

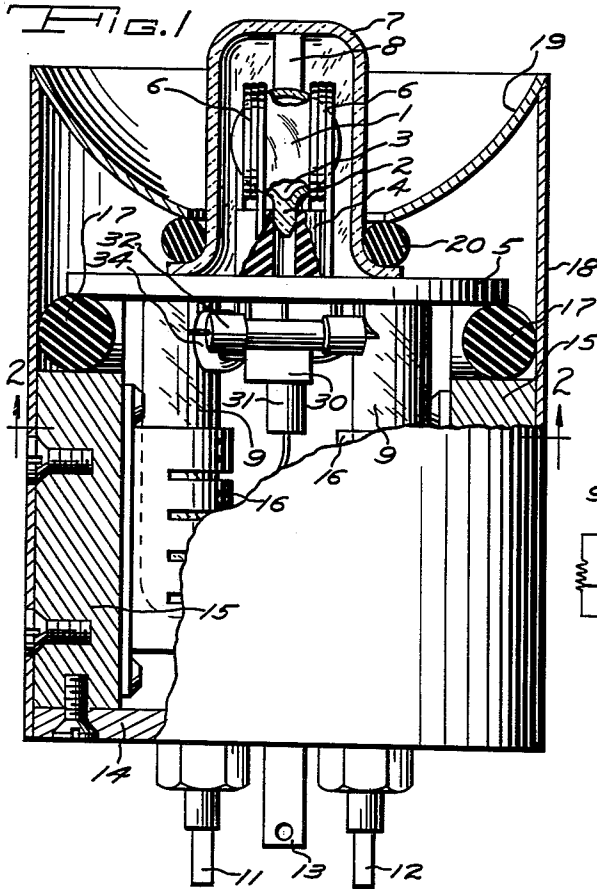
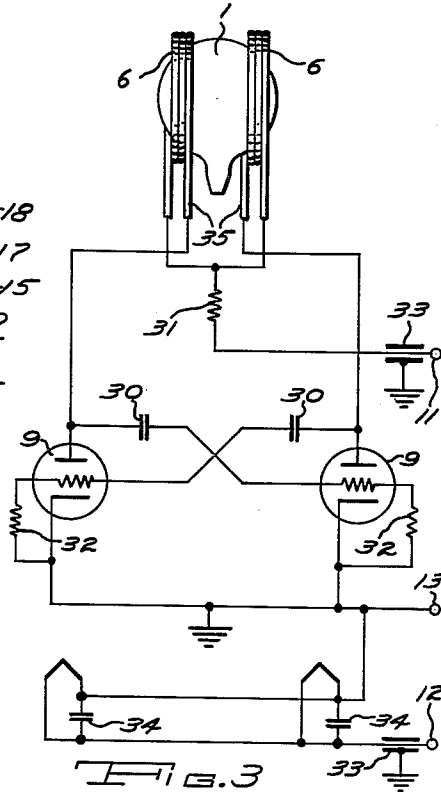
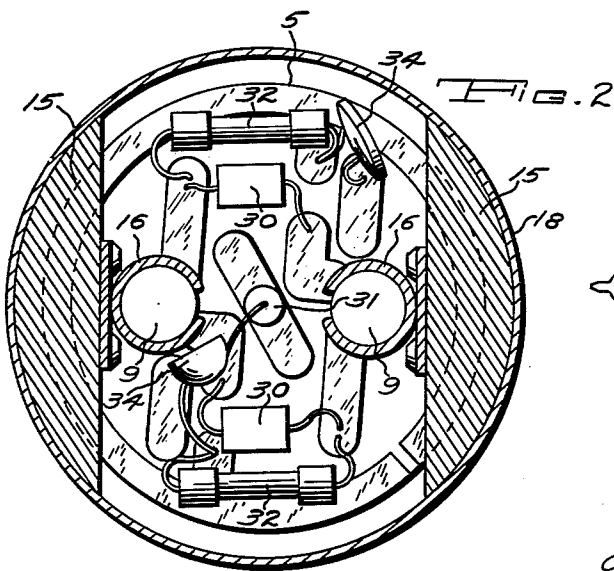
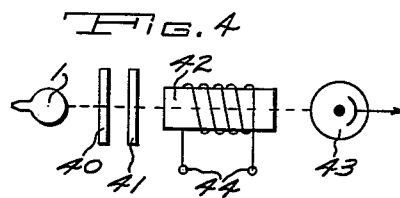
Nov. 5, 1963

