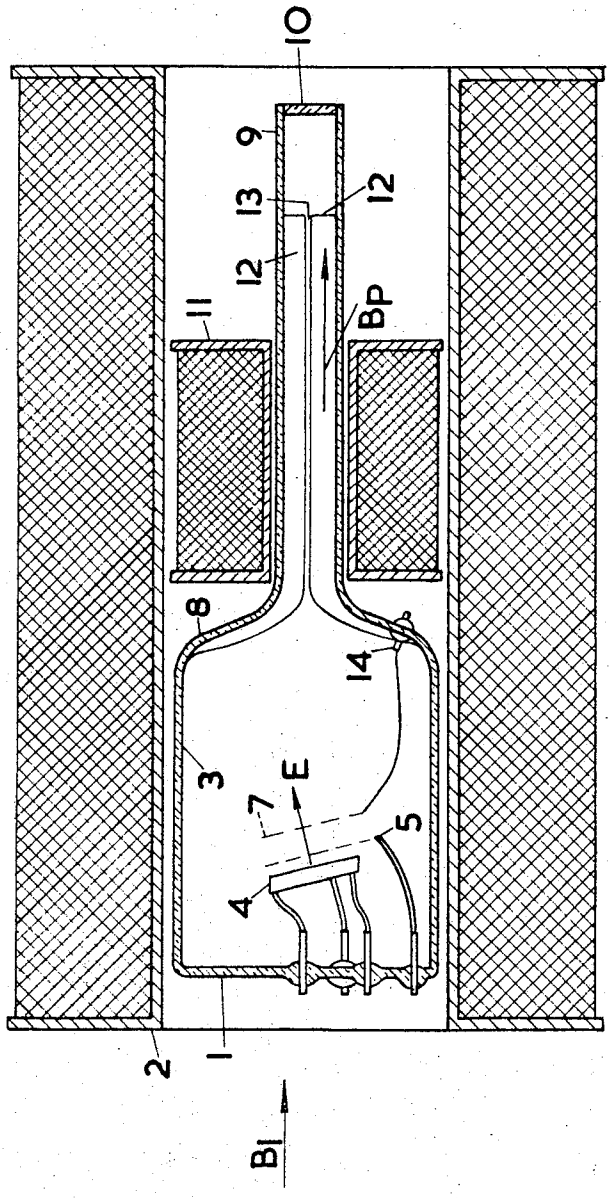


FIG. 1.

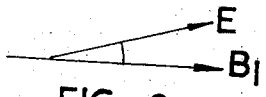


FIG. 2.

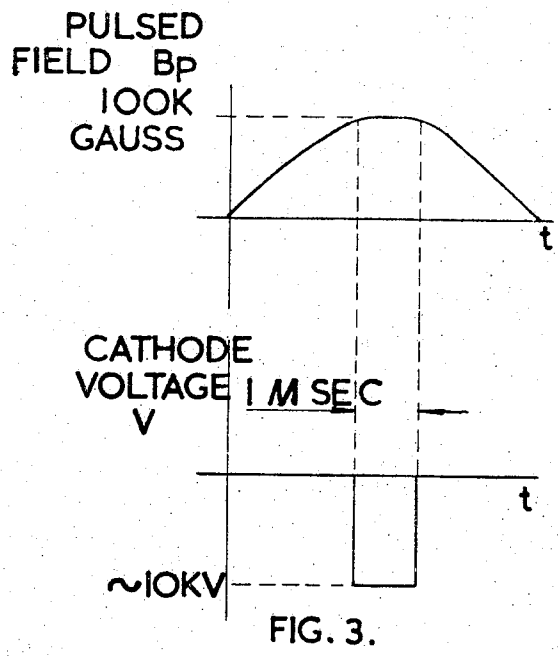


FIG. 3.

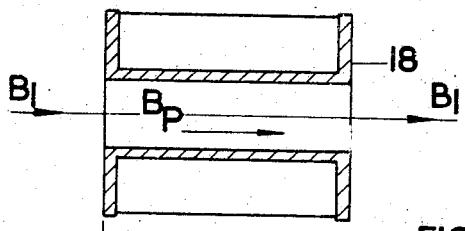
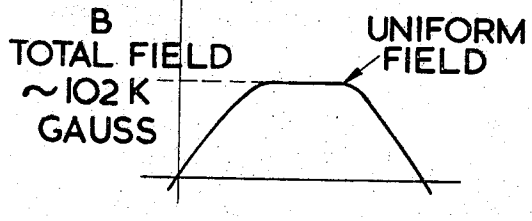


FIG. 4.



