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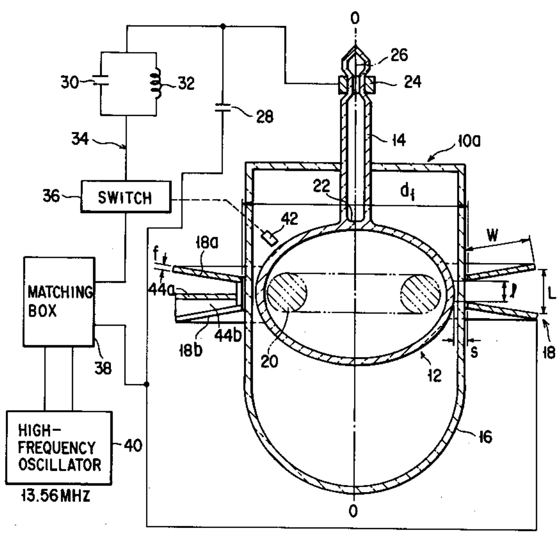
(54) **Magnetic-field discharge lamp and lighting device using the same**

(57) The present invention provides a magnetic-field discharge lamp having an improved overall efficiency of the lamp achieved by enhancing the coupling efficiency between the excitation coil and the bulb, and a lighting apparatus using the same. In specific, the invention is a magnetic field discharge lamp wherein discharge substances are sealed in a light-permeable bulb (12) and a discharge is induced in the bulb by the high-frequency excitation coil (18, 62, 64, 66, 68) provided to surround the bulb (12). The excitation coil (18) is made of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) of at least one coiling around the coil axis, and the flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies the relationship, $0.06 \leqq W/d_1 \leqq 0.5$ where d_1 represents the inner diameter of the ring plate and W represents the significant width of the passage for allowing current to flow in the circumferential direction.



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The present invention relates to a magnetic-field discharge lamp in which plasma is generated in a bulb by a high-frequency excitation coil, thereby allowing discharge materials in the bulb to discharge or emit light, and to a lighting device using such a discharge lamp.

A general high-voltage metal vapor discharge lamp, namely an HID lamp (high intensity discharge lamp), has electrodes consisting of a high melting point metal and sealed at both end portions of a light-emitting bulb. Arc discharge is caused to occur between the electrodes so as to ionize and excite the light-emitting metal sealed in the bulb, thereby emitting light. However, a lamp having such electrodes entails various problems as follows. That is, it is necessary to prepare electrode parts because electrodes must be arranged in a bulb. Further, the apparatus must include a complicated electrode-sealing structure, and a special care has to be paid to prevent leakage from the electrode-sealed portion. Furthermore, the electrodes are corroded since they are exposed to the discharge space, etc.

Regarding lamps which can remove the above-described problems, much attention has been given to the solenoid magnetic-field discharge lamp. In the solenoid magnetic-field discharge lamp, discharge substances and light-emitting substances are sealed in a transparent bulb, and a high-frequency excitation coil is arranged such as to surround this bulb. With this structure, plasma is generated in the bulb by this excitation coil so as to allow the discharge substances to discharge. Since the solenoid magnetic-field discharge lamp does not include electrodes in the bulb, it is also called the "non-electrode discharge lamp", and with the solenoid discharge lamp, the problems of the electrode-type lamp can be removed.

In this type of solenoid magnetic-field discharge lamp, the discharge is carried out at a low impedance. Therefore, it is necessary to supply a high-frequency current as large as about 20 amperes to the excitation coil, and the resistance loss in the coil influences greatly on the overall efficiency of the lamp itself. More specifically, the efficiency of the excitation coil is the key factor of the overall efficiency of the lamp. Therefore, in order to enhance the overall efficiency, the improvement of the efficiency of the excitation coil is desired.

Jap. Pat. Appln. KOKAI Publication No. 5-101895, for example, discloses a conventional solenoid magnetic-field discharge lamp. This publication discloses that it is important for the enhancement of the efficiency of the excitation coil, to reduce the loss of high-frequency current, caused by the excitation coil surrounding the bulb. In this publication, the conductivity of the surface of the excitation coil, and the reflectivity are rendered high.

However, it was found not only that the means for reducing the high-frequency loss of the excitation coil depends upon simply the conductivity of the surface of the excitation coil and the reflectivity, but also that the skin resistance should be decreased by increasing the surface area, the heat loss should be reduced, and the cutting-off of light by the coil should be suppressed.

The coil used in the conventional solenoid magnetic-field discharge lamp is made of a wire whose cross section is circular. Therefore, for the same cross sectional area, the surface area is smaller than that whose cross section is not circular. It is known that high-frequency current flows on the surface of conductor when passing therethrough. Therefore, as the surface area is rendered larger, the current pathway is made accordingly larger (skin effect), thus lowering the resistance. Thus, the resistance can be reduced by using a wire whose cross section is not circular, since the surface area thereof is larger than that having a circular cross section and the same cross sectional area.

Further, as the resistance reduces, the generation of heat accordingly reduces, thus preventing an increase in coil temperature. In addition, when the shape of the cross section is not circular, the surface area is larger, and therefore the heat radiation is larger, thus decreasing the coil temperature. Consequently, the coil efficiency is increased, and drawbacks such as surface oxidization and creeping deformation can be avoided.

In consideration of the above, the authors of the present invention focused on the non-circular cross sectional shape of a coil, as proposed in Jap. Pat. Appln. No. 3-247664.

Regarding the type of the apparatus disclosed in this publication, if adjacent coils are too close to each other, an induced current is created, and the coils are thermally influenced mutually with each other. Further, the light radiated from the bulb is shut by the coils. In order to solve this problem, a conductor having a flat shape elongated in the direction crossing with the coil axis direction, is used as the excitation coil. By using the coil of this type, the surface area can be increased, and therefore the high-frequency resistance can be decreased, the increase in temperature can be reduced, and thickness of the conductor can be reduced. In addition, with this coil, the distance between adjacent coils can be increased, and therefore the shutting-off of light can be reduced.

As described above, to enhance the skin effect by increasing the surface area, and suppress the increase in temperature by enlarging the heat radiation area, it would suffice if the conductor, of which a coil is made, is formed flat, and the width W of the annular portion of the ring-like coil is increased. However, if the width W of the flat annular portion of the ring-like coil is simply increased, the space for mounting the lamp, which also accommodates the coil will be excessively large, resulting in an increase in size of the overall apparatus system. Also, since high-frequency current flows in the outer periphery portion of the flat annular coil, there is a great possibility that the coupling efficiency of the high-frequency power with respect to the bulb located at the center portion is greatly degraded. In addition, the weight of the coil itself is increased, making it difficult to set the lamp.

Further, in the case where the width of the flat annular portion of the ring-like coil is set at constant, the surface area of the ring-like coil is increased as the inner diameter of the coil is increased. However, if the diameter of the coil is increased, the coils are located apart from the bulb, thus significantly decreasing the coupling efficiency between the coil and the bulb.

