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BULK-EFFECT NEGATIVE-RESISTANCE MICROWAVE APPARATUS EMPLOYING A COAXIAL MICROWAVE CIRCUIT STRUCTURE

Filed May 26, 1967

FIG. 1

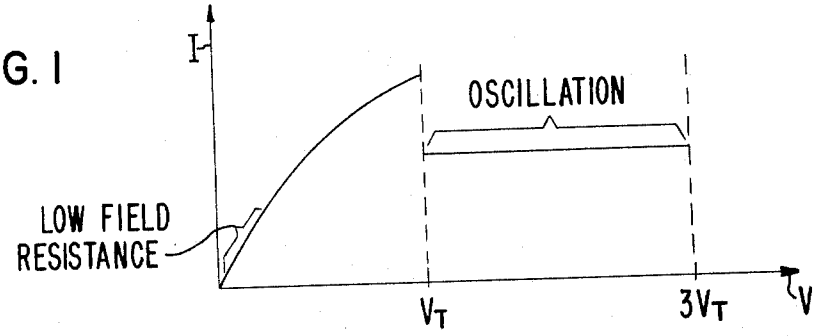


FIG. 2

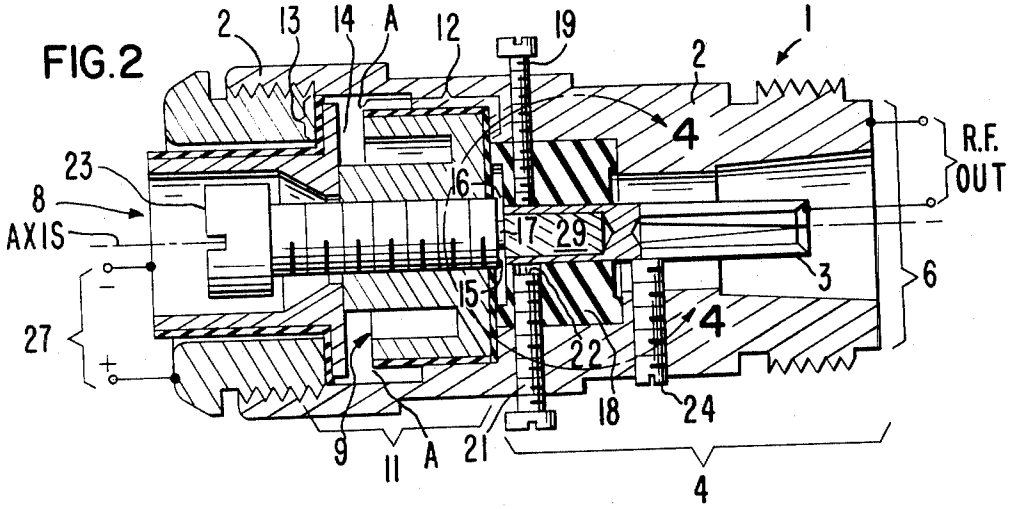


FIG. 3

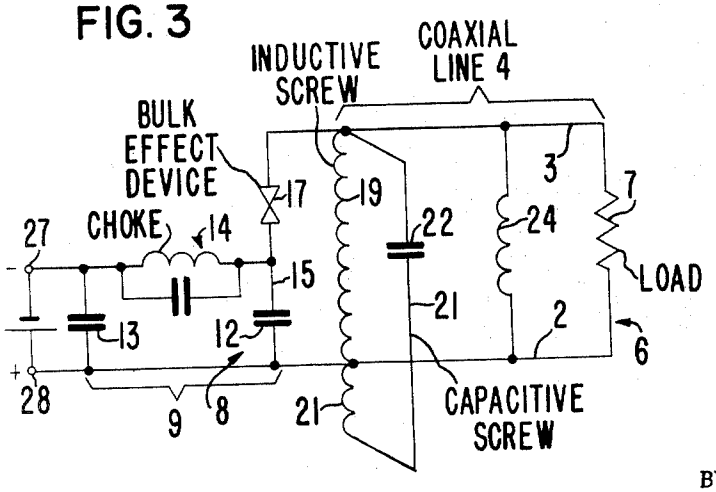
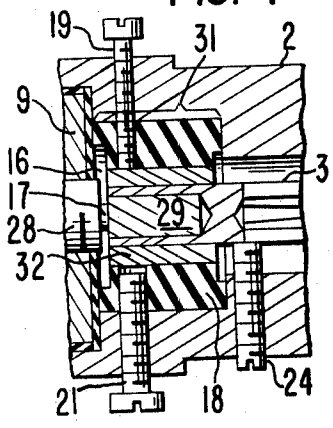


FIG. 4



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ABSTRACT OF THE DISCLOSURE

A bulk-effect negative-resistance semiconductor microwave oscillator is disclosed. The microwave circuit includes an *rf* output section of coaxial line which is closed at one end for microwaves by a DC insulated and microwave choked conductive plug disposed across the outer conductor. The center conductor of the section of coaxial line terminates near the inner face of the plug. A pair of conductive posts are disposed in the coaxial line adjacent the plug to form a lumped constant resonant microwave circuit. One post is conductively connected between the inner and outer conductors and is predominately inductive while the other post is predominately capacitive and may be made movable for tuning the microwave circuit.

