

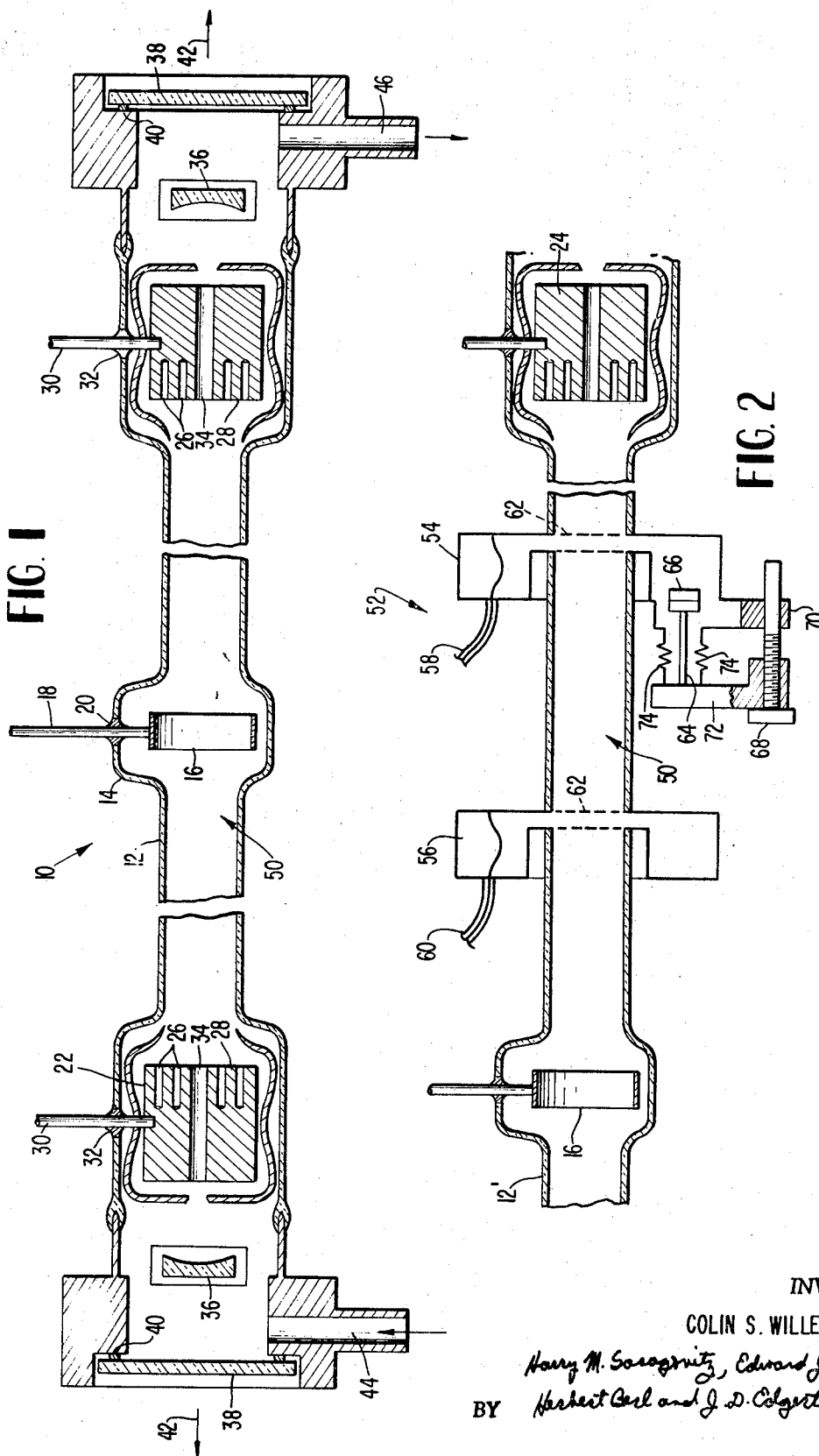
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BRUSH CATHODE DISCHARGE MASER

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BRUSH CATHODE DISCHARGE MASER
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ABSTRACT OF THE DISCLOSURE

Disclosed is a maser employing a brush cathode type discharge. The maser includes a pair of inverse brush cathodes spaced from a central ring anode. The discharge produces a recombination dominated plasma in a molecular gas which acts as a maser medium to produce a maser output in the far infrared region. Also disclosed are a pair of resonant cavities for interacting a microwave signal with the maser to either modulate the maser output or to produce microwave amplification.