The present invention has been proposed in consideration of the above drawbacks, and the object thereof is to provide a magnetic-field discharge lamp in which the coil efficiency of the excitation coil itself is raised so as to have a high coupling efficiency between the coil and bulb, thereby achieving an high overall efficiency, and a lighting apparatus using the same.

An object of the present invention is to provide a magnetic discharge lamp having a light-permeable bulb in which a discharge substance is sealed, and a high-frequency excitation coil arranged to surround the bulb, the excitation coil functioning to generate a discharge in the bulb,

characterized in that the high-frequency excitation coil consists of at least one coiling of a flat ring plate having a width in a direction crossing an axial direction of the coil, around an axis of the bulb, and the flat ring plate satisfies a relationship:

$$0.06 \leqq W/d_1 \leqq 0.5$$

where d_1 (mm) indicates an inner diameter of the ring plate and W (mm) indicates a significant width of a passage which allows current to flow in a circumferential direction.

Another object of the present invention is to provide a magnetic discharge lamp having a light-permeable bulb in which a discharge substance is sealed, and a high-frequency excitation coil arranged to surround the bulb, the excitation coil functioning to generate a discharge in the bulb,

characterized in that the high-frequency excitation coil consists of at least two coiling of a flat ring plate having a width in a direction crossing an axial direction of the coil, around the bulb, and has a distance between outer peripheries of the at least two coiling of a flat ring plate larger than that between inner peripheries thereof, and the flat ring plate satisfies a relationship:

$$0.06 \leqq W/d_1 \leqq 0.5$$

where d_1 (mm) indicates an inner diameter of the ring plate and W (mm) indicates a significant width of a passage which allows current to flow in a circumferential direction.

Still another object of the present invention is to provide a discharge lamp lighting device characterized by comprising:

a magnetic field discharge lamp according to the above; and

a high frequency oscillating circuit for inducing discharge in the bulb by supplying a predetermined high-frequency current to the high-frequency excitation coil.

Still another object of the present invention is to provide a discharge lamp lighting apparatus having a magnetic discharge lamp comprising a light-permeable bulb in which a discharge substance is sealed, and a high-frequency excitation coil arranged to surround the bulb, the excitation coil functioning to generate a discharge in the bulb, and a reflector having a light projecting section for reflecting light emitted from the lamp to outside,

characterized in that the high-frequency excitation coil consists of at least two coiling of a flat ring plate having a width in a direction crossing an axial direction of the coil, around an axis of the bulb, and has a distance between outer peripheries of the at least two coiling of a flat ring plate larger than that between inner peripheries thereof, and the flat ring plate satisfies a relationship:

$$0.06 \leqq W/d_1 \leqq 0.5$$

where d_1 (mm) indicates an inner diameter of the ring plate and W (mm) indicates a significant width of a passage which allows current to flow in a circumferential direction.

Still another object of the present invention is to provide a magnetic discharge lamp having a light-permeable bulb in which a discharge substance except for mercury is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb,

characterized in that said high-frequency excitation coil consists of at least one coiling of a flat ring plate having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate satisfies relationships:

$$0.06 \leqq W/d_1 \leqq 0.5$$
$$10 \leqq f \leqq 100$$
$$10 \leqq d \leqq 50$$
$$250 \leqq d \cdot f \leqq 7.5P$$

where d (mm) represents an inner diameter of the bulb (12), d_1 represents an inner diameter of said ring plate, W (mm) represents a significant width of a passage for allowing current to flow in the circumferential direction, f (MHz) represents a frequency of a high-frequency power supplied to said excitation coil, and P (watt) represents a rated input supplied to said excitation coil.

Still another object of the present invention is to provide a discharge lamp lighting apparatus having a magnetic discharge lamp comprising a light-permeable bulb in which a discharge substance except for mercury is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb, and a reflector having a light projecting section for reflecting light emitted from said lamp to outside,

characterized in that said high-frequency excitation coil consists of at least one coiling of a flat ring plate having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate satisfies relationships:

$$0.06 \leqq W/d_1 \leqq 0.5$$
$$10 \leqq f \leqq 100$$
$$10 \leqq d \leqq 50$$
$$250 \leqq d \cdot f \leqq 7.5P$$

where d (mm) represents an inner diameter of the bulb (12), d_1 represents an inner diameter of said ring plate, W (mm) represents a significant width of a passage for allowing current to flow in the circumferential direction, f (MHz) represents a frequency of a high-frequency power supplied to said excitation coil (18, 62, 64, 66, 68), and P (watt) represents a rated input applied to said excitation coil.

Still another object of the present invention is to provide a discharge lamp lighting apparatus having a magnetic discharge lamp comprising a light-permeable bulb in which a discharge substance except for mercury is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb, and a cooling device for forcibly cooling said discharge lamp by means of cooling wind,

characterized in that said high-frequency excitation coil consists of at least one coiling of a flat ring plate having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate satisfies relationships:

$$0.06 \leqq W/d1 \leqq 0.5$$
$$10 \leqq f \leqq 100$$
$$10 \leqq d \leqq 50$$
$$250 \leqq d \cdot f \leqq 7.5P$$

where d (mm) represents an inner diameter of the bulb (12), d_1 represents an inner diameter of said ring plate, W (mm) represents a significant width of a passage for allowing current to flow in the circumferential direction, f (MHz) represents a frequency of a high-frequency power supplied to said excitation coil, and P (watt) represents a rated input applied to said excitation coil.

Regarding the magnetic-field discharge lamp of the above-described type, if the width W of the annular portion of the ring-like coil is excessively large, not only the system of the lamp enlarges, but also the light shutting-off effect increases, and the energy supplying efficiency for supplying energy to the bulb located in the center portion deteriorates since high-frequency current flows through the outer periphery of the annular portion of the coil. When the inner diameter d_1 of the ring-like coil is increased, the inner periphery of the ring-like coil is set apart from the bulb, thereby lowering the coupling efficiency. When the inner diameter d_1 is decreased, the inner periphery of the coil is rendered closer to the bulb, and the coupling efficiency between the coil and the bulb is increased, thereby increasing the energy supplying efficiency.

According to the solenoid magnetic-field discharge lamp of the present invention, the relationship between the inner diameter d_1 of a pair of ring-like coils constituting an excitation coil, and a width W of the annular portion thereof can be limited to reduce the resistance to the high-frequency current. Consequently, an increase in temperature can be suppressed, the coil efficiency is increased, and the coupling efficiency between the coil and bulb is raised, thus increasing the efficiency for supplying the high-frequency power.

Further, according to the lighting apparatus of the present invention, the solenoid magnetic-field discharge lamp is forcibly cooled by a cooling device, and therefore the lamp efficiency is further enhanced, thus increasing the efficiency of the whole system.

This invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a cross section of a solenoid magnetic-field discharge lamp according to the first embodiment of the present invention;

FIG. 2 is a schematic view of an excitation coil of the lamp shown in FIG. 1;

FIG. 3 is a diagram showing an example of the fixation device for fixing the lamp shown in FIG. 1;

FIG. 4 is a characteristic diagram showing the relationship between the inner diameter d_1 of a high-frequency excitation coil and the width W of the annular portion thereof of the first embodiment;

FIG. 5 is a cross section of a solenoid magnetic-field discharge lamp according to the second embodiment of the present invention;

FIG. 6 is a cross section of a solenoid magnetic-field discharge lamp according to the third embodiment of the present invention;

FIG. 7 is a cross section of a solenoid magnetic-field discharge lamp according to the fourth embodiment of the present invention;

FIG. 8 is a schematic view, including a partial cross section, of a high-frequency excitation coil according to the fourth embodiment of the present invention;

FIG. 9 is a side view of a roadway lighting apparatus according to the fifth embodiment of the present invention;

FIG. 10 is a cross section of the main portion of the lighting apparatus according to the fifth embodiment;

FIG. 11 is a cross section of a solenoid magnetic-field discharge lamp according to the sixth embodiment of the present invention;

FIG. 12 is a cross section of a solenoid magnetic-field discharge lamp according to the seventh embodiment of the present invention;

FIG. 13 is a cross section of a solenoid magnetic-field discharge lamp according to the eighth embodiment of the present invention;

FIG. 14 is a cross section of a solenoid magnetic-field discharge lamp according to the ninth embodiment of the present invention; and

FIG. 15 is a cross section of a solenoid magnetic-field discharge lamp according to the tenth embodiment of the present invention.

Embodiments of the present invention will now be described with reference to drawings.

FIGS. 1 through FIG. 4 show the first embodiment of the present invention, and a magnetic-field discharge lamp 10a comprises a light emitting bulb 12, a starting narrow tube 14, an outer tube 16 for accommodating the light-emitting bulb 12 inside, and an excitation coil 18. The light-emitting bulb 12 is made of a high-melting-point glass such as a synthetic quarts, or a transparent ceramic material such as alumina, and has an oval shape. Sealed in the bulb 12, are light-emitting substances for emitting light by an arc discharge 20 excited by plasma, for example metal halides such as $NaI\text{-}CeI_3$, $NaI\text{-}PrI_3$ and $ScI_3\text{-}NaI$. Apart from the light-emitting substances, the bulb 12 contains at least one starting noble gas such as argon, xenon, krypton or neon.

The outer tube 16 is made of quartz glass or the like, and designed to protect the bulb 12 from the light emission failure caused by touching with hand, and to keep the temperature of the light emitting tube, thereby maintaining a high optical efficiency. The outer tube 16 is situated such as not to be in contact with the bulb 12 in order for preventing the destruction of the lamp due to a factor relating to convection.

The starting narrow tube 14 is connected to one end of the bulb 12, such as to be located on the center line O. The narrow tube 14 should preferably be made of the same material as the bulb 12, and is separated from the inside of the bulb 12 via a partition wall 22. As starting noble gas, at least one of, for example, argon and krypton is sealed in the narrow tube 14.

Further, a starting electrode 24 is mounted on the starting narrow tube 14. In this embodiment, a small diameter portion 26 is formed in the middle of the narrow tube 14, and the starting electrode 24, which has a broken-ring (C) shape, is fit on the smaller diameter portion 26. The starting electrode 24 is connected to a starting circuit 34 including capacitors 28 and 30, and an inductance 32. The starting circuit 34 further includes a switch circuit 36, and is connected to a high frequency oscillation circuit 40 via a matching box 38.

The switch circuit 36, through is not illustrated in detail, is made of a known electronic switch and the like, and serves to intermittently open/close the starting circuit 34 until the lamp 10a is started. More specifically, the switch circuit 36 alternately repeats a turning on and off of the starting circuit 34, for example, turning it ON for 1 second, then turning it OFF for 1 second, and again ON for 1 second, and so on.

The switch circuit 36 can be placed in the OFF position when the alternation between ON/OFF is stopped, upon receiving a signal from an optical sensor 42 provided near the bulb 12. The optical sensor 42 outputs a signal based on the detection of the light emitting state of the bulb 12.

The excitation coil 18 is provided around the bulb 12. In this embodiment, the excitation coil 18 is wound two times. The excitation coil 18 consists of a pair of annular metal rings 18a and 18b, which are made of conductors corresponding to coil raw wire, having a good conductivity, such as gold, high-purity aluminum, copper or silver. The pair of annular metal rings 18a and 18b are arranged to cross the coil axis 0-0 direction, and parts of the inner portions thereof are connected to each other by welding to form a spiral electroconductive pathway as a whole.

More specifically, each of the pair of rings 18a and 18b is not continuous in the circumferential direction, but end portions thereof face to each other by a gap 18c. The inner periphery portion of either one of the annular rings, for example ring 18a, and that of the other ring 18b are mutually and partially connected to each other, thereby forming a spiral electroconductive pathway as a whole.

In this case, a connection protrusion 44a is formed in the inner periphery portion of the annular ring 18a, and similarly a connection protrusion 44b is formed in the inner periphery portion of the annular ring 18b. Then, the connection protrusions 44a and 44b are abutted against each other and welded together such that the conductive pathway having the spiral structure as a whole is formed.

The inner periphery portions of the pair of annular rings 18a and 18b are arranged mutually close to each other, and the outer periphery portions are apart from each other by a distance L, which is larger than a distance ℓ between the inner periphery portions. Also, in this embodiment, the annular rings 18a and 18b have a flat plate shape which stretches out in the radial direction.

The dimensions of the structure satisfies the following relationship:

$$0.06 \leqq W / d_1 \leqq 0.5 \qquad (1)$$

where d_1 represents the inner diameter of the annular rings 18a and 18b, and W represents the significant width of the conductive pathway, i.e. substantial width.

A specific example of the dimensions will be as follows: In the case of the outer diameter of the bulb 12 is 32 mm, the thickness t of the annular rings 18a and 18b, which serves as coil wires, is 2 mm, the inner diameter d_1 thereof is 35 mm, the significant width W of the current pathway is 14 mm, the distance ℓ between the inner periphery portions of the annular rings 18a and 18b adjacent to each other is 2 mm, and the distance L between the outer periphery portions thereof is 8 mm.

In the meantime, the excitation 18 has one end, which is connected to a high-frequency wave oscillating circuit 40 via the matching box 38, and the other end, which is connected to the ground 46. With this structure, a high-frequency current having a frequency of about 13.56 MHz supplied from the high-frequency oscillating circuit 40 is allowed to flow through the coil. Due to the high frequency current, a magnetic field is generated in the excitation coil 18 along the axial direction 0-0 of the coil 18. Accordingly, a doughnut-shaped arc discharge 20 is generated by plasma around the coil axis 0-0 in the bulb 12 accommodated in the central space of the coil 18. The light-emitting substances are dissociated and excited by the arc discharge 20, thus emitting light, which is radiated out through the bulb 12.