The bulk-effect semiconductive device is connected between the conductive plug and the end of the center conductor in the fields of the resonant circuit. The other end of the coaxial line forms a microwave output terminal for connection to a load. DC bias potential, which may be pulsed or continuous, is applied across the semiconductive device via the DC insulated plug and the inductive post.

In one embodiment the coaxial line includes a quarter wave impedance transformer section for matching the bulk-effect device to the load. An impedance matching stub is also provided for trimming the impedance match.

At X-band the microwave circuit is disposed conveniently inside a standard N-type coaxial cable connector body. Suitable bulk-effect devices include Gunn effect devices which may be operated in the transit time mode or in the limited space charge accumulation mode.

Description of the prior art

Heretofore, Gunn-effect microwave oscillators and amplifiers have been built wherein the bulk-effect device was connected in series with the center conductor portion of a coaxial line microwave resonator. Such a microwave device is described in an article titled, "Microwave Phenomena in Bulk GaAs," appearing in the January 1966 issue of IEEE Transactions on Electron Devices, Vol. ED–B, No. 1, pages 94–105. The problem with use of the coaxial cavity resonator is that it has harmonically related resonant modes which have relatively high Q. These modes become excited and couple to the device resulting in a loss of microwave power which is required to sustain resonance of these unwanted modes. In addition, the output of the device will have power in these unwanted harmonic modes.

Gunn oscillators have also been built at L-band using a stripline section of microwave circuit. Such a circuit is described in an article titled, "High-Peak-Power Gallium Arsenide Oscillators" appearing at pages 105–110 of the above cited periodical. This prior stripline circuit employed lumped constant elements to define the resonant circuit, thereby essentially eliminating unwanted harmonically related resonant modes. However, such a stripline circuit is relatively complex and difficult to build, especially at X-band.

Summary of the present invention

The principal object of the present invention is the provision of an improved microwave circuit for bulk-effect negative-resistance devices.

One feature of the present invention is the provision of an improved microwave circuit for bulk-effect negative-resistance devices wherein a lumped constant microwave resonator, which is coupled to the bulk-effect device, is formed by a pair of conductive posts positioned in a section of coaxial line, whereby a relatively simple, inexpensive and relatively wide band mode free microwave circuit is obtained.

Another feature of the present invention is the same as the preceding feature wherein one of the posts conductively interconnects the inner and outer conductors of the coaxial line to form a predominately inductive portion of the resonator and the other post is capacitively coupled to the inner conductor to form the capacitive portion of the resonator.

Another feature of the present invention is the same as the preceding feature wherein the capacitive post is adjustable for tuning the resonator and the inductive post provides a conductive path for applying a DC bias potential across the bulk-effect device.

Another feature of the present invention is the same as any one or more of the preceding features including the provision of a conductive plug disposed across the outer conductor of the coaxial line near an end of the inner conductor, such plug being insulated from the outer conductor for DC and choked for microwave energy to provide a conductive path to one terminal of the bulk-effect device for applying DC bias thereto while closing off one end of the coaxial line for microwave energy, whereby unwanted resonances associated with microwave coupling to the bias source are prevented.

Another feature of the present invention is the same as any one or more of the preceding features including the provision of a quarter wave impedance transformer between the bulk effect device and the output terminal end of the coaxial line for impedance matching the bulk-effect device to the load impedance.

Another feature of the present invention is the same as the preceding feature including the provision of an impedance matching stub at the load end of the quarter wave impedance transformer for trimming the impedance match to the bulk-effect device.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

Brief description of the drawings

FIG. 1 is a plot of DC current I vs. applied voltage V for bulk-effect negative-resistance semiconductive devices,

FIG. 2 is a longitudinal sectional view of a microwave oscillator employing features of the present invention,

FIG. 3 is an equivalent circuit diagram for the structure of FIG. 2, and FIG. 4 is a detail view of a portion of the structure of FIG. 2 delineated by line 4—4 and depicting an alternative embodiment of the present invention.

