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[54] **INDUCTION-COUPLED RING DISCHARGE DEVICE**

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[52] **U.S. Cl.** **313/161,** 313/225, 313/228, 313/229, 313/184, 315/344

[51] **Int. Cl.**.....**H01j 1/50**

[58] **Field of Search**.....313/161, 223, 225, 227, 228, 313/229, 184; 315/344

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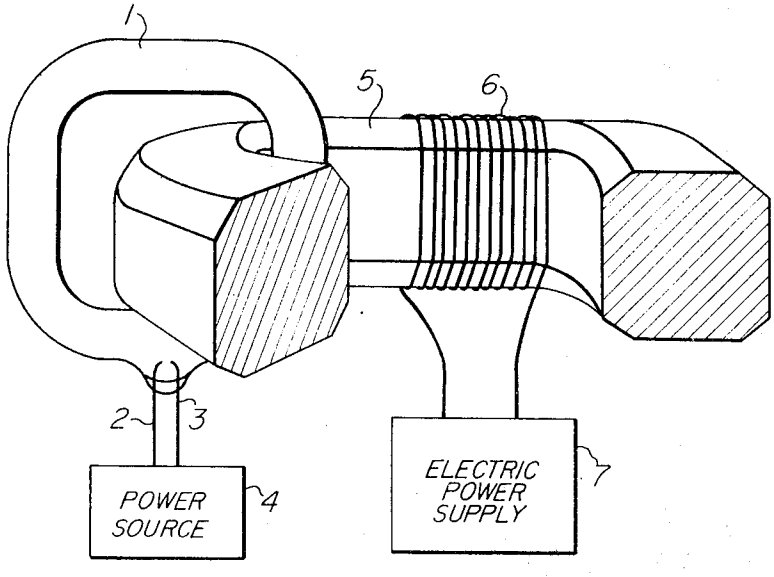
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[57] **ABSTRACT**

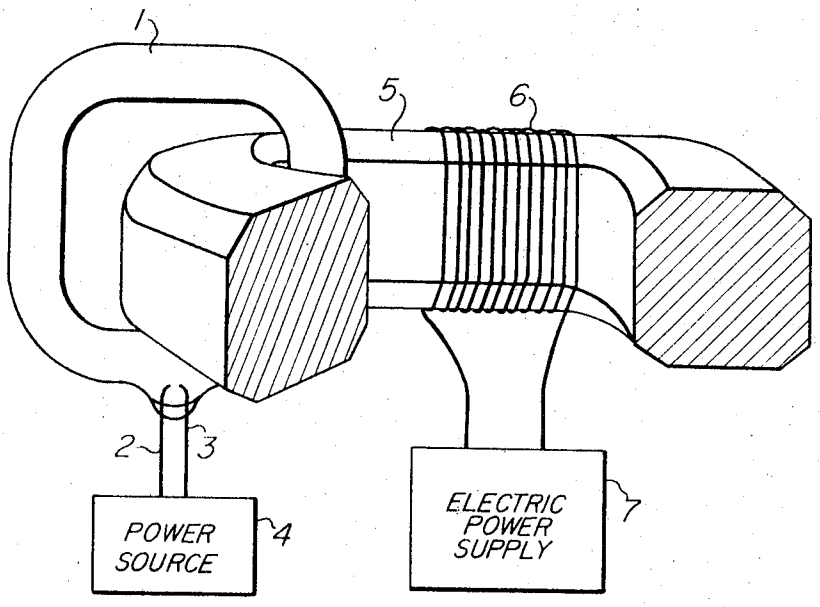
An induction-coupled ring discharge tube having a reduced electric field strength in the tube due to the charging of cadmium within the tube so that the discharge tube can operate with an electric power supply of relatively lower frequencies and the size of the magnetic core and discharge tube kept to a reasonable size.

9 Claims, 1 Drawing Figure



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INDUCTION-COUPLED RING DISCHARGE DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to discharge device and more particularly to an induction-coupled ring discharge tube which emits light by an electromagnetically induced discharge.

