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(54) Negative glow discharge laser

(57) A compact negative glow discharge helium-cadmium laser emits a laser beam having dual green lines of 5337Å and 5378Å at 30 Torr and approximately 1 mw of power. The laser is approximately 5 cm active length. The laser operates by charge transfer collisions between molecular helium ions and neutral cadmium atoms and has a central hollow cathode with a cylindrical anode spaced from each end of the cathode.

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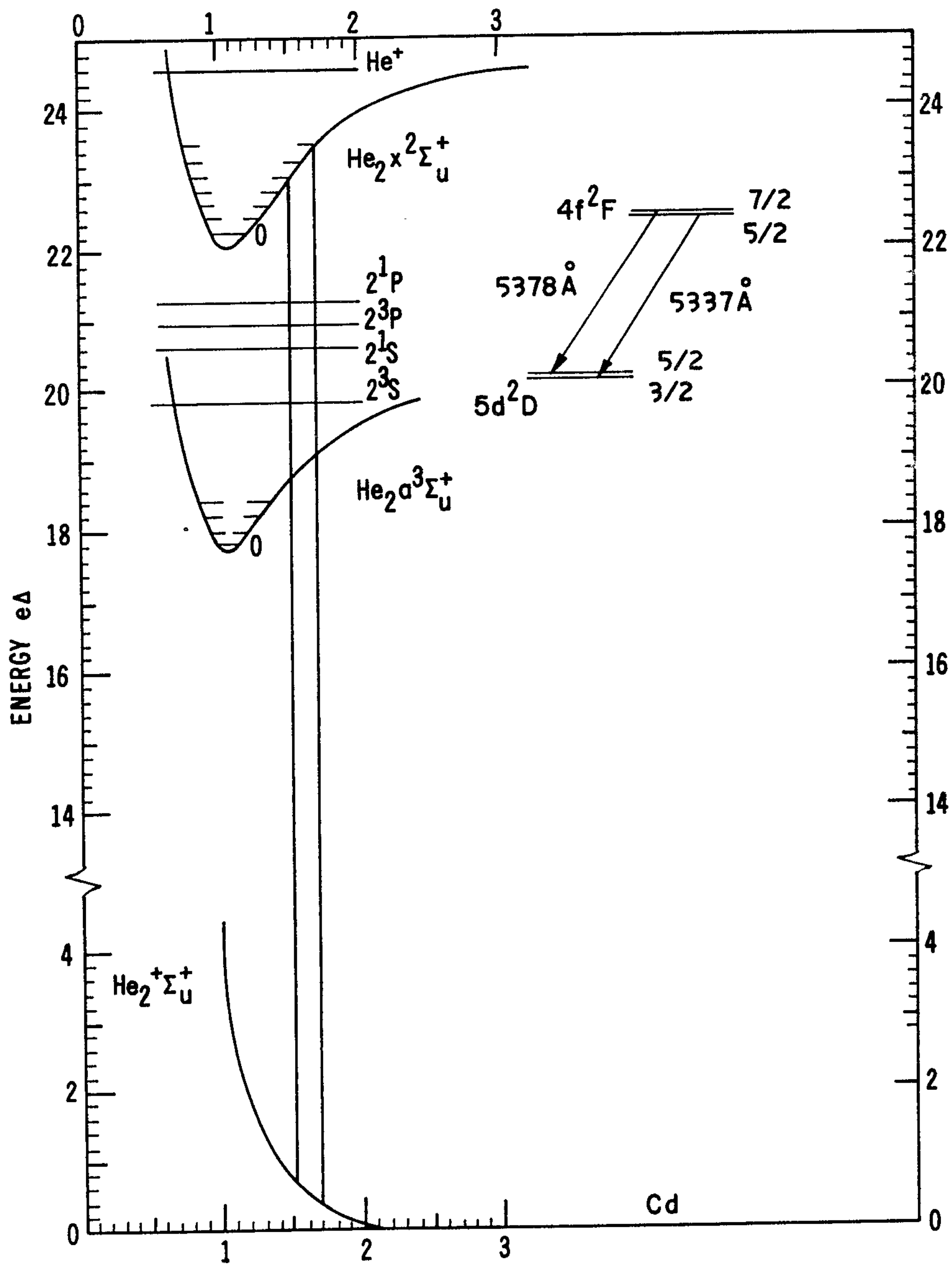
He+
He2 x 2Σu+
4f 2F
7/2
5/2
5378Å
5337Å
2 1P
2 3P
2 1S
2 3S
5/2
3/2
5d 2D
He2 a 3Σu+
ENERGY eV
He2+ Σu+
Cd