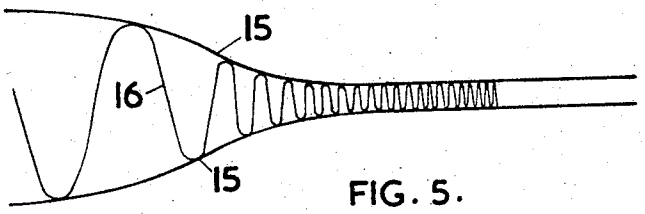


FIG. 5.

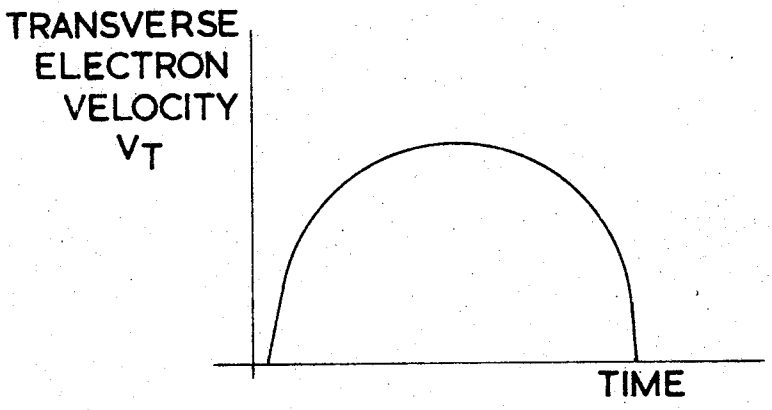


FIG. 6.

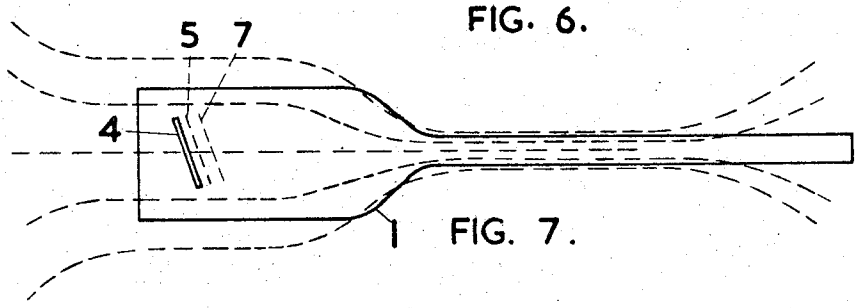


FIG. 7.

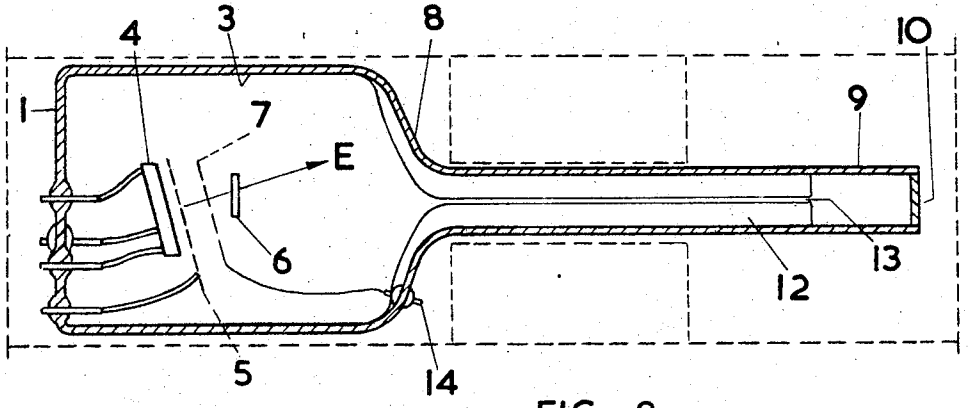


FIG. 8.