2. Description of the Prior Art

Prior art discharge tubes were provided with an electrode the function of which was to supply electric power from an external power supply into the discharge tube. In the discharge tube, the structure and material of the electrode were a matter of importance in order that the electrode could satisfactorily perform the above function. More precisely, the suitability of the electrode for the desired electron emission not only had a great influence on the electrical and optical characteristics of the discharge tube during the operation of same, but was also closely related to the breakdown voltage for initiating the discharge tube, and thus undesirable variations of the electrical characteristics of the discharge tubes as well as irregular fluctuations of the current and light flux during the operation of the discharge tubes were brought forth depending on the properties of the electrode. Further, the electron emission substances of the electrode were subject to collapse due to sputtering and evaporation during the starting and operation of the discharge tube thereby deteriorating the electron emission ability of the electrode, and the substances sputtered from the electrode caused blackening of the tube wall. Thus, the electron emission substances of the electrode were an important factor determining the service life of the discharge tube.

Various problems attributable to the presence of the electrode are more marked in the so-called metal-halide discharge lamp in which metal compounds in the form of halides are contained in a glass envelope to obtain emission spectra of the metals. The halogens liberated by the discharge promote damage to the electrode due to their chemical activity and accelerate the deterioration of the discharge lamp. For example, the service life of a high-pressure mercury vapor discharge lamp presently in use which contains a metal halide therein is less than one-third of a discharge lamp of this kind which does not contain any metal halide therein. However, the metal-halide discharge lamp is highly appreciated as an illuminating light source because it has the advantages of high efficiency and good color rendition. Thus, it has been strongly demanded that the service life of the metal-halide discharge lamp be extended as much as possible.

In an attempt to meet the above demand, Japanese Pat. No. 303,725 entitled "Electrodeless Discharge Tube" has been proposed. The electrodeless discharge tube is operable without the use of an electrode of the kind described above and is based on the principle such that a ring discharge tube per se is provided with a secondary winding of a transformer so as to electromagnetically induce an electrodeless discharge within the discharge tube.

While the electrodeless discharge tube has had the advantages of stable operation for an extended period of time, less tendency toward deterioration of light flux and a longer service life, it has been defective in that a relatively high electric field strength in the tube results in the need for an electric power supply of high frequency and in an excessively large size of the magnetic core and discharge tube. There has therefore been a strong demand for an electrodeless discharge tube, or more specifically, an induction-coupled ring discharge tube having a reduced electric field strength.

SUMMARY OF THE INVENTION

A series of experiments and studies have been made by the inventors to overcome the above defects so as to thereby obtain an improved discharge tube of this kind.

It is a primary object of the present invention to provide a discharge tube in which the electric field strength in the tube is kept at a low value and which exhibits a high efficiency and an improved degree of color rendition.

BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a schematic view illustrating the principle of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to the FIGURE showing an induction-coupled ring discharge device of the present invention in a partly sectional view, the reference numeral **1** designates a ring discharge tube made from a light-transmitting and heat-resistive material such as fused silica, light-transmitting alumina or beryllia. Metals or their iodides and any desired gas such as an inert gas which may be xenon or argon are contained within the tube **1**. The reference numerals **2** and **3** designate ignition electrodes made from tungsten containing thoria. A starter **4** having an open circuit voltage of about 1,000 V and a short circuit current of about 0.1 A is connected to the ignition electrodes **2** and **3**. A magnetic core **5** is disposed in crossed relation with the ring discharge tube **1**, and a primary winding **6** is electromagnetically coupled to the discharge tube **1** through the magnetic core **5**. An electric power supply **7** for the main discharge operable at a frequency of about 5 to 10 kHz and rated at a maximum power output of 10 kW is connected to the primary winding **6**.