W. E. BELL ET AL

3,109,960

ELECTRODELESS DISCHARGE LAMP APPARATUS

Filed Sept. 16, 1960



Inventors
William E. Bell
Arnold L. Bloom

By Wm. Nolan
Attorney

1

3,109,960 ELECTRODELESS DISCHARGE LAMP APPARATUS

William E. Bell, Palo Alto, and Arnold L. Bloom, Los Altos, Calif., assignors to Varian Associates, Palo Alto, Calif., a corporation of California

Filed Sept. 16, 1960, Ser. No. 56,412
20 Claims. (Cl. 315-248)

This invention relates in general to narrow band optical systems, and more particularly to electrodeless discharge lamp apparatus for use in such systems. The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 426; 42 U.S.C. 2451), as amended.

In our copending U.S. application, Serial No. 33,339, filed June 1, 1960, now Patent 2,975,330, assigned to the same assignee, there is disclosed an electrodeless discharge lamp in which an optical discharge is excited by an external radio frequency coil. Under proper thermal operating conditions, it is possible to concentrate the optical output of this lamp in very narrow spectral bands with a minimum of intensity fluctuation and noise. Such lamps are important in various high resolution optical systems, and, in particular, have contributed to the recent development of commercially feasible instruments employing the principle of optical transmission monitoring of magnetic sublevels of atoms or other quantum systems.

It is an object of the present invention to provide an improved electrodeless discharge lamp of the above-described type which is characterized by compactness and ruggedness of construction, and by enhanced efficiency, stability and reliability of operation.

One feature of the present invention is the provision of a novel lamp bulb, adapted to minimize self-reversal of spectral lines under high frequency excitation.

Another feature of the present invention is the provision of a special krypton gas filling which provides optimum stability, reliability of operation, and ease of starting in an alkali metal vapor discharge lamp.

Another feature of the present invention is the provision of a hermetically sealed atmospheric pressure air chamber for maintaining an optimum thermal environment for the lamp bulb under all operating conditions.

Another feature of the present invention is the provision of a simple and efficient high frequency oscillator circuit for energizing a discharge excitation coil.

Still another feature of the present invention is the provision of an inside-out excitation coil configuration permitting easy starting of an electrodeless discharge.

These and other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawing, wherein:

FIG. 1 is an elevational view, partly in cross section, of an electrodeless discharge lamp in accordance with the present invention,

FIG. 2 is a cross sectional view taken along line 2-2 in FIG. 1,

FIG. 3 is a schematic diagram of the oscillator circuit used to excite the lamp of FIG. 1, and

FIG. 4 is a schematic diagram illustrating the arrangement of certain elements in an optical monitoring system.

In FIG. 1, there is shown, on an approximate 2:1 scale, an extremely compact and light-weight lamp structure capable of withstanding extreme thermal and vibrational environmental conditions, and particularly useful as a high intensity source of alkali metal vapor "D" line

2

radiation in a compact and portable optical monitoring instrument package.

