

[54] **HIGH PRESSURE METHOD FOR
PRODUCING AN ELECTRODELESS
PLASMA ARC AS A LIGHT SOURCE**

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abandoned.

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313/220, 313/224, 313/226, 313/227

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

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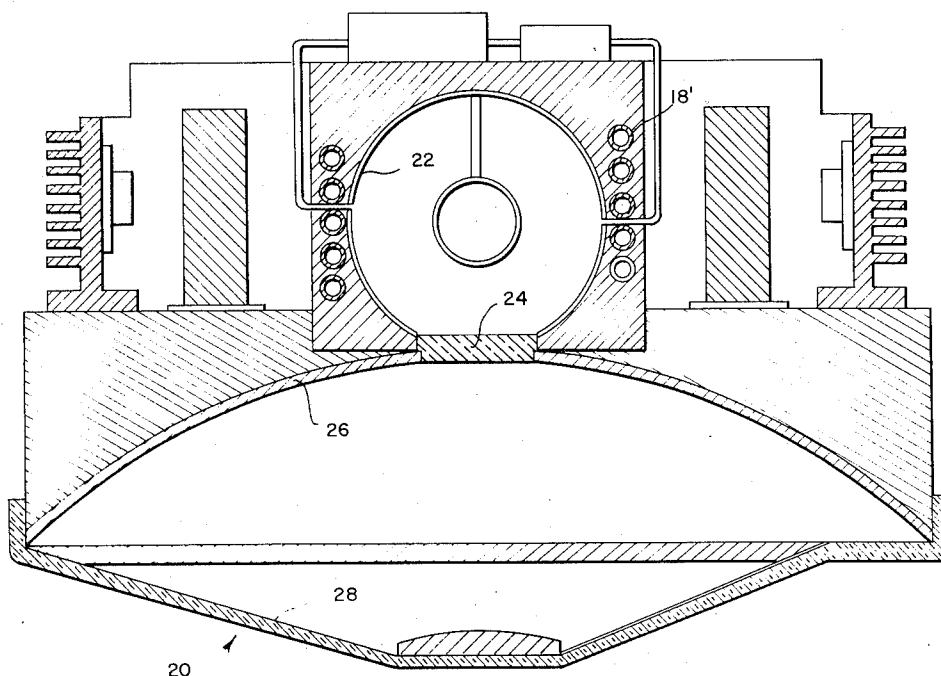
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[57]

ABSTRACT

Method of generating an electrodeless plasma arc as a light source including confining a plasma-forming gas such as xenon within a quartz sphere, pressurizing while confining the gas, and generating of power externally of the container so as to develop an induction field extending through the container and into the gas such that the gas is ionized as a plasma arc within the container.

