Oct. 2, 1956 J. F. ZALESKI 2,765,445

GAS-FILLED DIODE DISCHARGE TUBE

Filed Nov. 15, 1952

FIG. 1

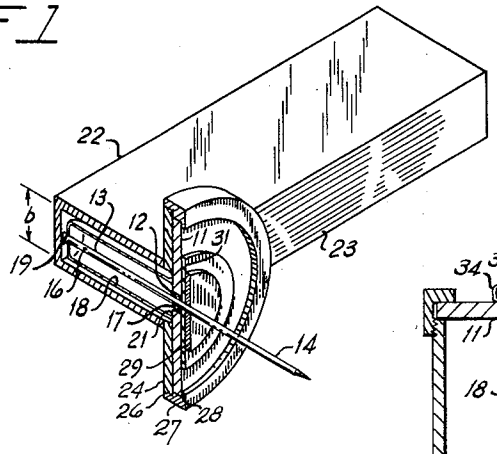


FIG. 2

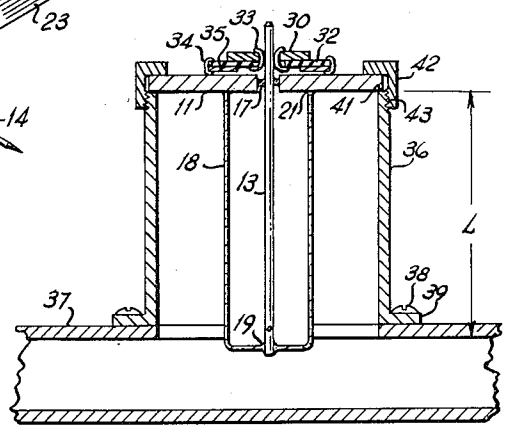
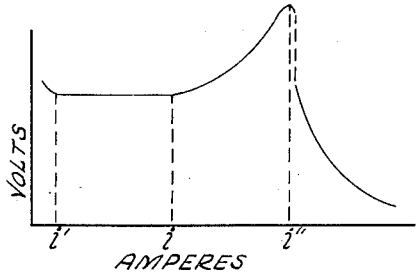


FIG. 4



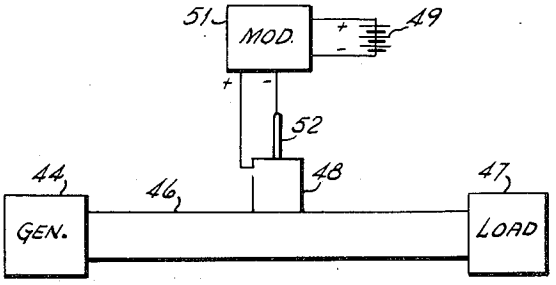


FIG. 3

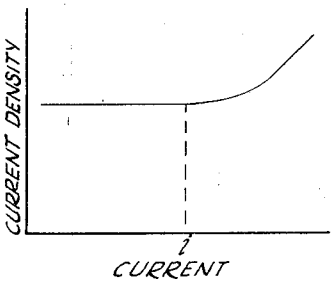


FIG. 5

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GAS-FILLED DIODE DISCHARGE TUBE

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11 Claims. (Cl. 333—13)

This invention relates to discharge tubes of the gas-filled cold-cathode type having two electrodes, and more specifically to such tubes designed for use in microwave circuits such as modulators, mixers, attenuators or detectors.

The discharge tube of this invention in general consists of a disc or cone anode and a rod cathode coaxially disposed relative to the anode and projecting through a central hole therein. The electrodes are enclosed in a glass envelope filled with gas at a suitable pressure, and provision is made to minimize microwave energy leakage through the diode whether ignited or unignited. Provisions for assembling the diode to a microwave guide component are equally as important as the tube constructional details, since the tubes are designed for performance in or associated with microwave fields existing inside microwave guides. These assembly provisions include resonant and non-resonant means for assembling the tube in the narrow side, broad side or the end of rectangular hollow guide, or in corresponding positions in round hollow or coaxial guide.

The principle underlying this invention utilizes the properties of the blue negative glow that occurs at the cathode of a glow discharge tube. This glow can be made to vary in exent or density by varying the tube current, and these variations of the glow can be made to present variations in impedance to a microwave field impinging upon the glow plasma. Since the tube current can be controlled in the external tube power supply circuit, such a discharge tube can be used to control or detect microwave energy in a number of ways.

One purpose then of this invention is to provide convenient means including a gas-filled diode discharge tube for efficiently modulating microwave guided energy.

