United States Patent [19]

Hollister

[11] **3,860,854**

[45] ***Jan. 14, 1975**

[54] **METHOD FOR USING METALLIC HALIDES FOR LIGHT PRODUCTION IN ELECTRODELESS LAMPS**

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[*] Notice: The portion of the term of this patent subsequent to Oct. 2, 1990, has been disclaimed.

[22] Filed: **Sept. 17, 1973**

[21] Appl. No.: **398,108**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 218,496, Jan. 17, 1972, Pat. No. 3,763,392.

[52] **U.S. Cl.** **315/248,** 313/161, 313/184, 313/220, 313/224, 313/226, 313/227

[51] **Int. Cl.** **H01j 61/12,** H05b 41/24

[58] **Field of Search** 313/184, 221, 161, 234, 313/220, 224, 225, 226, 227; 315/236, 248, 267, 344, 348

[56] **References Cited**

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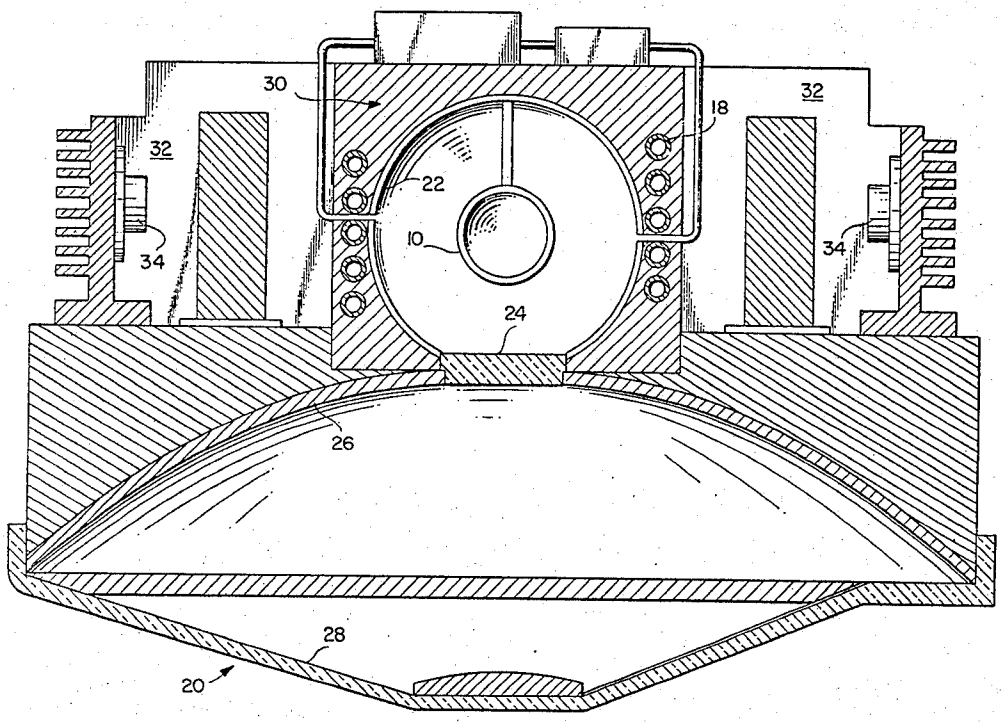
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Primary Examiner—John Kominski
Assistant Examiner—Lawrence J. Dahl

[57] **ABSTRACT**

Method of generating an electrodeless plasma arc as a light source including confining a plasma-forming gas within a suitable envelope pressurizing while confining the gas, and applying radio refrequency power exteriorly of the envelope so as to develop magnetically an induction field extending through the envelope and into the gas such that the gas is ionized as a plasma arc suspended within the envelope, and independently of the walls of the envelope, and of lesser diameter than the envelope. Particularly optimizing such electrodeless arc discharge by the use of an inductor/reflector which avoids inductor shadowing to obtain maximum radiation output from discharge, hence to produce an optimized electrodeless arc light source.