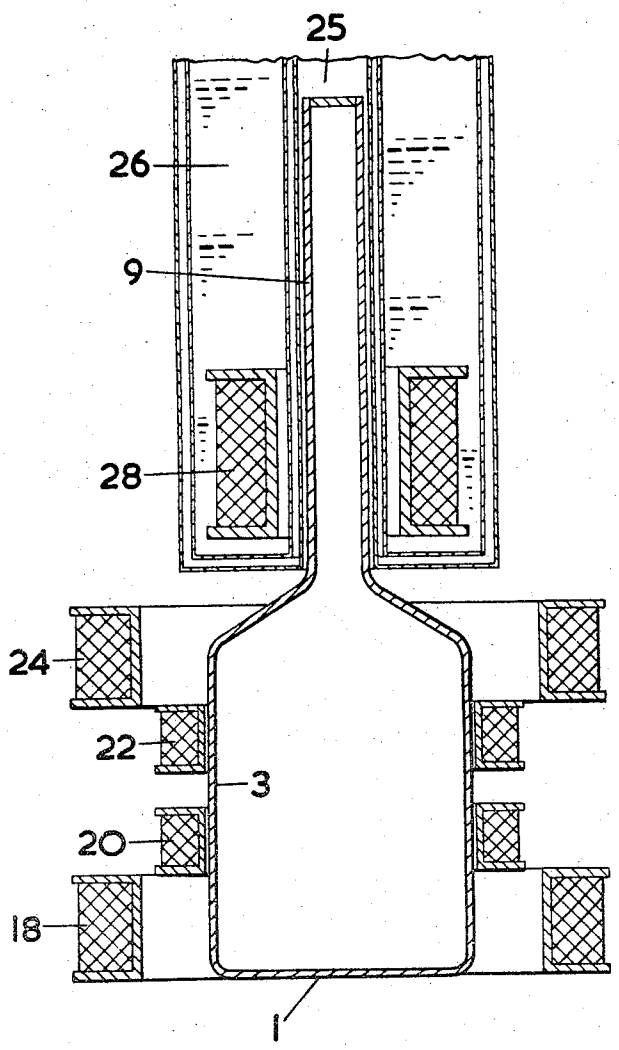


Fig. 9.

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RADIATION GENERATOR OPERATING IN THE MILLIMETER AND SUBMILLIMETER WAVELENGTH RANGE

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9 Claims. (Cl. 313—154)

This invention relates to radiation generators.

It is an object of the invention to provide a radiation generator operating in the millimetre and sub-millimetre ranges for use in spectroscopy and the like.

According to the invention means for generating electromagnetic radiation comprises means for emitting a stream of electrons in a magnetic field, means for generating an intense magnetic field and means for causing the electron stream to pass through the said intense magnetic field.

In order to make the invention clearer, examples of a radiation generator embodying the invention will be described, reference being made to the accompanying drawings, in which:

FIGURE 1 shows schematically a radiation generator according to the invention,

FIGURES 2–7 show explanatory diagrams to assist in an understanding of the invention,

FIGURE 8 shows an improved construction of the tube of FIGURE 1, and

FIGURE 9 shows an alternative arrangement of the tube of FIGURE 1.

The glass envelope of an electron tube 1 fits co-axially in a solenoid 2. The tube 1 has an enlarged part 3 containing a cathode 4, a grid 5 and an anode 7. From the enlarged part 3 the tube tapers through a short section 8 to an elongated part 9 which is of smaller cross section than the part 3. The part 9 is located within a further solenoid 11 and is closed by a quartz window 10. The solenoid 11 is itself located within the solenoid 2 and is situated immediately adjacent section 8 of the tube (pushed up against the shoulder).

The inside surface of the section 8 and the elongated part 9 carry a silver coating 12 which is divided longitudinally by a slot 13. An electrode 14 secured in the silvered wall of the section 8 of the tube 1 is connected to the anode 7.

The cathode 4 together with the grid 5 and the anode 7 of the tube 1 constitute an electron gun which is aimed in a direction indicated by the arrow E at an angle to the longitudinal direction of the field B1 produced by the solenoid 2. This is indicated in FIG. 2.

In operation the solenoid 2 is energized and produces a field B1 of approximately 2,000 gauss longitudinally of the tube 1 and the solenoid 11 is conveniently connected to a source of current pulses which establish a uniform, concentrated pulses flux Bp in the second part 9 of the tube. The practical effect is that a region of uniform magnetic field is produced in the part 3 around the electron gun assembly and a very concentrated pulsed field is established having a short uniform region within the solenoid 11.

