Nov. 14, 1967 T. H. MAIMAN 3,353,115

RUBY LASER SYSTEMS

Original Filed April 13, 1961 5 Sheets-Sheet 1

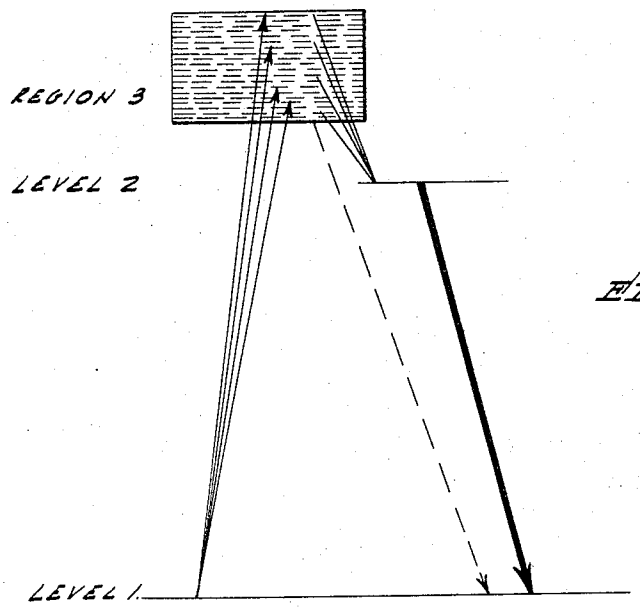


FIG. 1.

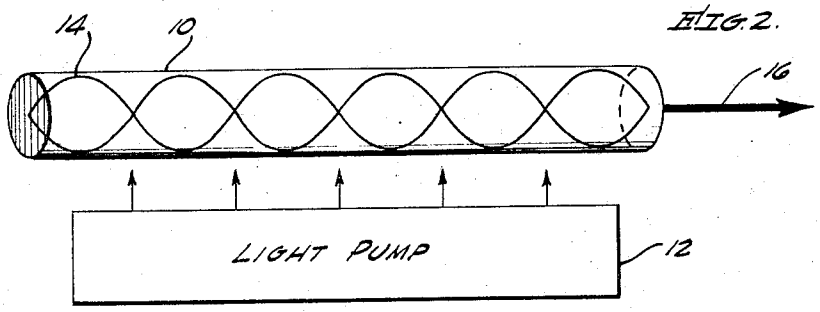


FIG. 2.

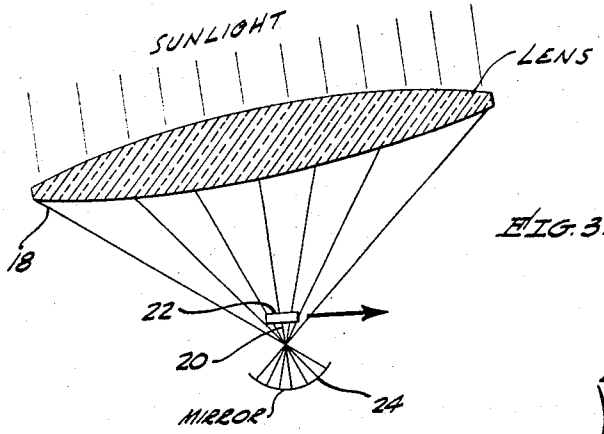


FIG. 3.

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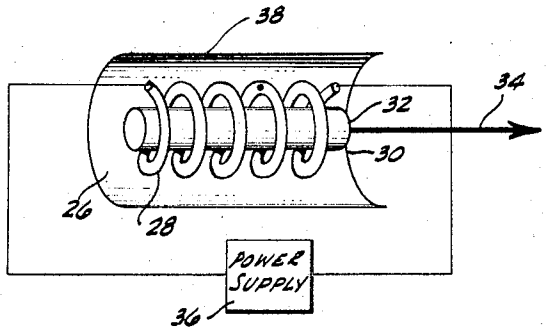


FIG. 4.

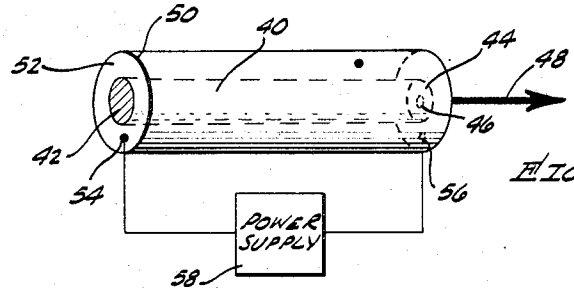


FIG. 5.

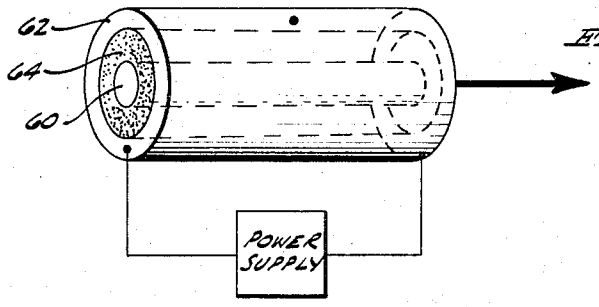


FIG. 6.

