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Strull et al.

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[54] **ANTENNA-COUPLED SOLID-STATE MICROWAVE GENERATOR SYSTEMS CAPABLE OF PRODUCING COHERENT OUTPUT RADIATION**

[75] Inventors: **Gene Strull**, Baltimore; **Herbert Cooper**, Hyattsville; **Charles Herbert Grauling, Jr.**, Ellicott City, all of Md.

[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

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[52] **U.S. Cl.**..... **325/105**, 331/107 G, 331/107 R, 343/824

[51] **Int. Cl.** **H03b 7/00**

[58] **Field of Search** ..... 317/100, 101; 325/15, 25, 325/101, 105, 180, 14; 331/46, 56, 107 G, 107 T, 115, 132; 333/80 T; 343/751, 824, 835

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Primary Examiner—George H. Libman
Attorney, Agent, or Firm—D. Schron

[57] **ABSTRACT**

Described are solid-state microwave generator systems employing a plurality of semiconductor oscillator devices, such as space charge accumulation devices, Gunn oscillators and the like, locked together to produce coherent radiation by means of a plurality of interacting antenna elements.

7 Claims, 5 Drawing Figures

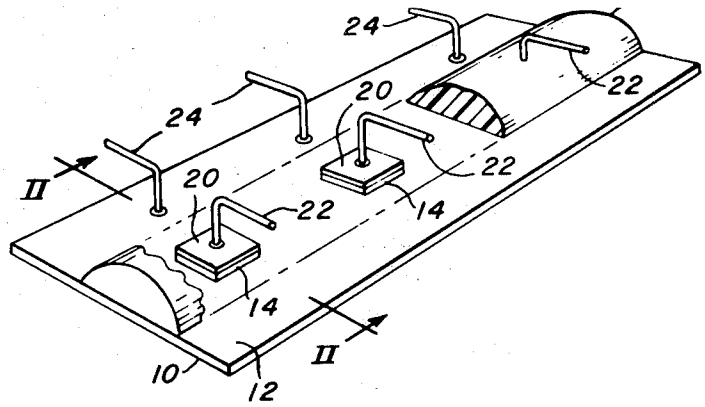


FIG. 1.

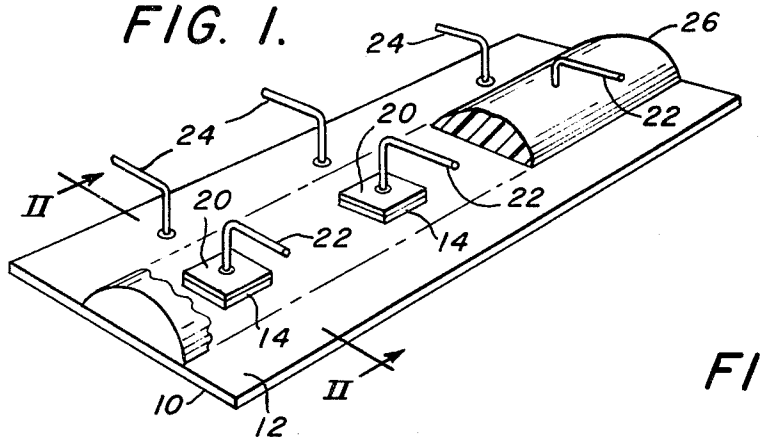


FIG. 2.

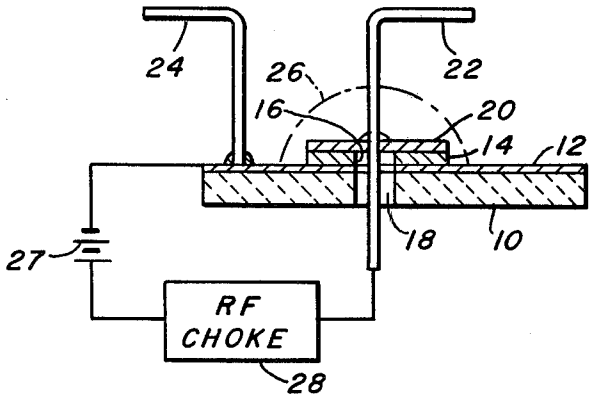


FIG. 3.