The lamp bulb 1 is press-fitted by means of the thickened, protruding wall 2 of a small alkali metal reservoir 3 into a flexible silicone rubber spacer 4 cemented to a copper-clad, glass epoxy printed circuit board 5, and is captured in spring-like engagement by the split winding excitation coil 6 which extends from the circuit board 5. The bulb 1 is maintained in a thermal environment of air at atmospheric pressure by means of a glass dome 7 resin-sealed to circuit board 5, a small crescent-shaped silicone rubber supporting spacer 8 being pressed between the dome 7 and the bulb 1. Secured to the underside of the circuit board is a self-regulating constant current oscillator circuit, to be described in detail with reference to FIG. 3, including a pair of sub-miniature triode amplifier tubes 9 energized through power supply terminal 11, heater terminal 12 and ground lug terminal 13, which are mounted on an aluminum header 14. Also mounted on the header 14 is a pair of segmented cylindrical aluminum heat blocks 15 to which are attached a pair of silver-plated clamps 16 engaging tubes 9 in good heat conducting relation. A silicone rubber O-ring 17 cemented to the top of heat blocks 15 provides a cushion support for the circuit board 5. The entire lamp-oscillator assembly is removably inserted in a snugly fitting aluminum housing sleeve 18 and is tightly cushioned against the reflector 19 enclosing the upper end of sleeve by means of O-ring 20.

The bulb 1 is about one centimeter in diameter in order to provide a small, intense source capable of sharp focusing. The minimum excitation frequency for this bulb size is about 60 mc. However, higher frequencies are found to yield narrower emission lines, less intensity noise, and a slower rate of metal clean-up, apparently due to the shorter mean free path per cycle of the charged particles in the discharge. A very simple, efficient and low-noise circuit for obtaining a suitable excitation is shown in FIG. 3. The excitation coil 6 functions as a self-resonant tank coil fed in push-pull by the triode amplifier tubes 9 which are cross-coupled through grid-plate feed-back capacitors 30 to maintain oscillations at about 100 mc. The grid leak resistor 32 establishes a negative bias for class C operation. Plate resistor 31, lead-in capacitors 33, and filament capacitors 34 function to decouple R.F. frequency components from the D.C. power supply.

It will be noted that two halves of the excitation coil 6 are wound in an inside-out relation; that is, the two end turns 35 are placed adjacent to each other. When the discharge is initiated a strong electric field will be established between these end turns to aid in the striking of the discharge, the discharge being thereafter maintained by the R.F. magnetic field of the coil 6 which uniformly threads the bulb 1 in close-coupled relation. Further, this split coil arrangement minimizes the blocking of useful optical radiation.

A large internal impedance constant-current plate power supply is used so that the plate voltage, and hence, R.F. output power, varies inversely with the conductivity of the lamp discharge. Since the intensity of the discharge is directly related to its conductivity, changes in lamp intensity are stabilized by counteracting changes in excitation power. Also, the constant-current supply provides a transient over-voltage for initiating the discharge. In an exemplary embodiment, the total power consumption, including heater power, was only about 6 watts.

The bulb 1 is made of a material which exhibits a moderate amount of electrical loss at the lamp excitation frequency. One material which is quite suitable

for this purpose, and also has the further advantages of being simple to fabricate, having no tendency to dissolve the alkali metal and being capable of withstanding substantial thermal shock, is a borosilicate glass, such as Pyrex 7740 glass blown to a thickness in the approximate range of 5 to 10 mils. The excitation energy dissipated by the bulb will then be divided between the glass and the discharge, the penetration of the excitation field being limited by the conductivity of the discharge. Under these conditions, the atoms giving rise to the spectral radiation are those close to the bulb which are maintained at a proper radiating temperature by the power dissipated in the glass, thereby minimizing a phenomenon known as self-reversal whereby the optical radiation is self-absorbed by intervening cold atoms which have a narrow absorption line corresponding with the emission line of the radiating atoms. Further, this arrangement has an additional stabilizing influence on the discharge since the tendency of the discharge to weaken, for example, is counteracted by an increase in the amount of radio frequency power dissipated in the discharge resulting from the accompanying decrease in conductivity.

