United States Patent [19]

Fischer et al.

[11] **3,733,510**

[45] **May 15, 1973**

[54] **ELECTRON DISCHARGE DEVICES USING ELECTRON-BOMBARDED SEMICONDUCTORS**

[75] Inventors: **Paul Fischer**, Oakhurst; **Park Richmond**, Farmingdale; **Gunther E. Wurthmann**, Lincroft, all of N.J.

[73] Assignee: **The United States of America as represented by the Secretary of the Army**, Washington, D.C.

[22] Filed: **Aug. 17, 1971**

[21] Appl. No.: **172,456**

[52] **U.S. Cl.** ....**315/5.24,** 315/3, 313/65 AB

[51] **Int. Cl.** **H01j 25/22**

[58] **Field of Search**....................315/1, 3, 5.24, 5.25; 313/65 AB, 66, 64.1

[56] **References Cited**

UNITED STATES PATENTS

2,638,561	5/1953	Szikai	315/5.25
3,020,438	2/1962	Szikai	315/3 X
2,656,483	10/1953	Apstein	315/5.24 X
3,219,873	11/1965	Kaufman	315/5.24 X
2,981,891	4/1961	Horton	315/3 X
2,600,373	6/1952	Moore	315/3 X

Primary Examiner—Rudolph V. Rolinec
Assistant Examiner—Saxfield Chatmon, Jr.
Attorney—Harry M. Saragovitz et al.

[57] **ABSTRACT**

Amplifying and oscillating devices wherein an element beam from an appropriate electron gun is directed through an apertured microwave cavity resonator means and bombards a coaxially mounted semiconductor p-n junction.

In the case of an amplifier, an input r-f signal is coupled into the cavity resonator and modulates the electron beam. In the case of an oscillator, a pair of closely coupled microwave cavities is used to achieve the feedback essential to oscillation. In either case, a microwave cavity resonator means can be tuned mechanically or thermally.