14 Claims, 14 Drawing Figures



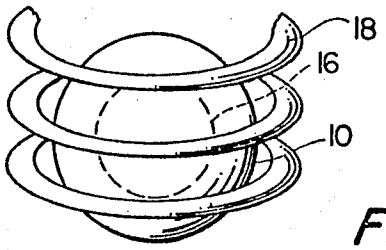


FIG. 1

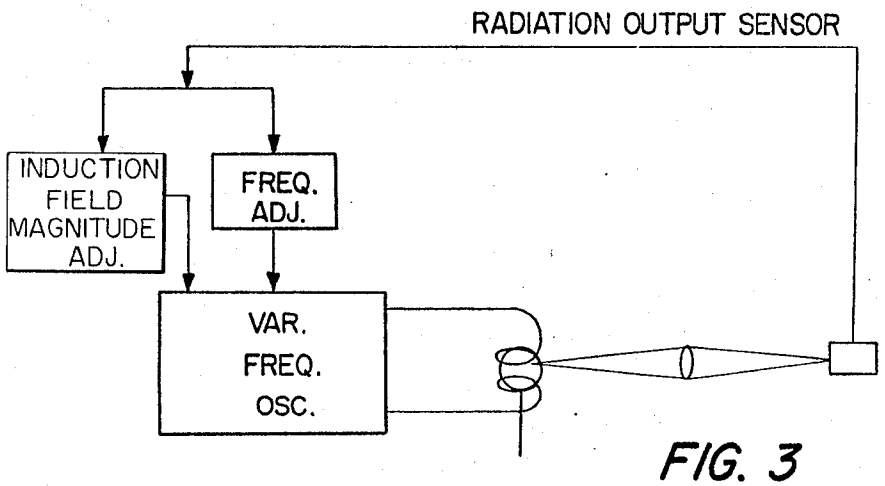


FIG. 3

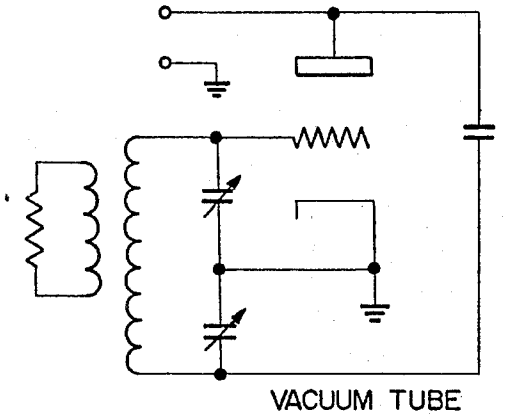


FIG. 4

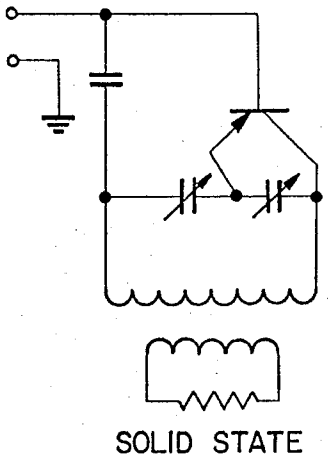