FIG. 1

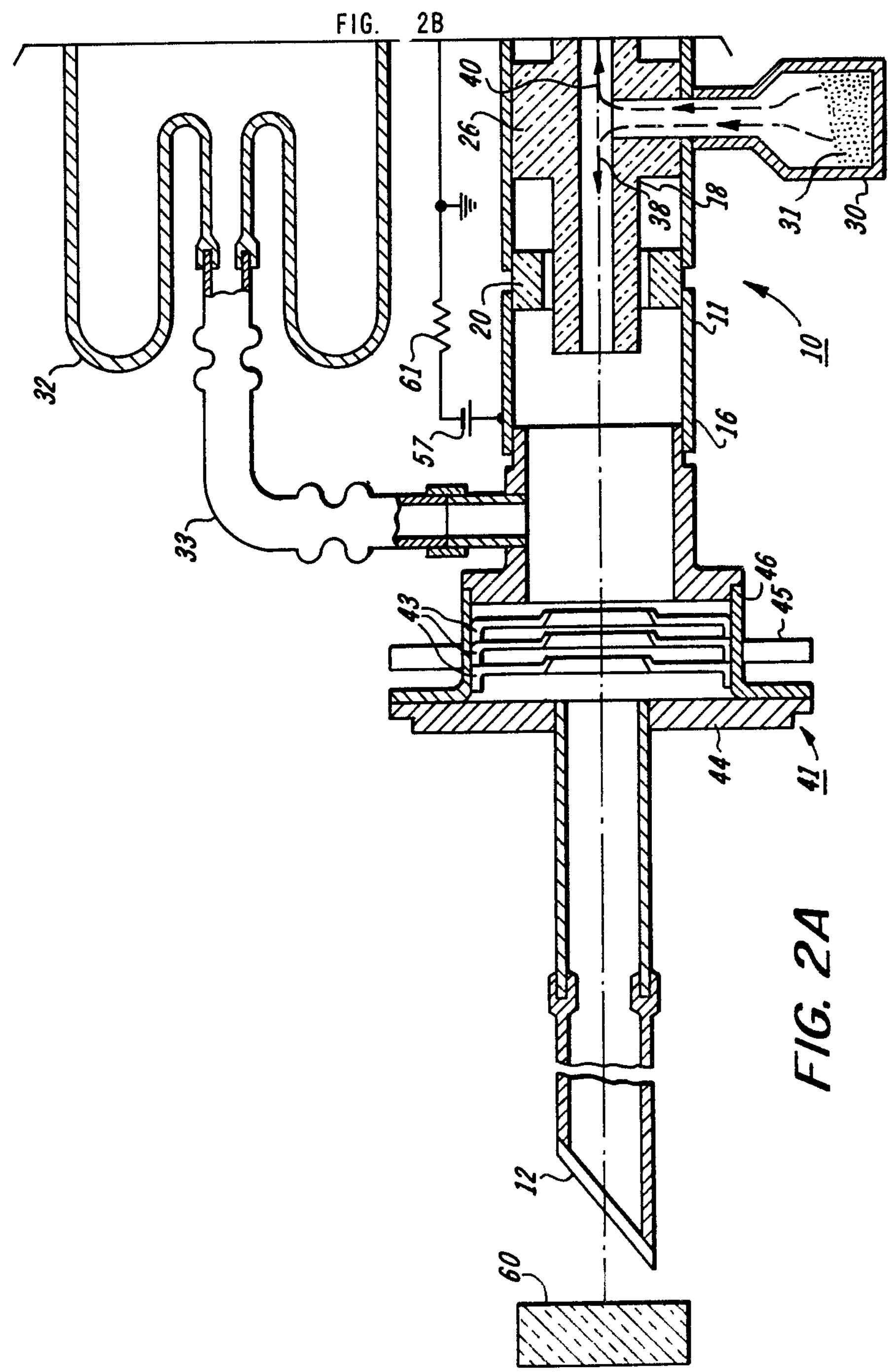

FIG. 2A

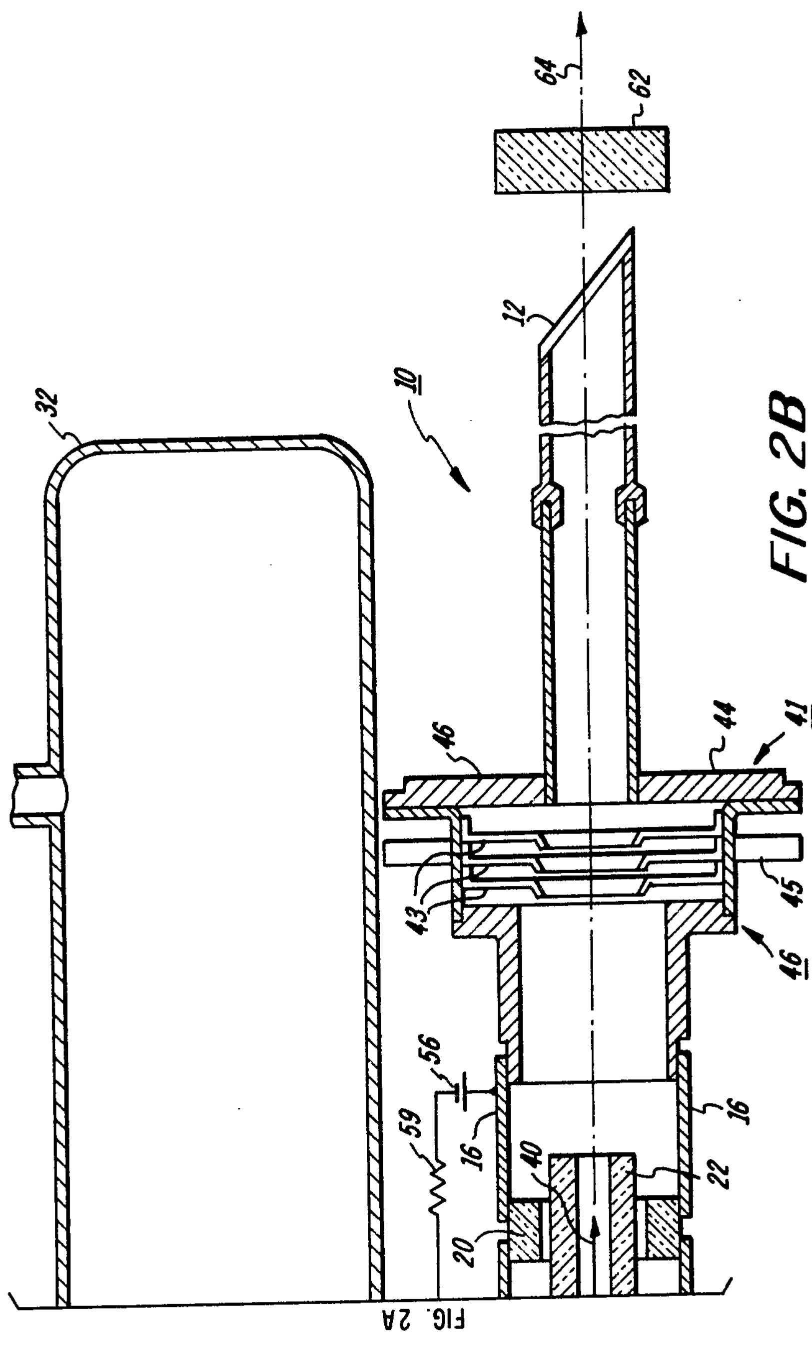

FIG. 2B

SPECIFICATION

Gas laser

The present invention relates to lasers and, in particular, to gas lasers which operate in the negative glow discharge mode.

Positive-column metal vapor lasers, such as the helium-cadmium laser disclosed in U.S. Patent No. 4,184,474, have been available on a commercial basis in recent years. These conventional helium-cadmium lasers generate blue laser light, operate at low (typically in the range from 400 to 650 Nm^{-2}) pressures and have had typical active lengths of from 300 to 400 mm. The relatively large active lengths are necessitated by the power requirements of the generated laser beam since the beam power density is linearly proportional to the active length. Obviously, for most commercial applications, the active length of the laser must be restricted for various reasons including cost and space considerations.

What would be desirable is to provide a compact laser (short active length) which generates a laser beam of high enough power to be useful in many machine applications, such as in printers and copiers.

The present invention provides a hollow cathode helium-cadmium laser operating in the negative glow discharge mode wherein a laser beam having two green lines of 533.7 and 537.8nm is generated. The laser is operated at approximately $4kNm^{-2}$ has an active length of about 50 mm. (overall tube length of about 100 mm) and a power density in the range from about 1 mW to about 5 mW. The laser operates by charge transfer collisions between molecular helium ions and neutral cadmium atoms and allows operation of a laser at high gain per unit length in a desired spectral region for certain recording mediums and also provides for a high level of laser compactness.

For a better understanding of the invention as well as other objects and further features thereof, reference is made to the following description which is to be read in conjunction with the following figures wherein:

Figure 1 is an energy diagram of He, He_2^+ and Cd^+; and

Figures 2A and 2B form a cross-sectional view of the laser of the present invention.