13 Claims, 3 Drawing Figures

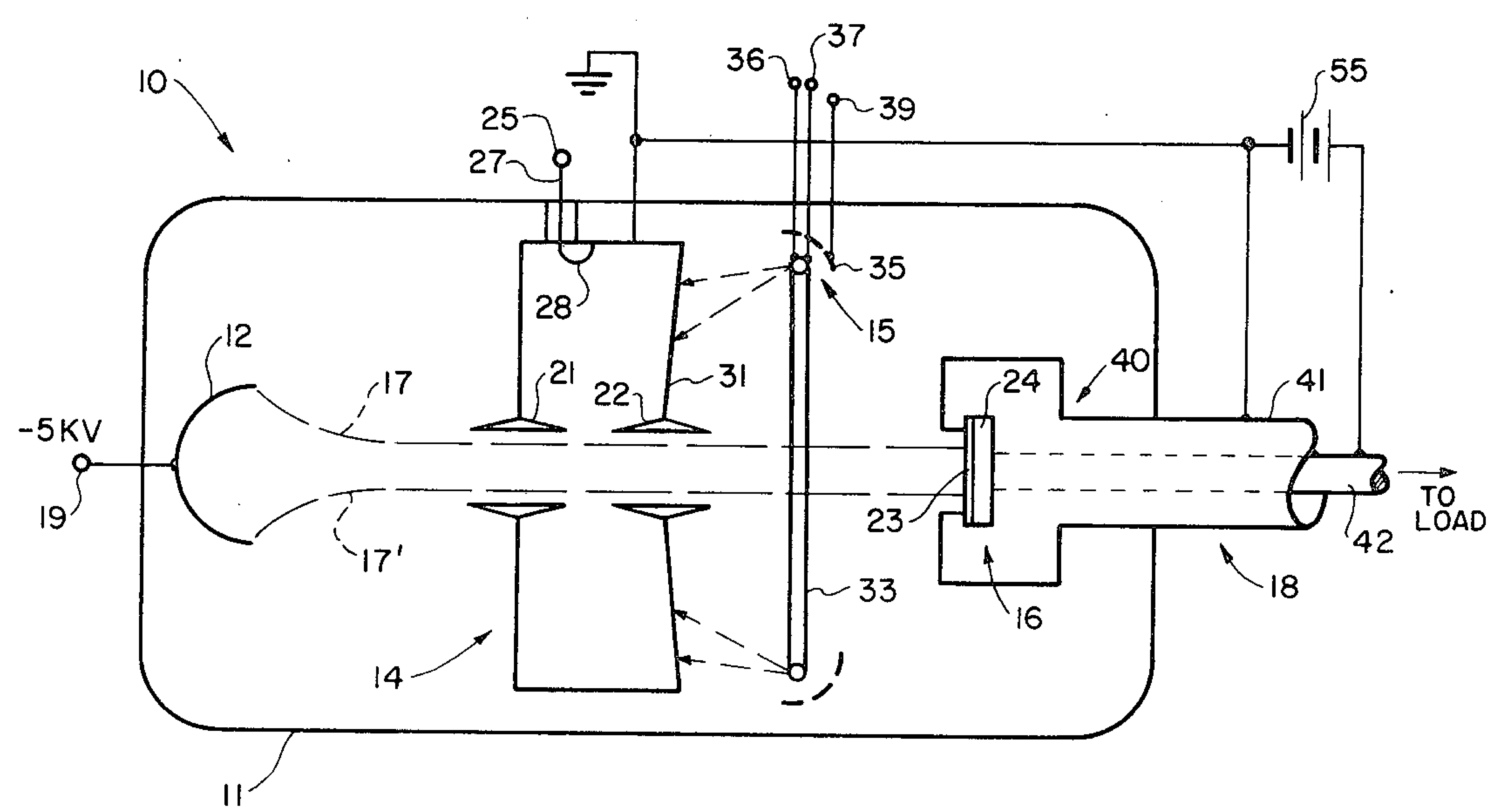