5 Claims, 5 Drawing Figures



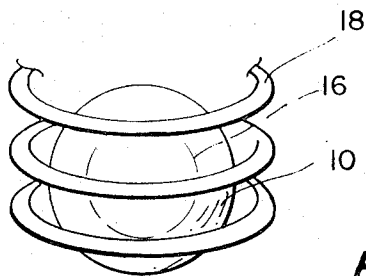


FIG. 1

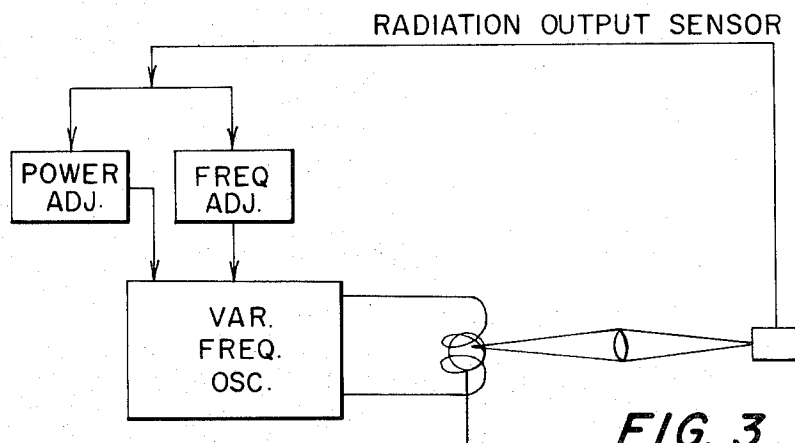


FIG. 3

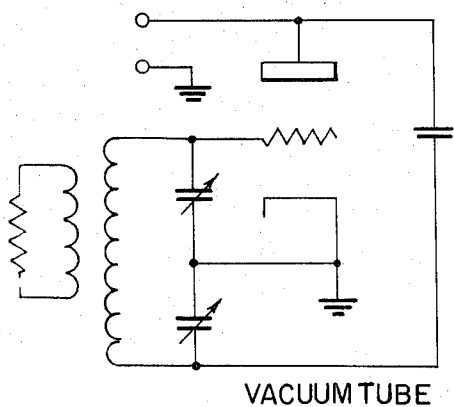


FIG. 4

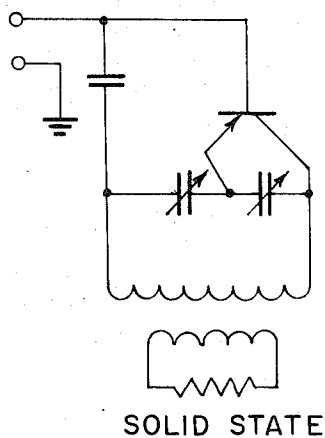
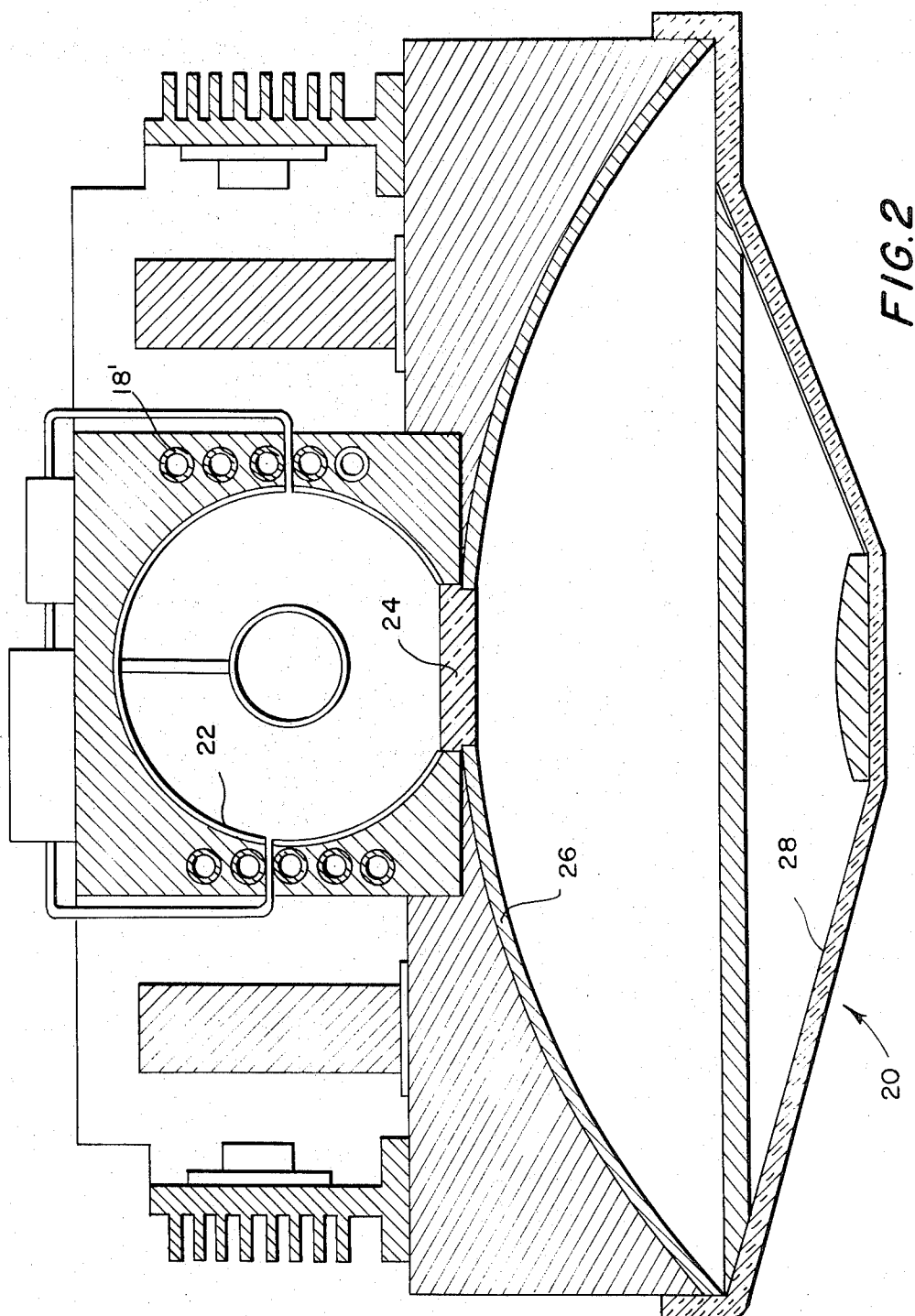


FIG. 5

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HIGH PRESSURE METHOD FOR PRODUCING AN ELECTRODELESS PLASMA ARC AS A LIGHT SOURCE

CROSS-REFERENCES TO RELATED APPLICATIONS

This application is a continuation of application Ser. No. 63,870, filed Aug. 14, 1970, and now abandoned.

BACKGROUND OF THE INVENTION

This invention relates to the specific application of an electrodeless arc discharge to the production of high intensity radiation, including radiation in the visible, ultraviolet, and infrared bands, and to a specific, integrated system design for the efficient recovery, direction, and projection of such radiant energy, both for purposes of lighting and for radiant heating, and for combinations thereof in application. 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 projection 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 an aperture-limited system; however, source-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 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 the 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. Gas throughflow recently was found unnecessary for discharge stability; therefore, a convective loss need not be present in an electrodeless arc. 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 65 percent actually have been measured in prototype devices using xenon as the discharge gas. The present invention enables an approach to the theoretical limit for radiation production efficiency and enables the fabrication of the novel and useful luminaires and hybrid illumination/heating systems.

