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DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Improvements in or relating to Gas Lasers

5 We, WESTERN ELECTRIC COMPANY, INCORPORATED, of 195 Broadway, New York City, New York State, United States of America, a Corporation organized and existing under the laws of the State of New York, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 This invention relates to gas lasers.
The laser, also known as the optical maser, is a relatively recent invention of far-reaching technological importance because of its ability to amplify light and to generate coherent oscillations at light frequencies. Through a selective excitation known as pumping, an abnormally high proportion of atoms or other particles within an active medium of the laser is raised to a predetermined high energy state, defining a condition known as population inversion. As the particles decay to lower energy levels they inherently emit radiation at a characteristic frequency. It is possible to stimulate the emission of this radiation at a predetermined frequency for the purpose of generating coherent light or for amplifying light of a frequency corresponding to the radiation frequency.

30 In the usual form of gas laser, neutral component atoms of a gas plasma active medium are excited by establishing a gas discharge in the gas. The gas discharge may be maintained by applying a radio frequency electric field, or by establishing a direct current between a positively charged anode and a cathode, as is done in conventional gas discharge tubes. In either case, the gas discharge region is normally defined by an extended tubulation the axis of which is coincident with the light beam to be generated or amplified. The desired laser action results from in-phase radiation at a specific frequency

by a large number of excited neutral atoms as they decay to a lower energy state. The net gain of the device is normally proportional to the total length of the gas plasma through which the resultant light wave propagates.

Improved forms of gas lasers are described in the publications, "Visible Laser Transitions in Hg" by W. E. Bell, *Applied Physics Letters*, Vol. 4, No. 2, P. 34, January 15, 1964, and "Laser Oscillation in Single Ionized Argon in the Visible Spectrum", by William B. Bridges, *Applied Physics Letters*, Vol. 4, No. 7, P. 128, April 1, 1964. These publications describe devices now generally referred to as ion lasers which use much higher direct electrical current through the gas plasma than do conventional gas lasers. Rather than exciting neutral gas atoms as in the conventional gas laser, the ion laser excites ions of the gas plasma to a condition of population inversion. It has been found that when pulsed direct current electrical discharges are used, the ion laser is capable of generating a significantly higher pulsed output power at higher gain than conventional gas lasers. The ion lasers may therefore be substantially shorter than comparable conventional gas lasers, which can be an important advantage.

Efforts to operate the ion laser continuously have been rather disappointing. The output power of the ion laser under continuous operation has been found to decrease as a function of time to a much lower value than the high power initially attained.

We have discovered in investigating the decrease of output power in ion lasers that continuous direct current operation unbalances the gas pressure throughout the device. This results in a gas pressure gradient from the anode to the cathode; part of the laser tube therefrom contains a higher than optimum gas pressure, while the remainder is of a lower than optimum gas pressure. As the pressure gradient becomes more pronounced as a func-

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tion of time, the gain of the device, and hence its output power, decreases and oscillations may actually cease.

According to the present invention there is provided a gas laser comprising an enclosure containing an active gaseous medium, and means for producing a gas discharge in said medium, said enclosure forming a first path for enclosing said gas discharge and a second path for equalizing the gas pressures along said first path.

One embodiment of the invention comprises an ion laser of the general type described above. A gas discharge path is defined by a linear discharge tube which extends between enclosures containing the cathode and the anode. A triggering mechanism surrounds or is placed adjacent to the discharge tube to trigger a gas discharge in a known manner. A significantly higher continuous electrical current is transmitted through the discharge region than is true of conventional gas lasers. This high current is capable of exciting an appropriate population inversion of the component ions which results in the stimulated emission of light radiation.

An auxiliary tubulation extends between the cathode enclosure and the anode enclosure to equalize the gas pressures therebetween. The inside diameter of the auxiliary tubulation is much larger than that of the discharge tube. The mechanical conductance of gas through a tube is proportional to the cube of the inside radius of the tube; the auxiliary tube will therefore transmit gas much more freely than the discharge tube and be highly efficient in equalizing gas pressures.