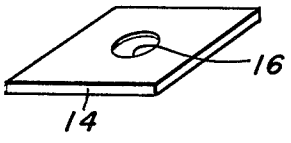


FIG. 4.

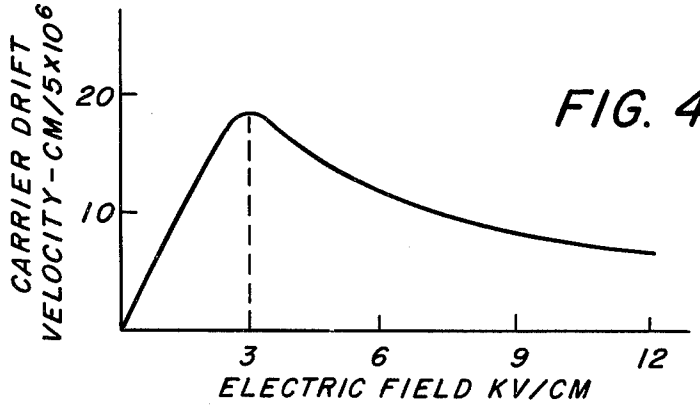
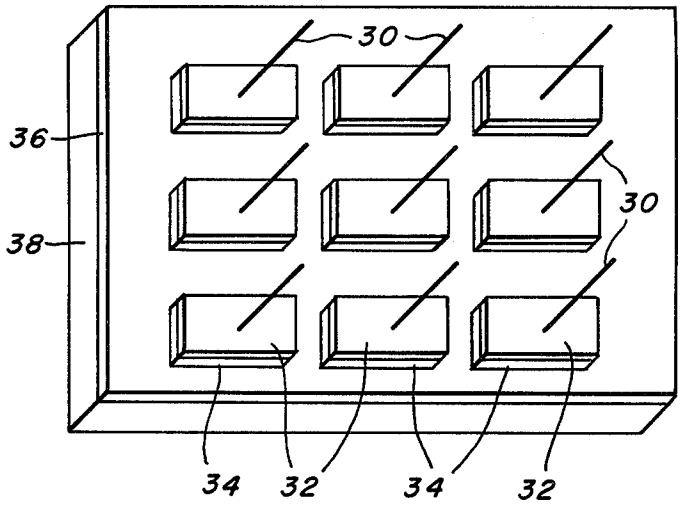


FIG. 5.



ANTENNA-COUPLED SOLID-STATE MICROWAVE GENERATOR SYSTEMS CAPABLE OF PRODUCING COHERENT OUTPUT RADIATION

BACKGROUND OF THE INVENTION

As is known, much effort has been expended in developing solid-state microwave sources of radiant energy since these devices are inherently smaller, more efficient, more rugged, and less expensive than the traditional microwave sources. Materials such as gallium arsenide and indium phosphide present excellent substances for fabrication of such solid-state oscillators. When a small voltage is applied across a body of gallium arsenide, for example, the electric field and conduction current density are uniform throughout the body. The current is carried by free electrons, which are drifting through a background of fixed positive charges, so no space charge exists within the body.

Thus, at low voltages, the gallium arsenide is ohmic because the drift velocity of the electrons is proportional to the electric field. However, when the voltage on the gallium arsenide body is increased above a threshold value, typically about 3000 volts per centimeter, the electron drift velocity begins to decrease as the electric field increases; and the material exhibits negative resistivity. When the field is below the threshold value, groups of excess electrons disperse because of electrostatic repulsion; and until the negative charge density of the electrons is equal to the positive background charge density. Above the threshold value, however, the excess electrons will not disperse, but pile up at a rapid rate as though they were attracted to each other. This piling-up process occurs because the increased electric field in front of the excess electrons now makes the electron stream slow down, and the decreased field behind makes the electron stream speed up.