This invention relates to a continuous molecular maser and more particularly to a gas maser employing a brush cathode type discharge to produce a recombination dominated plasma maser medium. The invention also includes apparatus for producing interaction between the maser medium and a microwave source so as to form either a maser modulator or a microwave amplifier.

Present high power molecular masers employ as the principal working gas carbon dioxide. This is usually in combination with nitrogen and helium; nitrogen, xenon and helium; or xenon and helium. The carbon dioxide maser, working C.W., uses as an excitation medium the positive column of a glow discharge in a mixture of gases mentioned above. It is known that the excitation of the upper maser level in the carbon dioxide laser proceeds via two stages. The first, production of metastable nitrogen molecules by electron impact excitation; and the second, energy transfer from the nitrogen metastables to the carbon dioxide. The upper maser level is only about 0.25 electron volt above the ground state. Although it was believed earlier that direct electron impact excitation of the upper maser level by low energy electrons was responsible for the selective excitation, it is now known that electrons of approximately 2.0 electron volts energy are required to excite the nitrogen metastable molecules. In carbon dioxide lasers which do not involve nitrogen, electrons of slightly less energy are required (about 1.8 electron volts). Nitrogen, as well as playing a role in the selective excitation process, reduces the electron temperature of the discharge. The use of these molecular gases and the necessary addition of large quantities of helium, has the disadvantage that very large voltages of the order of tens of kilovolts are required to maintain the discharge about 1 meter long.

The present invention is directed to a maser which overcomes the difficulties of high voltage operation of the discharge at low electron temperatures by utilizing a brush cathode type discharge. This discharge is characterized by the production of high energy electron beams in the form of long streams from a brush or inverse brush cathode and the discharge is further characterized by a long negative glow region with high electron and ion concentrations. It is believed that the high energy electrons undergo many collisions with the gas particles so as to produce a recombination dominated plasma with a large ion concentration and a large concentration of predominantly low energy electrons. That is, by using a recombination dominated plasma, the electron temperature is low and molecular vibrational/rotational proc-

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esses are enhanced. This plasma is particularly suited for the formation of a molecular maser of the carbon dioxide type where the electron temperature should be low, and for gas lasers which rely on charge transfer in recombination dominated plasmas for selective excitation of their upper laser levels. Furthermore, since the plasma is continuously maintained and has a very high electron concentration, it is possible to amplify high frequency radiation at a frequency determined by the high electron concentration. At the same time, the system oscillates at the maser frequency and coupling of the two radiation fields results.

The device of the present invention is useful as a maser or microwave amplifier, as a maser modulator, or as a simple high power maser oscillator which has one or more maser wavelengths in the atmospheric window at about 10.6 microns so as to be quite useful for communications and fuze applications.

It is therefore one object of the present invention to provide an improved molecular maser.

Another object of the present invention is to provide a maser employing a brush cathode type discharge to produce excitation of the maser medium.

Another object of the present invention is to provide a higher power gas maser capable of continuous operation.

Another object of the present invention is to provide a maser incorporating a recombination dominated plasma as the maser medium.

Another object of the present invention is to provide novel apparatus for coupling maser and microwave radiation fields to form either amplifier or modulator devices.

These and further objects and advantages of the invention will be more apparent upon reference to the following specification, claims, and appended drawings, wherein:

FIG. 1 is a vertical section showing a brush cathode discharge maser constructed in accordance with the present invention; and

FIG. 2 shows a maser plasma and microwave amplifier or modulator interaction device which may be incorporated in the basic maser structure of FIG. 1.

Referring to the drawings, the maser, generally indicated at 10 in FIG. 1, comprises an elongated hollow tube 12 preferably formed of quartz-fused silica or Pyrex which encloses the plasma. The center of the tube is enlarged as at 14 and houses a ring electrode 16 forming an annular anode for the discharge. This ring is supported by and electrically connected to a rigid electrical lead 18 passing outwardly through tube 12 by way of a suitable glass-to-metal seal, indicated at 20.