FIG. 1

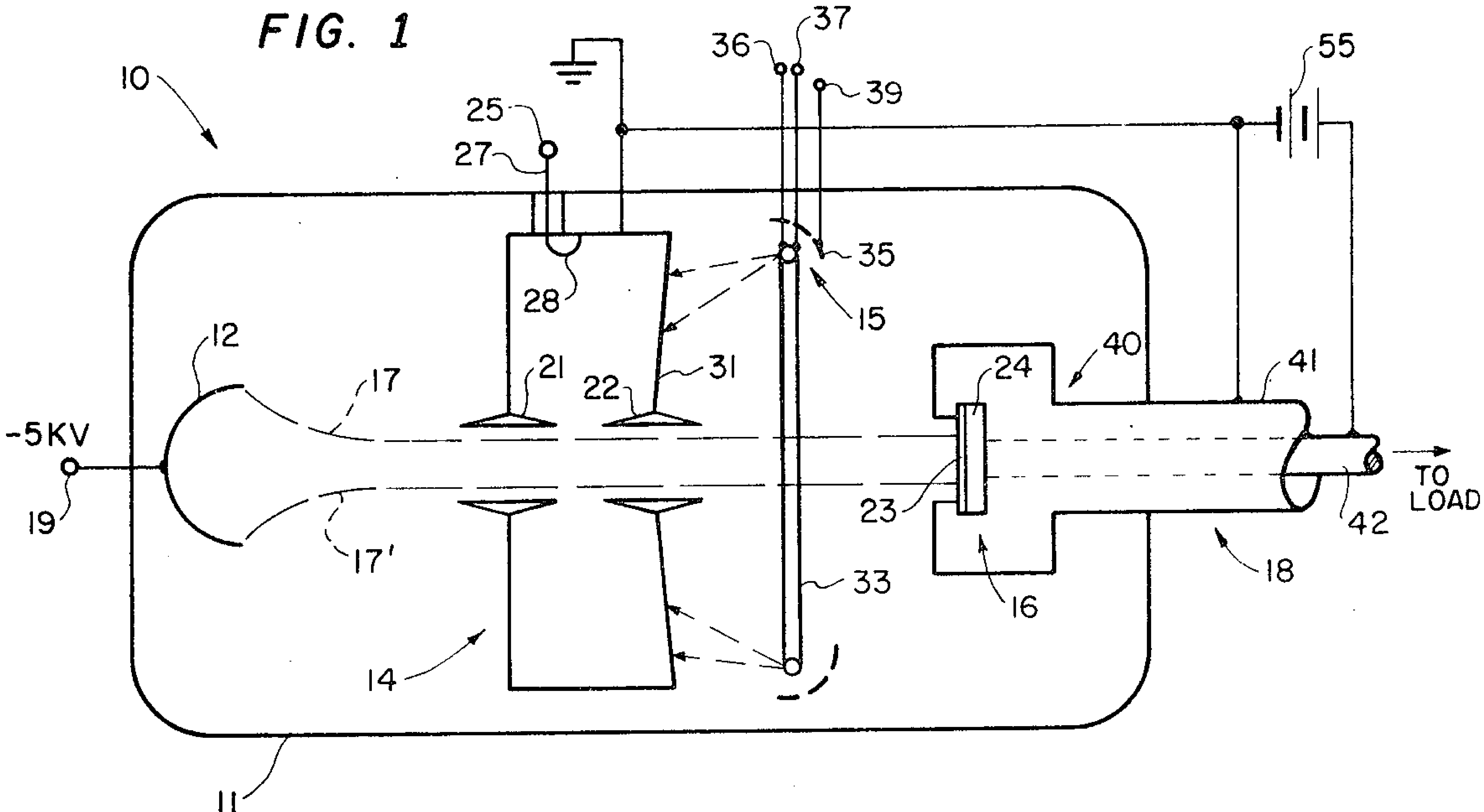


FIG. 2