FIG. 4 shows the field distribution within the solenoid 11 including the region of uniform field.

The grid 5 is connected to a bias source which may be varied from +50 v. to −50 v. relative to the cathode; the electrode 14 is connected to earth and the cathode 4 together with the grid 5 is pulsed.

The cathode voltage pulses have a length of 1 msec. and each pulse is timed to occur at the middle period

of the pulses driving the solenoid 11. Although the concentrated magnetic field is pulsed, it varies only slightly during the 1 msec. pulse of the tube current. The electron beam may therefore be thought of as seeing a DC magnetic field configuration substantially as shown in FIG. 7.

The magnetic field configuration is the vector sum of the fields due to the two solenoids, fringe fields, and eddy current fields in the metal associated with the experimental apparatus.

Electron from the gun are thus aimed at an angle to the longitudinal field in the part 3 so that they each describe a helical path which can be considered as extending along a tube of magnetic force of the field B1. As the field in the tube 1 concentrates through the section 8 finally reaching the region of uniform field within the solenoid 11 the helical path of an electron decreases in pitch and radius, somewhat as in the manner indicated in FIG. 5 where lines 15 are taken to represent boundaries of one tube of force and the line 16 shows the helical electron path of a typical electron. In the region of uniform field in the solenoid 11 interaction of the field and the electrons in the cavity formed by the silvered coating of the part 9 and the reflecting surface of the quartz window 10 results in radiation of electro-magnetic waves; these waves travel longitudinallly along the part 9 of the tube 1 and emerge through the quartz window 10 as a beam of radiation. The silvered coating of the part 9 serves as an electron collector and waveguide in this operation whilst the slot 13 restricts eddy currents which might flow in the silvering and prevents the plane of polarization of the beam of radiation from rotating in the circular waveguide. The power radiated is found to be several orders (about 2) greater than that predicted by classical electromagnetic theory for incoherent radiation. Typically the volume occupied by the radiated electrons is a cylinder 2½ cm. long by 0.5 cm. diameter. The variation of transverse electron velocity V_T in the uniform low field region (where V_T is the component of electron velocity perpendicular to the tube axis) is shown in FIG. 6. The electron gun is designed so that electrons are passed through the anode gauze with controllable and uniform velocity vectors: in particular the transverse velocity is controllable. Measurements suggest that the radiation emitted from the window 10 is partially coherent. A precise theoretical analysis of the operation of the tube has not yet been carried through.

In a typical tube as shown in FIG. 1 the cathode 4 is a 3 cm. diameter flat oxide coated disc; in the interests of simplicity connections to the pulse sources and the bias sources of the tube are not shown; similarly the sources feeding the solenoids 2 and 11 are also omitted in FIG. 1. Initial considerations which are important in the setting up of the generator are the value of the field B_1 due to the main solenoid 2, the anode-to-grid spacing, the grid-anode voltage V^1, the angle between the field B_1 and the normal E to the cathode and the ratio B_p/B_1. The output frequency of the generator may be varied by adjustment of the field B_p. A typical grid-anode voltage is 10 kv., the grid and the cathode 4 are pulsed together; the field B_1 is typically 2,000 gauss for a field B_p due to the solenoid 11 of 100 kilogauss (giving an outlet at approximately 1 mm. wavelength). Simple empirical values can be worked out to determine optimum conditions of operation of a tube. A power output of 1 mwatt has been obtained at a wavelength of 1 mm.

The radiation generated may be amplitude modulated using grid 5, or frequency modulated by inserting an additional grid and using this to alter the longitudinal velocity of the electrons and hence doppler shift the output frequency. In the latter case the grid 5 would be servo-controlled from the tube output to prevent amplitude

modulation due to variation of electron density in the high field region.

The generator may be operated continuously where DC magnetic fields are available.

A construction has been devised which gives improved operation. In FIG. 8 a modified tube **1** is shown in which a totally reflecting mirror **6** is positioned transversely of the tube **1** within the part **3** and opposite the quartz window **10** along the axis of the narrow part **9** of the tube **1**. This improves the resonant cavity comprising the silvering and the quartz window **10**, which is partially reflecting.

A further development consists in providing means for adjusting the position of the mirror **6** or alternatively of providing a further reflecting mirror transverse to the tube axis and outside the tube beyond the quartz windows **10**, and adjustable axially.