FIG. 5

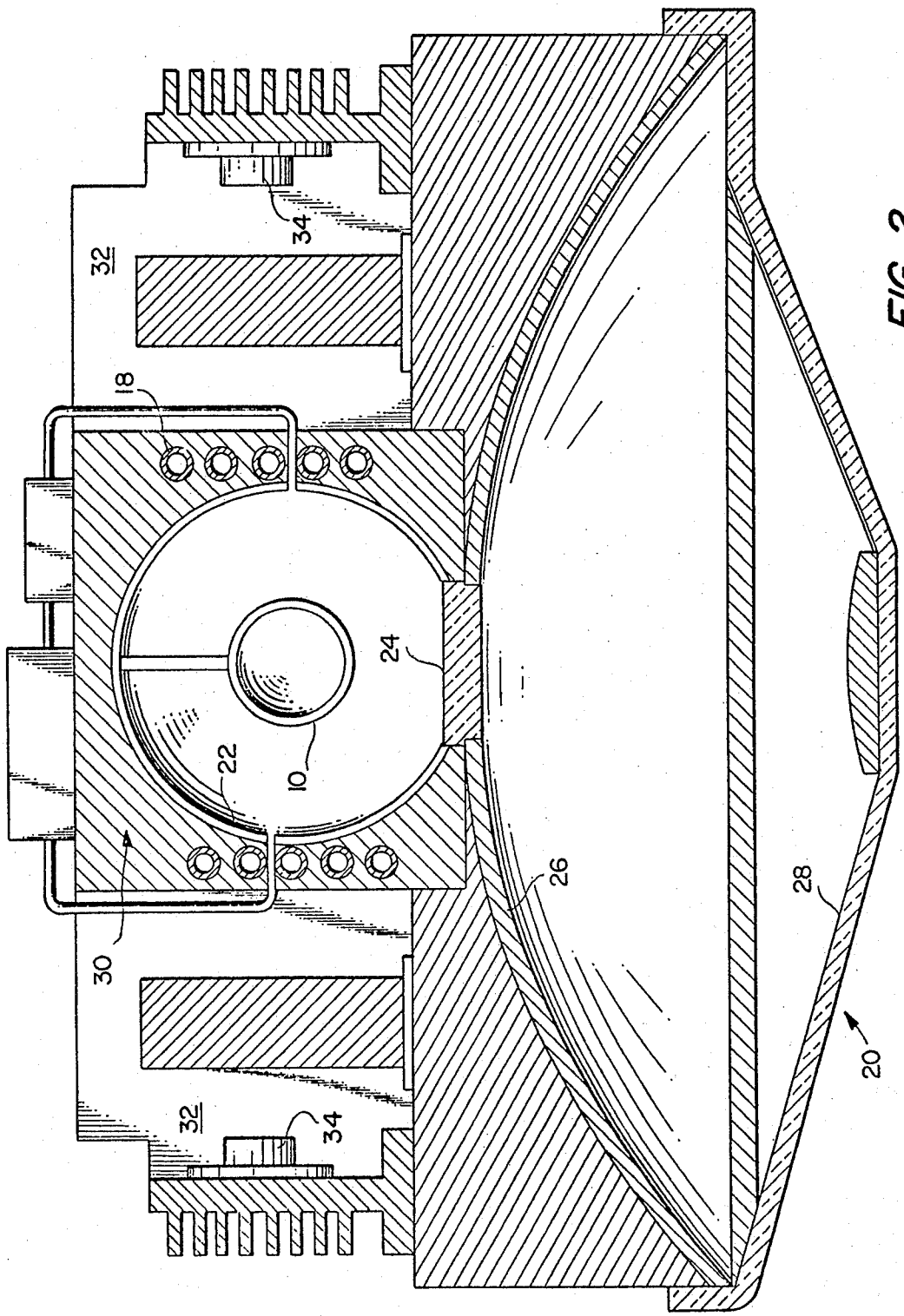


FIG. 2

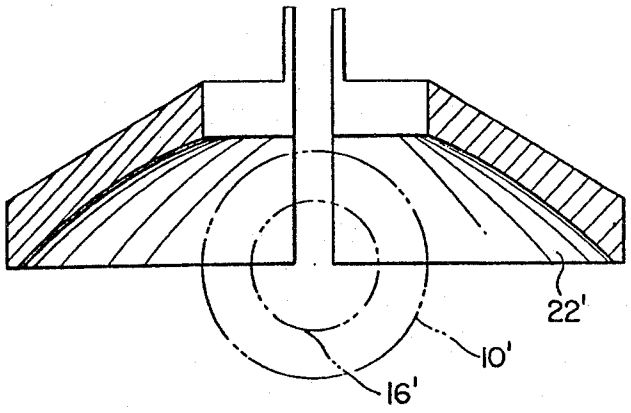


FIG. 6

FIG. 7

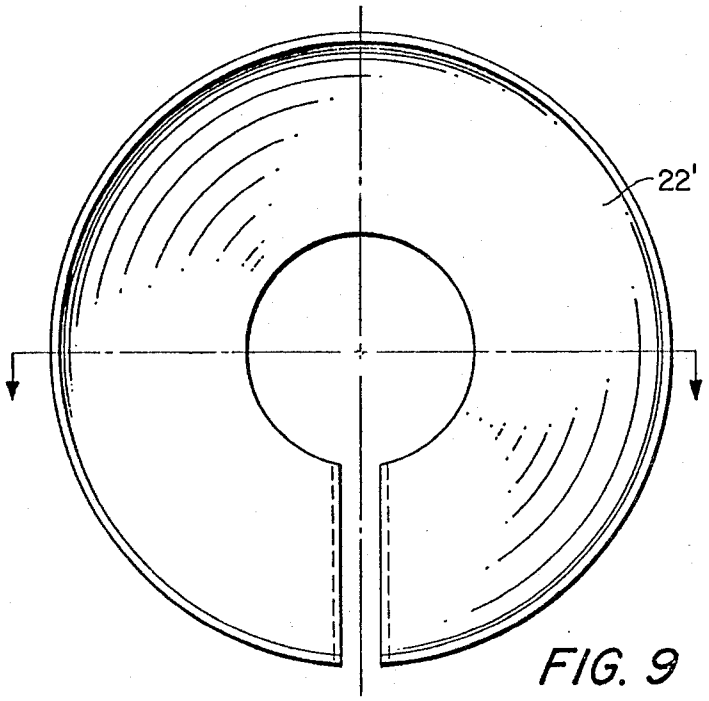
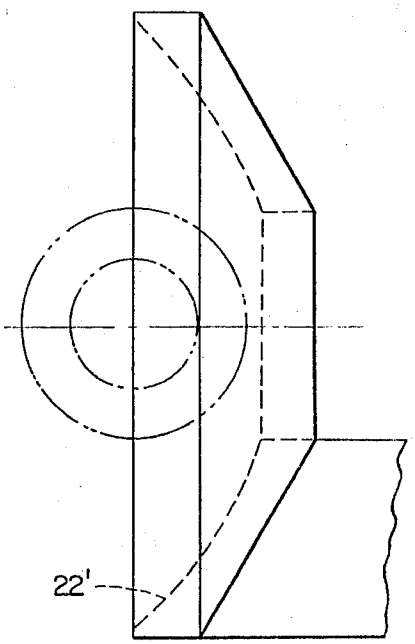