Similarly, if there is a region in which there is a deficiency of electrons, so that the space charge is positive, the electron stream will move away from this region faster than it moves toward it and the deficiency will grow. This region may, therefore, become completely depleted of electrons. As a result of the space-charge growth, the gallium arsenide body breaks up into domains or regions of high and low electric fields separated by layers of space charge. When the applied voltage is greater than the threshold voltage, the charge domains grow and then propagate across the material in what can be compared to a traveling wave, thereby producing oscillations across a load impedance connected to the gallium arsenide body. This, in essence, is the principle of the so-called Gunn oscillator described, for example, in *Solid-State Communications*, Vol. 1, pages 88–91, September, 1963 and in U.S. Pat. No. 3,365,583 issued January 23, 1968.

Microwave generators of the type described above formed from gallium arsenide or indium phosphide, while capable of generating microwaves, are limited in the degree of coherence attainable, meaning that the output frequency of the generator will vary as a function of certain variables, including the purity of the semiconductor material itself.

SUMMARY OF THE INVENTION

As an overall object, the present invention seeks to provide a new and improved system for generating coherent microwave energy with the use of semiconductor oscillator devices.

More specifically, an object of the invention is to provide a system for generating coherent microwave energy by the use of a plurality of semiconductor oscillator devices interlocked by means of antennas, or possibly transmission lines, whereby the radiation patterns generated by the antennas will overlap and all space charge accumulation devices coupled to the antennas will oscillate at the same frequency.

In accordance with the invention, a solid-state microwave generator system is provided comprising a plurality of adjacent semiconductor space charge accumulation devices, together with means for connecting a source of driving potential across all of said devices whereby they will exhibit negative resistivity and produce oscillations by limited space charge accumulation effects. Antenna means are coupled to the devices, and the spacing between the antennas is such that their radiation fields will overlap and the frequency of oscillation of all of the space charge accumulation devices will be the same by virtue of interlocking between antennas.

The above and other objects and features of the invention will become apparent from the following detailed description taken in connection with the accompanying drawings which form a part of this specification, and in which:

FIG. 1 is a perspective view of one embodiment of the invention;

FIG. 2 is a cross-sectional view taken substantially along line II-II of FIG. 1;

FIG. 3 is a perspective view of the semiconductor space charge accumulation device utilized in the embodiment of the invention of FIGS. 1 and 2;

FIG. 4 is a plot electric field versus carrier drift velocity for N-type gallium arsenide; and

FIG. 5 is a perspective view of still another embodiment of the invention.

With reference now to the drawings, and particularly to FIGS. 1 and 2, the embodiment of the invention shown comprises a substrate **10** having a ground plane **12** deposited on its upper surface as by vapor deposition techniques or the like. Spaced along the ground plane are a plurality of semiconductor wafers which are preferably gallium arsenide or indium phosphide; however any semiconductor material may be employed which will exhibit the space charge accumulation effects hereinafter described. The semiconductor wafers **14** are shown in FIG. 3 and comprise a flat wafer having a hole **16** extending through the center thereof. As shown in FIG. 2, the openings **16** are aligned with openings **18** in the ground plane **12** and substrate **10.** Electrically bonded to the top of each semiconductor wafer **16** is an electrical contact **20** which receives one element **22** of a dipole antenna. The element **22,** it will be noted, passes through the contact **20** and is electrically connected thereto. It also passes through the opening **16** in the wafer **14** and thence through the opening **18** in the ground plane **12** and substrate **10.** In this manner, oscillations produced within the wafer **14** in the manner hereinafter described will be coupled to the element **22.** The other element **24** of the dipole antenna

is electrically connected to the ground plane as shown in FIG. 2, the spacing between the elements 22 and 24 and their general configuration being a function of the frequency of the wave energy to be generated. All of the spaced wafers 14 and their contacts 20 may be encased by means of a dielectric covering, generally indicated by the reference numeral 26, and forming a dielectric image line.

As shown in FIG. 2, a direct current potential is established across each of the semiconductor wafers 14 by means of a battery 27 having its negative terminal connected to the ground plane 12 and its positive terminal connected through an RF choke 28 to antenna element 22 and, hence, to the upper contact 20.