More specifically, a purpose of this invention is to provide a gas-filled cold-cathode diode discharge tube for modulating microwave energy by changes in the impedance of its negative glow plasma.

Another purpose of this invention is to provide a gas-filled diode detector for the demodulation of modulated microwave guided energy, such detector not being subject to burnout or other injury by the application thereto of energy of considerable magnitude, while affording high sensitivity.

Still another purpose of this invention is to provide a gas-filled diode mixer for microwave circuits.

Still another purpose of this invention is to provide an electrically controlled attenuator for use in microwave circuits.

A further understanding of this invention may be secured from the detailed description and associated drawings, in which:

Figure 1 is a sectional view of the discharge tube of the invention secured in the narrow side of a rectangular microwave guide.

Figure 2 is a sectional view of the discharge tube secured by a holder to the broad side of a rectangular microwave guide.

Figure 3 depicts a microwave circuit illustrating use of the discharge tube of the invention.

Figures 4 and 5 are graphs depicting characteristics of glow discharges.

Referring now to Fig. 1, a diode discharge tube is provided with an anode **11** in the form of a flat conductive disc or ring made of a metal which can be welded to glass and which has a low surface resistivity for microwave energy. This anode is provided with a central aperture **12**. A cathode **13** consisting of a straight rod of the same metal as the anode is positioned coaxially with the anode **11**, extending through the aperture **12** therein. The rod cathode **13** is preferably thin and round in order to present minimum disturbance of the microwave field surrounding it and to increase the direct-current voltage gradient at its surface, promoting voltage breakdown and initiation of the glow discharge. The rod cathode **13** may be coated with electron-emitting compounds, and is provided with an axial bore extending from its end **14** to a point near its other end, a transverse port **16** being provided at this point for communication between the axial bore and the space exterior to the rod **13**. The axial bore and the port **16** serve in exhausting the tube, and after exhaustion the tip **14** is sealed off. The rod cathode **13** and disc anode are bound together mechanically, while insulated electrically, by a gas-tight glass seal **17**. The left end of the cathode, as seen in Fig. 1, is enclosed in a gas-tight glass envelope **18**, sealed to the tip of the cathode at **19** and sealed to the anode **11** in a ring seam indicated at **21**. The left end of the cathode preferably projects through the seal **19** so that the metal end of the cathode projects beyond the glass envelope, as this construction makes the uniformity of capacitance of the projecting tip easier to control in manufacture. The envelope **18** is filled through tubulation **14** with an appropriate filling gas at such pressure as to permit use of the diode in the glow discharge region, and at a part of that region at which the negative glow plasma of the glow discharge offers low resistance to microwave field energy. For example a mixture of neon and less than 1% of argon at a pressure of between 1 and 10 mm. of mercury is suitable.

The diode as so far described is suitable for general application to microwave energy control and detection in association with a variety of microwave guides. In Fig. 1 the diode is shown applied to the narrow side of a microwave hollow rectangular guide **22** for transmitting microwave energy of a selected wavelength or band of wavelengths, with the rod cathode **13** passing nearly or not quite across the guide, midway of the broad sides and perpendicular to both the axial line of the guide and the direction of the electric field component of the microwave energy carried by the guide. The length of the rod **13** should not, however, equal one-quarter of the free space wavelength or of any of the band of wavelengths carried by the guide **22**, or any odd multiple thereof, because such length of rod even when perpendicular to the direction of the microwave electric field exhibits resonance effects and will both absorb and reflect microwave power to some extent.

In order to permit insertion of the discharge tube into the guide the rectangular guide **22** is provided in one of its narrow sides **23** with a round opening having a diameter equal to the smaller cross-sectional dimension *b* of the guide. A circular disc or flange of metal **24** having a central bore of diameter *b* is secured to the outside surface of the narrow side **23** so that its central bore surrounds the opening in the narrow side of the guide. The outer edge of the flange **24** is threaded at **26**. A cap member **27** is provided with internal threads engaging the threads **26** of the flange and the anode disc **11** is

seated in a recess 28 so that the anode disc 11 is clamped between bottom of the recess and the flange 24.

In order to prevent escape of the microwave energy from the wave guide 22 through the aperture 12, a metal disc 29 is provided snugly secured to the rod 13 and extending well beyond the edges of the aperture 12. This disc 29 is insulated from the anode 11 for direct current by an insulating disc 31 which may be of mica. The disc 29 thus serves as an electrostatic shield at the aperture 12 while the combination of the disc 29, insulator 31 and anode plate 11 forms a condenser that effectively by-passes the aperture 12 at microwave frequencies.