The bulb 12 is inserted into the center space of the excitation coil 18 and fixed thereto by means of a mounting mechanism shown in FIG. 3. The excitation coil 18 is fixed to a base plate 48 via a mount piece 18d of the coil. The base plate 48 has a gas probe 50 formed at a predetermined position thereof such as to project in the direction of insertion of the bulb 12. Provided between the gas probe 50 and the excitation coil 18, is a socket 52 for fixing the outer tube 16 when it is set thereon. The starting electrode 24 is set in the starting narrow tube 16 such as to be brought into contact with a terminal (not shown) in the socket 52.

Vertically standing up on the base plate 48, are the inductance 32 and the substrate 54. Further, a jacket 56 is designed to cover the inductance 32, the substrate 54 and the like, and a heat pipe 58 and an external radiator 60 are designed to radiate heat of an amplifying transistor (not shown) mounted on the substrate 54.

The operation of the solenoid magnetic-field discharge lamp having the above-described structure, i.e. electrodeless discharge lamp, will be explained.

When lighting the lamp, a starting voltage is supplied from the high-frequency oscillating circuit 40 to the starting electrode 24, and at the same time, a high-frequency current is allowed to flow through the excitation 18, thereby generating an electric field in the bulb 12 by the high-frequency magnetic field. Consequently, a potential difference is created between the starting electrode 24 and the electric field in the bulb 12, and therefore the noble gas in the narrow tube 14 generates a glow discharge. Consequently, a gradient of an electric field is created between the glow discharge in the narrow tube 14 and the electric field in the bulb 12. Therefore, a plasma discharge is induced in the bulb 12, thus generating a ring-shaped discharge 20.

In this embodiment, a starting voltage is supplied to the starting electrode 24 intermittently by the ON/OFF operation of the switching circuit 36. Consequently, a glow discharge is intermittently generated in the narrow tube 14. Thus, the electric field intermittently acts upon a partition wall 22, in other words, a concentration electric field is not continuously applied on the partition wall. Therefore, an increase in the temperature of the partition 22 is suppressed, thus avoiding the melting thereof.

When the lamp is started as above, the light-emitting substances in the bulb 12 are dissociated and excited, thereby emitting light. When the optical sensor 42 detects the light emitted, the switch circuit 36 is turned off to stop the operation of the starting circuit 34, and thereafter, the starting circuit 34 is opened while emitting light.

In the solenoid magnetic-field discharge lamp which operates in the above manner, the high-frequency excitation coil 18 which induces the plasma discharge in the bulb 12 consists of a pair of annular rings 18a and 18b which have a flat cross section, and therefore the surface area of the rings is increased as compared to case where they have a circular cross section for the same cross sectional area.

Consequently, the skin effect is increased, and the loss of the high-frequency current is decreased. More specifically, when the surface area is increased, the current pathway is enlarged. Accordingly, the resistance of the current is reduced, thereby improving the coil efficiency. Further, since the surface area is large, the radiation area is increased. Therefore, the cooling efficiency is enhanced, and the surface temperature of the coil is decreased along with the decrease in the current resistance described above. Thus, the loss of energy, which is wasted in the form of heat, is reduced, and the coil efficiency is enhanced. At the same time, since the temperature of the coil is decreased, drawbacks including the oxidization of the surface and creep deformation, are prevented. The creep deformation is a phenomenon in which a material is gradually deformed due to a small amount of stress during a period when heat is also being applied even though the amount of stress is so low that under normal room temperature conditions no deformation would occur.

Each of the pair of annular rings 18a and 18b stretches out in the radial direction, more specifically, extends along the radial?? direction in which the magnetic line of force expands. With this structure, the magnetic line of force is less likely shut off by the annular ring 18a and 18b. Therefore, it is less likely that an eddy current is generated in each of the annular rings 18a and 18b. Thus, the generation of joule heat is prevented, reducing the heat generation.

Further, since the distance L of the outer periphery portions of the annular rings 18a and 18b is larger than the distance l of the inner periphery portions, the shutting-off ratio of the light radiated by the bulb 12 is reduced, and accordingly the irradiation efficiency is enhanced.

In addition, each of the annular rings 18a and 18b satisfies the relationship (1), $0.06 \leqq W / d_1 \leqq 0.5$, and therefore the efficiency of energy supplied to the bulb 12 from the excitation coil 18.

More specifically, when the width W of the annular rings 18a and 18b is increased, the cross section thereof is accordingly increased; therefore the electric resistance is reduced. Further, since the surface area is increased, and the heat-radiating area is increased, thereby enhancing the coil efficiency. However, if the width W is excessively enlarged, current flows through a portion of each ring which is distant from the bulb 12 located in the center portion of the coil 18, since current flows through the outer periphery of each of the annular rings 18a and 18b. Therefore, the energy supplying efficiency with respect to the bulb 12 is degraded.

If the inner diameter d_1 of the annular rings 18a and 18b is increased, the width W of the annular rings 18a and 18b must be increased accordingly in order to maintain an electric resistance of a predetermined level or less. As a result, the similar drawbacks to those of the case where the width W is increased, rise. Therefore, if the inner diameter d_1 of the annular rings 18a and 18b is increased, the coupling efficiency is decreased since the inner periphery portions of the annular rings 18a and 18b are set away from the bulb 12.

In contrast, if the inner diameter d_1 of the annular rings 18a and 18b is decreased, the inner periphery portions of the annular rings 18a and 18b are set close to the bulb 12, a gap $\underline{s}$ between the circumferential surface of each of the inner periphery portions of the annular rings 18a and 18b is decreased, thus improving the coupling efficiency. Therefore, the efficiency of supplying energy from the coil 18 to the bulb 12 is improved. It can be thus concluded that the inner diameter d_1 should be made smaller if the width W of the annular rings 18a and 18b is constant.

The thickness t of the annular rings 18a and 18b is a factor for determining the size of the cross section area. However, a pair of annular metal rings 18a and 18b, which are made of a good conductive material such as high-purity aluminum, copper or silver, are formed to have a thickness of about 2 mm, and as along as this value greatly varies, the amount of variance is negligible. Therefore, the thickness t is not particularly restricted.

In consideration of the above, the authors of the present invention carried out an experiment. In the experiment, it was confirmed that the overall efficiency could be improved as shown in FIG. 4 when the relationship between the inner diameter d_1 of the annular rings 18a and 18b and the width W was set to satisfy the relationship (1).

FIG. 4 shows a graph with the vertical axis taken as the efficiency of energy transmitted from the coil 18 to the bulb 12, and with the horizontal axis as the value of W/d_1. As a parameter, the coil inner diameter d_1 is used. In the case where the significant current pathway width W of the coil is varied maintaining a constant coil inner diameter, the decrease in the efficiency can be suppressed within 5% from its peak if the W/d_1 value is maintained within a range of 0.06 to 0.5.

As the gap $\underline{s}$ between the inner periphery portions of the annular rings 18a and 18b and the circumferential surface of the bulb 12 becomes smaller, the coupling efficiency is more increased, and so is the efficiency for supplying energy from the coil 18 to the bulb 12. However, the gap $\underline{s}$ should be determined in consideration of the dispersion of the bulb 12, the coil 18, or devices involved in the apparatus but not shown in the figures. More specifically, the bulb 12, the coil 18 and the devices not shown inevitably contains process errors and assembly errors, and in many cases, the bulb 12 and the coil 18 are not disposed at a high accuracy at the position as designed.