FIG. 9



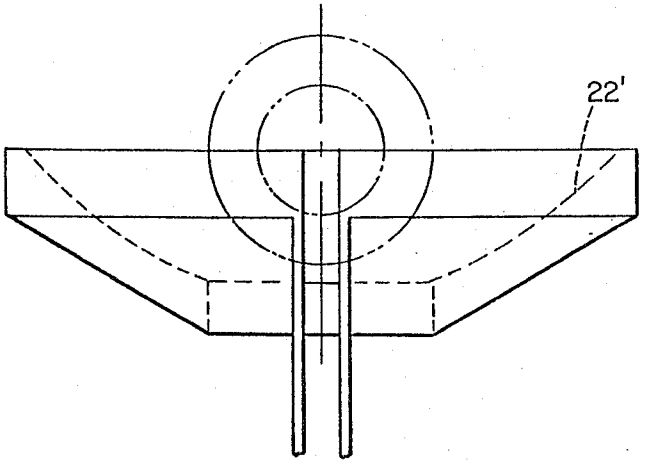


FIG. 8

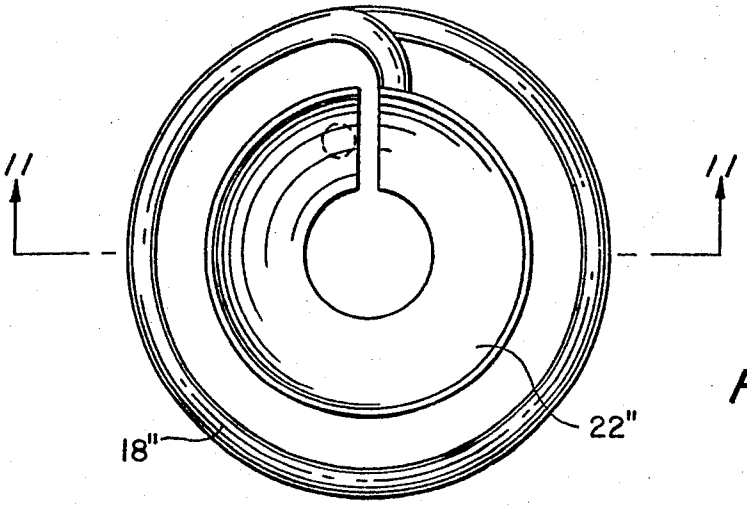


FIG. 10

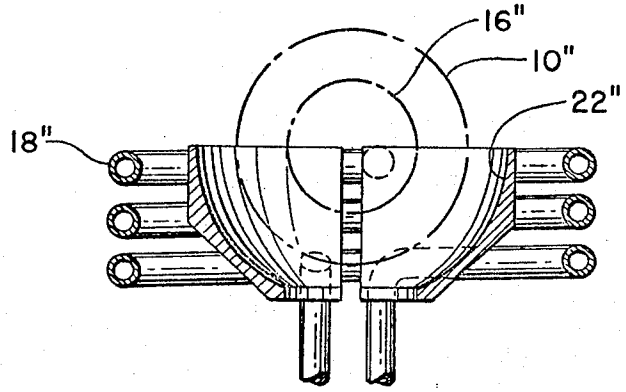


FIG. 11

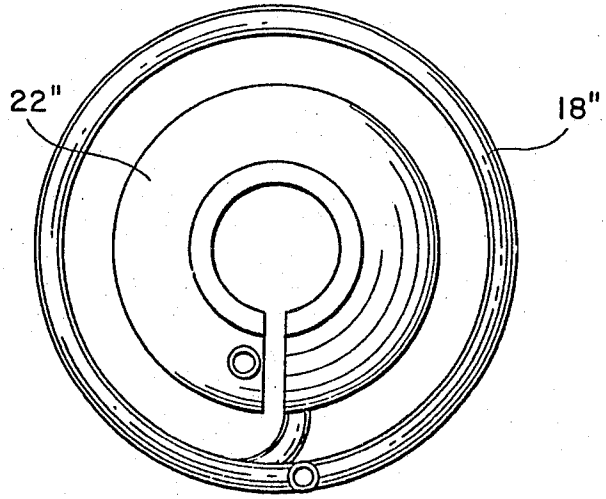


FIG. 12

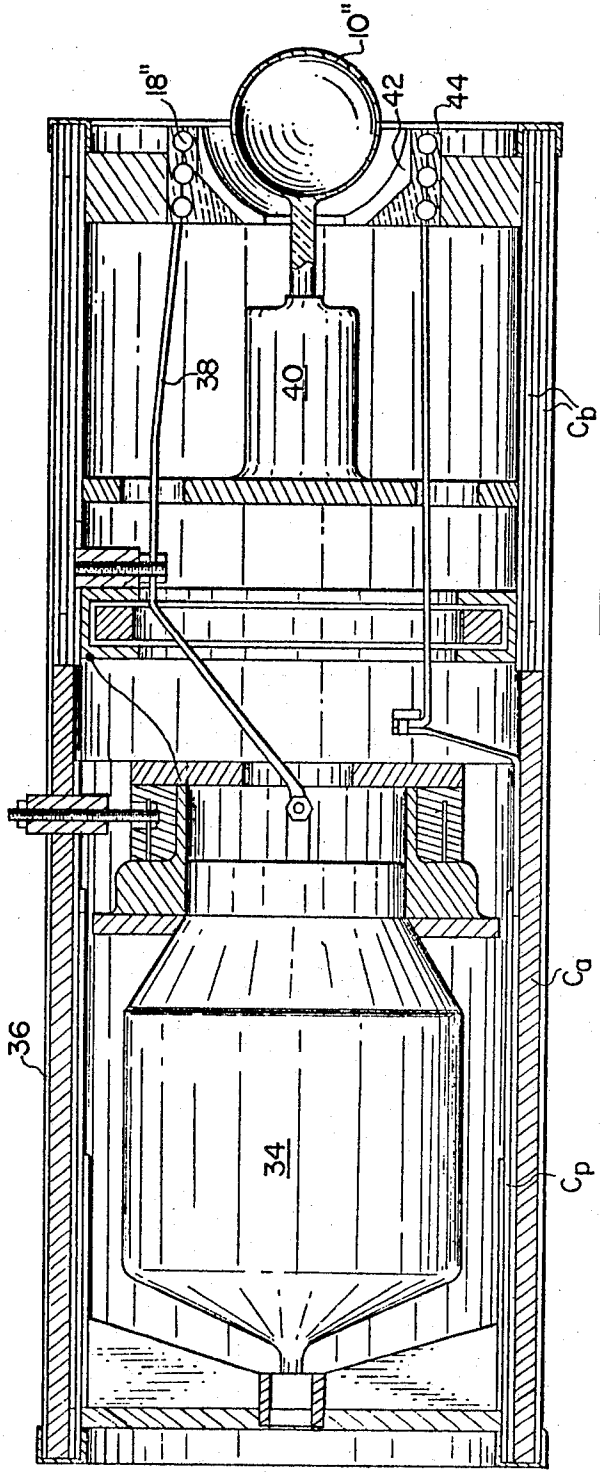


FIG. 13

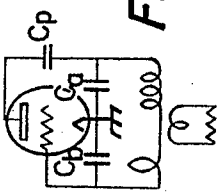


FIG. 14

METHOD FOR USING METALLIC HALIDES FOR LIGHT PRODUCTION IN ELECTRODELESS LAMPS

CROSS REFERENCES TO RELATED APPLICATIONS

A continuation-in-part of applicant's earlier filed "High Pressure Method for Producing an Electrodeless Plasma Arc as a Light Source" (Ser. No. 218,496), filed Jan. 17, 1972 and issued as U.S. Pat. No. 3,763,392.

BACKGROUND OF THE INVENTION

It is the intent of the present disclosure to teach the method whereby an electrodeless arc discharge effectively can be employed at high power levels (i.e., above one kilowatt) to produce light for lighting applications including and similar to illumination of large spatial areas and surfaces. In such applications economic considerations dictate that high operational efficiency of the light source always be maintained, thus it is also the intent of the present disclosure to teach those methods whereby the electrodeless arc light source can be made operationally and economically efficient at high power levels, hence, therefore, commercially viable. Such methods yield electrodeless arc lamps which operate at pressures of several- to several-tens of atmospheres, and at power levels in excess of, for example, one kilowatt, although operation of electrodeless arc lamps at lower pressures and power levels has been found to be practicable for several specialized applications.

There are two basic types of luminous systems; however, no clear-cut delineation exists between them. One type is a system which is optically limited by a stop or a set of stops and is called an "aperture-limited" system. Examples of aperture-limited systems are given by narrow beam searchlights and collimation and similar systems. The other type of luminous system is optically limited by the source itself and is called a "source-limited" system. Typical examples of source-limited systems are floodlights and industrial luminaires. The preferred embodiment of the present invention is a source-limited system; however, aperture-limited forms of the invention exist.