The drift velocity of conduction band electrons in N-type gallium arsenide versus electric field is plotted in FIG. 4. It should be understood, however, that indium phosphide, for example, has a similar plot and that the invention is equally applicable with any other semiconductor materials which have the characteristic carrier drift velocity-electric field relationship of FIG. 4. Such devices are collectively referred to herein and in the appended claims as "semiconductor limited space charge accumulation devices". Note that the carrier drift velocity increases more or less linearly as the electric field is increased until the field is biased above 3000 volts per centimeter. At this point, called the threshold, electron drift velocity begins to decrease as the electric field increases, and the material exhibits negative resistivity. Furthermore, when the voltage applied across the gallium arsenide sample 16 is below the threshold value of about 3000 volts per centimeter, the field across the sample is uniform, groups of excess electrons in the gallium arsenide dispersing because of electrostatic repulsion. However, above the threshold value, a high field domain forms near the negative terminal of the sample that reduces the electric field in the rest of the material, causing the current to drop to about two-thirds of its maximum value. The high field domain at the negative contact then drifts with the carrier stream across the sample and disappears at the anode contact. As the old domain disappears at the anode, the electric field behind it increases until the threshold field is reached and the current increases back to the threshold value. At this time, a new domain forms at the cathode; the current drops; and the cycle begins anew with the high field domain drifting with the carrier stream across the sample to the anode. In this manner, oscillations are produced in the circuit, the frequency of the oscillations being a function of the applied voltage and other considerations. As was mentioned above, however, the output frequency from such a space charge accumulation device is not coherent.

In accordance with the present invention, the radiation patterns emanated by the dipoles shown in FIG. 1, for example, overlap to effect an inductive phase locking action such that all of the oscillators are interlocked and will produce oscillations of a single, coherent frequency. The system of FIG. 1, for example, it particularly adapted for use in an antenna array wherein a plurality of individual antenna elements are required. However, it should be understood that the radiation from the dipole antennas could be collected and utilized for purposes other than radiation into space.

In FIG. 5, another embodiment of the invention is shown which is similar in construction to that of FIGS. 1 and 2 except that the antennas 30 from an end-fired array. Each antenna is electrically connected to a contact 32 on top of a wafer 34 of gallium arsenide, for example, which rests on a ground plane 36 deposited on a substrate 38. The antennas extend through openings in the wafers and ground planes as in FIG. 2. With this arrangement, each individual generator is inherently broadband; however, a large number of such oscillators will put out a peak power at the same frequency with a very narrow bandwidth. The prospects for high power from such a configuration are also favorable.

Although the invention has been shown in connection with certain specific embodiments, it will be readily apparent to those skilled in the art that various changes in form and arrangement of parts may be made to suit requirements without departing from the spirit and scope of the invention. In this respect, it should be apparent that while limited space charge accumulation devices have been stressed herein, the invention has utility with other semiconductor oscillators such as Gunn oscillators, Impatt oscillators and the like.

We claim as our invention:

1. A solid-state microwave generator system comprising a plurality of adjacent semiconductor oscillator devices, means for connecting driving potential means across all of said devices whereby the devices will exhibit negative resistivity and produce oscillations, and an antenna coupled to each of said devices, the spacing between said antennas being such that their radiation fields will overlap and the frequencies of oscillation of said devices will be locked together at one coherent frequency.

2. The solid-state microwave generator system of claim 1 wherein said oscillator devices are semiconductor space charge accumulation devices and are formed from a material selected from the group consisting of gallium arsenide and indium phosphide.

3. The solid-state microwave generator system of claim 1 wherein said semiconductor devices comprise wafers having a hole extending through the center thereof, means connecting a ground plane to one side of said wafer, a metallic contact on the other side of said wafer, and means connecting a source of driving potential between said ground plane and said metallic contact.

4. The solid-state microwave generator system of claim 3 wherein said antennas comprise dipole antennas.

5. The solid-state microwave generator system of claim 4 wherein one element of said dipole antenna extends through said contact and through said opening in said semiconductor wafer, and the other element of said dipole antenna is connected to said ground plane.

6. The solid-state microwave generator system of claim 5 wherein said one element of the dipole antenna also extends through an opening in said ground plane whereby wave energy generated within said semiconductor wafer will be coupled to said one dipole element.

7. The solid-state microwave generator system of claim 1 wherein said antennas form an end-fired array.

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