For example, in the case where the bulb 12 and the coil 18 are disposed eccentrically with respect to each other, it is necessary to align the axis of the coil and that of the arc so as to prevent the bias and fluctuation of the arc. Therefore, the gap $\underline{s}$ between the inner periphery portions of the annular rings 18a and 18b and the circumferential surface of the bulb 12 should be set about 2 mm in consideration of allowance in adjustment.

Thus, the gap $\underline{s}$ contains an allowance in the direction crosses with the coil axis, and due to the allowance, the coupling efficiency is somewhat lowered. However, it is rendered possible, with the allowance, that the positions of the bulb 12, the coil 18 and other devices which are not shown can be adjusted within a range of the gap $\underline{s}$ (= 2 mm) even if the bulb 12, the coil 18 and other devices have erroneous dimensions and erroneous positional relationship. Consequently, the alignment between the center of the arc of the plasma 20 and the center axis of the coil 18 can be facilitated, thereby enabling the prevention of an decrease in startability or efficiency. In addition, since the mutual interference between the bulb 12 and the coil 18 is removed, the assembly of the apparatus can be also facilitated.

Other embodiments which also satisfy the relationship (1) will be described. In these embodiments, the outer tube 16, the electrical circuits, and the mount mechanism are the same as those of the above embodiment, and the explanation thereof will not be repeated. For simplification of the explanation, only a different section from the above embodiment will be described.

FIG. 5 shows a structure of the second embodiment of the present invention. According to the second embodiment, the solenoid magnetic-field discharge lamp 10b has a pair of annular metal rings 62a and 62b, which constitute a high-frequency excitation coil 62, and the annular rings have a structure in which they extend in the radial direction but are bent from the middle portion. In the annular metal rings 62 having such a structure, the significant width W of the pathway for current flowing in the circumferential direction can be expressed as $W = W_1 + W_2$, and it suffices only that the relationship (1) is satisfied therewith.

FIG. 6 shows a structure of the third embodiment of the present invention, and illustrates an example in which a pair of annular metal rings 64a and 64b, which constitute a high-frequency excitation coil 64 of a solenoid magnetic-field discharge lamp 10c, are formed to have a curvature in the radial direction. In the annular metal rings 64a and 64b having this structure, the significant width W of the pathway for current flowing in the circumferential direction is equivalent to the length W' taken along the curvature ($W = W'$). Thus, the relationship (1) should be satisfied based on the above.

FIG. 7 shows a structure of the fourth embodiment of the present invention. According to a solenoid magnetic-field discharge lamp 10d of the fourth embodiment, a pair of annular metal rings 66a and 66b, which constitute a high-frequency excitation coil 66, have a structure in which one of the rings is horizontally disposed and has a small width W_3, and the other is disposed at an angle and has a large width W_4 ($W3 < W_4$). In the annular metal rings 66a and 66b having this structure, the significant width W of the pathway for current flowing in the circumferential direction is equivalent to the width W_3 of the metal ring having the smaller width ($W = W_3$). Thus, the relationship (1) should be satisfied based on the above.

FIG. 8 shows a structure of the fifth embodiment of the present invention. In the fifth embodiment, each of a pair of annular metal rings 68a and 68b, which constitute a high-frequency excitation coil 68, has slits 68c cut in the radial direction, which divide each of the annular rings 68a and 68b into heat radiating fins 68d.

The heat of the annular rings 68a and 68b is radiated by the heat radiating fins 68d, and therefore an increase in the temperature of the annular rings 68a and 68b can be effectively prevented. Further, with this structure, the high-frequency current is concentrated in the inner periphery portions of the annular rings 68a and 68b and allowed to flow in the circumferential direction. Therefore, the coupling efficiency of the high-frequency magnetic field with respect to the plasma discharge 20 generated in the bulb is improved.

In this structure, the significant width W of the pathway for current flowing in the circumferential direction corresponds to the width taken from the inner periphery portions of the annular rings 68a and 68b to the inner end periphery of the slits 68c. Thus, the relationship (1) should be satisfied based on the above.

FIGS. 9 and 10 show the sixth embodiment of the present invention, and illustrate a lighting apparatus using a magnetic-field discharge lamp 10.

FIG. 9 shows a light pole 70 for lighting a road such as a highway, having a lighting apparatus 72 provided on its upper end portion. The height H of the pole 70 is set such that it is about $\lambda/2$ or an integer number of times of $\lambda/2$, where λ represents the wavelength of high-frequency current supplied to the magnetic-field discharge lamp 10.

The reason for setting the height H of the pole 70 to about $\lambda/2$ or an integer number of times of $\lambda/2$ is to avoid a high voltage applied to the pole 70. For example, when the output frequency of the high-frequency oscillator 26 is 13.56 MHz, the wavelength λ is 22.1m. Therefore, the height H of the pole is set to 11.05m ($\lambda/2$).

The lighting apparatus 72 provided on the end portion of the pole 70 has a main body 74 with an open bottom surface which is closed by a prism cover 76, as shown in FIG. 10. Further, a reflection mirror 78 is provided in the main body 10, and a magnetic-field discharge lamp 10 is situated at a predetermined position in the reflection mirror 78. The light radiated from the discharge lamp 10 reflects on the reflection mirror 78, and is directed by the prism cover 76 to be applied on the road. The main body 74 accommodates the member for maintaining the lighting up of the discharge lamp 10, and more specifically, in the main body, a print circuit substrate 80, on which the main lighting circuit including the high-frequency oscillator 40 and the matching circuit 38 are provided, and a starting circuit part 82 for starting the light-up of the discharge lamp are accommodated.

One of the annular rings of the high-frequency excitation coil 18 which constitutes the discharge lamp 10 has an end portion extending to be mechanically and electrically connected to the print circuit substrate 80. The other one of the rings of the coil 18 is connected to a ground electrode 46 (FIG. 1) using the main body 74 as the ground. The main body 74 is grounded via the pole 70 to have the same potential as the ground.

Further, a cooling fan 84 is provided in the main body 74. The fan 84 serves to blow cooling winds to the discharge lamp 10 via ducts 86a and 86b. The fan 84 is driven while the discharge lamp 10 is on, and therefore the magnetic field discharge lamp 10 is forcibly cooled down by winds generated by the fan 84 whenever the lamp is on. Consequently, even if the heat is generated in the cylindrical wall of the bulb by the plasma having a ring shape along the wall, the cylindrical wall is forcibly cooled. Thus, the deformation or breakage of the bulb, or undesirable reaction between substances sealed therein can be prevented, and an increase in the temperature of the excitation coil 18 can be suppressed.

With the above operation, the electric field can be intensified and concentrated, thereby enabling the enhancement of the startability. Also, the size of the lamp can be reduced by forming it of a single tube. Further, since the coil is cooled, it is rendered possible to apply a large electric supply, thereby increasing the light emitting efficiency.

