

PATENT SPECIFICATION

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DRAWINGS ATTACHED.

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COMPLETE SPECIFICATION.

Improvements in or relating to Gas Lasers.

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:—

This invention relates to gas lasers.

An important deficiency of gas lasers hitherto has been their very low efficiency, typically small fractions of one per cent. A variety of factors is responsible. Among the most important is the fact that in prior art forms it is extremely difficult to populate a desired excited level with high selectivity. Typically, the excitation process used results in some excitation of particles to both of the two levels between which population inversion, and so lasing action, is sought to be established. The lower level becomes populated either directly or by the relaxation thereto of particles pumped to one or more higher non-useful levels. This action makes for inefficiency not only because it is wasteful of power to excite particles to the lower of such two levels but, additionally, because the populating of such lower level reduces the amount of population inversion achieved and so the amount of stimulated emission.

We have found that efficiency may be improved by minimizing the populating of the lower of the two levels between which the stimulated emission is to occur.

An embodiment of the invention employs a two gas system, one of which serves as the exciting gas and the other as the lasing gas from which the desired radiation is

stimulated, and there is avoided undesired excitation of the lasing gas by avoiding any treatment of the lasing gas which gives rise to such undesired excitation. Specifically, the lasing gas is not itself subjected to a discharge, in contradistinction with the usual practice in prior art forms of gas lasers.

In a preferred embodiment of the invention, nitrogen serves as the exciting gas and carbon dioxide as the lasing gas. The nitrogen is excited in a separate chamber and thereafter made to flow therefrom into an interaction chamber for mixing there with the carbon dioxide which is introduced in an unexcited state. A continuous flow of both gases is employed for continuous operation. The carbon dioxide becomes excited in the interaction chamber by collisions with the excited nitrogen in a highly selective fashion. The interaction chamber is positioned within an optical cavity which provides the regeneration for achieving stimulated emission from the excited carbon dioxide.

The feasibility of this technique depends on the availability of an exciting medium which includes an excited level which has a relatively long lifetime, typically longer than 0.1 second, and which is not readily destroyed by wall collisions. Additionally, such excited level needs to have an energy closely matching that of a suitable level of a lasing medium, whereby the selective excitation of the matching level of the lasing medium occurs by a two body collision when the lasing and exciting gases are mixed in the interaction chamber. In particular, in the preferred embodiment there results selective excitation of carbon dioxide molecules from a ground electronic state to a vibrational level in such ground electronic state through transfer of vibrational energy of nitrogen

molecules in the $v = 1$ vibrational level of their ground electronic state.

The invention will now be described with reference to the accompanying drawings, in which:

FIG. 1 shows schematically a partially cut away view of a preferred embodiment of the invention; and

FIG. 2 is a partial energy level diagram of the N_2 - CO_2 system, which will be useful in describing the invention.

With reference now to the drawing, the laser shown in FIG. 1 includes a first section where the nitrogen which serves as the exciting gas is treated for the production of molecules in the vibrational level of the ground electronic state. In the preferred embodiment depicted, this involves subjection of the nitrogen to a d-c discharge where electron-ion recombination and atom-atom recombinations as well as cascades provide the desired excitation of the nitrogen molecules. In particular, nitrogen, advantageously of a purity better than 99.99%, is introduced into the discharge region via an inlet port 11 for continuous flow, for example, at a linear flow rate of the order of 500 centimeters per second. The discharge is confined within the multisection glass tube 12. In the design being described specifically, this tube had an inner diameter of about 20 millimeters. The discharge region in this tube is defined by the cathode 14 and the pair of anodes 15. The use of two spaced anodes permits elongation of the discharge path without a corresponding increase in the d-c voltage required. A d-c voltage source (not shown) supplies the power necessary. For the design being described involving a separation of about 60 centimeters between the cathode and each anode, 2000 volts with a current flow of 9 milliamperes proved satisfactory.

The now excited nitrogen is made to flow out of the discharge region into the interaction region, into which is also introduced unexcited carbon dioxide, also advantageously of high purity, by way of inlet port 17 and distribution tube 18. The interaction region is enclosed within a glass tube 20. In the design being described, this tube had an inner diameter of about 25 millimeters. To improve the mixing of the exciting nitrogen and the lasing carbon dioxide, the nitrogen and carbon dioxide are each introduced into the interaction region at a number of separate inlets 21, spaced apart along the interaction region as shown. To keep small the amount of atomic nitrogen introduced into the interaction region, and thereby to improve the efficiency of the interaction, the distance between the discharge region and the point at which nitrogen enters the interaction region advantageously is made in each instance at least 6

centimeters to provide time for substantial completion of all the atomic and electron-ion recombination in the nitrogen before mixing with the carbon dioxide. In the design discussed, the carbon dioxide and nitrogen flow rates were adjusted to be nearly equal with a total gas pressure of 0.8 Torr in the interaction region.