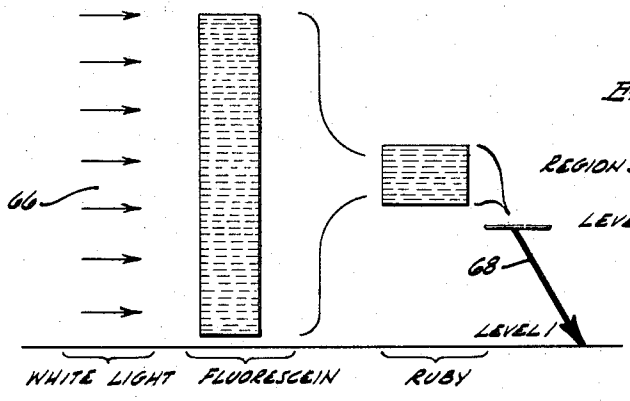


FIG. 7.

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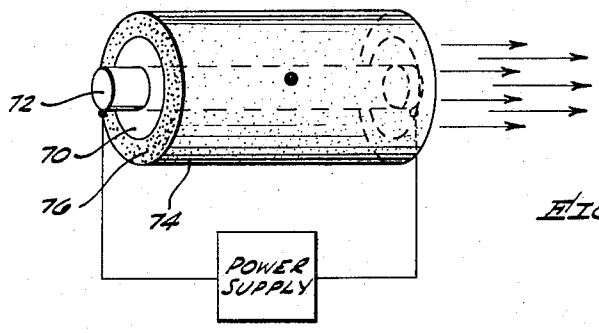


FIG. 8.

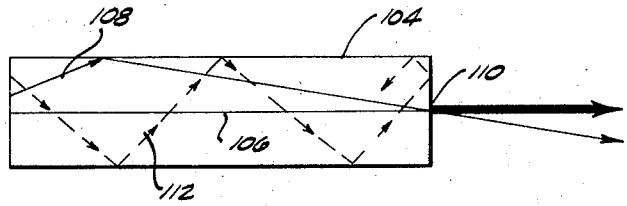


FIG. 10.

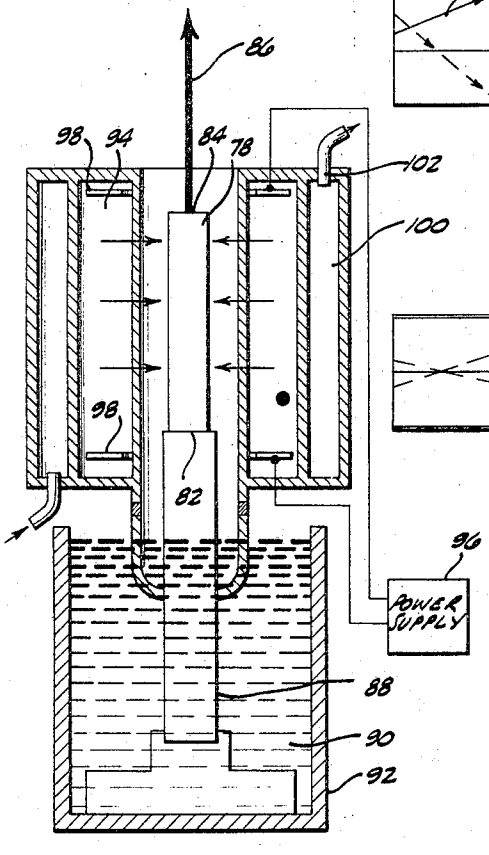


FIG. 9.

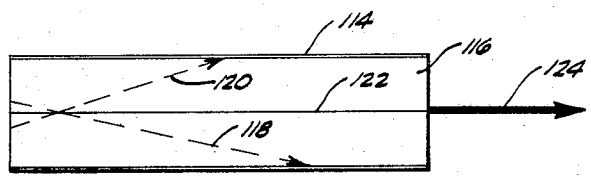


FIG. 11.

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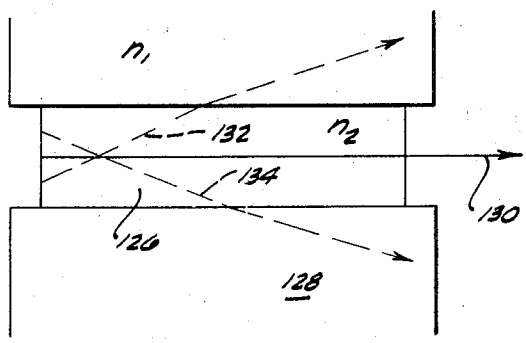


FIG. 12.

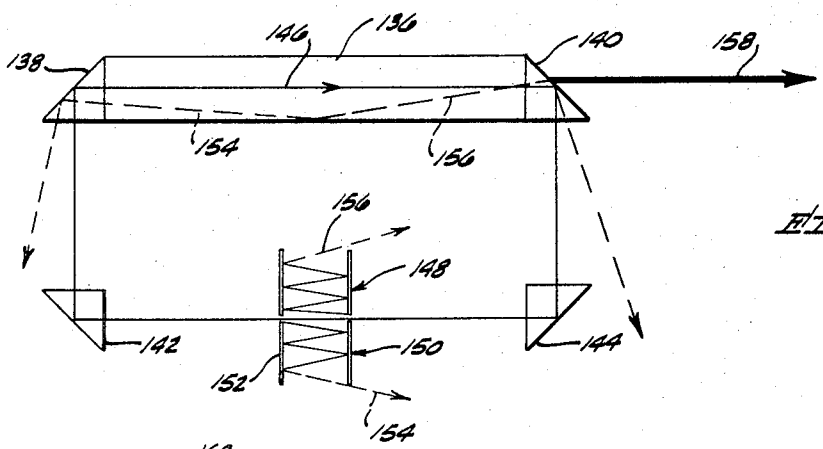


FIG. 13.