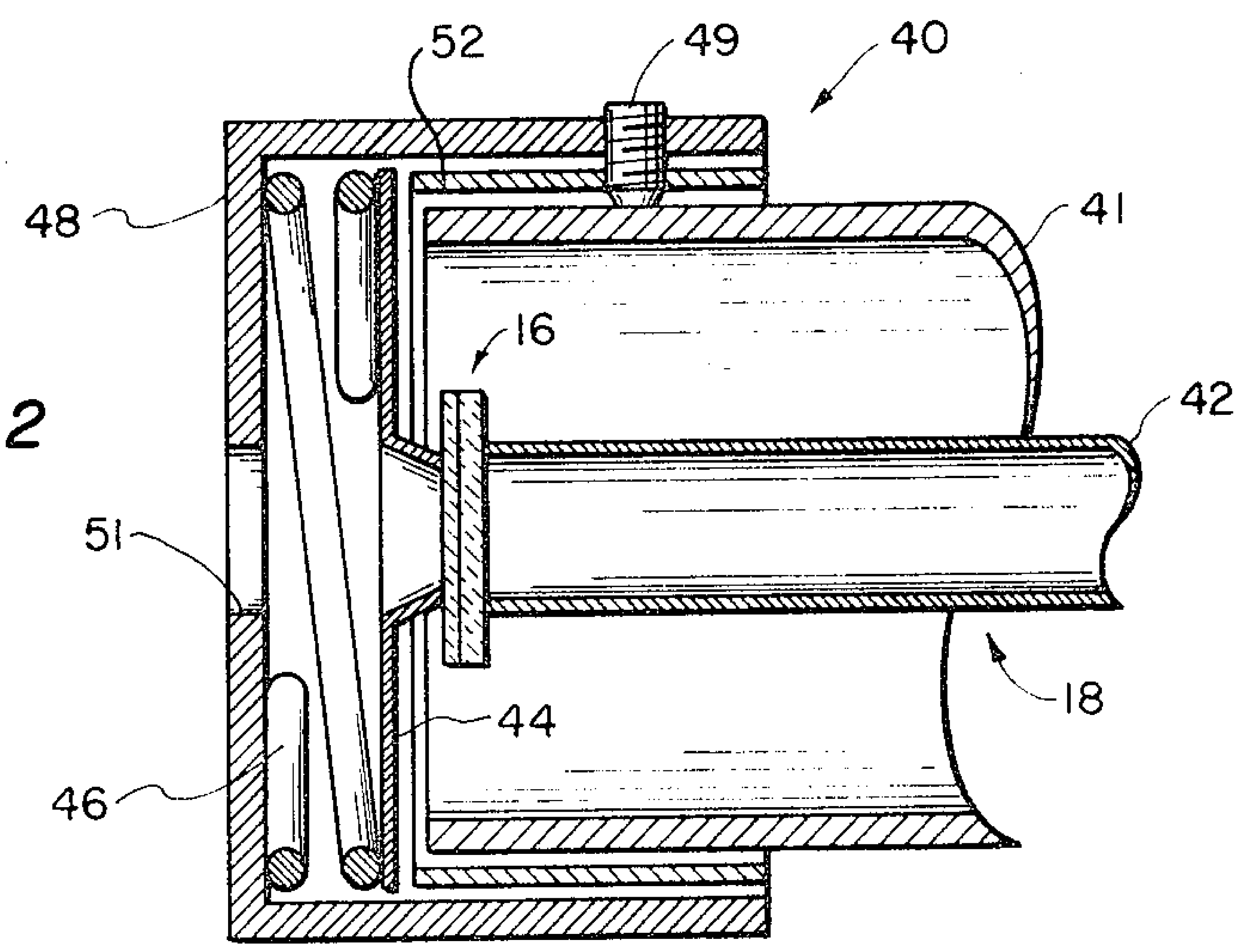
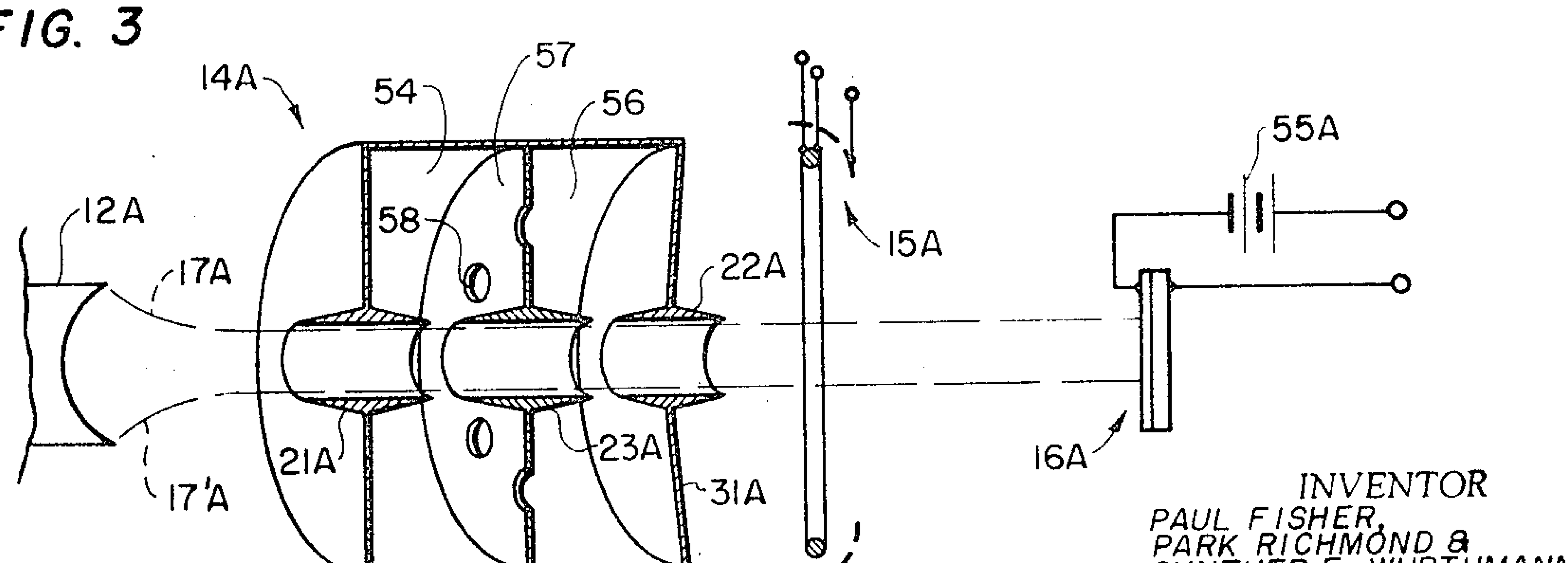