The spent gases are withdrawn from the interaction region by way of the exhaust port 30 under the action of a pump 31 which controls the flow. Advantageously, as shown, the mixture evacuated is supplied to apparatus shown schematically for separating the two components and after separation returning the separate components to the appropriate inlet ports of the system. The separation apparatus has not been shown in detail as the techniques for such separation are known. Typically, separation would involve passing the mixture through a cold trap for solidification of the carbon dioxide.

To achieve oscillations, it is important to enclose the interaction region in an optical resonator. In the specific design being discussed, the resonator was formed by a pair of near confocal concave mirrors 33, 34 spaced apart about 1.4 meters and supported by suitable mirror mounts 35, 36 respectively. The mirrors were coated to be opaque with vacuum-deposited gold, and energy was coupled out from the resonator through a 0.5 millimeter aperture in the centre of mirror 33.

If the laser be intended for use as a straight-through amplifier, the resonator becomes unnecessary and the mirrors can be eliminated. In some instances, it may be preferred to locate the mirrors outside the interaction region in which case Brewster angle windows can be used to confine the interaction region.

A discharge in low pressure nitrogen results in very efficient production of nitrogen molecules in the vibrational levels of their ground electronic state. Since nitrogen has a zero permanent dipole moment, such molecules cannot decay to the $v = 0$ vibrational level through electric dipole radiation. Thus, the effective lifetimes of these states are governed primarily by de-activation through collisions with other molecules and walls, and accordingly can be high, for example, several seconds.

In FIG. 2, there is shown the vibrational level $v = 1$ for nitrogen with respect to the ground state of nitrogen. The other vibrational levels have been omitted for simplicity as unimportant. There have also been shown the vibrational-rotational levels of carbon dioxide of interest, with respect to its ground state (00°0). It can be seen that N_2 ($v = 1$) at 2330.7 cm^{-1} is in very close coincidence with the (00°1) vibrational

level of CO_2 at 2349.16 cm^{-1} . Thus, a collision of the second kind can have a large cross-section because of the near-perfect coincidence. The lower maser level ($10^0 0$) on the other hand is removed from N_2 ($v = 1$) by more than 900 cm^{-1} and hence the cross-section for exciting the CO_2 ground state molecules to the lower maser level will be very much smaller. Moreover, the excitation of CO_2 ($00^0 0$) molecules to level ($10^0 0$) involves a reaction which includes transitions which are optically forbidden. Thus, when the excited nitrogen molecules are allowed to mix with the carbon dioxide molecules, a selective excitation of CO_2 ground state molecules to the ($00^0 1$) level takes place. Moreover, since the lifetimes of the ($00^0 1$) levels are longer than the lifetimes of the ($10^0 0$) levels, the required conditions for laser action on the ($00^0 1$)—($10^0 0$) transitions are satisfied. The particles thereafter relax from the ($10^0 0$) level to the ground state with spontaneous emission in cascade fashion as depicted schematically.

Laser oscillations were obtained at a number of wavelengths involving P-branch rotational transitions from P(14) to P(26). The strongest transition, corresponding to P(20), occurs at 10.5915 microns and continuous wave power in excess of 1 milliwatt was readily obtained with less than 20 watts' input power.

There are a large number of reactions through which one can produce various diatomic molecules in vibrationally excited levels and hence the selective excitation through vibrational energy transfer is applicable for obtaining laser action on vibrational-rotational transitions of polyatomic molecules in other mixed systems. Molecules in vibrationally excited levels are of special importance because of the longer lifetimes available with such molecules. Another requirement on the exciting gas is that its excited molecules not be easily destroyed by wall collisions, making it feasible for transport of these molecules from the discharge region to the interaction region without excessive destruction. In some instances, it may be advantageous to treat the walls to minimize their effect on the lifetimes of incident excited particles. Also, it is advantageous that the molecule exhibit no permanent dipole moment so as to avoid radiative transitions between vibrational levels. This ordinarily means that the molecule of the exciting gas should be composed of like atoms. Additionally, of course, there is required the close coincidence between the vibrational level of the exciting gas and an upper level of the lasing gas, which level is optically connected to a lower level.

The specified conditions are also met, for example, in an $\text{N}_2\text{-N}_2\text{O}$ system and an $\text{O}_2\text{-CS}_2$ system (the first gas being the excit-

ing gas and the second the lasing gas). In particular, the apparatus described has been used to generate oscillations in the $\text{N}_2\text{-N}_2\text{O}$ system at 10.8422 microns and other wavelengths.

It is a further advantage of lasers of the kind described that due to the absence of any discharge in the interaction region, the usual inverse relation of optical gain with diameter of the interaction region is typically not applicable here. Thus, the diameter of the interaction chamber can be increased with little adverse effect on the optical gain. Rather, because an increase in diameter can be translated into an increase in number of excited molecules, the optical power output can be increased by increasing the diameter of the interaction chamber.