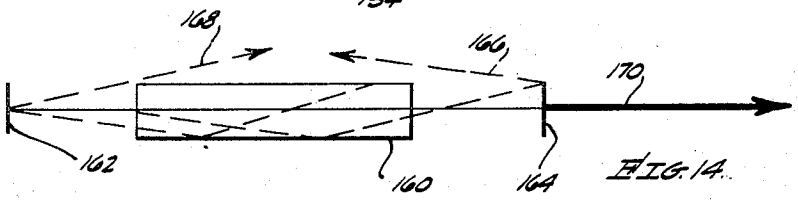


FIG. 14.

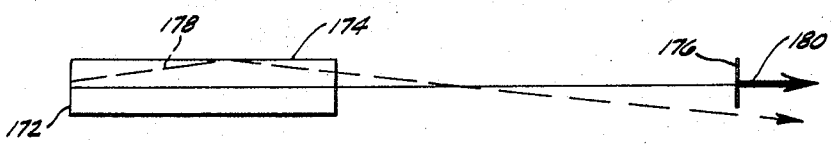


FIG. 15.

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RUBY LASER SYSTEMS

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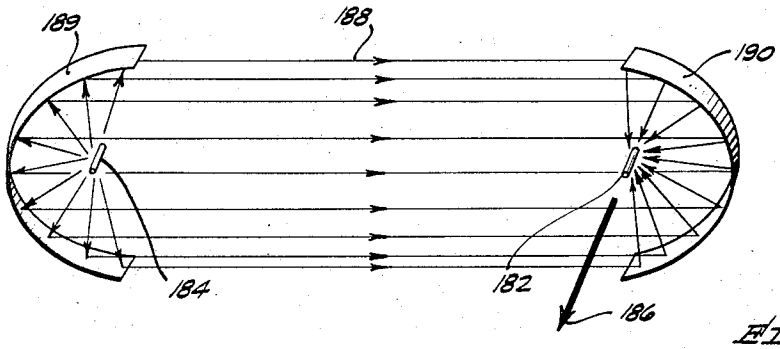


FIG. 16.

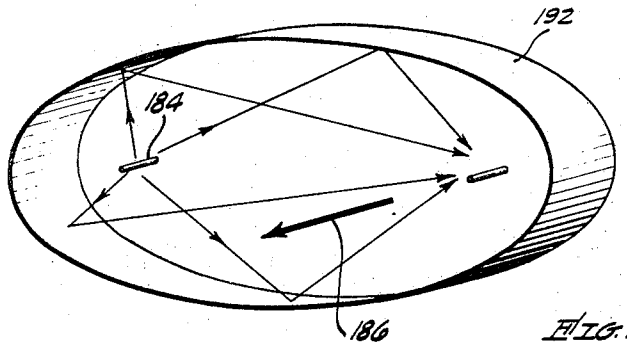


FIG. 17.

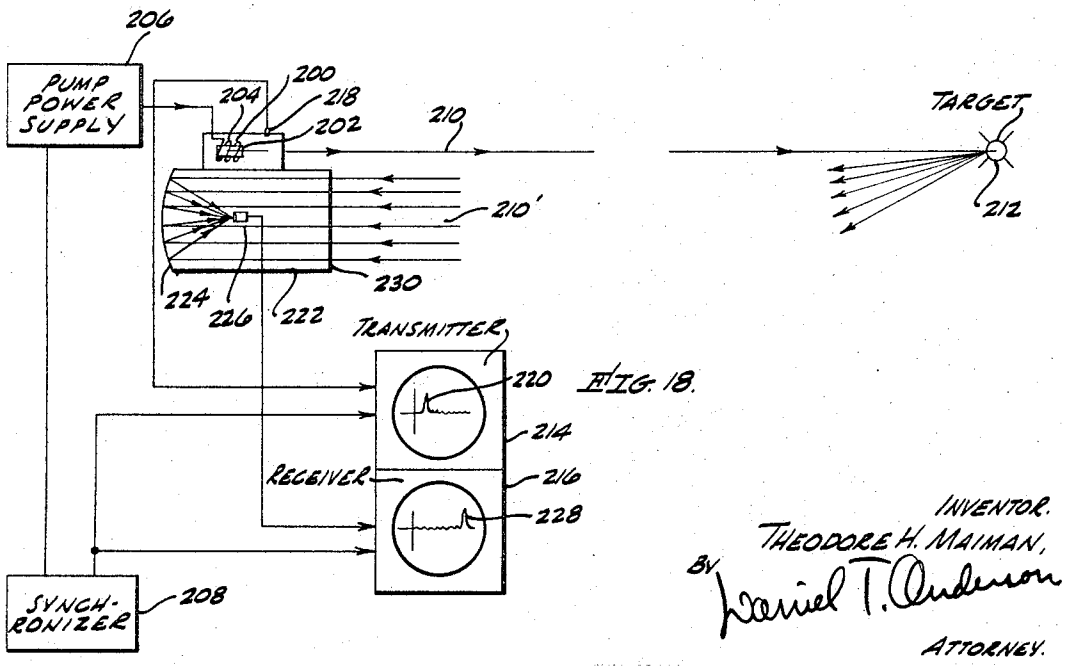


FIG. 18.