RF induction plasmas (electrodeless arcs) have not as yet found significant application as illumination sources. Most known studies of the high pressure electrodeless arc have reported the use of gas throughflow as being required for discharge stability, but the power loss suffered by the discharge system through forced convection of high enthalpy plasma from the discharge seriously degrades the efficiency with which an electrodeless arc that is struck in a flowing gas can radiate. In the present invention, gas throughflow has been found unnecessary for electrodeless arc discharge stability; therefore, a convective loss need not be present in an electrodeless arc light source. The resulting stationary discharge dissipates electrical energy and balances this against conductive wall transport, radiation, and a relatively small internal convective circulation in a sealed-off discharge vessel. Radiation conversion efficiencies (i.e., rf power to radiated power) as high as 90 percent have been computed for such systems, and efficiencies as high as 79 percent actually have been measured in prototype devices using xenon as the discharge gas. Thus, an additional purpose of the present invention is to teach those methods, heretofore unreported, by which an electrodeless arc lamp can be optimized for maximum radiation production efficiency.

An essential feature of any light source system is that efficient recovery of radiation be possible. All electrodeless arc sources heretofore considered incorporate induction coils which, to some extent, surround the plasma forming gas to produce the high frequency induction field required to power the discharge. The geometric shadowing of the discharge by its induction coil reduces the effectiveness of the source in direct proportion to the relative physical size of the induction coil. Thus, as an example, if an induction coil shadowed one-half an electrodeless arc lamp, which by itself can be assumed to be essentially a uniform radiator, then one-half of this source's light output will be cut out by the induction coil, the resulting system efficiency will be reduced by one-half, a non-uniform polar distribution of radiant energy will obtain, and the resultant light-source will not be commercially viable because it is inefficient geometrically. Thus, another purpose of the present invention is to teach a method whereby the induction coil can be combined with an optical reflecting surface to form an inductor/reflector structure to eliminate the "coil-shadow" problem.