A brief description of the excitation processes is first set forth to enable the reader to understand the operation of the laser configured in accordance with the present invention.

The laser device of the present invention is operated in the negative glow discharge mode, an abundance of molecular ion species thereby being readily available. In particular, the laser operates in helium and cadmium vapor mixtures such that the excitation of the green laser transition is accomplished through the charge transfer collision process of the following reaction:

$$He_2 \times {}^2\Sigma_u^+ (V \geq 4) + Cd \rightarrow Cd^+ (4f^2\,F) + 2\,He$$

wherein He_2^+ is the molecular helium ion, Cd is the symbol for cadmium and $4f^2$ F is the excited Cd state. Conventional low pressure He-Cd lasers operate in a manner such that the collisional excitation processes only involve He metastables and He ions. The effective potential energy of $He_2^+ (V \geq 4)$ is in near resonance with that of Cd^+ (cadmium ion) $4f^2$ F levels that warrant large reaction rates as shown in the energy level diagram of He, He_2^+ and Cd^+ in Fig. 1. Since the formation of He_2^+ is quadratically proportional to He pressure, the rate of selective pumping of Cd^+ $4f^2$ F for the green laser transition also is enhanced accordingly. It has been determined that under constant laser cavity arrangements and operation conditions, the green laser power output increases superlinearly with increase of the helium pressure within the operation range allowed by the specific laser tube design. The green laser of the present invention operates by charge transfer collision between the molecular helium ion and the cadmium atom which is different from conventional low pressure helium-cadmium lasers wherein the process is either Penning ionization or charge transfer process involving helium ions only. The strong dependance of laser gain and power output on helium pressure allows the laser structure to be more compact and efficient and offers a rugged, durable tube design which will lead to lower unit manufacture cost.

Referring to Fig. 2, an embodiment of the laser tube device 10 of the present invention is illustrated, the embodiment utilizing Brewster windows 12 and including laser tube envelope 11.

A center-located short cylindrical hollow cathode 18 is provided and two cylindrical anodes 16 (shown as comprising part of tube envelope 11) are located symmetrically on each side of the cathode 18. The anodes 16 and cathode 18 are electrically insulated by cylindrical metal-to-ceramic seals 20. A substantial portion of the outer surface 22 of cathode 18 may be partially covered with glass or ceramic insulating sleeves (not shown) to prevent electrical discharge in the outer cathode surface and promote effective inner cathode discharge. The cathodes, made preferably of molybdenum, are thermally connected to the external enviroment through extension structure 26 and the laser tube envelope 11 which is made of stainless steel or Kovar. Structure 26, preferably cylindrical in shape, can be separately made and secured to the cathodes or made as part of the cathode structure as shown. Thus, the heat generated within the cathodes due to the electrical discharge can be effectively conducted away to the environment which allows higher input power loading to the cathodes when higher laser excitation power is required for higher laser power output. This feature allows the laser device to be more compact than would otherwise be possible. For laser operation utilizing metal vapors, a reservoir 30 containing the particular metal 31 to be utilized is provided. The reservoir 30 is thermally decoupled from the cathode assembly through a heat-choke arrangement so that the metal vapor pressure can be separately and independently controlled by external heater means (not shown). Reservoir 30 is shown connected within cathode 18. In the embodiment illustrated, an auxiliary gas, such as helium, is stored in reservoir 32 and connected into the mean tube envelope 11 *via* tubing 33. Although gases other than helium may be utilized, helium will be discussed hereinafter since the laser of the present invention is particularly useful in helium-cadmium or other helium-metal vapor, helium-rare gas (such as argon), helium-metal halides and dimer lasers. In the case when cadmium metal is to be utilized as the active lasing medium, a predetermined charge of cadmium metal 31 is placed in reservoir 30 and the reservoir is then heated. A controlled amount of metal vapor is released into the cathode section, and is transported from cathode 18 to anodes 16 by natural diffusion. The path of the vapor flow is illustrated by reference numerals 38 and 40. Thus, near uniform vapor density can be assured within and throughout the cathode 18. The adjustable Brewster window end sections are attached to each end of the anode-cathode assembly. Each section comprises a Brewster window 12, and a metal vapor condensor portion 41. Metal vapor condensor portion 41 comprises a flexible flange 44 and one rigid flange 45, a fixture 46 acting as a condensing baffle to protect against the diffusion of metal vapor, such as cadmium, to windows 12. The fixture 46 comprises a plurality of apertured Kovar discs 43. Adjustment of fixture 46 by screws (not shown) allows adjustment of the Brewster angle of window 12 which can compensate for any offset from the correct angle due to the final assembly processes.