The induction-coupled ring discharge device having such a construction operates in a manner as described below. At first, a small electric current of about 0.1 A is supplied from the starter **4** to the ignition electrodes **2** and **3** to generate a weak electric discharge in the discharge tube **1** so as thereby to cause the preliminary ionization of the inert gas (xenon or argon) within the discharge tube. Power is then supplied from the electric power supply **7** to the primary winding **6** to induce the main discharge within the ring discharge tube **1** through the magnetic core **5**. In the initial stage of the main discharge, the discharge takes place in the inert gas or the vapor of a metal such as mercury having a considerable vapor pressure at room temperature so that the emission spectra inherent to these elements are thereby exhibited. With an increase in the temperature of the tube wall, other metals start to emit light. Generally, the electric field strength in the discharge tube increases with an increase in the vapor pressure in

the discharge tube and finally settles at a certain value which is dependent upon the types and amounts of the substances contained within the tube. The relation between the electric field strength and various parameters of the device will now be discussed.

Suppose now that λ is the arcuate length of the ring discharge tube and S is the sectional area of the magnetic core, then the electromotive force E induced in the longitudinal direction per unit length of the discharge tube is given by:

$$E = -S/\lambda \cdot \delta B/\delta t \quad (1)$$

For the sake of simplicity, it is supposed herein that the magnetic field varies sinusoidally with an angular frequency ω and its peak value is Bmax. In this case, the peak value Emax of the induced electric field can be deduced from equation (1) as:

$$E_{max} = S/\lambda \cdot \omega B_{max} \quad (2)$$

In order to maintain the discharge, the electric field strength *Ed* in the discharge tube must satisfy the following conditions:

$$Ed < S/\lambda \cdot \omega \cdot B_{max} \quad (3)$$

Considering the saturation flux density of many magnetic materials, B_{max} has appropriately a value of the order of $B_{max} \cong 1$ Wb/m^2. Further, considering the frequency characteristics of the circuit elements of the power supply, it is advantageous from the practical point of view that $\omega/2\pi$ lies in the range of $\omega/2\pi \lesssim 10^4$ Hz. Practical dimensions of the arcuate length λ of the tube and sectional area S of the magnetic core are of the order of $\lambda \cong 0.5$ m and S $\cong 10^{-2}$ m^2, although they may differ somewhat depending on the geometric configurations of the tube and magnetic core. By substituting S, λ, ω and B_{max} in equation (3) by these values, the condition for maintaining the discharge is approximately given by:

$$Ed \lesssim 10^3 \text{ V/m}$$

Although the numerical values specified above include sufficient margins to allow for fairly free selection thereof, it will be apparent as a general rule that many practical advantages can be obtained with a discharge tube having a lower electric field strength *Ed*.

The electric field strength *Ed* in the majority of conventional mercury vapor lamps and metal-halide discharge lamps is substantially as high as 2×10^3 V/m and exceeds the allowable limit for practical induction-coupled ring discharge lamps.

It will be understood from the foregoing description that an important feature of the present invention resides in the fact that the substances to be contained within the tube are suitably selected so as to remarkably reduce the electric field strength in the tube. It is known that a high emission efficiency and a good degree of color rendition can be obtained with a discharge tube containing therein an inert gas and metals such as mercury, sodium, thallium and indium or their iodides. The results of experiments and studies made by the inventors proved that the addition of cadmium to these known substances could remarkably reduce the electric field strength. The following table shows the arc voltage when cadmium in various amounts is added to a discharge tube of 18 mm inside diameter containing therein mercury, thallium iodide, sodium iodide, indium and xenon:

Table. Relation between amounts of cadmium and electrical characteristics

Amount of Cd (mg)	Electric power per unit length of tube (kW/m)	Current (A)	Electric field strength in tube (V/m)
0	8	4.3	2320
	12	6.1	2580
0.6	8	6.0	1720
	12	8.8	1860
3	8	6.3	1560
	12	8.8	1760
2*	8	11.3	840
	12	14.0	1100

* No mercury is contained and xenon only is sealed at a pressure 465 mmHg. From the above test results, it is apparent that the addition of cadmium is effective for the reduction of the electric field strength in the discharge tube. Especially, as shown in the last line of the table, the tube voltage is remarkably reduced when no mercury is contained and xenon is contained at a slightly higher pressure than usual.