Spaced from anode 16 at opposite ends of the tube are a pair of inverse brush cathodes 22 and 24 of identical construction. The cathodes may be formed of any suitable material which is electrically conducting, has a high secondary emission coefficient and a low sputter rate under ion bombardment. Each of the cathodes is drilled out to form a plurality of slots 26 and intermediate projections 28 spaced by the slots 26. While in the preferred embodiment shown and described, cathodes 22 are drilled out to form inverse brush cathodes, it is understood that brush cathodes may also be used in the maser of FIG. 1. Connected to each of the cathodes 22 is a rigid conducting lead 30 which supports the cathode in the tube and is sealed to the tube as at 32.

Inverse brush cathodes 22 and 24 are drilled through completely at the center as at 34 to permit transmission of maser radiation for the maintenance of a resonant cavity in the tube. Aligned with each of the apertures 34 is an adjustable mirror 36 for reflecting a portion of the radiation in the maser. The ends of the tube 12 are

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closed off by infrared windows 38 sealed to the tube as at 40. Infrared energy passed by the mirrors 36 passes outwardly through the windows 38 and forms the maser output as indicated by the arrows 42 in FIG. 1.

Gas is supplied to the interior of the hermetically sealed tube 12 from a suitable source by way of inlet 44. Gas exits from the tube 12 by way of a similar gas outlet 46 at the other end of the tube. The gas exiting from outlet 46 may be exhausted to a rotary pump for recirculation to the inlet 44 or the outlet 46 may be simply closed off since the maser of FIG. 1 will operate with either flowing gases or with a static gas concentration. The gas supplied to inlet 44 may be pure carbon dioxide or a mixture of carbon dioxide and nitrogen, as well as a combination of carbon dioxide, nitrogen and helium, or may comprise any other suitable molecular gas or gas mixture.

In operation, the anode 18 is connected to the positive side of a suitable power supply and the cathodes 22 and 24 are connected to the negative side of the power supply. The sustaining voltage for the discharge, depending upon size and configuration, may vary from 200 to about 500 volts D.C. impressed between anode and cathode. Under these conditions, a brush cathode type discharge is established between anode 18 and each of the cathodes 22 and 24 with a current in the range of from about 10 to about 500 microamps at a gas pressure within the tube from about 0.1 to a few tens of torr.

The brush cathode discharge is characterized by a long negative glow in which are established relatively long beams of high energy electrons which may extend for lengths of as much as 2 or 3 feet between anode and cathode while at the same time maintaining the discharge in tube 12. The electrons in this beam undergo a number of collisions with the gas particles in the tube to form a plasma region within the tube generally indicated at 50 which is recombination dominated and is characterized by a high ion concentration and a large concentration of relatively low energy electrons. By properly selecting the distance between mirrors, the maser 10 will oscillate at a molecular frequency in the neighborhood of 10.6 microns which is in the far infrared region at the atmospheric window. The conditions in the plasma are particularly suited for enhancing the molecular vibrational and rotational population and cascade processes in a molecular gas maser, particularly of the carbon dioxide-nitrogen type, and for enhancing selective excitation processes which involve charge transfer excitation transfer.

FIG. 2 shows an interaction device for producing an interaction between an electromagnetic field from a microwave source and the plasma maser radiation field. In FIG. 2, like parts bear like reference numerals and the interaction device, generally indicated at 52, may interact with the plasma to form either a microwave amplifier or to act as a modulator of the maser output.

In FIG. 2, the tube 12', corresponding in all other respects to the tube 12 of FIG. 1, incorporates a pair of resonant cavities comprising input cavity 54 and output cavity 56. Input cavity 54 is connected to a suitable source of microwave energy by way of a coaxial cable 58 and an output is taken from cavity 56 by way of a similar coaxial cable 60. The cavities are located intermediate one of the inverse brush cathodes, such as cathode 24, and the ring anode 16 in the plasma region within the tube 12'. Each cavity gridded gaps 62 and the input cavity is tunable by way of a plunger 64 carrying a tuning vane 66 movable into and out of the input cavity 54. Plunger 64 is moved by turning a screw 68 threadedly received in a projection 70 attached to the input cavity, which screw carries a base 72 on which the plunger is mounted. Movement of the plunger is resisted by springs 74.