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3,353,115

RUBY LASER SYSTEMS

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Continuation of application Ser. No. 102,698, Apr. 13, 1961. This application Nov. 29, 1965, Ser. No. 516,830
2 Claims. (Cl. 331—94.5)

This application is a continuation of my copending application Ser. No. 102,698 entitled, Laser Systems, filed Apr. 13, 1961, now abandoned.

This invention relates to the generation, amplification, and utilization of electromagnetic waves in the infrared, visible and ultraviolet portion of the spectrum, and more specifically to lasers and laser systems. A laser, the term being an acronym for light amplification by stimulated emission of radiation, is a device capable of generating or amplifying coherent light. The principle of operation is similar to that of a maser and is therefore also referred to as an optical maser.

Much effort has been expended in the fields of electronics and physics in attempts to generate or amplify coherent light. Such an achievement, it was known, would make available a vast new region of the electromagnetic spectrum for a multitude of purposes including communications and metrology (measurements) applications. Such coherent light would have the properties of being monochromatic and of having its component waves propa gating in phase with each other. Thus, as at radio or microwave frequencies, a great deal of energy could be concentrated at or extremely near to a single frequency and be utilized in methods analogous to those at radio frequencies.

Ordinary techniques of generating or amplifying electromagnetic waves, including microwave maser techniques, cannot be extended usefully into the optical frequencies because such techniques require components, such as maser cavities, for supporting wave oscillations which must have physical dimensions of the order of a wavelength. Obviously, such components can neither be manufactured nor meaningfully utilized at optical frequencies where the wavelengths are of the order of atomic dimensions. When it is attempted to use cavities which have dimensions corresponding to a large number of wavelengths, many modes are supported, coherence is degraded, and impracticably large sources of pumping power are required.

A laser has been proposed by Schawlow and Townes, see United States Patent No. 2,929,922, issued March 22, 1960, which suggests using as the negative temperature medium certain gaseous state materials such as alkali metal vapors. Such materials may be shown to have energy levels in their atomic systems corresponding to appropriate optical frequencies for absorbing optical pump energy to invert the population from the stable equilibrium state and thus provide the material with what is known as a negative temperature or excited, non-equilibrium state. Then by stimulation or spontaneous relaxation the atomic system falls back to its normal equilibrium state by one or more steps emitting energy of certain optical frequencies.

Such proposed gaseous state devices are of great interest as theoretical models and represent significant academic advances, however, they have not been shown to provide a net generation or amplification of light. In addition, the structure of gaseous state systems is complex and requires the mainttenance of critical vapor pressures and temperatures. Impurities in the gas is another very serious problem. The inter-atomic spacing of the gas severely limits the efficiency of coupling between the stimulated

emission and a coherent wave propagating through the medium. In addition, the frequency of operation of any given gas laser may be effectively tuned only by Stark or Zeeman effects which can provide a tuning range of only approximately 5×10^{10} cycles per sceond. Further, the construction of a gas cell is extremely critical in that the end plates must be highly reflective and perfectly parallel so that the many reflections required because of the low density gaseous material will be accomplished.

It is therefore an object of the present invention to provide an operable, low noise, efficient laser.

It is another object to provide a laser which is mechanically stable and of noncritical construction.

It is another object to provide a laser which operates at room temperature or cryogenic temperatures for additional simplicity and even greater flexibility in design parameters.

It is another object to provide a laser which does not require critical vacuum or vapor pressure techniques and which operates in a medium of high dielectric constant.

It is another object to provide a laser capable of much higher power handling.

It is another object to provide a laser which is tunable over aproximately a 5×10^{11} cycles per second range.

It is another object to provide an optical radar system utilizing the advantages of a laser.

Briefly, these and other objects are achieved in accordance with the present invention in a system including a solid state negative temperature medium.

In one example a segment of solid state active laser material such as a cylindrical ruby (Al_2O_3 doped with Cr_2O_3) rod with reflecting coating at each end is coaxially placed in a helical flash lamp. White light or, predominantly, the green and blue components thereof, is absorbed by the ruby; and red light is emitted therefrom and coupled out of the system through a hole in the reflective coating at one end of the rod. The reflecting coatings provide a regeneration related to the coupling between the reflecting wave, traveling back and forth many times, and the emitting atoms. In other words, a resonating, standing wave is provided which derives energy from the negative temperature dielectric. Thus the rod may be considered as a resonator having different Q's for different modes of oscillation. The mode having the highest Q corresponds to waves traveling nearly parallel to the rod axis since it supplies the highest degree of regeneration. This effect causes the output to be an extremely parallel beam so that it propagates immense distances without spreading. Inherent in the regeneration process is the coherent amplification of an extremely narrow band of frequencies, thus providing a menochromatic output. Additional discussion of principles of operation, of further objects and advantages, including uses, and of other examples will be presented below in connection with a description of the accompanying drawings in which:

FIG. 1 is an energy level diagram for the atoms of a substance exhibiting laser properties;

FIG. 2 is a schematic diagram illustrating optical pumping of negative temperature laser material;

FIG. 3 is a schematic diagram of means for optically pumping the laser material with sunlight energy;

FIG. 4 is a schematic diagram of one embodiment of the present invention which utilizes a helical gas-filled flash tube for optical pumping of the laser material;

FIG. 5 is a diagram of an alternative embodiment utilizing a hollow gas-filled cylinder for optical pumping of the laser material;

FIG. 6 is another embodiment of the present invention which utilizes a hollow cylindrical gas-filled optical pumping means which is radially separated from the active laser material by a fluorescent material;

FIG. 7 is an energy level diagram illustrating the method of operation of the embodiment of FIG. 6;