In order to enable the easy starting of an alkali vapor discharge, it had been usual to include a filling gas such as argon. The use of such a filling, however, frequently lead to a phenomenon whereby the discharge was transferred back and forth from the filling gas to the alkali vapor, resulting in severe intensity oscillations. We have discovered that a filling gas of krypton at a pressure between 1 and 3 mm. Hg completely eliminates this oscillation instability while still permitting ease of starting and reliable high spectral quality operation. Use of the radioactive isotope krypton-85 in the lamp filling has been found to still further reduce the starting requirements whenever such reduction is required. Exemplary rubidium vapor spectral lamps containing one milligram of rubidium mixed with a 2 mm. Hg krypton filling were tested and found to have a minimum expected life of 1,000 hours with complete stability. The krypton filling is useful with isotopically enriched rubidium as well as natural rubidium. Natural rubidium lamps, however, are generally preferable since they have been found effective in the optical monitoring of optical absorption cells enriched in either rubidium-85 or rubidium-87, and yet they avoid the difficulty of processing enriched rubidium which is generally available only in salt compounds.

The bulb 1 is quite simply maintained in a constant thermal insulating environment by the atmospheric pressure air bubble hermetically sealed under glass dome 7. This is as effective as a good vacuum in maintaining the discharge at an optimum temperature (about 130° C. in the case of rubidium) regardless of external conditions, and also insures that the discharge is confined to the lamp even at very low external pressures. The temperature of the metal reservoir 3 is maintained at a temperature (about 100° C. in the case of rubidium) yielding an optimum vapor pressure in the discharge by means of a heat leak path through reservoir wall 2, spacer 3 and circuit board 5, the heat generated by tubes 19 being dissipated throughout the housing 18 to form an effective heat sink at a temperature of about 50-60° C. Since the temperature of the reservoir is less than that of the discharge region, condensation of vapor on the lamp walls and discharge-disturbing migration of metal particles are prevented.

An example of an optical monitoring system is shown in FIG. 4. The optical beam from a rubidium spectral bulb 1 is successively passed through an interference filter 40 which suppresses the 7800 Å. D₂ line while passing the 7948 Å. D₁ line, a circular polarizer 41, and an optical absorption cell 42 containing enriched rubidium-85 vapor, and is intercepted by photocell 43. The ground state of the atoms in the cell 42 is split by the

external magnetic field into several magnetic sublevels separated by a frequency of 4.66 cycles per gamma (1 gamma=10⁻⁸ gauss), one of these sublevels being non-absorbing with respect to the filtered and polarized light beam passing through the cell 42. Under the influence of the optical radiation most of the atoms will be rapidly oriented in the non-absorbing sublevel by a process known as optical pumping whereby the absorbing atoms are raised to the excited P state and decay back to the non-absorbing sublevel. If a radio frequency current at precisely the frequency of sublevel separation is applied to the coil 44 surrounding the absorption cell 42, the population of atoms in the various sublevels will equalize and produce a signal in the photocell 43 due to the increased absorption by the cell.

This system finds one important application as a magnetometer in which the coil frequency giving rise to the photocell signal indicates the magnitude of the external magnetic field. To minimize distortion of the magnetic field being measured, ceramic-titanium triodes 9 are used. In view of the push-pull symmetry of the excitation circuit, the magnetic fields arising from the D.C. plate current are effectively cancelled to a first order. To still further reduce the distortion it may be necessary to couple the tubes to the excitation coil through a long transmission line.

In another exemplary embodiment (not shown), the cell 42 is filled with an enriched rubidium-87 vapor and placed in a microwave cavity, the filter 40 and the polarizer 41 being replaced by a filter cell containing an enriched rubidium-85 vapor. Under these conditions a signal will appear in the photocell when the frequency of the signal applied to the microwave cavity is equal to the 6834 megacycle hyperfine transition frequency. Since this transition is independent of the external magnetic field, the signal derived from photocell 43 can be used to stabilize the frequency of the microwave signal source and thereby provide an atomic frequency standard.

Since the spectral intensity of the lamp 1 is highly resolved within the absorption line of the cell 43, the optical intensity outside this line, which would contribute noise, but no signal, is substantially reduced. As previously discussed, there exists very little intensity fluctuation in the radiation which does contribute to the signal. Thus the optical monitoring instruments according to the present invention are characterized by extremely high sensitivity and low noise. With reference to the described embodiments, for example, magnetometer sensitivities of .01 gamma, and short-time frequency standard stabilities of 1 part in 10¹² are now reliably obtained.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. An electrodeless discharge lamp comprising a discharge bulb made from a material exhibiting a high frequency electrical loss, and means adjacent said bulb for exciting a high frequency field which initiates a discharge therein and also heats the walls of said bulb so that the intensity of said discharge is concentrated within a narrow spectral band.