FIG. 3



INVENTOR
PAUL FISHER,
PARK RICHMOND &
GUNTHER E. WURTHMANN

BY Daniel D. Sharp
Harry M. Saragovitz
Edward J. Kelly
Herbert Berl
ATTORNEYS

ELECTRON DISCHARGE DEVICES USING ELECTRON-BOMBARDED SEMICONDUCTORS

SUMMARY OF THE INVENTION

Electron discharge devices now used for microwave amplification or generation include klystrons, magnetrons, and traveling wave type devices. Since the gain of traveling wave tubes is a function of the length of the interaction region, these devices became somewhat bulky. Magnetrons often are bulky devices, because of the heavy anode blocks; furthermore, magnetrons, like traveling wave tubes, involve somewhat complicated delay structures or anode blocks. Klystron amplifiers, in contrast with applicants' amplifier, in order to provide suitable amplification, normally require at least two cavities not to mention the usual close tolerances on inter-grid spacings which depend upon the frequency of operation.

The gain of the electron discharge device, according to the invention, unlike the traveling wave tube, is not determined primarily by length. The distance traveled by the electron beam, which, incidentally, can be derived from any of several types of small electron guns — well known in the art — is not critical, except that the semiconductor junction should be positioned at a distance (relatively close) from the cavity exit aperture of the single cavity resonator so as to maximize the r-f energy incident thereupon; this distance is not as critical as in the case of grid-collector spacings for a klystron. Unlike high power klystrons, the amplifying electron discharge device, according to the invention, needs but a single cavity resonator, while the dual-cavity oscillator of the invention can be constructed of a single cylindrical member divided into two portions by a centrally apertured diaphragm.

Summarizing, the electron discharge device of the invention is a small device of relatively simple construction, consisting basically of a small electron gun, a microwave cavity resonator, maintained positive with respect to the electron gun for focusing the beam and for accelerating the beam to a high energy level, said cavity resonator modulating the beam at a microwave rate, and a reverse biased p-n junction, comprising a region of p-type conductivity type material and a region of n-conductivity type material, upon which the modulated electron beam passing through the cavity resonator impinges. The peak output power of this device, taken from across the p-n junction, as by a coaxial output line to which the p-n junction diode is mounted, is quite high, and this high power is obtained, to a great extent, because of the high current gain (several thousand times) inherent in the reverse biased p-n junction.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a diagrammatic view of an amplifying device in accordance with the invention;

FIG. 2 is a view showing details of the coaxially mounted p-n junction diode of FIG. 1; and

FIG. 3 is a view showing pertinent portions of an oscillating device in accordance with the invention.

SPECIFIC DESCRIPTION OF INVENTION

Referring to FIG. 1, an amplifier electron discharge device 10 is shown comprising an evacuated envelope 11 within which is disposed an electron gun 12, a cavity resonator 14, resonant cavity tuning means 15, and a p-n junction diode 16 mounted on a coaxial output line

18 which extends externally to the envelope 11. The electron gun can be one of several existing types of guns which include means for beam forming and, in some instances, means for accelerating the electron beam emitted by the electron source. One example of an electron gun can be used in the electron discharge device; the well known Pierce type gun. This type of gun is described in FIG. 10.2 on page 167 of "Theory and Design of Electron Beams" published 1969 by Van Nostrand which contains a Chapter X entitled "Electron Guns" on pages 167–187. Since the invention does not involve the electron gun, per se, it has been shown in FIG. 1 simply as a curved line which is more or less representative of a typical curved electron emissive surface from which emanates an electron beam, whose boundaries are represented by the dashed lines 17 and 17′. The electron gun includes means to cause the electron beam to converge so as to pass through entrance and exit drift tubes 21 and 22 of the cavity resonator 14 without impinging upon the resonator walls or the drift tubes. The cavity resonator 14 may be maintained positive with respect to the electron gun cathode, and may thereby provide the proper electron beam acceleration required for a high energy electron beam. By way of example, the resonator may be maintained at ground potential and the cathode of the electron gun connected to a terminal 19 which is at a negative potential in the order of from 4 to 5 kilovolts with respect to its ground. Higher values of voltage, of course, are within the scope of this invention and would provide a higher energy electron beam; it is necessary, however, that the beam energy level not exceed a level which would destroy the junction diode 16. Alternatively, high energy may be imparted to the beam by applying a large voltage between the cavity resonator 14 and the mounting cap 48. The entrance and exit drift tubes 21 and 22 normally include relatively massive tapered portions, as shown in FIG. 1, in order to dissipate heat accidentally produced within the cavity resonator 14 by inadvertent defocussing of the electron beam.