FIG. 8 is a schematic diagram of an embodiment of the invention in which the active laser material is a hollow cylinder surrounding a cylindrical gas-filled flash tube, the entire assembly being surrounded by a second hollow cylinder of coolant of a high index of refraction;

FIG. 9 is a cut-away view of an embodiment of the present invention in which the laser material is refrigerated;

FIG. 10 is a diagram of a segment of laser material;

FIG. 11 is a diagram of a coated segment of laser material;

FIG. 12 is a diagram of a segment of laser material which is surrounded by a coolant having a high index of refraction;

FIG. 13 is a schematic diagram of a portion of a laser system illustrating the use of an interferometer;

FIGS. 14 and 15 are schematic diagrams illustrating additional types of interferometers;

FIGS. 16 and 17 are diagrams of a laser system in which the optical pump utilizes an exploding wire; and

FIG. 18 is a schematic diagram of a practical colidar system utilizing a laser.

The laser to be herein below described utilizes the interaction of electromagnetic radiation with a material having an appropriate set of discrete energy levels. Consider, for example, a pair of such levels with energies E_1 and E_2 where E_2 is greater than E_1. An electromagnetic wave of frequency

$$\nu_{21}=\frac{E_2-E_1}{h}$$

where h is Planck's constant, coupled to the system stimulates both absorption and emission. In other words, atoms in the lower level make transitions to the upper level, each absorbing energy $E=\nu_{21}$ and similarly upper level atoms are stimulated downwardly, each of these giving up energy to the wave by radiating a like quantum of energy. The net absorption of the radiating wave interacting with the system is proportional to N_1-N_2 where N_1 and N_2 are respectively the number of atoms in these two levels. Since in thermal equilibrium N_1 is greater than N_2 the indicated difference is positive and a wave propagating the length of the material is attenuated.

In a substance with a third energy level E_3 higher than either of the other two levels, energy can be supplied to the system by a radiating wave of frequency

$$\nu_{31}=\frac{E_3-E_1}{h}$$

If other parameters, and, in particular, relaxation times, in the material are suitably related, an inverted population will be produced such that N_2 is greater than N_1; then the net interaction with a radiating wave of frequency ν_{21} is emission and the wave is amplified. Also, by providing a feedback mechanism oscillation can be produced.

Visible light covers the electromagnetic spectrum approximately 4×10^{14} cycles per second, that is, red light to approximately 7.5×10^{14} cycles per second which is violet light. In substance as described above with energy levels such that ν_{21} lies in this frequency range can therefore amplify or generate visible light.

Referring specifically to FIG. 1 an energy level diagram is illustrated for the atoms of a material such as Al_2O_3 which may exhibit laser action in accordance with the present invention. Level **1** may be considered the ground state corresponding to E_1 and region **3** in the relatively high energy state corresponding to E_3 which is actually a broadband of energy levels rather than a discrete energy level. The atoms, or ions, as the case may be, are excited or pumped from the level **1** to the region **3** by means of an optical pumping source having the energies or frequencies ν_{31} corresponding to the difference between the energy of level **1** and those of the levels throughout region

3. Because of the broadness of region **3**, doping atoms, which for example may be the chromium atoms, may accept pumping energy over a correspondingly broad band. The atoms thus excited may then decay from the region **3** back to the ground state or, alternatively, they may decay to level **2** corresponding to E_2 and thence to level **1**. The latter course is definitely the favored one and the atoms in decaying to level **2** do not emit energy. In other words, it is a radiationless thermal type of transition which funnels the energy distributed in the board region **3** into the very narrow region **2**. The energy level **2** is in fact a single energy level, or may in the presence of a magnetic field be a doublet, and the atoms of this state of excitation will emit the correspondingly discrete frequency ν_{21} corresponding to the difference between level **2** and level **1** that is E_2-E_1 when they are appropriately stimulated or triggered to do so. Further, when an appropriate stimulation does occur, the atoms in the particular segment of laser material will fall together or emit their radiated energy coherently with each other and with the stimulating wave. Thus it may be seen that the mechanism is a funneling of energy from a broadband incoherent source into a discrete frequency that is monochromatic coherent radiation.

Referring to FIG. 2, there is shown a schematic representation of the mechanism of optically pumping the atoms such as those of chromium in a ruby rod **10**. A light pump **12** emits a high intensity "white" light or, in this example, it may be broadly green, toward the ruby rod **10**. The broadband light thus radiated includes at least some light in the frequency range ν_{31}. This light is absorbed by the ruby rod and causes the doping atoms to be excited in the energy state represented by region **3** of the diagram of FIG. 1. This excitation is equivalent to an inversion of the population of the chromium atoms as discussed above. The excited atoms then relax by thermal processes down to the level **2** and may remain there until stimulated to fall to the level **1** thereby emitting the desired monochromatic light of frequency ν_{21}. This stimulation may be by an external source of radiation at frequency ν_{21}, or it may be triggered spontaneously as by optical noise. When the energy at frequency ν_{21} is emitted from the atoms in the ruby rod **10** it causes a wave to propagate through the rod and if the wave is parallel to the axis it may reflect repeatedly from the ends of the rod. If the rod is of an appropriate length a standing wave **14** may be set up. In either event the repeated reflections through the material stimulate the emission of substantially all the atoms from level **2** to their ground state level **1**. The emission of the enregy at frequency ν_{21} combines in phase with the stimulating wave **14** thus adding coherently with it. This energy may then be coupled out of the rod as a beam **16** which is monochromatic at frequenvy ν_{21} and which is traveling or propagating in a direction parallel to the axis of the ruby rod **10**.

