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(72) Inventors: WELLS, William, E., Jr. ; 405 East Vine Street, Oxford, OH 45056 (US). MARCUM, S., Douglas ; 604 South Main Street, Oxford, OH 45056 (US). DOWNES, Lawrence, Wayne ; 556 Brookfield Drive, Apartment 201, Fairfield, OH 45014 (US). TILTON, Richard, A. ; 9027 Bogata Circle, San Diego, CA 92126 (US).

(74) Agents: BISSELL, Barry, S. et al.; Patent Administrator, Battelle Development Corporation, 505 King Avenue, Columbus, OH 43201 (US).

(54) Title: COLLISION LASER

(57) Abstract

Electromagnetic radiation (10) in a gas mixture (12) including helium in the X(1) state and nitrogen in the Y(1) state. The helium is pumped to excite a high population density of its atoms from the X(1) state to the X(2) state; and photons (15) of suitable frequency are injected into the mixture (12) to excite, via a three-body radiative collision of an atom of X(2) with a molecule of Y(1) and a photon (15), a high population density of molecules of the nitrogen from the Y(1) state to the Y(3) state, followed by a substantially simultaneous return of a substantial portion of the excited helium atoms to the X(1) state and a substantial depopulation of the Y(3) state of the nitrogen, causing the molecules thereof to drop to the lower energy Y(2) state, thereby stimulating the emission from the nitrogen of two photons (10) at the same wavelength for each absorbed photon (15), and thus providing a total quantity of photon emission (10) with sufficient gain for amplification of electromagnetic radiation (10), and finally resulting in the depopulation of the molecules in the Y(2) state by autoionization.
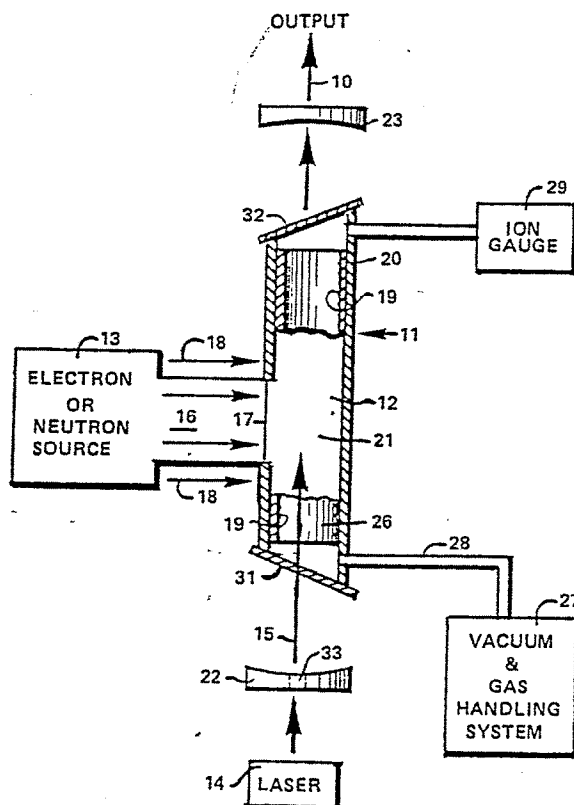
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COLLISION LASER

FIELD

This invention relates to methods and apparatus for
providing stimulated emission of electromagnetic radiation.
Typical embodiments of the invention comprise laser
5   amplifiers and laser oscillators.

The invention is especially advantageous as a new
type of laser amplification system, based upon a process
of stimulated emission radiative collisions. The system
produces a high population density of long lived excited
10 atoms that, in a three-body collision with a suitable
atom or molecule in its ground state and with a photon of
appropriate energy, results in photon emission with
sufficient gain for laser amplification.

The invention typically uses the photon induced
15 collision between a metastable excited atom or molecular
species and a ground-state molecule, to which metastable
energy is transferred with high efficiency, simultaneously
stimulating the emission of two photons at the same wave-
length for each absorbed photon. The gain of the system
20 depends upon an inversion of the _products_ of the population
densities of atomic or molecular states. The term
"density" as used herein always means _number_ density
(unless the context shows otherwise) regardless of whether
the density is of state population, or of collisions.

25   The invention comprises a novel way to provide
inversions, in that energy can be stored in one atom
species in the upper laser levels, whereas the lower levels
of the other atom or molecule of the collision pair can be
depopulated as by a rapid decay mechanism. When this
30 principle is applied to a system in which a high density
of upper level states is populated, while at the same time
the lower level is rapidly depopulated, the gain and
efficiency are significant, and conditions can be realized
to provide a high power, high energy laser amplifier.