2. A lamp according to claim 1 wherein said material is a borosilicate glass.

3. A lamp according to claim 2 wherein said glass is blown to a thickness in the approximate range of 5 to 10 mils.

4. A lamp according to claim 1 wherein said bulb has a reservoir region for containing a deposit of a substance evolving a vapor to said discharge, and means providing a heat leak path from said reservoir region for maintain-

5

ing said region at a temperature which is lower than said discharge temperature.

5. A lamp according to claim 4 wherein said substance is an alkali metal.

6. A lamp bulb characterized by enhanced intensity stability which comprises a filling consisting of alkali metal, and krypton at a pressure in the range from 1 to 3 mm. Hg.

7. A bulb according to claim 6 wherein said alkali metal is rubidium.

8. A bulb according to claim 7, approximately one centimeter in diameter and containing approximately one milligram of rubidium.

9. An electrodeless discharge lamp comprising a discharge bulb, means adjacent said bulb for exciting a high frequency discharge therein, and means hermetically sealing said bulb in a thermal environment of air at atmospheric pressure.

10. A lamp according to claim 9 wherein said bulb is made from a material exhibiting a high frequency loss whereby the walls of said bulb are heated so that the intensity of said discharge is concentrated within a narrow spectral band.

11. An electrodeless discharge lamp comprising a discharge bulb, an excitation coil encircling said bulb, and a high frequency oscillator circuit for energizing said coil, said circuit comprising a pair of triode amplifier tubes cross-coupled through grid-plate capacitors.

12. A lamp according to claim 11 wherein said excitation coil is fed in push-pull by said tubes, said excitation coil functioning as a self-resonant tank coil.

13. A lamp according to claim 12 wherein said tubes are energized by a constant current power supply.

14. An electrodeless discharge lamp comprising a discharge bulb, and a coil encircling said bulb for exciting a high frequency discharge therein, said coil being wound so that the end turns thereof are adjacent each other to provide a strong electric field for starting said discharge.

15. A lamp according to claim 14 wherein said coil is a split coil and each of said adjacent end turns is included in a separate section of said split coil.

6

16. An electrodeless discharge lamp comprising a discharge bulb having a reservoir region therein for containing a deposit of a substance providing an optically excitable vapor, means for mounting a vacuum tube circuit which excites a discharge in said vapor, means for housing said lamp and for providing a heat sink dissipating the heat generated by said vacuum tube circuit, and means providing a heat leak path from said reservoir region to said heat sink for maintaining said reservoir region at a temperature which is lower than the temperature of said discharge.

17. An alkali metal vapor discharge lamp for use as a high resolution, low noise, spectral line source in optical transmission monitoring instruments and the like, comprising: a discharge bulb having a reservoir therein for containing a deposit of alkali metal, said bulb being made from a material exhibiting a high frequency electrical loss; means hermetically sealing said bulb in a gaseous thermal environment; means adjacent said bulb for exciting a high frequency electrodeless discharge therein and for heating the walls of said bulb to a temperature at which the intensity of said discharge is concentrated within a narrow spectral band; and means providing a heat leak path from said reservoir region for maintaining said region at a temperature which is lower than said discharge temperature.

18. A lamp according to claim 17 wherein said bulb material is a borosilicate glass.

19. A lamp according to claim 17 wherein said bulb contains natural rubidium with a krypton filling gas.

20. A lamp according to claim 14 further including means energized by a constant current supply for supplying high frequency energy to said coil.

References Cited in the file of this patent

UNITED STATES PATENTS

2,118,452	Le Bel	May 24, 1938
2,974,243	Marrison	Mar. 7, 1961