The auxiliary tube is much longer than the discharge tube in order to prevent a gas discharge from being formed in the auxiliary tube. The auxiliary tube is preferably helical in shape in order to conserve space. We have also found that for maximum gas transmission through the auxiliary tube, the ratio of inside diameter to the total length of the auxiliary tube should approximately equal the ratio of inside diameter to total length of the discharge tube. Under these conditions, the discharge will be limited to the discharge tube while maximum mechanical gas transmission will occur through the auxiliary tube. Hence, the gas pressure is equalized between the anode and cathode in spite of the tendency of the gas discharge to create a pressure gradient. This gas pressure equalization ensures a substantially constant power output through a sustained period of continuous operation.

The invention will now be described with reference to the accompanying drawing, which is a partially sectioned schematic view of an illustrative embodiment of the invention.

Referring now to the drawing, there is shown a direct-current excited continuously operable ion laser comprising a discharge tube 11 for defining a linear gas discharge region.

A cathode 12 and an anode 13 are located within enclosures 15 and 16, respectively, which are attached to the discharge tube. The device is filled with an appropriate gas which is suitable for population inversion of component ions during discharge. Such a gas may, for example, be argon at a pressure of .45 Torr (millimeters of mercury). Other noble gases can alternately be used, as can vaporized mercury or various mixtures of such gases. An appropriate voltage between the cathode and anode maintains a gas discharge path which extends from cathode 12 through discharge tube 11 to anode 13. The gas discharge is triggered in a known manner by electrical energy from a pulse source 17. A water jacket 18 surrounding the discharge tube transmits water to cool the device.

During operation, a relatively high current is generated by a current generator 19 which is transmitted along the gas discharge path by way of discharge tube 11. This high current, which may be, for example, in excess of 4 amperes, causing a substantial part of the gas molecules or atoms within the device to become ionized. Additionally, the ions are excited to a condition of population inversion which is characterized by the existence of an abnormally high proportion of ions at a high, unstable, energy state. As these ions decay to lower, more stable energy states, they radiate light energy at a characteristic frequency in accordance with known laser phenomena.

Located at opposite ends of discharge tube 11 are light transparent windows 20 and 21 which are tilted at a proper "Brewster angle" for maximizing transmission efficiency. When the device is used as an amplifier, light waves are admitted to tube 11 through either window 20 or 21 and become amplified through the additive effect of the stimulated emission from the excited gas ions. Mirrors may be placed on opposite sides of the window in a known manner for multiplying the amplification or for feeding back a sufficient portion of the energy to permit the device to operate as an oscillator. The mirrors may also be substituted for the windows in an internal mirror configuration.

Since ion lasers have a much greater gain than conventional gas lasers, they can be relatively short and still deliver high output power. The tube of FIG. 1 may, for example, have a discharge length of only 25 centimeters with an inner diameter of the discharge tube of 1.2 millimeters to deliver output power approaching .5 watt. The voltage between the cathode and anode may be 300 volts. Gain in the device increases rapidly with tube current, and it appears that, with the modifications we now propose, the only limitation on output power is the capability of the tube to withstand the high temperatures that are generated. The water jacket 18 signi-

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significantly increases the temperature capacity of the device. Additionally, discharge tube 11 may advantageously be made of quartz or other heat-resistant material.

The device of FIG. 1 is intended for use under conditions of continuous operation, as opposed to pulsed operation. It has been observed that the gain, and hence the output power, of known ion lasers decreases significantly as a function of time when they are operated continuously. Our investigations have shown that this decrease in gain is due to the creation of a pressure gradient from the cathode to the anode. As this pressure gradient becomes more pronounced the mechanism of ion excitation becomes less efficient with a resultant decrease in the gain along the discharge path.

It is our belief that this pressure gradient is caused by a number of factors. At relatively modest currents, positive ions migrate toward the cathode and recombine with electrons to increase the gas pressure in the cathode enclosure over that in the anode enclosure. Another factor is a negative potential which builds up on the inner wall of discharge tube 11 and attracts positive ions while repelling electrons. Rather than giving up their momentum which they have gained from the axial electric field to neutral gas atoms by collision, a relatively large number of positive ions tend to impinge on the inner wall of the tube. On the other hand, most of the electron momentum is imparted to the gas atoms. At higher currents the predominant force exerted on the gas by electrons tends to create a higher gas pressure in the anode enclosure. Moreover, when mixtures of different gases are used as the active medium or gas plasma, a cataphoresis condition may also develop wherein the atoms of one gas tend to migrate predominantly toward the cathode while the atoms of another gas tend to migrate toward the anode. This situation additionally degrades the performance of the laser.