It is understood that the remaining portions of the device illustrated in the embodiment of FIG. 2 are identical to that of FIG. 1 with the exception of the tuning cavities and associated structure as illustrated. In FIG. 2

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2, an input signal on lead 58 can be made to interact with the plasma 50 to produce an amplified microwave output on output lead or coaxial cable 60. Alternatively, a microwave input signal to the input cavity can also be used to modulate the maser output from one or both of the windows 38 in FIG. 1.

The exact nature of the interaction between the microwave energy and the maser radiation is not fully understood. However, it is believed that the microwave input to the cavity acts on the plasma to modify the electron concentration in the plasma. That is, the plasma frequency is proportional to the square root of the electron concentration and the modification of the electron concentration by the electromagnetic field generated by the cavities in the plasma in modifying the electron concentration varies the population levels in the plasma, and particularly the ground state level, so as to modify the maser action. Also, through a correct choice of microwave frequency in accordance with the electron concentration in the plasma, an interaction occurs which produces an increased microwave signal on output lead 60. In the first case, the microwave signal acts to modulate the output of the maser, whereas in the second case the maser radiation reinforces the microwave signal to produce an amplified microwave output.

Various changes and modifications will readily occur to those familiar with maser and microwave operation. For example, the mirror and infrared window assembly can be replaced by an infrared Brewster's angled infrared window in KCl, NaCl, Irtran 2 or 4, or other suitable material, and extra mirrors used. A maser output may be taken from one end, in which case the mirror at the opposite end can be made highly reflective with minimum transmission. If a number of interaction devices such as device 52 of FIG. 2, are connected together, the output of one can be supplied to the input of the following, i.e., the device can be cascaded, either with or without feedback to produce large microwave amplification. The system can be of large cross section if desired and can be provided with a multipass arrangement to produce a multipass maser amplifier.

As is apparent from the above, the present invention provides an improved maser and a microwave maser interaction device particularly suited for use in continuously operating gaseous masers, particularly of the molecular type. The device incorporates a brush type discharge to produce a plasma region which is recombination dominated and characterized by high ion and electron concentrations to enhance the molecular vibrational and rotational processes required for maser operation.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. A maser employing a brush cathode discharge comprising an anode and a brush cathode of the type which will sustain a brush cathode discharge characterized by the production of long streams of high energy electrons and further characterized by a long negative glow region having a high ion concentration and a large concentration of relatively low energy electrons, and means to apply a low voltage across said cathode and said anode to sustain said brush cathode discharge.

2. A maser comprising a sealed gas chamber including a maser output window and means in said chamber for establishing a brush cathode discharge through the gas in said chamber, said means comprising an anode and a brush cathode of the type which will sustain a brush

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cathode discharge characterized by the production of long streams of high energy electrons and further characterized by a long negative glow region having a high ion concentration and a large concentration of relatively low energy electrons, and means to apply a low voltage across said cathode and said anode to sustain said brush cathode discharge.

3. A maser according to claim 2 wherein said cathode is an inverse brush cathode.

4. A maser according to claim 2 including a pair of brush cathodes adjacent opposite ends of said chamber, said anode being located intermediate said cathodes in said chamber.

5. A maser according to claim 4 wherein said anode comprises a ring approximately midway between said cathodes.

6. A maser according to claim 4 wherein said cathodes are each provided with transmission apertures, and a maser reflector aligned with said aperture at each end of said chamber for reflecting at least a portion of the maser energy back and forth between the ends of said chamber.

7. A maser according to claim 1 wherein said brush cathode discharge is established in said chamber to form a recombination dominated plasma in said chamber, and means in said chamber for coupling microwave energy to said plasma.

8. A maser according to claim 7 wherein said coupling means comprises a microwave resonant cavity between said anode and cathode.

9. A maser according to claim 7 wherein said coupling means comprises spaced input and output microwave resonant cavities between said anode and cathode, means coupled to said input cavity for supplying microwave energy to it, and means coupled to said output cavity for deriving an output signal from it.

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10. A maser according to claim 1 filled with a molecular gas.

11. A maser according to claim 10 wherein said gas is formed at least partly of carbon dioxide.

12. A maser according to claim 10 wherein said gas is formed at least partly from a mixture of carbon dioxide and nitrogen.

13. A maser according to claim 10 wherein said gas is at a pressure of over about 0.1 torr.

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