The reason why the addition of cadmium is so effective for the reduction of the tube voltage is not yet clear. In this respect, the following fact was experimentally determined. That is, spectroscopic examination of the intensity of spectral lines and the temperature of the plasma at different points between the central axis of the discharge tube and the tube wall proved that mercury and cadmium luminesced in a region of relatively high temperatures adjacent to the center of the tube while other metals luminesced in a region of relatively lower temperatures adjacent to the peripheral wall of the tube. This is consistent with the fact that the excitation energy for mercury and cadmium is higher than that of the group of other metals. It is the central high temperature region of the tube that is principally affected by the addition of cadmium, and the temperature in that region is reduced from about 6,000° K. which is observed without the addition of cadmium to about 5,000° to 4,000° K. with an increase in the amount of cadmium. The low temperature region adjacent to the peripheral wall of the tube is substantially free from the addition of cadmium and the temperature in this region lies in the range of 2,000° to 4,000° K. It seems that such a temperature reduction in the region adjacent to the center of the tube is related to the reduction in the tube voltage.

The discharge tube containing cadmium therein exhibits a good degree of color rendition and high emission efficiency. When the discharge tube contains cadmium but does not contain mercury therein, to improve the emission efficiency it is effective to charge an inert gas at a considerably higher pressure. When, for example, xenon is charged at a pressure higher than 300 mmHg or argon is charged at a pressure higher than 500 mmHg, the emission efficiency of the discharge tube will be as high as about 80 λ m/W or more.

It will be understood from the foregoing detailed description that the present invention provides an induction-coupled ring discharge tube have a reduced electric field strength in the tube due to the charging of the tube with cadmium. The present invention is thus advantageous in that the discharge tube can operate with an electric power supply of relatively lower frequencies and the size of the magnetic core and discharge tube can be kept down.

The present invention is further applicable to a discharge tube which is designed to emit a coherent

light, or more precisely to a laser discharge tube. At present, it is observed that a discharge through a metal element such as copper, lead or manganese also produces a laser beam. According to common practice, a very troublesome method comprising heating the discharge tube in an electric furnace is employed in order to obtain the vapor of these metals. It will be appreciated that the present invention can be advantageously applied to the discharge tube of this kind to obtain a sufficient vapor pressure at a temperature far lower than that attainable with a simple substance of these metal elements thereby to easily produce a laser beam.

We claim:

1. An induction-coupled discharge device comprising a ring discharge tube consisting of a closed ring including a gas for discharge and a vaporizable metal substance and cadmium used for reducing an electric-field strength and a magnetic core for supplying low-frequency induction power lower than 10^4Hz to said ring discharge tube.

2. An induction-coupled space discharge apparatus, comprising:

a ring discharge tube including a rare gas and a vaporizable metal substance;

means, coupled to said tube, for inducing preliminary ionization within said discharge tube;

means, coupled to said tube, for inducing a main discharge within said tube, said main discharge inducing means comprising a magnetic core inductively coupled with said tube and with an electric power supply therefor; and

means for reducing the electric field strength of said discharge tube comprising cadmium contained within said tube.

3. An apparatus according to claim 2, wherein said preliminary ionization inducing means comprises a pair of discharge electrodes disposed in said tube and connected to an additional power source.

4. An apparatus according to claim 2, wherein said discharge tube is a closed ring discharge tube, around which said core passes, said core including an inductive winding wound thereon and being connected to said electric power source therefor.

5. An apparatus according to claim 4, wherein said rare gas consists of xenon.

6. An apparatus according to claim 4, wherein said rare gas consists of argon.

7. An apparatus according to claim 4, wherein said vaporizable metal substance comprises at least one element selected from the group consisting of mercury, thallium and indium.

8. An apparatus according to claim 5, wherein said xenon gas is at a pressure greater than 300 millimeters of mercury.

9. An apparatus according to claim 6, wherein said argon is at a pressure greater than 500 millimeters of mercury.

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