In the embodiment of the invention shown in the drawing, a gas pressure equilibrium is maintained throughout the device by an auxiliary tubulation 22 which interconnects cathode enclosure 15 with anode enclosure 16. This auxiliary tubulation has a higher mechanical conductance of gases than does discharge tube 11, which equalizes gas pressure and prohibits the establishment of a pressure gradient along the discharge tube.

A relatively large mechanical conductance of gas through the auxiliary tube 22 is ensured by making the inside diameter of the auxiliary tube large with respect to that of the discharge tube. It can be shown that

$$C \approx \frac{l}{r^3} \quad (1)$$

where C is the mechanical gas conductance

of a tube, r is the inside radius of the tube and l is the length of the tube. As shown in equation (1), the radius of a tube has a much more pronounced effect on its gas conductance than does its length. Gas is therefore transmitted more readily by the auxiliary tube than the discharge tube as it is required for optimum stabilization of gas pressure.

It is also important that the gas discharge be limited to the discharge tube 11, since a gas discharge through the auxiliary tube would degrade the performance of the device. The voltage required for maintaining a gas discharge is given by

$$V \approx \frac{l}{r} \quad (2)$$

It can be seen from equation (2) that the voltage required for maintaining a discharge through a tube is inversely proportional to the radius of the tube. The large-radius auxiliary tube 22 must therefore be made longer than discharge tube 11 if a gas discharge breakdown through auxiliary tube 22 is to be prevented. For purposes of compactness, the auxiliary tube 22 is preferably of a helical shape to give the additional length required for preventing a gas discharge therethrough. In addition, the helical structure eliminates strains resulting from differential expansion of the two tubes.

With pulse source 17 being coupled only to discharge tube 11, it is possible for tube 11 and tube 22 to have the same breakdown voltage and still limit the discharge to tube 11. It is therefore possible for the ratio of the length to the radius of auxiliary tube 22 to be equal to the ratio of length to radius of discharge tube 11, or,

$$\frac{l_1}{r_1} = \frac{l_2}{r_2} \quad (3)$$

where l_1 is the length of auxiliary tube 22, r_1 is the inside radius of the auxiliary tube, l_2 is the length of discharge tube 11, and r_2 is the inside radius of discharge tube 11. Conformance with equation (3) permits a large inside radius of auxiliary tube 22 as is required for maximum mechanical gas conductance together with a minimum total length for the auxiliary tube. If the pulse source is not used for restricting the gas discharge to discharge tube 11, then a higher resistance to gas discharge breakdown should be provided in the auxiliary tube 22. This is done by complying with the relationship

$$\frac{l_1}{r_1} > \frac{l_2}{r_2} \quad (4)$$

It should be clear that the described technique has application to other forms of gas discharge devices wherever an undesirable pressure gradient is established between spaced regions of the gas discharge.

WHAT WE CLAIM IS:—

1. A gas laser comprising an enclosure containing an active gaseous medium, and means for producing a gas discharge in said medium, said enclosure forming a first path for enclosing said gas discharge and a second path for equalizing the gas pressure along said first path.
2. A laser according to claim 1, in which an electrically pulsed trigger device is closely adjacent only to that portion of said enclosure forming said first path.
3. A laser according to claim 1 or 2, in which said gaseous medium is present in such quantity that it is capable of population inversion in an ionized condition.
4. A laser according to claim 1, 2 or 3, in which said first path comprises a first tube and said second path comprises a second tube having an effective length substantially longer than the length of said first tube.
5. A laser according to claim 4, in which said second tube is formed into a helix.
6. A laser according to claim 4 or 5, in which said second tube has a substantially larger internal radius than said first tube.
7. A laser according to claim 6 as appended to claim 2, in which the ratio of inside radius to total length of said second tube is substantially equal to that of the discharge tube.
8. A laser according to any one of the preceding claims, in which said means for producing said gas discharge comprises a cathode and an anode, said first and second paths each extending between said cathode and anode.
9. A laser according to claim 8, in which said enclosure includes a first portion containing said cathode and a second portion containing said anode, said two portions being interconnected separately by said first and second paths.
10. A gas laser arranged and adapted to operate substantially as herein described with reference to and as shown in the accompanying drawing.

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