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(54) IMPROVEMENTS IN OR RELATING TO GAS LASERS

(71) We, UNITED KINGDOM ATOMIC ENERGY AUTHORITY, London, a British Authority, 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:–

The present invention relates to lasers, and more particularly to transversely-excited electrical discharge gas lasers.

According to the present invention there is provided a pulsed mode laser having a gaseous mixture including carbon dioxide as the lasing medium, wherein the lasing medium is cooled to a temperature such that the thermal population of the lower energy level of an output lasing transition between a higher energy level and a lower energy level of the carbon dioxide molecule is reduced, and in each pulse the lasing medium is initially energised to create the population inversion which results in the lasing transition at a rate which is slow enough to ensure that significant thermal population of the lower energy level is avoided.

In a preferred form of the invention, the laser utilises a transition between the $02^{\circ}0$ and $01^{1}0$ vibrational energy levels of the carbon dioxide molecule as the source of the laser radiation, and the laser medium is a mixture of one or more of the gases hydrogen, helium or argon together with nitrogen and carbon dioxide. The N_2/CO_2 ratio is chosen to be $\gtrsim 9$, i.e. it is higher than that conventionally employed in gas lasers using carbon dioxide as the laser medium in order to reduce pumping of the CO_2 symmetric and bending modes relative to the antisymmetric CO_2, and N_2 vibration modes. The hydrogen, helium and/or argon admixture is chosen to relax the $01^{1}0$ energy level of the carbon dioxide molecule, but the optimum proportion of these gases varies with the total pressure due to collisional coupling between the $01^{1}0$, $10^{\circ}0$, $02^{2}0$ and $02^{\circ}0$ levels, and to practical considerations such as heating effects associated with some types of preionization.

An embodiment of the invention will now be described, by way of example, with reference to the drawings, accompanying the provisional specification in which:

Figure 1 is a schematic drawing of a gas laser embodying the invention, and

Figure 2 shows schematically the relevant energy transitions used in the laser of Figure 1.

Referring to Figure 1, a transversely excited gas laser employed a mixture of carbon dioxide, nitrogen, and helium (or the other additives) as the lasing medium, consists of a closed system of ducting 1, which includes a region 2 having plane parallel or other suitable surfaces through one of which laser radiation can be extracted. The system of ducting 1 includes a circulating pump 3 and a heat exchanger 4. Anode and cathode electrodes 5 and 6 respectively allow an exciting gaseous discharge 7 to be maintained in the region 2 of the system of ducting 1. The discharge 7, which is maintained transversely to the direction of gas flow 8 in the system of ducting 1 and of the direction of the emitted laser readiation, is the source of the energy used in generating the laser radiation. Upstream of the electrodes 5 and 6 is a baffle 9 which creates uniform turbulent conditions in the lasing medium flowing into the discharge region 2.

The lasing medium is a mixture of carbon dioxide ($C^{12}0^{16}{}_2$), nitrogen and helium having volumetric proportions of approximately 1:9:10. It is supplied to the discharge region 2 at a pressure of about 0.1 – 0.6 (absolute) atmospheres and a temperature in range 140–230°K. The lasing medium is ionized by passing an auxiliary electron beam having an energy of up to 240 KeV through a 0.001" titanium foil for a period of about 10 μ secs to give an energy deposition of some 150– 200J/litre atmospheres from the main (pump) capacitors. Neither the foil nor the electron beam is shown in the drawing, but of course, the foil must be situated where the electron beam can provide a suitable ionisation source to control the main discharge. Alternatively, pulsed ultraviolet ionization can be used for the same purpose, with a suitable easily-ionised organic additive such as trimethylemine.