Combining the foregoing, the present invention enables an electrodeless arc lamp system to approach the theoretical limit for radiation production efficiency in a practical lighting system suitable for commerical illumination applications at high power levels.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a fragmentary perspective view of an electrodeless plasma arc assembly showing a quartz sphere positioned axially with respect to a radio-frequency coil, the plasma arc shown in phantom, having been developed as a white light source within the sphere;

FIG. **2** is a transverse section on an electrodeless arc radiation production system developed as a white light source;

FIG. **3** is a circuit diagram of a circuit for limiting magnitude and frequency, so as to regulate the discharge parameters of the plasma arc independently of the walls of the quartz sphere;

FIG. **4** is a simplified circuit diagram, showing a vacuum tube circuit for energizing the apparatus shown in FIG. **3**;

FIG. **5** is a simplified circuit diagram, showing a solid state circuit for energizing the apparatus shown in FIG. **4**;

FIG. **6** is a fragmentary vertical section of a first suggested parabolic inductor/reflector device, showing the quartz sphere and suspended plasma arc in phantom;

FIG. **7** is a fragmentary side elevation;

FIG. **8** is a fragmentary bottom plan;

FIG. **9** is a front elevation;

FIG. **10** is a front elevation of a second inductor/reflector device, showing an inductor coil integrated with the reflector;

FIG. **11** is a vertical section thereof, with the quartz sphere and suspended plasma arc shown in phantom;

FIG. **12** is a bottom plan thereof;

FIG. **13** is a schematic view of the FIGS. **10–12** lamp mounted within a housing, including structural and electronic details of the rf power generator; and

FIG. **14** is the electronic circuit diagram thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The electrodeless discharge described herein is a high pressure gaseous discharge occurring within the volume of a magnetic structure that carries high frequency current. The components of the high frequency magnetic field of this structure each contribute to the induction of an alternating electric field in accordance with Faraday's law, and electric currents driven by this field heat the gas ohmically and maintain ionization within the discharge. The discharge can be produced in a gas in the absence of central massflow, under which conditions it is self-stabilizing through a balance of electrodynamic and thermodynamic forces. This balance occurs subject to a condition existence for the electrodeless arc that is independent of the discharge-vessel wall boundary conditions; hence, the discharge need not be attached to the wall or any other physical boundary, but, rather, obtains an approximately circular cross-section and is suspended within the discharge vessel away from the vessel's wall.

In the general sense, electrodeless discharges most often are produced by the action of the high frequency, axial magnetic field of a solenoid surrounding the discharge as in FIG. **1** which induces a high frequency azimuthal electric field within the discharge vessel such that, once started, a continuous gaseous discharge can be maintained within discharge vessel inside the solenoid's volume. More particularly, both the axial and the radial components of the high-frequency magnetic field (i.e., the induction field) yield an azimuthal electric field suitable for the maintenance of an induced discharge in accordance with Maxwell's electromagnetic equations. Thus, induction coils (i.e., inductors) for energizing electrodeless lamps have been successfully fabricated of turns of conductor wound not only into the usual solenoid shape, but also into the "pancake" shape (i.e., flat), as well as the intermediate conical shape. In each case, however, the electrodeless discharge produced by the inductor's field necessarily is located in a position near the inductor such that considerable shadowing of the discharge by the inductor must exist. The optical efficiency of such a system, therefore, is degraded by the shadowing effect of the induction coil. In particular, each and every known application of the electrodeless arc discharge as a light source has associated with it this "coil-shadow" problem to an extent which heretofore has prevented any serious commercial utilization of this light source.

The present invention overcomes the shadowing effects of the inductor employed in all previous high-frequency electrodeless lamps by combining the functions of inductor and reflector in a single unit. Thus, in the preferred embodiment of this invention the induction field is provided by high-frequency currents on the polished surface of an inductor which has been shaped according to optical and electrodynamic considerations.

For example, a successful laboratory prototype inductor/reflector was constructed by machining a face of a four-inch diameter brass rod to the parabolic surface $y^2 = 4x$, boring out a one-inch hole in the center (to form the circular current path), then silverplating and polishing the remaining piece. A one-quarter inch gap was machined along a radius of the circular paraboloid thus formed to provide access and egress paths for high frequency current, and this structure was attached to a parallel plate transmission line, and then electrically connected to a vacuum tube source (not illustrated) of high frequency current. This structure is depicted in FIGS. **6–8.**

The discharge induced by the field of the paraboloidal inductor was in xenon gas sealed into a 37 mm diameter quartz sphere at atmospheric pressure (STP). It was found that discharge powers ranging from three hundred watts to levels in excess of five kilowatts were produced by the inductor/reflector device, where the operating pressure (i.e., hot) was in excess of ten atmospheres at the one kilowatt level.

Subsequent studies of the properties of the inductor/reflector device have indicated that combinations of the classical solenoid or pancake style induction coil with optically shaped conducting surfaces can yield very high operational performance. As an example, excellent operational performance has been obtained from an inductor/reflector structure such as is illustrated in FIGS. **10–12** and consisting of four turns of silverplated circular copper rod welded in series to a coaxial, hemispherically-shaped, silvered, single turn of brass. This structure was found to produce a nearly uniform optical output beam over 2π steradians, hence simulating a point source of radiation.

Economic and commercial considerations dictate that a mass-producible inductor/reflector structure can be formed either of stampings or spun metal (i.e., such as aluminum) in addition to the stated construction from machined solid stock. Critical optical systems formed by depositing thick coatings of aluminum or silver on polished glass or similar surfaces also are fully practicable.