FIGURE 9 shows an alternative arrangement of the tube of FIGURE 1. For simplicity the electrodes of the tube are not shown. The envelope **1** of the tube is disposed with its enlarged part **3** surrounded by four solenoids **18**, **20**, **22** and **24** spaced along the enlarged part **3** of the tube in that order. The solenoids **18** and **24** are of greater diameter than the solenoids **20** and **22**.

The elongated part **9** of the tube is located in an axial lobe **25** in a cylindrical cryostat **26**. A superconducting solenoid **28** in the cryostat is capable of delivering a continuous magnetic field of 50 kilogauss.

By this arrangement the tube is capable of delivering continuous radiation instead of pulsed radiation.

The arrangement of the solenoids **18**, **20**, **22** and **24** is to produce a uniform magnetic field in the enlarged part **3** of the tube in the following manner. The magnetic field due to the solenoid **28** is falling off in the region under consideration, i.e. it is higher in the region of the solenoid **22** than in the region of the solenoid **20**. Therefore the solenoid **22** is arranged to deliver a magnetic field opposing that due to the solenoid **28** and the solenoid **20** is arranged to deliver a magnetic field reinforcing that due to the solenoid **28**. In this way an approximately uniform magnetic field is generated throughout the length of the enlarged portion **3** of the tube **1**. The solenoids **18** and **24** may be used to deliver magnetic fields in which a way that the total field is more uniform and by varying the intensities of the fields delivered by the solenoids **18**, **20**, **22** and **24** the total field may be varied within limits while still remaining fairly uniform.

I claim:

1. Means for generating magnetic radiation in the millimeter and sub-millimeter ranges, comprising

means for generating a uniform first magnetic field;

means arranged in said first magnetic field for emitting an electron stream of substantial initial thickness at an oblique angle to the first magnetic field;

means defining a microwave cavity arranged to receive said electron stream;

and means for generating in said microwave cavity an intense second magnetic field applied contemporaneously with said first magnetic field to reduce the diametric size of the electron stream.

2. Apparatus as defined in claim **1**, wherein said means for generating said intense second magnetic field comprises a superconducting solenoid.

3. Apparatus as defined in claim **1**, wherein said means defining said microwave cavity comprises a tube having at one end a quartz window, and further including axially adjustable reflecting means transverse of and situated outside the said tube.

4. Apparatus as defined in claim **1**, wherein said means emitting said electron stream comprises an electron gun including a cathode and an anode, and said means defining said microwave cavity comprises a tube having at one end a window, said means generating said first magnetic field comprising a first solenoid surrounding said gun, and said means generating said second magnetic field comprising a second solenoid surrounding the tube.

5. Means for generating magnetic radiation in the millimeter and sub-millimeter ranges, comprising

a glass envelope including an enlarged portion, an elongated tube portion of smaller diameter than said enlarged portion, window means closing one end of said elongated portion, and a short neck portion connecting the other end of said elongated portion with said enlarged portion;

means cooperating with said window to define in said tube portion a resonant cavity, said cavity defining means including a unitary conductive layer at least partially covering said neck and elongated portions;

first solenoid means arranged concentrically about at least the enlarged portion of said envelope for establishing therein a uniform first magnetic field of relatively low intensity;

second solenoid means arranged concentrically about the tube portion of said envelope for establishing therein a second magnetic field of relatively high intensity applied contemporaneously with said first magnetic field; and

electron gun means including an anode and a cathode arranged in said enlarged envelope portion for emitting an electron stream of substantial initial thickness at an oblique angle to the first magnetic field and for directing said electron stream into said cavity to effect reduction in the diametric size of the beam.

6. Apparatus as defined in claim **5** wherein said first magnetic field has an intensity of approximately 2 kilogauss and said second magnetic field has an intensity of approximately 100 kilogauss.

7. Apparatus as defined in claim **6**, wherein said cathode comprises a disk and said electron stream has an initial diameter of approximately 3 cm., and further wherein said electron stream has adjacent said window a diameter of approximately 0.5 cm.

8. Apparatus as defined in claim **7**, and further including means electrically connecting said conductive layer with said anode.

9. Apparatus as defined in claim **5**, wherein said cavity-defining means further includes a mirror arranged within the enlarged envelope portion opposite said window.

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