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 having been developed as a white light source within the sphere;

FIG. 2 is a transverse section of 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;

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

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

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The electrodeless discharge described herein is a gaseous discharge occurring within the volume of a solenoid that carries high frequency current. The axially directed alternating magnetic field inside the solenoid induces an alternating azimuthal electric field in accordance with Faraday's law, and azimuthal currents, driven by this field, ohmically heat the gas and maintain ionization within the discharge. The discharge can be produced in a gas in the absence of central mass-flow, under which conditions it is self-stabilizing through a balance of electrodynamic and thermodynamic forces. This balance occurs subject to a condition of existence for the electrodeless arc that is based on a principle of minimum entropy production and is independent of the discharge-vessel wall boundary conditions; hence, the discharge is not attached to the wall or any other physical boundary, but, rather, obtains a circular cross-section normal to the direction of the induction field and is suspended within the discharge vessel near the axial position at which the induction field has the greatest magnitude. Upon application of the minimum required "discharge maintenance power," and in the absence of gravity and gravitational effects, the shape of the plasmoid "fireball" would be 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 will exhibit little or no participation in the electrical or radiative transport phenomena which occur. Application of power in excess of the minimum discharge maintenance power causes an elongation of the plasma, forming a constricted plasma column, or thermal "pinch."

The electrodeless arc has been found to exhibit a three-dimensional set of operational characteristics which are exploited in the invention to produce a novel optical source with unique properties which is highly versatile in its operation. This development is based on the fact that the physical parameters which actually specify the electrodeless arc, that is, those 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. Thus, given a discharge gas at a given pressure, one is enabled to adjust the total dissipation and the discharge temperature profile (hence, the discharge radiation

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, the gas in which the electrodeless arc is struck is contained at high pressure within a sealed, spherical envelope 10 made of quartz glass, which is hereinafter referred to as the "source". The source is positioned within an optically reflecting cavity including reflector 22 and lens 24, which is coaxial with the high frequency induction coil 18 of the electrodeless arc generator. The reflecting cavity has a shape and curvature which depend on the system's intended application. In this description, the cavity is assumed to have spherical shape, and the source is concentrically positioned within the cavity such that radiation emitted by the source is reflected back into the discharge wherever it strikes the reflecting wall surface. The choice of a spherical reflecting chamber in this disclosure is intended for purposes of demonstration and information, rather than for purposes of suggesting an application. The essential feature of the reflecting chamber is manifest by the presence of a high-pressure electrodeless arc-discharge at a focal position within the chamber. The 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. The high pressure source is cooled by liquid flow. A suitable coolant at high pressure enters the bottom area of the reflecting chamber and flows by the spherical source, removing heat from the source envelope by conduction, and exits the chamber at the top. Heat is removed from the coolant by means of a heat exchange mechanism that is completely sealed. The induction coil 18 is mounted in such a manner as to surround the reflecting chamber 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 coil is embedded within a glass-cloth tape-wound structure 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. An opening in the reflecting cavity allows a fraction of the total radiant emission to leave the cavity and enter a modified Cassegranian optical system where it impinges on a hyperbolic or similarly shaped reflecting surface and is redirected onto an additional reflecting surface of suitable curvature for the formation of an optical beam.

The liquid coolant can incorporate absorbing material for specialized application. Thus, a completely convert 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.

In the source-limited configuration of the invention, the spherical (or equivalent) reflecting chamber is absent and is replaced by a conventional optical projection system. The induction coil in this configuration is wound about the reflector to avoid shadowing effects. Convective cooling of the source is employed in this configuration.

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. 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 the 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 do not contact the walls of the quartz discharge vessel. Such a source 10 and its coil 18 and electrodeless arc discharge 16 are shown in FIG. 1. The white light source 10 in general will contain a heavy gas at high pressure - xenon, for example, at several atmospheres pressure when at STP. A source designed for UV production may include a mercury or similar 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 similar appropriate commercial ceramics.

I claim:

1. Method for producing an electrodeless plasma arc as a high intensity 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 energy exteriorally of said container, so as to develop magnetically an induction field extending through said container and into said gas, such gas is ionized as a plasma arc suspended within said container independently of the walls of said container;
 - D. further including pressurizing said gas, limiting frequency and magnitude of induction field so that the discharge of said plasma arc is of lesser diameter than the diameter of said container.
2. Method for producing an electrodeless plasma arc as in claim 1, wherein said plasma forming gas is xenon.
3. Method for producing an electrodeless plasma arc as in claim 2, wherein the gravitational buoyance of said ionized xenon is counteracted by use of a less dense, light background gas selected from the group consisting of argon, neon, helium, and hydrogen.
4. Method for producing an electrodeless plasma arc as in claim 1, wherein said plasma forming gas is mercury vapor.
5. Method for producing an electrodeless plasma arc as in claim 1, wherein said plasma forming gas is an alkali metal vapor.

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