Within the inductor/reflector structure, and upon application of the minimum required "discharge maintenance power," and in the absence of gravity and gravitational effects, the shape of the plasmoid "fireball" is approximately spherical; however, in practice, a somewhat flattened discharge is observed in a pure gas at pressures greater than atmospheric. This effect is most pronounced in the heavier gases (i.e., xenon) and is attributable to the buoyancy of the discharge in the unionized background gas. Mixtures of gases, therefore, are often employed to offset plasma buoyancy, such as xenon illuminant in an argon, neon, or hydrogen atmosphere, it having been found that the gas with the lesser ionization potential will break down within such a mixture while the background gas, which does influence internal heat transport, will exhibit little or no direct participation in the electrical or radiative transport phenomena which occur.

Additionally, the "rest" position of the electrodeless arc plasmoid within its chamber has been found to depend upon the squares of the magnitudes of local gradients of the induction field, such that the discharge will position itself in a region of stronger induction field. Hence, the discharge position can be regulated and adjusted within the envelope of an electrodeless arc lamp through the application of a suitable shaped rf induction field of predictable magnitude. In a practical electrodeless arc lamp system, the discharge plasmoid therefore can be positioned at a system focal point electrodynamically through means external to the lamp to provide a focusing capability for the electrodeless arc lighting system.

Numerical solutions of the energy balance equation for the electrodeless arc in high-pressure gases indicate that the basic physical parameters which define (i.e., specify) the electrodeless arc, that is, those four parameters which determine both the discharge energy balance and the internal electric and thermodynamic distribution functions, are the gas in which the discharge is formed, its pressure, and the magnitude and frequency of the induction field impressed on the discharge. Additionally, the existence condition for this discharge, which is derivable from basic thermodynamic principles, is independent of the discharge outer boundary conditions (i.e., those at the wall of the electrodeless arc lamp); thus, the discharge within an electrodeless arc lamp exists independently from the lamp's wall, and hence, the diameter of the electrodeless arc discharge must be recognized as a dependent variable, the value of which depends upon the above four discharge parameters. Likewise, the level of discharge operating power is a dependent variable, the value of which depends upon the above four discharge parameters. Since the discharge size (i.e., radius) and power level depend upon the above four stated discharge parameters, the discharge energy density does also, and, hence, so does the discharge color temperature and net radiation production efficiencies.

Thus, given a discharge gas at a given pressure, one is enabled to adjust both the total dissipation and the discharge temperature profile (hence, the discharge radius, radiation output, and its color temperature) by adjusting the magnitude and frequency of the induction field. Since these parameters are capable of adjustment by means entirely external to the discharge, the discharge radiation output and color temperature are externally adjustable.

In the preferred embodiment of the invention (illustrated in FIG. 2), the gas in which the electrodeless arc is struck is contained at high pressure (i.e., in excess of one atmosphere) within a sealed, spherical envelope **10** made of quartz glass, which is hereinafter referred to as the "source." The source **10** is positioned within an optically reflecting cavity **22** formed by the high frequency induction coil **18** of the electrodeless arc generator, hereinafter referred to as the inductor/reflector. The inductor/reflector has a shape and curvature which depend on the system's intended application. The essential feature of the inductor/reflector is manifested by the presence of a high-pressure electrodeless arc discharge at a focal position within the chamber. The plasma arc discharge is maintained at conditions of pressure and temperature such that it is optically thick, and, hence, can reabsorb its own radiation. Under these circumstances, the discharges obtain a nearly rectangular temperature profile and require appreciably less maintenance power than would be required in the absence of the reflecting chamber.

At very high power levels the high pressure source can be cooled by liquid flow. A suitable coolant at high pressure enters the bottom area **32** of the inductor/reflector unit and flows by the spherical source, removing heat from the source envelope by conduction, and exits the unit at the top. Heat is removed from the coolant by means of a heat exchange mechanism **34** that is completely sealed. The inductor/reflector unit **22** is mounted in such a manner as to surround the source **10** as in the former case, and is cooled by liquid throughflow which can be provided either by means of the source-cooling system or an additional, independent cooling system. The unit is embedded with a glasscloth tape-wound structure **30** which has been wound under tension about the reflecting chamber, thereby compressively stressing the chamber. This method of assembly tends to offset the tensile stress placed on the chamber by the high-pressure coolant, which, itself, places the spherical source under a compressive load and, thus, enables the electrodeless arc discharge which is contained within this spherical source to operate at a pressure in excess of that allowed by the tensile strength of quartz.

The liquid coolant can incorporate absorbing material for specialized application. Thus, a completely covert infrared illuminator would require a coolant which passes infrared and absorbs radiation in the UV and visible bands. Similar principles apply to UV and white light illuminators.