35   Hereinafter described in more detail is a new type

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of laser based on radiative collisions, with a specific
gas selection, namely He-N$_2$, as a typical embodiment.
Gain in such a system can be described by the equation

$$\text{Gain} = \frac{d\rho}{\rho dz} = \hbar\omega k\{[g_{X(2)}g_{Y(1)}\ [X(2)][Y(1)]\ -g_{Y(2)}\ g_{X(1)}\ [Y(2)][X(1)]\},$$

5   which is dealt with in detail later. For a given situation,
when the numerical value of this equation is positive,
amplification of a light signal can take place through
stimulated emission.

To date, lasers have required a population inversion
10 within a single species. The analysis hereinafter shows
that laser gain can be obtained by the inversion of the
product of two densities, rather than just the individual
densities. This is also shown in the equation above.

Such inversions are usually not possible for systems
15 of atomic or molecular species in thermal equilibrium.
This invention provides specific means by which it is
possible to produce the inversion of product population
density.

The typical embodiment comprising a mixture of He and
20 N$_2$ is described by the equation

$$\hbar\omega + \text{He}(2^3\text{S}) + \text{N}_2(x) \rightarrow \text{He}(1^1\text{S}) + \text{N}_2{}^*(x,v=3) + 2\hbar\omega,$$
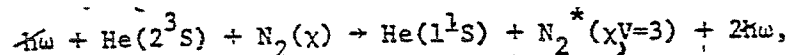
where He(2^3S) represents the excited helium atoms produced
in the gas mixture by the pumping source; N$_2$(X), the
nitrogen molecules in their initial ground state; He(1^1S),
25 the ground-state helium atom products of the 3-body
collision; and N$_2{}^*$(X,v=3), the product nitrogen molecules
remaining after stimulated emission has occurred. As
seen in the equation above, to achieve gain in the system
the product densities in the right-hand term of the
30 equation must be low. In the present invention, this has
been unexpectedly achieved by taking advantage of the
fact that the N$_2{}^*$(X,v=3) molecule, which is still in an
excited state with a high population density, is an auto-
ionizing state with a very short lifetime. It

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self-destructs rapidly, thereby depleting its population
and making the product density of the right-hand term
negligible.

BACKGROUND

5   In 1972, Gudzenko and Yakovlenko[1] described a process involving, effectively
a three-body collision between atomic or molecular species X and Y, and a photon
$\hbar\omega$. Figure 1a shows the energy level for atoms X and Y that corresponds to

$$X(1) + Y(2) + \hbar\omega \rightarrow X(2) + Y(1). \tag{1}$$
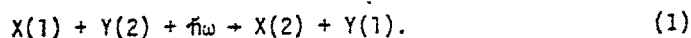
The absorption of the photon, having an energy $\hbar\omega$, allows a resonant two-body
10   collision.

The production rate of state X(2) can be written

$$\frac{d[X(2)]}{dt} = k\rho \, [X(1)] \, [Y(2)], \tag{2}$$

where [] indicates concentration, ρ is the photon flux field and k is a three-body
rate coefficient for the radiative collision. If we look at $k\rho$ in terms of a
15   normal binary collision, then

$$k\rho = <\sigma v>, \tag{3}$$

where σ is the event cross section and v is the velocity, thus (2) becomes

$$\frac{d[X(2)]}{dt} = <\sigma v> \, [X(1)] \, [Y(2)]. \tag{4}$$

Alternately, if we look at k in terms of photon absorption, then

$$k \, [Y(2)] = B_{12}, \tag{5}$$

20   where B_{12} is an Einstein-like absorption coefficient. Now (2) can be written as

$$\frac{d[X(2)]}{dt} = B_{12} \, \rho \, [X(1)]. \tag{6}$$

When cast in the form of a collision, as in (3) and (4), the cross section
σ, becomes a function of ρ, the photon flux field. When written in the form
25   of a radiative absorption, as in (5) and (6), the Einstein stimulated absorption
coefficient, B_{12}, becomes a function of the density, [Y(2)]. The photon, $\hbar\omega$
does not have the energy of the difference between X(2) and X(1), but approximately
the energy difference between X(2) and Y(2). A third method of describing these
collisions would be the absorption of a photon by a quasi-molecule or collision
30   complex Y(2)X(1). This model is conceptually useful.

Harris[2] has used the collisional model to describe his observations of

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