FIG. 3 illustrates an example of the invention in which the light pump **12** of FIG. 2 is the sun or some other source of parallel "white" light. The lens **18** focuses the light so that it is of relatively high intensity in a region **20** where an element of active laser material **22** is disposed. An auxiliary mirror **24** may further intensify the light in the region of the laser material. The mirror **24** may be a spherical reflector which merely sends the unabsorbed pumping light back through the focal point of the lens **18** and thence through the laser material **22** a second time.

Referring to FIG. 4, an embodiment of the invention is shown in which an active laser rod **26** is disposed coaxially within a helical gas-filled flash tube **28**. The ends of the rod **26** may be suitably plated as by a partial coating of silver in order to provide the reptitive reflections of the monochromatic emitted light. The system of stimulation is so efficient that a plating **26** which will provide approximately 10 percent reflection is adequate. One end

of the rod 30 has a nonreflective opening 32 in the end plating to provide unobstructed passage of the coherent monochromatic beam 34 as shown. A power supply 36 provides the flashing energy for the tube 28. An outer enclosing cylinder 38 is provided which has a very highly reflecting inner surface for reflecting the pumping energy repeatedly through the rod 26 for improved efficiency of the system as compared with operation when the light energy of the tube 28 is permitted to radiate indefinitely in all directions causing only a fraction of its energy to pass through the rod 26.

Referring to FIG. 5, a rod of active laser material 40 is shown which again has reflectively coated ends 42, 44 with an opening 46 in the plating 44 to permit passage of the laser output beam 48. The light pump in this example is a hollow cylinder 50 which is coaxially disposed about the rod 42 with the radial space therebetween being filled with a flashing gas 52. Appropriate electrodes 54 and 56 at opposite ends of the cylinder 50 are energized by a power supply 58 to cause the gas 52 to emit high intensity "white" light when desired. Again, the inner surface of the cylinder 50 is highly reflective for added efficiency of the light pump mechanism.

FIG. 6 illustrates an embodiment of the invention in which a rod 60 of active laser material similar to rods 26 and 42 is disposed coaxially within a hollow flash tube 62. The radial space between the rod 60 and the flash tube 62 is filled with a fluorescent material 64, such as fluorescein. The fluorescent material efficiently absorbs the "white" light emitted by the flash tube 62 and re-emits predominantly green light which is more efficiently absorbed by the laser rod 60. Thus, as illustrated in FIG. 7, the broadband "white" light 66 is directed into the fluorescein which re-emits incoherent green light predominantly in the region 3 of the material discussed in connection with the description of FIG. 1. Thus the fluorescein effectively funnels the "white" light into green light which energy is further funneled and subsequently emitted as a single frequency or monochromatic light by the laser material, as indicated by the heavy vector 68 between lever 2 and level 1 of FIG. 7. Again in FIG. 6 the inner surface of the cylinder surrounding the tube 62 may be highly polished for even greater efficiency of pumping.

Referring to FIG. 8 there is illustrated an example of the invention in which the active laser material is in the form of a hollow cylinder 70 within which is coaxially disposed a cylindrical flash tube 72. Thus when the flash tube is energized, substantially all of its pumping radiation is emitted in a radial direction and must therefore pass through the laser material. The laser material 70 is in turn coaxially surrounded by a cylinder 74 filled with a coolant 76. The coolant 76 may be chosen to have a high index of refraction for the advantages and purposes discussed below. Cylinder 74 may have a highly polished internal surface for reflecting energy of the flash tube 72 back through the laser material 70.

Referring to FIG. 9, an embodiment of the invention is shown in which the laser material is refrigerated to liquid nitrogen temperatures for the purpose of making its output beam even more purely monochromatic because the line width of the laser transition (frequency ν_{21}) is much sharper in most solids at low temperature. A rod 78 of active laser material has plated ends 80 and 82 with a coupling hole 84 in the upper end for emitting the laser beam 86. The opposite end of the rod is mounted on a thermally conductive rod 88 which may be of copper or sapphire. The major portion of the rod 88 is immersed in liquid nitrogen 90 within a Dewar flask 92. A hollow cylindrical flash tube 94 is disposed coaxially about the laser rod 78 and is energized from a power supply 96 through a set of annular electrodes 98 disposed at opposite ends of the gas tube 94. A further hollow cylinder is disposed coaxially about the flash tube 94 and is filled with a coolant 102 to cool the flash tube 94.

FIG. 10 illustrates schematically a segment of laser material 104 for purposes of illustrating internal reflections of the stimulating wave when the segment is not coated but is merely surrounded by material of a low index of refraction, such as air. A ray of energy 106 is shown as propagating parallel with the axis of the rod and therefore never reflects against the side of the segment 104. A ray 108, however, has a radial component of direction and reflects, as shown, off the side boundary of the segment 104. Such reflections cause two deleterious effects. One is that the effective length of the resonating segment is greater than that for an axially traveling ray such as 106. Thus the ray 108 may represent a component of energy at a frequency slightly different from the desired or designed frequency of operation. Secondly, the ray 108, if it finds its way out of the coupling hole 110 of the segment 104, will cause a spreading of the beam thereby detracting from the otherwise extremely narrow beam of the laser and contributing to its noncoherence. A ray 112 propagating in a direction even further removed from that of the axis of the segment may obviously reverberate substantially endlessly through the segment causing by its interference with the desired energy a decrease in the coherence and narrowness of bandwidth of the laser output.