Discharge vessels for the electrodeless arc plasma source are classified according to the application to which the discharge plasma is put. Several examples of discharge vessel are presented below for purposes of illustration, but these are only "typical" cases and are not intended to express or imply limits of applicability in any way. Thus, the discharge vessel for an electrodeless arc light source would require no provision for throughflow because a convective mode of energy transport, if present, would degrade discharges' radiation production efficiency. The simplest and most easily fabricated discharge vessel for employment as an electrodeless arc source of white light is a quartz sphere into which a predetermined amount of illuminant gas has been sealed. When properly sized according to the intended operating frequency and power level, such sealed-off sources yield discharge plasmas of approximate spherical shape which are smaller than the vessel, and do not contact the walls of the quartz discharge vessel. Various modifications of such a source **10** and its coil **18** and electrodeless arc discharge **16** are shown in FIGS. **2, 6–9** and **10–12.**

In FIG. **13** the FIGS. **10–12** modified structure is shown mounted within a housing **36** supporting a power generator **34** which is conductively connected as at **38** to induction coil **18.** Coil **18** may be constructed from copper tubing brazed to spherical induction/reflector **42** supported within porcelain/Teflon insulator-spacer **44.** A lock lamp mounting assembly **40** may support quartz sphere **10.** The white light source **10** in general can contain a heavy gas at high pressure—the vapor of metallic halides, for example, at one or several atmospheres pressure. The spectral qualities of an electrodeless arc light source may also be tailored by the use of metals, including the alkaline metals, in their halide form. A source designed for UV production may include a mercury and additive seeding material, or pure mercury initially at a relatively low partial pressure, while a highly efficient electrodeless arc IR source is provided by the discharge in cesium (or a similar alkali metal) vapor at approximately one atmosphere pressure. Because of the chemical activity of hot alkali metals in quartz, however, the discharge vessel for the IR production application is best fabricated of sapphire (presently available in cylinder form only) or one of several appropriate commercial ceramics, such as polycrystalline alumina (PCA). Additionally, the induced currents of an electrodeless arc lamp need not be azimuthally symmetric, nor must the inductor/reflector

structure possess similar symmetry to be effective. For example, longitudinal electrodeless arcs have been maintained at high power levels with high efficiency in long tubular lamps by means of the transverse induction field provided by the high frequency current carried by an extended inductor/reflector device mounted near the lamp. To one experienced in the art, such geometric manipulations of lamp and inductor/reflector shapes will be obvious embodiments of simple conformal transformations of the basic inductor/reflector concept disclosed herein.

I claim:

1. Method for producing an electrodeless plasma arc as a high intensity reflected light source comprising:

A. confining a plasma-forming gas within an electrodeless container;

B. pressurizing said plasma forming gas to at least one atmosphere;

C. generating radio-frequency electromagnetic power in an inductor/reflector device positioned exteriorly of said container, so as to develop magnetically an induction field extending through said container and into said gas, such that said gas is ionized as a plasma arc suspended within said container independently of the walls of said container, and

D. further including pressurizing said gas, limiting frequency and magnitude of said induction field, so that the discharge of said plasma arc is of lesser than the diameter of said container.

2. Method for producing an electrodeless plasma arc as in claim **1,** wherein said plasma forming gas is provided by the ionized vapors of mixtures of metallic halide additives in a starting gas background of the group consisting of argon, krypton and xenon.

3. Method for producing an electrodeless plasma arc as in claim **1,** including high pressurizing of a heavy gas such as xenon, so as to develop said plasma as an electrodeless white light source.

4. Method for producing an electrodeless plasma arc as in claim **1,** including high-pressurizing of mercury vapor within said container, so as to develop said plasma as an electrodeless ultraviolet light source.

5. Method for producing an electrodeless plasma arc as in claim **1,** including pressurizing of an alkali metal vapor within said container so as to develop said plasma as an electrodeless infrared light source.

6. Method for producing an electrodeless plasma arc as in claim **1,** wherein said container is a quartz sphere.

7. Method for producing an electrodeless plasma arc as in claim **1,** wherein said container is a sealed tube or cylinder.

8. Method for producing an electrodeless plasma arc as in claim **1,** wherein said container is a sapphire cylinder.

9. An electrodeless arc assembly for production of plasma as a white light source, comprising:

A. a quartz vessel;

B. a plasma-forming gas sealed within said vessel;

C. a radio-frequency inductor/reflector unit supported exteriorly of said vessel, so as to induce a magnetic field within said vessel where the induction field magnitude and frequency is sufficient to develop a plasma independent of the walls of said vessel, and is of lesser diameter than that of said vessel; and

D. a high frequency current generator in contact with said inductor/reflector unit and capable of delivering power to said inductor/reflector.

10. An electrodeless arc assembly for plasma production, as in claim **9,** wherein said plasma-forming gas ia an alkali metal vapor.

11. An electrodeless arc assembly for plasma production, as in claim **9,** wherein said plasma forming gas is the vapor of metallic halide additives.

12. An electrodeless arc assembly for plasma production as in claim **9,** further including:

E. a reflection element supported exteriorly of said sphere, so as to concentrate and reflect said light in one sector; and

F. a lens system intersecting reflected light in said sector.

13. Method for producing an electrodeless plasma arc as in claim **3,** wherein the gravitational buoyancy of said ionized xenon is counteracted by use of a less dense, light background gas selected from the group consisting of argon, neon, helium, hydrogen, and similar light gases.

14. Method for producing an electrodeless plasma arc as in claim **3,** wherein the gravitational buoyancy of said ionized xenon is counteracted by use of induction field gradients.

* * * * *