The discharge lamp 10 is grounded via the lighting apparatus 72 and the pole 70, and the height H of the pole 70 is set to a half of the wavelength λ or an integer number of times of $\lambda/2$; therefore the lighting apparatus 72 and the ground are rendered equivalent to each other in terms of voltage and current. Consequently, the pole 70 does not function as a distribution constant circuit, and the application of a high voltage on the pole 70 is avoided, enabling to avoid the control failure and breakage of the lighting circuit.

FIGS. 11 through 14 shows the seventh to tenth embodiments, respectively, and each illustrates a magnetic field discharge lamp capable of dimming.

Conventionally, there has been no dimable magnetic field discharge lamp capable of dimming its light by controlling the intensity of light while the light is on, or each time the light is turned on. However, in order to achieve the optimal brightness, light distribution, and power-saving, the dimming control of a magnetic field discharge lamp such as mentioned above is required. Thus, embodiments shown in FIG. 11 through 14 each illustrate a system for dimming light in electrodeless discharge lamp.

FIG. 7 shows the seventh embodiment, in which a conductive metal body 88, a mesh or a metal rod, movable in the directions indicated by arrow A, is situated along the axial direction of the high-frequency excitation coil 18 but apart therefrom. The structure of the conductive metal body 88 will not be described in detail, but it is provided to be movable in the axial direction of the coil, in other words, capable of being brought into contact with the excitation coil 18.

With the structure mentioned above, the conductive metal body 88 and the excitation coil 18 are electrically coupled, thereby equivalently lowering the impedance of the lamp. Further, an eddy current is allowed to flow into the conductive body 88, thus consuming the power supply. Consequently, part of the power to be originally input to the bulb 12 is shunted to the conductive metal body 88, and therefore the power actually input to the bulb 12 is reduced, thus accordingly decreasing the light intensity of the lamp. The dimming rate is increased as the distance between the conductive metal body 88 and the excitation coil 18 is rendered smaller, since as it becomes smaller, the coupling efficiency between the conductive metal body 88 and the coil 18 is increased. More specifically, the distance between the metal body 88 and the excitation coil 18 is controlled by moving the metal body 88 in the directions indicated by A, thus enabling the control of the light intensity. Consequently, so-called "dimming" can be carried out.

FIG. 8 shows the eighth embodiment, in which a dummy lamp 90 incapable of emitting light is provided, in place of the conductive metal body 88 shown in FIG. 11, along the axial direction of the high-frequency excitation coil 18 but apart therefrom, movably in the directions indicated by arrow A so that the dummy lamp can be brought into contact with the coil. The dummy lamp 90 has a bulb 12 in which noble gases are sealed, and has a similar function to that of the conductive metal body 88 shown in FIG. 11.

More specifically, when the dummy lamp 90 is brought closer to the coil 18, the dummy lamp 90 is electrically coupled with the coil, and part of the current flowing in the coil 18 is allowed to flow into the dummy lamp 90. Consequently, the power input to the bulb 12 is decreased. Thus, the dimming of light can be carried out by changing the distance between the dummy lamp 90 and the coil 18 in the directions indicates by arrow A.

FIG. 13 shows the ninth embodiment, in which the high-frequency excitation coil 18 is moved relative to the bulb along the axial direction of the coil, thereby dimming the light.

The discharge lamp 10e of this embodiment involves the following operations. That is, a ring-shaped arc discharge 20 generated by plasma tends to be generated on the largest possible longitudinal axis of the bulb 12, near the bulb wall. When the coil 18 is moved along the axial direction, not the arc discharge 20 but the center of the magnetic field moves along with the movement of the coil 18, thereby decreasing the amount of flux passing through the arc discharge 20 of the bulb 12. Therefore, the magnetic force applied on the arc discharge 20 is decreased, thereby reducing the amount of luminescence, and dimming the light. Thus, the modulation of light can be performed by displacing the high-frequency excitation coil 18 relatively along the axial direction of the coil 18.

FIG. 14 shows the tenth embodiment, in which the modulation of light is performed by inclining the high-frequency excitation coil 18 with respect to the ellipsoidal bulb 12.

In the case of the discharge lamp 10f, the ring-shaped arc discharge 20 created by plasma tends to be generated on the largest possible longitudinal axis of the bulb 12 and near the bulb wall. When the coil 18 is inclined in the direction indicated by arrow B such that the coil axis intersects the axis of the bulb, the arc discharge 20 does not move, but the amount of flux passing through the arc discharge 20 in the bulb 12 decreases.

Therefore, the magnetic force applied to the arc discharge 20 is decreased, thereby reducing the amount of luminescence. Thus, the modulation of light can be conducted by inclining the high-frequency excitation coil 18 relative to the bulb 12.

Next, the eleventh embodiment of the present invention will now be described with reference to FIG. 15. The eleventh embodiment involves a noble gas discharge lamp in which no mercury is sealed in the bulb 12. This embodiment has the same electrical circuit as that of FIG. 1 in the external portion of the discharge lamp, and therefore the electric circuit will not be illustrated.

In the case of a lamp which does not use mercury, the Penning effect, which will be explained below, is not expected, and therefore the startability of the lamp is low. In a conventional electrode lamp, when the excitation energy of a metastable excitation atom is higher than the dissociation energy of some other mixture gas constituting atom, such as argon against mercury or neon against argon, the atom having a lower dissipation voltage is dissociated due to energy exchange collision between the excitation atom and the dissociated atom. The possibility of the dissociation is higher than the case of dissociation of only one type of gas involved, thus easy to discharge. Such a phenomenon is called Penning effect. More specifically, in the magnetic discharge lamp, an electric field is generated in the circumferential direction within the bulb 12 due to the electromagnetic conduction. However, in the case where no mercury is used, the Penning effect cannot be expected, and therefore the intensity of the electric field cannot be rendered sufficient enough to induce the start of the operation. Thus, the glow discharge diffusing from the gas probe 14 to the bulb 12 is not easily transformed into a ring-like arc discharge.

In general, the electric field E (V) generated in the circumferential direction can be calculated by dividing the voltage applied on the inner diameter surface of the lamp and obtained by the Faraday's law of electromagnetic conduction by the circumference thereof, and expressed by the following equation.

$$E\ (V) = \mu \cdot \omega / r \int_0^r x \cdot H(x) \cdot dx \quad \ldots (2)$$

where r indicates the radius of an imaginary circle, the center of which agrees with the coil axis, in the equator surface of the bulb 12, and r may be regarded to be equal to the inner diameter of the bulb 12 when the coil axis and the bulb axis accord with each other, μ indicates the magnetic permeability, ω indicates the angular frequency, and H (x) is a component of the magnetic field in the coil axis direction at a position x with respect to the coil axis of the equator surface of the bulb 12.