To minimize the deleterious effects of the rays 108 and 112 of FIG. 10 a coating 114 may be applied to an active laser segment 116 as illustrated in FIG. 11. The coating 114 may be chosen to be transparent to the pumping energy but highly absorptive of the frequency of light energy near to that of the desired laser output frequency so that rays 118 and 120 which are not parallel to the axis 122 of the segment are absorbed at the boundary by the coating 114 and hence do not degrade the desired characteristics of the output beam 124.

FIG. 12 illustrates an alternative system for minimizing the deleterious effects due to the reverberation of nonparallel rays of the active laser segment 126. The segment is shown surrounded by a coolant material 128 having a high index of refraction in immediate contact with the surface of the segment 126. Again an axially directed ray 130 which is propagated back and forth along the length of the segment 126 can ultimately be coupled out of the segment resonator as a portion of the laser output beam. Nonparallel rays 132, 134 strike the side boundaries of the segment 126 and tend to be transmitted through the material of high index of refraction where they would otherwise be reflected by the boundary surface with a material such as air. The prime reason for this is that the critical angle between the rays 132, 134 incident upon the boundary is increased in proportion to the ratio of n_1 to n_2 where n_1 is the index of refraction of the material beyond the boundary. The critical angle is defined as that angle between the incident ray and a line normal to the boundary at which substantially all the energy transmits the boundary instead of being reflected by it. It is highly desirable that the critical angle be as large as possible so as to minimize the energy which is reflected by the boundary. In other words, it is desired to transmit the nonparallel rays 132, 134 out of the laser material where they may be dissipated without interfering with the laser regeneration mechanism and the output beam 130. It is apparent that if n_1 is as large as n_2 the critical angle would be 90° and, optically speaking, there would be no boundary so that even energy grazing the surface would be transmitted therethrough. A practical example of a material having a suitably high index of refraction, as well as being an effective coolant, is diodomethane which has an index of refraction of 1.75 which compares to the index of refraction of ruby which is approximately 1.76.

It is useful to provide a coolant for the active laser material in order to control its frequency of operation since the magnitude of the energy level 2 in a solid state substance is dependent upon temperature. This need not

be a disadvantage since it affords a highly useful means for tuning the device over a relatively broad range, that is, approximately 5×10^{11} cycles per second. However, it is important in many applications for the frequency to be controlled and constant by controlling or maintaining constant the temperature of the active substance. To this end, the active segment may be cooled and the heat energy of the pump removed by flowing appropriate coolants over their surfaces.

FIG. 13 illustrates a system in accordance with the present invention which utilizes an interferometer for providing even greater coherence and narrow bandwidth. In this embodiment a rod **136** of active laser material does not have coated ends but rather has prisms **138** and **140** coupled to each end of the rod **136**. An additional pair of mirrors or prisms **142** and **144** are disposed so that a ray of light **146** which is axially directed through the rod **136** may propagate along the closed path determined by the reflecting surfaces of the 4 mirrors. Disposed between the mirrors **142** and **144** is an interferometer **148** which may be a Fabry-Perot interferometer. The interferometer comprises a pair of parallel plates **150** and **152**, the distance between which may be adjusted to "tune" the regenerative circuit for the ray **146**. Thus a ray of the proper wavelength will resonate between the parallel plates **150, 152** while waves of other frequencies will be dissipated and lost in the interferometer. The circuit defined by the reflective prisms and the interferometer is practically non-negotiable for rays of light which are not propagating exactly parallel to the axis of the rod **136**. Nonparallel rays **154** and **156** in the figure illustrates how their energy is lost from the system because their direction precludes their traversal of the circuit past the first reflective prisms. Furthermore, even if a ray was almost parallel to the axis of the rod **136** it would not make a large number of traversals around the circuit before it would become lost from the edge of one of the prisms. Also the coupling through the interferometer may be made highly directive to further discriminate against waves which are not propagating in exactly the desired direction. As shown by rays **154** and **156** emanating from the interferometer, waves which are not propagated in the proper direction are lost out the sides of the interferometer and thereby removed from the system. The laser output beam **158** may be coupled out of the system in any appropriate manner such as for example by an appropriate discontinuity in the reflective face of the prism **140**.

FIG. 14 illustrates another type of interferometer in which the active laser segment **160** does not have reflective ends. Instead, mutually parallel plates **162** and **164** are disposed perpendicularly to the axis of the segment **160** which is the desired direction of propagation. The plates may be disposed at some distance from the laser material; the greater the distance and the smaller their size the more the system discriminates against nonparallel light rays **166** and **168**. Again the desired energy may be coupled out of the system through a small opening in the reflective plate **164** to provide a laser output beam **170**.

FIG. 15 illustrates the use of an interferometer similar in some respects to the device of FIG. 14. In this example one of the reflective plates **172** may be placed directly on the active laser segment **174** while the other reflective plate **176** may be axially disposed at some distance from the segment **174**. As shown, the nonparallel ray **178** will not be re-reflected between the two reflective plates **172** and **176** thereby minimizing its deleterious effects on the monochromatic output beam **180**.

FIGS. 16 and 17 illustrate methods of optically pumping the active laser segment **182** by a source **184** of broadband light which is disposed some distance from the laser segment. In each case the output beam **186** of the laser is directed out of the rod-shaped laser segment in a direction parallel to the axis of the rod. In FIG. 16 two parabolic reflectors **189** and **190** are directed toward each other so that the light source **184** at the focal point of reflector **189** emits a substantially parallel beam of pumping light **188** which is collected by the parabolic reflector **190** and focused to pass through the laser segment **182**. The parabolic surfaces **189** and **190** may be parabolic cylindrical surfaces as shown or they may be paraboloidal surfaces of revolution symmetrically disposed about the line joining their respective foci.