The diode is suitable for use in the rectangular guide as shown as a modulator, mixer, attenuator and demodulator, employing suitable circuits such as are well known in the art.

The diode may be applied to a rectangular guide and perform its intended function even though the diode does not project appreciably into the guide or even when the diode does not enter the guide at all. In such instances a holder is attached to the external surface of a broad guide face, with an aperture connecting the interior of the holder with the interior of the guide. An iris opening may be employed at the aperture for further control, and the length of the holder may be made so that the holder together with the contained discharge tube may be non-resonant, resonant, or anti-resonant at the microwave frequency employed in the guide.

A preferred form of holder is shown in Fig. 2 containing a discharge tube similar to that of Fig. 1. The discharge tube contains anode 11, rod cathode 13, and envelope 18, with glass welds at 17, 19 and 21. Protection against escape of microwave energy is provided by a prefabricated button-type condenser 32 pressed on to the cathode rod 13 so that its central eyelet terminal 33 is in good electrical contact therewith as well as in contact with one condenser plate 30. The peripheral rim terminal 34 is in electrical contact with the other condenser plate or plates 35 and with the anode disc 11 of the diode. This condenser may be of either the ceramic or silver-mica variety, for example, and its capacitance is not critical. As an example of its electrical size, a button condenser having a capacitance of 100 $\mu\mu$f. has been found to prevent the escape of any measurable quantity of microwave energy at a frequency of 10,000 mc. p. s.

The discharge tube is fastened in a holder including a cylinder 36 having an internal diameter greater than that of the envelope 18 but not greater than the larger internal cross sectional dimension of the guide 37, upon which guide face the cylinder is secured by screws 38 passing through a flange 39 threaded into the guide. The area of the guide's broad side encompassed by the cylinder is partly or entirely cut away to provide access for microwave field energy between the interior of the guide and the interior of the cylinder. The anode ring 11 rests upon the upper end 41 of the cylinder, where it is secured by a screw thimble 42 in threaded engagement at 43 with the upper end of the cylinder 36. The cylinder 36 together with the cathode rod 13 thus forms a reentrant or coaxial cavity closed at one end by the disc anode 11 and open or partly open at the other end to the interior of the guide. It is preferable that the effective length L of this cavity be any integral multiple of one-half of the microwave length of the energy existing in the coaxial cavity. The open end of the cavity then presents no obstacle to passage of microwave energy through the guide.

This combination of discharge tube and holder is suitable for use as a modulator, mixer, attenuator and detector.

Forms of by-pass condenser other than those illustrated in Figs. 1 and 2 can be used to prevent the escape of microwave energy from the guide, and other structures well known in the art can be employed. In all cases it is required that the escape of microwave energy be prevented both when the tube is unfired or unenergized by the direct current or modulating source, and when it is fired or is in the glow discharge condition. The requirements also indicate a compact and easily made design which does not interfere with the operation of the glow discharge.

It is obvious that the discharge tubes of this invention can be employed for the mentioned purposes not only in hollow rectangular guide and in coaxial guide, but also in round guide carrying microwave energy of the proper mode and phase so that operation as described may occur.

Operation as a modulator or mixer of the type of discharge tube and holder shown in Fig. 2 in the broad side of a rectangular wave guide is illustrated in Fig. 3. A microwave generator 44 generates microwave energy of a selected wave length and applies it for transmission through a rectangular hollow wave guide 46 to a non-reflective load 47. A discharge tube and holder such as shown in detail in Fig. 2 is indicated at 48. A direct-current source of potential sufficient to start a glow discharge in tube 48 is indicated by the battery 49. This potential source is current amplitude modulated in any desired manner by a modulator 51 and the output is applied to tube 48, the rod cathode 52 being connected to the negative terminal of the modulator.

Returning now to Fig. 2, when direct current potential is applied between anode and cathode which is above the sparkover potential, with the current flow controlled, a self-sustained negative glow appears at the point where anode and cathode most nearly approach each other. If current be restricted to a value normally in the neighborhood of 1 ma., the glow discharge will be confined to a short length of the cathode rod near the anode. As the current is increased, the negative glow creeps along the cathode in proportion, until at some current value i, the glow reaches the end of the cathode terminating at the seal 19. If the current be further increased, the current density per unit area of rod increases, probably by both increase in diameter and increase in density of the plasma constituting the negative glow. Finally, at some value of current, usually above 40 ma., the character of the discharge changes from a glow to an arc. This volt-ampere characteristic is illustrated in Fig. 4, the region from i' to i'' being the glow discharge region, and the region above i'' being the arc discharge region.