Description of the preferred embodiments

Referring now to FIG. 1, there is shown the DC current I versus DC bias voltage V characteristics for a typical bulk-effect negative-resistance semiconductor device. As the voltage is increased, the current increases until a certain threshold voltage V_T is applied. At V_T the current drops and remains nearly constant with increasing voltage. Concurrent with the drop in current the device breaks into microwave oscillation, thereby converting DC

power into microwave power. The oscillations are associated with a bulk-effect negative-resistance. As used here, "bulk-effect negative-resistance devices" are defined to mean devices which convert DC power into microwave power due to mechanisms arising predominately out of the bulk properties of the semiconductive device as contrasted with other types of negative-resistance devices which convert DC power to microwave power predominately due to properties of a p–n junction. Such junction devices are typified by tunnel diodes, whereas, bulk-effect devices are typified by Gunn devices.

Such Gunn devices may be operated in any one of a number of possible modes of oscillation such as, for example, either the transit time mode or the limited space charge accumulation mode. In the transit time mode, Gunn devices exhibit a characteristic frequency of oscillation determined largely by the thickness of the semiconductor wafer, typically, GaAs. In the limited space charge accumulation mode, the operating frequency is independent of wafer thickness and is more dependent upon the resonant frequency of the microwave circuit to which it is coupled.

Referring now to FIGS. 2 and 3 there is shown a bulk-effect oscillator incorporating features of the present invention. More specifically, at X-band, the microwave circuit is conveniently contained within a standard N-type coaxial cable connector body 1. The connector body 1 comprises a hollow cylindrical outer conductor 2 containing a coaxial inner conductor 3 to define a section of coaxial line 4. One end of the coaxial line section 4 forms a microwave output terminal 6 for connection to a suitable utilization device or load 7. The other end 8 of the coaxial line section 4 is closed off for microwave energy by means of a conductive plug 9.

The conductive plug 9 includes a low pass filter circuit 11 disposed around its periphery for blocking passage of microwave power past the plug 9. More particularly, a pair of coaxial bypass capacitors 12 and 13 are formed at axially spaced positions on the plug 9. A folded quarter wave choke 14 is formed in series with the plug 9 between the bypass capacitors for reflecting microwave energy tending to propagate around the plug 9. Also, the length of the first bypass capacitor 12 is selected to be a quarter wave long from the face 15 of the plug 9 to a point A of increased characteristic impedance for reflecting a microwave short circuit to the junction of the outer conductor 2 with the face 15 of the plug 9. The capacitors 12 and 13 also isolate the plug 9 for DC from the outer conductor 2 to provide a path for DC bias voltage, as more fully described below.

The inner face 15 of the conductive plug is essentially at the same microwave potential as the outer conductor 2. The center conductor 3 of the coaxial line section 4 terminates near the inner face 15 of the plug 9 to define a gap 16 therebetween.

The bulk-effect negative-resistance device 17 is disposed in the gap 16 with one terminal connected to the plug 9 and the other terminal connected to the end of the center conductor 3. The center conductor 3 is supported from the outer conductor by a cylinder 18 of dielectric fill material.

A pair of conductive posts 19 and 21 project into the coaxial line section 4 adjacent the inner face 15 of the conductive plug 9. The inner face 15 of the plug 9 forms a microwave ground plane member for the posts 19 and 21. Post 19 conductively interconnects the inner and outer conductors 3 and 2, respectively, and has a length and diameter to provide a predominately lumped inductance in shunt with the coaxial line section 4 at the end thereof. The term "lumped" as used herein is defined to mean that the active length of the post or element is physically shorter than ¼ of a free space wavelength at the center frequency of its operating frequency band. In the case of posts 19 and 21, their active lengths are those portions which extend into the coaxial line section 4.

Post 21, on the other hand, is spaced at its inner end 22 from the center conductor 3 to provide predominately a lumped capacitance in shunt with the coaxial line at the end thereof. Post 21 also introduces some shunt inductance. However, the diameter of post 21 is larger than that of post 19 to provide increased capacitance and reduced inductance. In a typical example at X-band, posts 19 and 21 are formed by 0–80 and 3–56 machine screws, respectively.

Posts 19 and 21 provide a lumped constant resonant microwave circuit connected in shunt across the end of the coaxial line section 4. Post 21 is adjustable for tuning the resonant frequency of the lumped constant microwave resonator. The electromagnetic resonant fields of the lumped constant resonator are coupled into the bulk-effect device for electromagnetic interaction with the charge carriers therein to produce coherent output microwave power which is coupled to a load via the output terminal 6.