Symmetrical anodes 16 contribute the main discharge to the cathode thus providing a uniform discharge throughout the cathode section and also inhibits movement of the metal vapor towards Brewster windows 12 by the cataphoretic effect.

It should be noted that other active lasing media could be utilized, such as metals (such as zinc and selenium), metal halides (such as copper chloride and mercury chloride), rare gases (such as helium-argon and helium-nitrogen) and selenium iodide (dimer type lasers). The preferred assembly has an envelope window-to-window spacing of about 100mm, 20mm outside diameter, 17mm inside diameter, a molybdenum hollow cathode 18 of approximately 50mm length, 3mm inside diameter, and 9mm outside diameter on each side. The dc electrical discharge between anodes 16 and cathode 18 is maintained at a dc voltage level in the range of from about 250 to about 350 volts by voltage sources 56 and 57 with a corresponding variable current ranging from about 20–200 milliamps being maintained. Voltage sources 56 and 57 apply a potential to anodes 16 *via* ballast resistors 59 and 61, respectively. The discharge within the cathode 18 is operated in the mode of negative glow discharge. The active length (in this case, the length of hollow-cathode 18) of the device may be in the range from about 10 to 100 mm and CW laser action has been obtained simultaneously in two green laser transitions (533.7 and 537.8nm) with a helium pressure in the range from about 500 to 6700 Nm^{-2} and a cadmium temperature of about 310° C. In particular, a one milliwatt laser with only a 50mm active length and having a green laser transition was demonstrated at a helium pressure of about $4kNm^{-2}$. The anomalous pressure dependence of these transitions, in which both the power output and spontaneous emission were substantially enhanced at higher helium pressures while that of the Cd^+ red transition was quenched in the same pressure regime, has been observed. The explanation for this effect is thought to be on the possible existence of a new channel of excitation process for the green transition at higher helium pressures involving a change transfer collision of molecular ion He_2^+ with the cadmium atom.

As set forth hereinabove, since the formation of He_2^+ is quadratically proportional to He pressure, the rate of selective pumping of Cd^+ $4f^2$ F of the green laser transition is also enhanced accordingly. It has been determined that under constant laser cavity arrangements and operation conditions, the green laser power output increases superlinearly with increases of helium pressure within the operation range allowed by the specific laser tube design. It is believed that even higher pressure will offer much higher gain and power output according to this new excitation mechanism.

By appropriate choice of reflectors 60 and 62 which form the optical resonator, a desired output wavelength(s) can be produced. Reflectors 60 and 62 may be multiple layer dielectric coated reflectors, reflector 62 being typically adapted to be partially transmissive to enable a portion 64 of the coherent radiation to be extracted from the laser device 10. Reflector 62 may be a broadband output reflector if output 64 is multicolor.

It should be noted that in an alternate arrangement, the Brewster windows 12 and the optical reflectors 60 and 62 can be replaced with integral mirror subassemblies.

CLAIMS

1. A gas laser device for producing an output laser beam wherein at least one green laser transition is excited, said laser device being operated in the negative glow discharge mode, comprising:

a gas-filled envelope having a longitudinal axis;

a hollow cylindrical cathode located within said envelope and coaxially disposed with respect to said longitudinal axis, a first cylindrical anode spaced from one end of said cathode, a second like anode spaced from the other end of said cathode;

coaxially aligned end members, said end members and said envelope being adapted to provide a structure for confining a gaseous medium therein; and

means for applying an electric field between said anodes and said cathode whereby a discharge between said electrodes is created, a laser output beam having at least said one green laser transition thereby being produced.

2. The laser device of claim 1, wherein said gaseous medium is a mixture of at least two gases.

3. The laser device of claim 2, wherein one gas is helium.

4. The laser device of claim 2 or 3 wherein another gas is of cadmium vapour.

5. The laser device of any preceding claim, wherein the ends of said tube envelope are sealed by Brewster windows, and further including reflectors coaxially aligned with, and adjacent, the Brewster windows.

6. The laser device of claim 5, wherein one of the reflectors is fully-silvered and the other is partially-silvered.

7. The laser device of any preceding claim wherein two green laser transitions of 533.7 and 537.8nm are produced.

8. The laser device of claim 3, and any claim dependent therefrom, wherein the helium pressure is in the range from 500-6700 Nm^{-2}.

9. The laser device of any preceding claim, wherein the length of said cathode is from 20 to 100mm.

10. The laser device of claim 9, wherein the power in said output laser beam is in the range from about 1 milliwatts to about 5 milliwatts.

11. The laser device of any preceding claim, wherein said anodes form part of said envelope and are symmetrically disposed with respect to said cathode and coaxially disposed with respect to said longitudinal axis.

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