The electrodes 5 and 6 are operated in a suitably time pulsed mode with a current pulse duration of some tens of microseconds. (This pulse length is sufficiently long as enable the electrical discharge to pump the carbon dioxide (001) and the nitrogen v = 1 vibration energy levels, sufficiently slowly for the subsequent population inversion between the carbon dioxide (02°0) and 01^10) vibrational energy levels not to be lost due to the lower energy level becoming populated thermally). Having been energised the carbon dioxide is caused to relax with the almost simulataneous sequential emission of pulses of coherent radiation at wavelengths of 9.4 to 9.6 μm and 16.2 μm, resulting from the (vibrational) energy transitions (00°1) – (02°0) and (02°0) – (01^10) respectively.

The 9.4 to 9.6 μm pulse may need to be provided by an auxiliary TEA laser, of an intensity sufficient to saturate the (00°1) – (02°0) transition of the carbon dioxide, and to have a duration in the range of 1 to 300 nanoseconds. This method allows independent control of inital excitation and subsequent inversion on the 16 μm transition. The 16.2 μm output pulse then has a small signal gain coefficient $\beta_o \geqslant 2 \times 10^{-3}$, cm^{-1}, and under optimum conditions the overall efficiency is greater than 0.25%. In general, the 9.6μm and 16.2μm pulses need to have durations $\lesssim$ (30/p) nanoseconds where p is the total pressure in atmospheres.

The laser is operated in a pulsed mode, both to enable the lasing medium to be pumped relatively weakly, that is to say slowly, to avoid thermal population of the (01^10) vibrational energy level, which would otherwise destroy the necessary population inversion, and so that the transient nature of the 9.6 μm pulse and the subsequent 16.2 μm output pulse avoids collisional de-excitation of the population inversions.

The embodiment of the invention described is readily scalable so permitting operation at a wide range of peak and mean powers. Also it can be operated at pressure of at least 1 atmosphere (to give wide-band amplifier operation with low gas consumption). The addition or substitution of other isotopic modifications of carbon dioxide (such as $C^{12}0^{16}0^{18}$, $C^{12}0^{18}{}_2$ or $C^{13}0^{16}{}_2$) in general extends the tuning range of the laser; however, chance near-coincidences of absorption from the rotational manifold of the vibrational ground state (00°0) in particular, and of other low-lying levels in general, must be avoided by a judicious choice of parameters. As an illustrative example, at wavelengths in the neighbourhood of the $C^{13}0^{16}{}_2$ R913) lasing transition an amplifier operating with a pure $C^{13}0^{16}{}_2$ constituent should be run at the lowest practicable temperature, at a total pressure $\lesssim$ 0.2 atmospheres, in order to avoid unwanted absorption from the p (26) ground-state (00°0 to 01^10) transition. Conversely, at pressures of the order of 1 atmosphere, gain is also available from a few (02^20) to (01^10) transitions due to collisional population of the (02^20) level, under favourable kinetic conditions).

As a narrow-band laser oscillator, the system can be efficiently operated on a range of discrete rotation-vibration transitions with several of the isotopic variants of CO_2 at pressure typically in the range 10^{-1} – 10^{-2} atmospheres, i.e. at pressure sufficiently low to ensure that the life-time (τ) of the transient inversion is sufficiently long so that oscillation can build up from the level of noise to saturation; to ensure this, the produce $\alpha_o C \tau$ should exceed a factor of about 30, where C is the velocity of light. Chance near-coincidences with absorbing transitions from the (00°0) ground state again place an additional upper limit on the total pressure: as illustrative examples the (02°0) – (01^10) $C^{13}0^{16}{}_2$R (13) transition can be generated at a total pressure of about 10^{-1} atmospheres, but the R (15) and R (17) transitions would require significantly lower pressures.

WHAT WE CLAIM IS:–

1. A pulsed mode laser having a gaseous mixture including carbon dioxide as the lasing medium, wherein the lasing medium is cooled to a temperature such that the thermal population of the lower energy level of an output lasing transition between a higher energy level and a lower energy level of the carbon dioxide modecule is reduced, and in each pulse the lasing medium is initially energised to create the population inversion which results in the lasing transition at a rate which is slow enough to ensure that significant thermal population

of the lower energy level is avoided.

2. A laser according to Claim 1 wherein the lasing transition is between the (02°0) and (01¹0) vibrational energy levels of the carbon dioxide molecules.