A conductive impedance matching stub on post 24 projects into the coaxial line section 4 approximately a quarter wave from the bulk-effect device 17 for trimming the impedance match between the bulk-effect device 17 and the output load. The post or stub 24 need not make electrical contact with the center conductor. For bulk-effect device 17 which has a low field resistance greater than about 10Ω, the post 24 preferably does not make electrical contact with the center conductor 3 for the best impedance matching.

In a typical example at X-band, the coaxial line section 4 had a characteristic impedance of 50Ω. The bulk-effect device 17 was a Gunn effect GaAs wafer dimensioned for the transit time mode and had a thickness of 10 microns and was 15 mils square in cross section. The device had a low field impedance of 2.1Ω. A pulsed source of bias potential applied 10 volts across the device via bias terminals 27. The pulse rate was 1000 pulses per second of 150 nanosecond duration. The oscillator provided 5.9% DC to microwave conversion efficiency at a center frequency of 7.65 gHz. with peak output microwave power of 1.55 watts. The output was tunable over the range of 6.5 gHz. to 10.5 gHz. by adjusting tuning post 21.

For heat sinking, the bulk-effect device 17 has one terminal soldered to the end of a copper stud 28 which is screwed into the center of and forms a portion of the plug 9. The stud 28 presses the other terminal of the device 17 against a copper plug 29 which fills the center of the inner conductor 3 of the coaxial line section 4.

For higher output power, a plurality of the bulk-effect device 17 are connected in parallel across the gap 16. In this case, their low field resistance may drop to a fraction of an ohm. Improved impedance matching is obtained by providing a quarter wave transformer section 31 between the device 17 and the load as shown in FIG. 4.

The characteristic impedance Z_2 of the quarter wave transformer section 31 is defined by: $Z_2=\sqrt{Z_1 Z_2}$ where Z_1 in the load impedance (50Ω) and Z_1 is 20 to 30 times the low field impedance of the composite device 17, as of, for example, 25 (0.2Ω to 2Ω)=5 to 50Ω. The low impedance section 31 is conveniently formed by a conductive sleeve 32 inserted over the center conductor 3 in the transformer section 31.

Use of the lumped constant microwave resonator avoids many possible harmonic modes of oscillation heretofore encountered with distributed field resonators. Also the tuned choke 14 in the bias supply circuit eliminates resonances associated with leakage of microwave power into the bias circuit. Use of the N-type coaxial cable connector housing 1 greatly simplifies the circuit and reduces the expense thereof.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter

contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. In a bulk-effect negative-resistance apparatus, means forming a section of coaxial line having an outer conductor and an inner conductor, means forming a conductive plug closing off one end of the coaxial line for microwave energy and being spaced from one end of the inner conductor of said coaxial line section to define a gap therebetween, means forming a microwave output terminal at the other end of said section of coaxial line, means forming a bulk-effect negative resistance semiconductive device disposed in the gap between said inner conductor and said conductive plug, the improvement comprising, means forming a pair of conductive posts disposed in said section of coaxial line adjacent the plugged end thereof to define a lumped constant resonant microwave structure having its electromagnetic fields coupled into said bulk-effect device for electromagnetic interaction therewith to produce a microwave output signal.

2. The apparatus of claim 1 wherein one of said conductive posts conductively interconnects said inner and outer conductors of said coaxial line to define a predominately inductive portion of said lumped constant resonant structure and to provide a conductive path for a DC bias potential to be applied to one terminal of said bulk-effect device.

3. The apparatus of claim 1 wherein one of said posts terminates short of said inner conductor of said coaxial line to define a capacitive gap therewith and to form a predominately capacitive portion of said lumped constant resonant structure.

4. The apparatus of claim 3 wherein said capacitance defining post is movable for tuning of said resonant structure.

5. The apparatus of claim 1 wherein said conductive plug includes insulator means insulating same for DC from said outer conductor of said coaxial line to provide a conductive path for applying a DC bias potential to one terminal of said bulk-effect device.

6. The apparatus of claim 5 including means forming a microwave choke structure formed in the outer periphery of said plug to block passage of microwave energy around said plug.

7. The apparatus of claim 1 wherein said section of coaxial line includes a quarter wave impedance matching section for matching the impedance of said bulk-effect device to the impedance of a microwave load connected to said output terminal.

8. The apparatus of claim 7 including means forming an impedance matching stub projecting into said coaxial line section at the output terminal end of said quarter wave impedance matching section for trimming the impedance match obtained by said transformer section.

No references cited.

JOHN KOMINSKI, *Primary Examiner.*

U.S. Cl. X.R.

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