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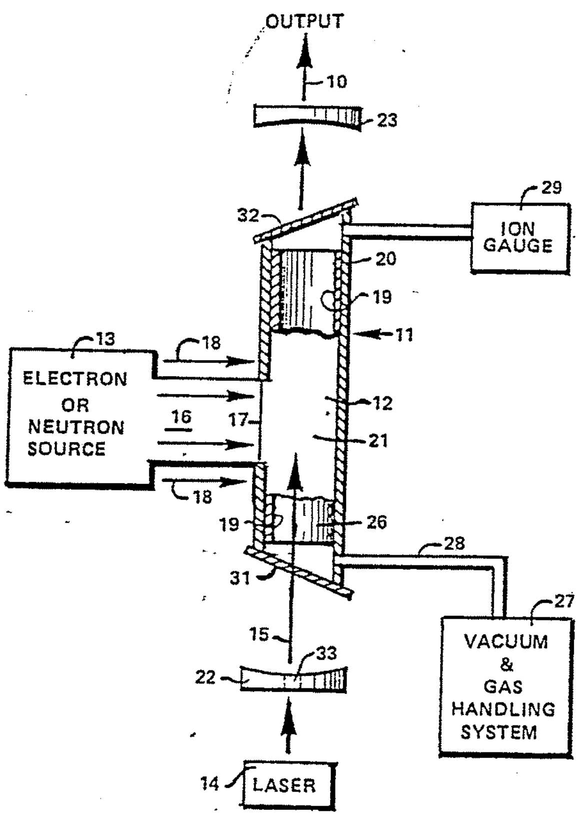
(57) Abstract

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 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 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 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 wavelength for each absorbed photon. The gain of the system 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.

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 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.

Hereinafter described in more detail is a new type 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

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

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 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 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 N_2 is described by the equation

$$\hbar\omega + \text{He}(2^3S) + N_2(X) \rightarrow \text{He}(1^1S) + N_2^*(X, v=3) + 2\hbar\omega,$$

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

BACKGROUND

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 hω. Figure 1a shows the energy level for atoms X and Y that corresponds to

$$X(1) + Y(2) + \hbar\omega \rightarrow X(2) + Y(1). \quad (1)$$

The absorption of the photon, having an energy hω, allows a resonant two-body collision.

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

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

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 kρ in terms of a normal binary collision, then

$$k\rho = \langle\sigma v\rangle, \quad (3)$$

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

$$\frac{d[X(2)]}{dt} = \langle\sigma v\rangle\,[X(1)]\,[Y(2)]. \quad (4)$$

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

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

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

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

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 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, hω 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 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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