In general, the value of H (x) is substantially constant in the coil, and tends to increase as the parameter x moves towards the periphery portion, and therefore it is assumed that E (V) value increases, as the value of r increase. Similarly, E (V) increases as the frequency f of the high-frequency current input to the excitation coil 18 increases, and therefore it is assumed that the start of the operation can be facilitated by increasing r and frequency f.

In consideration of the above analysis, the author of the present invention conducted experiments, and discovered that a remarkable effect can be obtained by satisfying the following relationships:

$$10 \leqq f \leqq 100 \quad (3)$$
$$10 \leqq d \leqq 50 \quad (4)$$
$$250 \leqq d \cdot f \leqq 7.5P \quad (5)$$

where f represents the excitation frequency, d represents the inner diameter of the bulb, and P represents an input to the high-frequency excitation coil 18.

The above relationships (3) to (5) were established based on the results of the experiments, and the following is a description of the experiments.

The startability of the apparatus was tested by varying the inner diameter of the bulb 12 d = 2r, the excitation frequency f, and the rated input P to the excitation coil 18, and the results are summarized in tables 1-5.

The size of the excitation coil 18 was varied in the following relationships in accordance with the inner diameter d of the bulb:

$$d_1 \text{ mm} = d + 4,$$
$$D \text{ (coil outer diameter) mm} = 4.8d + 8,$$
$$1 \text{ mm} = 0.1d,\ L \text{ mm} = 0.3d.$$

The testing conditions were set in the following situation. Since the bulb temperature is substantially proportional to P/d^2, the upper limit of the rated input power upon turning on the apparatus is defined from this proportional relationship. The power applied to the excitation coil 18 upon starting, should not exceed the upper limit value, and therefore the power was set to 0.5 W/mm^2. The upper limit of the excitation frequency f was set to 100 MHz.

The testing method was as follows. That is, a power defined by $P = 0.5d^2$ is applied to lamps, and such an operation was repeated 20 times. Those which were lit in all 20 trials, were regarded to be good, and marked by ○, and any of which fails to light even only once were regarded to be no good, and marked by X.

TABLE 1

Bulb inner diameter d(mm)	frequency f(MHz)	input P (W)	d•f	results
10	10	50	100	X
10	13.56	50	135.6	X
10	27.12	50	271.2	○
10	40.68	50	406.8	○
10	60	50	600	○
10	80	50	800	○
10	100	50	1000	○

TABLE 2

Bulb inner diameter d(mm)	frequency f(MHz)	input P (W)	d•f	results
20	10	200	200	X
20	13.56	200	271.2	○
20	27.12	200	542.4	○
20	40.68	200	813.6	○
20	60	200	1200	○
20	80	200	1600	○
20	100	200	2000	○

TABLE 3

Bulb inner diameter d(mm)	frequency f(MHz)	input P (W)	d•f	results
30	10	450	300	○
30	13.56	450	406.8	○
30	27.12	450	813.6	○
30	40.68	450	1220.4	○
30	60	450	1800	○
30	80	450	2400	○
30	100	450	3000	○

TABLE 4

Bulb inner diameter d(mm)	frequency f(MHz)	input P (W)	d•f	results
40	10	800	400	○
40	13.56	800	542.4	○
40	27.12	800	1084.8	○
40	40.68	800	1627.2	○
40	60	800	2400	○
40	80	800	3200	○
40	100	800	4000	○

TABLE 5

Bulb inner diameter d(mm)	frequency f(MHz)	input P (W)	d•f	results
50	10	1250	500	○
50	13.56	1250	678	○
50	27.12	1250	1356	○
50	40.68	1250	2034	○
50	60	1250	3000	○
50	80	1250	4000	○
50	100	1250	5000	○

The results of the experiments indicate a tendency in which the startability is deteriorated in a region of high frequency f. This is considered because as the inner diameter d_1 of the excitation coil 18 is rendered large as compared to the frequency f, the coil loss is increased. The loss of this kind is proportional to the input power P, and therefore the upper limit of the d • f value is made proportional to the input power P.

Therefore, from the above tables, it is understood that the startability of the non-mercury magnetic discharge lamp if the relationships (3) to (5) are satisfied.

In the embodiments shown in FIG. 9 onwards, any of the annular rings of the high-frequency excitation coils satisfy:

$$0.06 \leqq W/d_1/W \leqq 0.5 \qquad (1)$$

As described, according to the magnetic discharge lamp of the present invention, the coil efficiency of the excitation coil, and the supply efficiency of the high-frequency power from the excitation coil to the bulb are enhanced, thereby improving the efficiency of the lamp as a whole.

Further, according to the lighting device of the present invention, the magnetic discharge lamp is forcibly cooled by cooling wind, and therefore an increase in temperature of the coil and bulb is suppressed. Therefore, the lamp efficiency is increased, thereby enhancing the efficiency of the system as a whole.

Claims

1. A magnetic discharge lamp having a light-permeable bulb in which a discharge substance is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb,

characterized in that said high-frequency excitation coil (18, 62, 64, 66, 68) consists of at least one coiling of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies a relationship:

$$0.06 \leqq W/d_1 \leqq 0.5$$

where d_1 (mm) indicates an inner diameter of said ring plate and W (mm) indicates a significant width of a passage which allows current to flow in a circumferential direction.

2. A discharge lamp according to claim 1, characterized in that said high-frequency excitation coil (18, 66) is formed of a substantially flat shape expanding in a radial direction.

3. A discharge lamp according to claim 1, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is bent in the middle.

4. A discharge lamp according to claim 1, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is curved in the middle.

5. A magnetic discharge lamp having a light-permeable bulb in which a discharge substance is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb,

characterized in that said high-frequency excitation coil (18, 62, 64, 66, 68) consists of at least two coiling of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) having a width in a direction crossing an axial direction of said coil, around said bulb, and has a distance between outer peripheries of said at least two coiling of a flat ring plate larger than that between inner peripheries thereof, and said flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies a relationship:

$$0.06 \leqq W/d_1 \leqq 0.5$$

where d_1 (mm) indicates an inner diameter of said ring plate and W (mm) indicates a significant width of a passage which allows current to flow in a circumferential direction.

6. A discharge lamp according to claim 5, characterized in that said high-frequency excitation coil (18, 66) is formed of a substantially flat shape expanding in a radial direction.

7. A discharge lamp according to claim 5, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is bent in the middle.

8. A discharge lamp according to claim 5, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is curved in the middle.

9. A discharge lamp lighting device characterized by comprising:

a magnetic field discharge lamp (10, 10a, 10b, 10c, 10d) according to claim 5; and

a high frequency oscillating circuit (40) for inducing discharge in said bulb (12) by supplying a predetermined high-frequency current to said high-frequency excitation coil (18, 62, 64, 66, 68).

10. A discharge lamp lighting device according to claim 9, characterized in that said high-frequency excitation coil (18, 66) is formed of a substantially flat shape expanding in a radial direction.

11. A discharge lamp lighting device according to claim 9, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is bent in the middle.

12. A discharge lamp lighting device according to claim 9, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is curved.