Various other techniques are feasible for the excitation of the exciting molecules. Such modifications include the use of a radio frequency discharge rather than a d-c discharge and, most simply, heating the exciting gas to populate the desired $v = 1$ level. For example, with nitrogen at 1440°K ., the population corresponding to the Boltzman distribution in the $v = 1$ vibrational level is about 10 per cent of the total nitrogen population, which is more than adequate for achieving lasing action with carbon dioxide. Such heating can be achieved simply by flowing the nitrogen past a heating element before introduction into the interaction region. Additionally, chemical reactions, for example as described in the paper entitled "Vibrational Disequilibrium in Reactions Between Atoms and Molecules," Canadian Journal of Chemistry, Volume 38, page 1769 et seq. (1960), can be employed to populate vibrational levels.

WHAT WE CLAIM IS:—

1. A laser comprising means forming a first region into which a first gas is introduced, means for treating said first gas while in said region to populate an excited level of said first gas, and means forming a second region spaced from said first region into which the first gas is introduced after excitation and into which a second unexcited gas is introduced, the first and second gases interacting in said second region for the creation of an inverted population between a pair of optically connected levels in said second gas.

2. A laser according to claim 1, in which the first gas has a vibrational level which becomes populated in said first region and the second gas has a vibrational level whose energy closely matches that of the vibrational level of the first gas, whereby the matched level of the second gas becomes populated by collisions with the excited first gas in the second region.

3. A laser according to claim 2, in which

level of CO_2 at 2349.16 cm^{-1} . Thus, a collision of the second kind can have a large cross-section because of the near-perfect coincidence. The lower maser level ($10^0 0$) on the other hand is removed from N_2 ($v = 1$) by more than 900 cm^{-1} and hence the cross-section for exciting the CO_2 ground state molecules to the lower maser level will be very much smaller. Moreover, the excitation of CO_2 ($00^0 0$) molecules to level ($10^0 0$) involves a reaction which includes transitions which are optically forbidden. Thus, when the excited nitrogen molecules are allowed to mix with the carbon dioxide molecules, a selective excitation of CO_2 ground state molecules to the ($00^0 1$) level takes place. Moreover, since the lifetimes of the ($00^0 1$) levels are longer than the lifetimes of the ($10^0 0$) levels, the required conditions for laser action on the ($00^0 1$)—($10^0 0$) transitions are satisfied. The particles thereafter relax from the ($10^0 0$) level to the ground state with spontaneous emission in cascade fashion as depicted schematically.

Laser oscillations were obtained at a number of wavelengths involving P-branch rotational transitions from P(14) to P(26). The strongest transition, corresponding to P(20), occurs at 10.5915 microns and continuous wave power in excess of 1 milliwatt was readily obtained with less than 20 watts' input power.

There are a large number of reactions through which one can produce various diatomic molecules in vibrationally excited levels and hence the selective excitation through vibrational energy transfer is applicable for obtaining laser action on vibrational-rotational transitions of polyatomic molecules in other mixed systems. Molecules in vibrationally excited levels are of special importance because of the longer lifetimes available with such molecules. Another requirement on the exciting gas is that its excited molecules not be easily destroyed by wall collisions, making it feasible for transport of these molecules from the discharge region to the interaction region without excessive destruction. In some instances, it may be advantageous to treat the walls to minimize their effect on the lifetimes of incident excited particles. Also, it is advantageous that the molecule exhibit no permanent dipole moment so as to avoid radiative transitions between vibrational levels. This ordinarily means that the molecule of the exciting gas should be composed of like atoms. Additionally, of course, there is required the close coincidence between the vibrational level of the exciting gas and an upper level of the lasing gas, which level is optically connected to a lower level.

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ing gas and the second the lasing gas). In particular, the apparatus described has been used to generate oscillations in the $\text{N}_2\text{-N}_2\text{O}$ system at 10.8422 microns and other wavelengths.

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WHAT WE CLAIM IS:—

1. A laser comprising means forming a first region into which a first gas is introduced, means for treating said first gas while in said region to populate an excited level of said first gas, and means forming a second region spaced from said first region into which the first gas is introduced after excitation and into which a second unexcited gas is introduced, the first and second gases interacting in said second region for the creation of an inverted population between a pair of optically connected levels in said second gas.

2. A laser according to claim 1, in which the first gas has a vibrational level which becomes populated in said first region and the second gas has a vibrational level whose energy closely matches that of the vibrational level of the first gas, whereby the matched level of the second gas becomes populated by collisions with the excited first gas in the second region.

3. A laser according to claim 2, in which



the first gas is nitrogen and the second gas is carbon dioxide.

- 5 4. A laser according to claim 2, in which the first gas is nitrogen and the second gas is nitrous oxide.

5 5. A laser according to claim 2, in which the first gas is oxygen and the second gas is carbon disulphide.

- 10 6. A laser according to any one of the preceding claims, in which the means for treating the first gas to populate an excited level thereof comprises means for establishing a discharge in said gas.

7. A laser according to any one of the

preceding claims, including an optical resonator enclosing the second region for stimulating the emission of light. 15

8. A gas laser arranged and adapted to operate substantially as herein described with reference to and as shown in the accompanying drawings. 20

H. L. JACKSON,
Chartered Patent Agent,
5, Mornington Road,
Woodford Green, Essex,
Agent for the Applicants.

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