A microwave input is supplied to input terminal 25 and is coupled into the cavity resonator, as by a coaxial line 27 extending through the envelope 11 and including an r-f coupling loop 28 which protrudes into the cavity resonator 14. The high energy electron beam, upon passing through the cavity resonator 14, is velocity modulated at a microwave frequency determined by the resonant frequency of the cavity resonator 14; the resonant frequency is adjusted to conform to the microwave input frequency by means of the thermal tuner 15 disposed adjacent the exit wall 31 of the cavity resonator 14. This tuner 15 comprises essentially an annular cathode 33 which encloses a heater, not shown in the drawing, the leads 36 and 37 of which extend outside the envelope 11. The electrons emitted from the tuner cathode are directed by means of a supporting beam forming grid 35 — connected to a supply terminal 39 — onto the wall 31 of the resonator 14, which end wall is bent slightly inwardly so as to insure inward flexure as the electrons from the cathode strike said end wall. A number of electrons impinging upon the exit resonator wall 31 is proportional to the cathode voltage of the tuner 15, which for example, can be of the order of 50 to 250 volts. As the cavity resonator wall 31 is heated, it flexes inwardly, causing the exit grid 22 to move closer to the entrance grid 21. In this manner, the capacity of the cavity resonator 14 increases and the resonant frequency thereof decreases; this frequency change essentially is in direct proportion to the heater voltage applied at terminals 36 and 37. Other means for tuning the cavity resonator 14 of FIG. 1, or for that matter, the cavity resonator means 14A of FIG. 3, such as mechanical tuning, are within the scope of the invention.

The p-n junction diode 16 of FIG. 1 is indicated schematically as a two-layer structure whose thickness is exaggerated in the drawing, for the sake of clarity. This diode 16 can be formed, for example, by ion implantation of a p conductivity type material 23 and a body 24 of a semiconductor material of n-type conductivity. The p-type region 23 normally can be made to extend over an appreciable area of the n-type semiconductor region 24. In practice, this p-n junction can be very small and the thickness may be, for example, of the order of 35 angstrom units. The transverse dimensions are limited only by the inner diameter of the outer conductor of the coaxial line 18. It should be noted that the diode 16 could be made with the n-type conductivity material formed onto a p-type substrate. In either case, the diode 16 is reverse biased. As a result of high energy bombardment, an electron flow is established through the p-n junction, the coaxial line 18 and load. An aluminum coating, not shown, can be applied over the p-n junction to protect the latter from oxidation or environmental contamination. The diode 16 is positioned a short distance from the exit wall 31 of the cavity resonator. Although this distance is not especially critical, it is necessary that the spacings between the cavity resonator 14 and the bombarded p-n junction diode 16 be approximately one quarter reduced plasma wavelength at the microwave input frequency. In the manner, the diode 16 is located at a region of high electron beam current density and the electron beam energy imparted to diode 16 is maximized. The diode 16 is maintained in a coaxial output mount 40 which includes a coaxial line 18 having an outer conductor 41 and an inner conductor 42, one end of which is engaged by the diode. The details of construction of the coaxial output mount 40 is shown in FIG. 2. A flexible cylindrical diaphragm 44 has a reentrant portion which engages the diode 16 and holds the latter against one end of inner conductor 42 of coaxial line 18 by the pressure exerted by spring 46 which fits between mounting cap 48 and diaphragm 44. The coil spring 46 provides the constant pressure needed to hold the diode 16 in place without damaging the junction. The mounting cap 48, which is attached to the outer conductor 41 of the coaxial line 18 by one or more set screws 49, contains a central aperture 51 to allow passage of the high energy electron beam. A retainer 52 serves to prevent loss of the spring should removal of the mounting cap 48 be necessary. Electrical connection of the bias source 55 to the electron-bombarded surface of the diode 16 is achieved through a path including diaphragm 44, spring 46, end cap 48, set screw 49 and outer conductor 41 of coaxial line 18.