When the discharge tube of this invention is operated in this arc characteristic region, it has been found that the tube is an excellent noise generator. The tube can therefore be employed in an attenuator circuit for generating and introducing noise spectrum modulating frequencies into a microwave circuit.

When the tube is operated in the glow discharge region the current density per unit length of that part of the cathode that is covered with the glow discharge is shown in Fig. 5. The left part of this curve is horizontal and indicates constant glow density per unit area of rod as the glow creeps out along the rod. The current value i marks the extension of the glow to the extreme end of the rod, this current value terminating the horizontal part of the curve. Further input current increase then increases the current density and the curve bends upward. The horizontal part of this curve represents what is sometimes called the normal glow discharge, while the curved part represents the so-called abnormal glow discharge. The design of the instant discharge tube as used in Fig. 3 exploits the normal glow discharge.

Let it be supposed that in the use of the discharge tube and holder of Fig. 2 in the circuit of Fig. 3 such average modulating current is applied to the tube as to cause a negative glow to sheathe the rod cathode 13 for one-half of its length. The resistance of the plasma is such as to make the cavity absorb some microwave power. Therefore, as the cavity, tuned to the frequency of the microwave energy passing through the guide, abstracts energy from the guide, the cavity dissipates some of the abstracted energy and returns the remainder to the guide. This energy-absorbing property of the cavity

is highly sensitive to the length of the luminous sheath surrounding the rod cathode. This sheath length is in turn controlled by and directly proportional to the applied current and if, as here, the current is modulated in any manner, the modulations will appear as modulations of the sheath length, in turn very efficiently amplitude-modulating the microwave energy that is transmitted through the guide past the cavity. Thus by making use of the change in length of the negative glow sheath along the rod cathode **13**, the discharge tube in association with the microwave structure of Fig. 2 constitutes an efficient modulator of microwave energy.

It is obvious that any modulator of this type operating on the principle of energy absorption can serve as an attenuator. The loss of energy in guide **37**, Fig. 2, is a function of the direct current applied to the discharge tube, and therefore if in Fig. 3 a simple current control be substituted for the modulator **51**, the circuit becomes that of an attenuator.

The operation of the discharge tube is reversible in the sense that the strength of the microwave electric field surrounding the plasma and in contact with it has an effect upon the apparent impedance of the plasma and therefore upon the voltage drop across it at a selected current flow. The discharge tube can therefore be used as a detector or demodulator.

What is claimed is:

1. A gas-filled negative glow diode discharge tube for use with a waveguide comprising, an elongated cold cathode, a flat anode connected to said waveguide and containing an aperture, said cathode having an extension projecting through the aperture in said anode toward said waveguide, an insulating gas-tight envelope sealed to said anode and enclosing said cathode, gas at low pressure filling said envelope, and microwave means surrounding said cathode and positioned contiguous to said aperture for preventing the passage of microwave energy through said aperture.

2. A gas-filled negative glow diode discharge tube for insertion in a microwave field comprising, a rod-shaped cold cathode, a conductive annular anode containing an aperture, said cathode being provided with an extension projecting through said aperture, an insulating gas-tight envelope sealed to said anode and enclosing said cathode, a gas filling for said envelope, said gas filling having such composition and pressure as to permit the formation of a negative glow on said cathode upon flow of electric current between anode and cathode, the conductance of said negative glow for microwave field energy varying with said current, and microwave means surrounding said electrode and positioned contiguous to said aperture for preventing passage of microwave energy through said aperture.

3. A gas-filled negative glow diode discharge tube comprising, an elongated conductive electrode, a conductive anode in the form of a solid of revolution provided with a central aperture coaxially surrounding said electrode, one end of said electrode extending axially away from said anode to form a cold cathode, an insulating gas-tight envelope completely surrounding contiguous portions of said anode and electrode, ionizable gas filling in said envelope capable of forming a negative glow plasma around said cathode, means for immersing said cathode in a microwave field having a selected frequency, and microwave means surrounding said electrode and positioned contiguous to said aperture for preventing passage of microwave energy through said aperture.