3. A laser according to Claim 1 or Claim 2 wherein the lasing medium is supplied to a discharge region of the laser at a temperature within the range of approximately 140 – 230°K.

4. A laser according to any of Claims 1 to 3 wherein the lasing medium comprises carbon dioxide together with a mixture of nitrogen and one or more of the gases hydrogen, helium and argon.

5. A laser according to Claim 5 wherein the volume ratio of nitrogen to carbon is greater than 9.

6. A laser according to any preceding claim wherein the lasing medium is a mixture of carbon dioxide, nitrogen and helium in the volumetric proportions of 1 : 9 : 10 respectively.

7. A laser according to any preceding claim wherein the lasing medium is initially energised by a pulsed electrical discharge the duration of the pulses of which is of the order of tens of microseconds.

8. A laser according to Claim 7 wherein the lasing medium is irradiated by pulse of radiation having a wavelength in the region of 9.4 to 9.6 μm, of an intensity sufficient to saturate the (00°1) – (02°0) transition of the carbon dioxide molecule, and a duration approximately equal to or less than 30/p nanoseconds where p is the total pressure in atmospheres of the lasing medium.

9. A laser according to any of Claims 1 to 8 wherein the lasing medium is at a pressure such that the product $\alpha_0 C \tau$ should exceed a value of approximately 30 where α_0 is the small signal gain, C is the velocity of light, and τ is the lifetime of the transient population inversion which results in the lasing transition.

10. A laser according to any preceding claim wherein the lasing medium is at a total pressure within the range of approximately 0.1 to 0.6 atmospheres.

11. A laser according to any of Claims 1 to 8 wherein the lasing medium is at a total pressure of up to approximately one atmosphere.

12. A laser according to any preceding claim wherein the lasing medium is ionised prior to being energised to create the transient population inversion which results in the lasing transition.

13. A laser according to Claim 12 wherein the lasing medium is ionised by passing a pulsed auxiliary electron beam through a metal foil over which the lasing medium is caused to flow.

14. A laser according to Claim 12 wherein the lasing medium is ionised by means of a pulsed beam of ultra-violet radiation.

15. A laser according to Claim 12 wherein the pulsed beam of ultra-violet radiation is used in association with an easily-ionised organic additive such as trimethylamine.

16. A laser according to any preceding claim wherein the carbon dioxide includes molecules which are isotopic variants of natural carbon dioxide.

17. A laser according to Claim 16 wherein the lasing medium includes molecules of $C^{13}O^{16}_2$ and the total gas pressure is less than 0.2 atmospheres.

18. A gas laser according to Claim 16 wherein the total pressure of the lasing medium is approximately 10^{-1} atmospheres.

19. A laser substantially as hereinbefore described and with reference to the drawings accompanying the provisional specification.

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FIG.1.

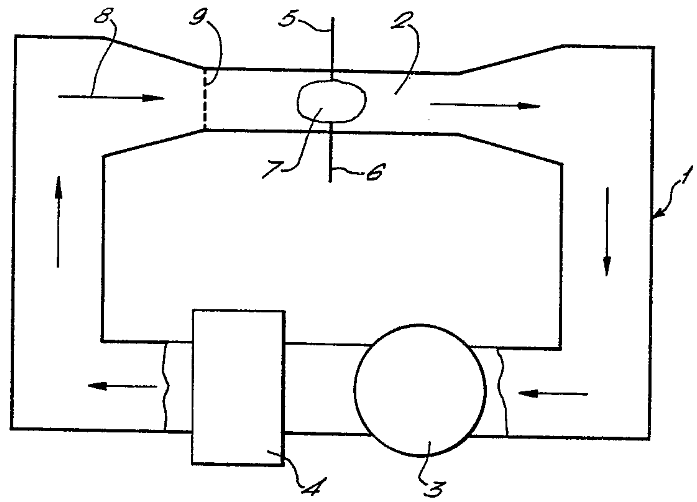

FIG.2.