In FIG. 3, an oscillator device is shown which, like the amplifier of FIG. 1, includes an electron gun 12A for producing a high energy electron beam which passes through cavity resonator means 14A and impinges upon a diode 16A reverse biased by supply 55A; the diode 16A can be mounted as shown in FIG. 2. A thermal tuner 15A can be provided, as is the case of the amplifier of FIG. 1, adjacent the cavity resonator means 14A for tuning purposes. The cavity resonator means 14A of FIG. 3 includes two distinct cavity resonators 54 and 55 which are separated by a member 57 containing one or more coupling slots or apertures 58 to produce the feedback necessary for sustaining oscillations. The cavity resonator means 14A of FIG. 3 includes an entrance drift tube 21A, an intermediate drift tube, 23A, and an exit drift tube 22A. The frequency of oscillation will be governed, as usual, by the geometry of the cavity resonator means 14A and by the capacitances between the intermediate drift tube 23A and each of the drift tubes 21A and 22A. The capacitance between drift tubes 22A and 23A can be varied by varying the spacing therebetween. This spacing, in turn, can be decreased by bombarding the flexible inwardly biased end wall 31A of the cavity resonator means 14A with electrons from tuner 15A, as described in connection with the amplifier of FIG. 1.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood, that, within the scope of the appended claims, the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An electron discharge device comprising cavity resonator means, means for producing a high velocity beam of electrons, means for directing said electron beam through said cavity resonator means along the axis thereof for deriving a velocity modulated beam also directed along said axis, a p-n junction diode disposed in the path of said velocity modulated beam, and a unidirectional source for reverse-biasing said diode.

2. An electron discharge device according to claim 1 wherein said cavity resonator means comprises a single cavity resonator to which is coupled a microwave input signal.

3. An electron discharge device according to claim 1 wherein said cavity resonator means comprises a pair of intercoupled cavity resonators for providing oscillations within said cavity resonator means.

4. An electron discharge device according to claim 2 further including a thermal tuner adjacent to said cavity resonator for bombarding with electrons a portion of said cavity resonator means to change the dimensions of at least a portion of said cavity resonator means.

5. An electron discharge device according to claim 3 further including a thermal tuner adjacent to said cavity resonator for bombarding with electrons a portion of said cavity resonator means to change the dimensions of at least a portion of said cavity resonator means.

6. An electron discharge device according to claim 2 wherein said cavity resonator means includes at least a pair of drift tubes.

7. An electron discharge device according to claim 3 wherein said cavity resonator means includes at least a pair of drift tubes.

8. An electron discharge device according to claim 1 wherein the thickness of said diode is of the order of 35 angstrom units.

9. An electron discharge device according to claim 1 further including a coaxial output line having an inner conductor and an outer conductor, mounting means for resiliently mounting said diode with one of two opposed major surfaces thereof in contact with one end of said inner conductor, said mounting means including

a centrally-apertured flexible diaphragm engaging the other major surface of said diode which is exposed to said beam, a mounting cap removably attached to the periphery of said outer conductor and containing a central annulus to allow passage of said beam, and a resilient member disposed between the end of said mounting cap and said flexible diaphragm.

10. An electron discharge device according to claim 9 wherein said unidirectional biasing source is connected between said inner and outer conductors.

11. An electron discharge device according to claim 8 wherein said cavity resonator means comprises a cavity resonator to which is coupled a microwave input signal.

12. An electron discharge device according to claim 9 wherein said cavity resonator means comprises a single cavity resonator to which is coupled a microwave input signal.

13. An electron discharge device according to claim 9 wherein said cavity resonator means comprises a pair of intercoupled cavity resonators for providing oscillations within said cavity resonator means.

* * * * *