4. A gas-filled negative flow diode discharge tube and holder comprising, a rod-shaped conductive electrode, a conductive annular anode surrounding but spaced from said electrode, one end of said electrode extending axially from said anode to form a cold cathode capable of emitting electrons upon bombardment with positive ions, an insulating gas-tight envelope completely surrounding contiguous portions of said anode and electrode, a modulated direct-current source connected between said anode and electrode, a gas filling within said envelope having such nature and pressure as to be ionized under electric tension by electron collision to form a negative glow plasma surrounding said cathode, the amount of said negative glow plasma varying with said modulation and the effective conductance of said plasma for microwave field energy varying with said amount of plasma, microwave means surrounding said electrode and positioned contiguous to the junction of said anode and electrode for preventing egress of microwave energy through the region of nearest approach of said anode to said electrode, a microwave guide, and a conductive holder surrounding said cathode and envelope and connected to said anode for attaching said discharge tube to said microwave guide, said holder together with said discharge tube forming a microwave reentrant cavity.

5. A discharge tube and holder in accordance with claim 4 in which the dimensions of said microwave resonant cavity are such that the cavity is resonant to microwave energy applied thereto from said microwave guide.

6. In a microwave component a gas-filled negative glow diode discharge tube for immersion in a microwave field comprising, a rod-shaped conductive electrode, a conductive annular anode coaxially surrounding but spaced from said electrode, one end of said electrode extending coaxially in one direction from said anode to form a cold cathode capable of emitting electrons upon bombardment with positive ions, the other end of said electrode extending through said anode in the other direction to form a cathode terminal, an insulating gas-tight envelope extending from said anode to the vicinity of the distal end of said cathode, a glass seal connecting the nearest parts of said electrode and anode and electrically insulating them from each other, means for applying direct current between said cathode terminal and said anode, a gas filling for said envelope at such low pressure as to be ionized by said current flow to form a negative glow surrounding said cathode said negative glow having relatively low impedance at microwave frequencies and having a short-circuiting effect upon a microwave field impinging thereon, while the potential of a microwave field impinging thereon affects the direct-current potential drop across said anode and cathode, and microwave means surrounding said electrode and positioned contiguous to the junction of said anode and electrode for preventing the egress of microwave field energy through the region of nearest approach of said anode and electrode.

7. A discharge tube in accordance with claim 6 in which said microwave means for preventing egress of field energy includes a by-pass condenser.

8. A diode gas discharge tube comprising, a flat disc shaped anode provided with a central aperture, a rod shaped cathode projecting through said aperture hermetically and insulatably sealed thereto, a glass envelope sealed at one end to one face of said anode extending axially of said cathode to enclose the major portion thereof, the distal end of said cathode projecting through the end wall of said envelope and being hermetically sealed thereto, means surrounding said cathode and positioned contiguous to the aperture in said anode for preventing transmission of microwave energy therethrough, and a gas filling for said envelope.

9. A diode gas discharge tube comprising, a flat disc shaped anode provided with a central aperture, a rod shaped cathode projecting through said aperture hermetically and insulatably sealed thereto, a glass envelope sealed at one end to one face of said anode extending axially of said cathode to enclose the major portion of the end of said cathode projecting from said one face of said anode, the distal end of said cathode projecting through the end wall of said envelope and being hermetically sealed thereto, a microwave bypass

condenser postioned adjacent said anode central aperture electrically interconnecting said anode and cathode, and a gas filling for said envelope.

10. A diode gas discharge tube comprising, a flat disc shaped anode provided with a central aperture, a rod shaped cathode projecting through said aperture hermetically and insulatably sealed thereto, a generally cylindrical glass envelope positioned concentrically with respect to said cathode and sealed at one end to said anode in an annulus intermediate the radial extent thereof, a conductive plate connected to and surrounding said cathode positioned adjacent the face of said anode opposed to that to which said envelope is sealed, a sheet of dielectric material interposed between said anode and conductive plate, and a gas filling for said envelope.

11. A diode gas discharge tube comprising, a flat disc shaped anode provided with a central aperture, a rod shaped cathode projecting through said aperture hermetically and electrically insulatably sealed thereto, a generally cylindrical glass envelope positioned concentrically with respect to said cathode and sealed at one end to said anode in an annulus intermediate the radial extent thereof, a member postioned on said cathode adjacent the face of said anode opposed to that to which said envelope is sealed, said member comprising at least one dielectric disc separating at least two conductive discs in mutual capacitive relation, said member having a conductive ring around its periphery and a metallic center eyelet, said eyelet contacting at least one of said conductive discs and said cathode, and a gas filling for said envelope.

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