FIG. 17 illustrates an elliptical system for reflecting the energy from the light source **184** to the laser segment **182** wherein the source **184** is disposed at one focus of an ellipse while the laser segment **182** is disposed at the opposite focus; hence, the elliptical surface **192** reflects substantially all of the energy radiating from the source **184** and refocuses it through the laser segment **182**. The elliptical surface **192** may be an elliptical cylindrical surface or it may be an ellipsoid.

The light source **184** in either of the above examples may make use of exploding wire phenomenon in which an extremely high current at low voltage is sent through a wire thereby exploding and vaporizing it. The light energy emitted by this phenomena may be extremely intense "white" light. Alternatively, the source **184** may be other conventional light sources such as gas-filled flash tubes, or carbon arc lamps. An advantage of the systems depicted in FIGS. 16 and 17 is that the light source and the active laser material may be independently handled and cooled due to their spacing from each other.

Referring to FIG. 18, there is illustrated a practical application of a laser in a colidar optical radar system. "Colidar" is an acronym for coherent light ranging. A laser unit **200** is the colidar transmitter and includes an active laser segment **202**. Surrounding the segment **202** is a gas-filled flash tube **204** which is pulsed from a pump power supply **206**. A synchronizer **208** triggers the pump power supply which in turn fires the flash tube **204** and the laser **200** transmits a beam **210** of monochromatic coherent light toward a target **212**, the range to which is to be determined. The synchronizer trigger also triggers the horizontal sweeps of a pair of oscillographs **214** and **216**. A sample of the laser output is determined by a photoelectric cell **218** which is coupled to the oscillograph **214** and presented on the face thereof as a "transmitter" pulse **220** to indicate the time at which the laser output pulse was transmitted. The laser beam **210** is reflected off a target **212** and a minute portion thereof is received as a parallel beam **210'** by the colidar receiver **222**. The received beam **210** impinges upon a parabolic reflector **224** and is focused into a photoelectric cell **226**. The electrical cell of the protoelectric cell **226** is coupled to the receiver oscillograph **216** where it is presented on the face thereof as a "receiver" pulse **228**. The time difference between the pulses **220** and **228** on the two oscillographs is, of course, a direct indication of the range from the colidar system to the target **212**. The two oscillographs **214** and **216** may alternatively be a dual trace, single oscillograph tube or, as in conventional radar "B-scope" presentation, be displayed with a single horizontal trace.

The advantages of such a ranging system which may obviously be extended to other forms of radar, such as plan position indicator types, include the fact that the transmitted beam is extremely narrow and may be sent over great distances with very little beam spreading. Also the wavelength is so small that extremely high resolution is obtained. It may also be seen that it is substantially impossible to jam a laser radar system because the jamming equipment would have to be placed precisely in line with the transmitter and the target would have to be directed at the receiver and would have to be at precisely the proper optical frequency in order to interfere with the laser receiver. For further improvements in this regard optical filters **230** may be placed in the receiver **222** to discriminate not only against deliberate jamming but also

against the minute amount of optical noise at the operating frequency.

There has thus been disclosed a laser system in which the active laser substance is solid state and which provides coherent monochromatic amplification and generation of electromagnetic wave energy in the optical or visible spectrum. The invention is effectively an efficient device which is mechanically stable and which may be operated at room temperature without complex vacuum or vapor pressure techniques. The invention as disclosed also is capable of tuning over a 5×10^{11} cycles per second range and may handle high powers for practical optical radar and communications utilization. In addition, because it provides light which can be focused extremely precisely, the laser opens new possibilities in the investigation of basic properties of mater, as well as in medicine where objects or very minute portions thereof can be selectively sterilized or vaporized.

What is claimed is:

1. A three energy level laser comprising:

a ruby having atoms exhibiting a first energy level corresponding to a ground atomic state, a substantially discrete second energy level above said ground state and third energy levels defining a relatively broadband absorption third region extending above said second level;

a pumping source of broadband light energy optically coupled to said ruby for illuminating it and exciting atoms thereof to exhibit excitation at said third energy levels from whence they decay without substantial radiation loss to said discrete second energy level so as to establish a population inversion between said discrete second energy level and said ground state;

interferometer means optically coupled to said ruby and tuned to the frequency corresponding to that of the energy difference between said second energy level and said first energy level for reflecting light energy of said frequency repeatedly through portions of said ruby to generate a coherent light beam;

and coupling means for extracting the monochromatic coherent light beam from said ruby.

2. A three energy level ruby laser system, comprising:

a ruby having atoms exhibiting a first energy level corresponding to a ground atomic state, a substantially discrete second energy level above said ground state and third energy levels defining a relatively broadband absorption third region extending above said second level;

broadband optical pumping means directly coupled to said ruby for exciting atoms of said ruby from said first energy level to said third energy levels from which radiationless energy transition of said atoms takes place to said second energy level to establish a population inversion between said second energy level and said ground state; and

light resonating means coupled to and forming a regenerative optical path through said ruby to stimulate radiant energy transitions of said atoms from said second energy level toward said ground state to produce a coherent monochromatic light beam having a frequency substantially corresponding to the energy difference between said ground state and said second energy level.

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