13. A discharge lamp lighting device according to claim 9, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is bent in the middle or curbed such as to be substantially along with magnetic line of force:

14. A discharge lamp lighting apparatus having a magnetic discharge lamp comprising a light-permeable bulb in which a discharge substance is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb, and a reflector having a light projecting section for reflecting light emitted from said lamp to outside,

characterized in that said high-frequency excitation coil (18, 62, 64, 66, 68) consists of at least two coiling of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and has a distance between outer peripheries of said at least two coiling of a flat ring plate larger than that between inner peripheries thereof, and said flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies a relationship:

$$0.06 \leqq W/d_1 \leqq 0.5$$

where d_1 (mm) indicates an inner diameter of said ring plate and W (mm) indicates a significant width of a passage which allows current to flow in a circumferential direction.

15. A magnetic discharge lamp having a light-permeable bulb in which a discharge substance except for mercury is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb,

characterized in that said high-frequency excitation coil (18, 62, 64, 66, 68) consists of at least one coiling of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies relationships:

$$0.06 \leqq W/d_1 \leqq 0.5$$
$$10 \leqq f \leqq 100$$
$$10 \leqq d \leqq 50$$
$$250 \leqq d \cdot f \leqq 7.5P$$

where d (mm) represents an inner diameter of the bulb (12), d_1 represents an inner diameter of said ring plate, W (mm) represents a significant width of a passage for allowing current to flow in the circumferential direction, f (MHz) represents a frequency of a high-frequency power supplied to said excitation coil (18, 62, 64, 66, 68), and P (watt) represents a rated input to said excitation coil (18, 62, 64, 66, 68).

16. A discharge lamp according to claim 15, characterized in that said high-frequency excitation coil (18, 66) is formed of a substantially flat shape expanding in a radial direction.

17. A discharge lamp according to claim 15, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is bent in the middle.

18. A discharge lamp according to claim 15, characterized in that said high-frequency excitation coil (62) expanding in the radial direction is curved.

19. A discharge lamp lighting apparatus having a magnetic discharge lamp comprising a light-permeable bulb in which a discharge substance except for mercury is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb, and a reflector having a light projecting section for reflecting light emitted from said lamp to outside,

characterized in that said high-frequency excitation coil (18, 62, 64, 66, 68) consists of at least one coiling of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies relationships:

$$0.06 \leqq W/d_1 \leqq 0.5$$

$$10 \leqq f \leqq 100$$
$$10 \leqq d \leqq 50$$
$$250 \leqq d \cdot f \leqq 7.5P$$

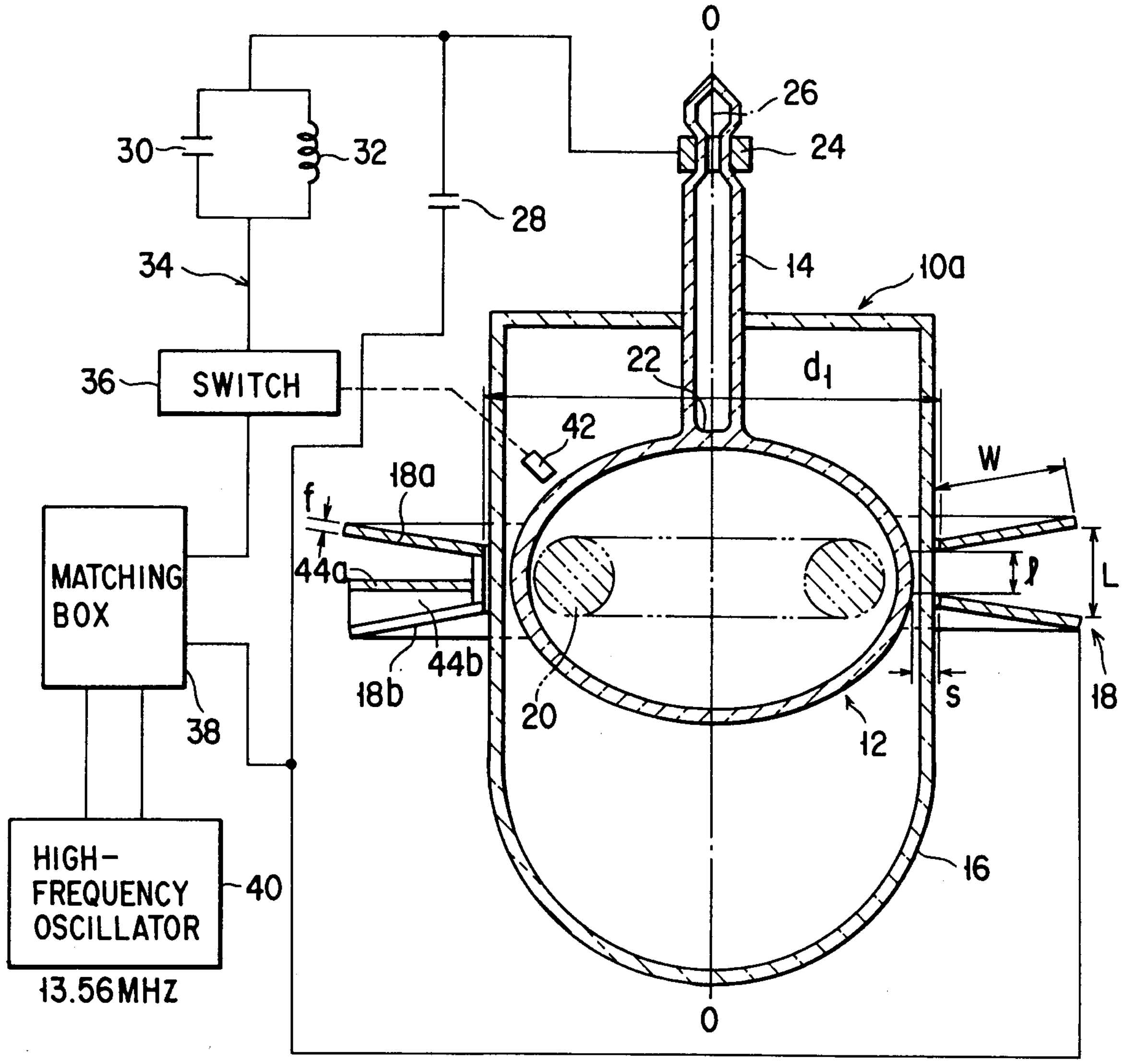
where d (mm) represents an inner diameter of the bulb (12), d_1 represents an inner diameter of said ring plate, W (mm) represents a significant width of a passage for allowing current to flow in the circumferential direction, f (MHz) represents a frequency of a high-frequency power supplied to said excitation coil (18, 62, 64, 66, 68), and P (watt) represents a rated input to said excitation coil (18, 62, 64, 66, 68).

20. A discharge lamp lighting apparatus having a magnetic discharge lamp comprising a light-permeable bulb in which a discharge substance except for mercury is sealed, and a high-frequency excitation coil arranged to surround the bulb, said excitation coil functioning to generate a discharge in said bulb, and a cooling device for forcibly cooling said discharge lamp by means of cooling wind,

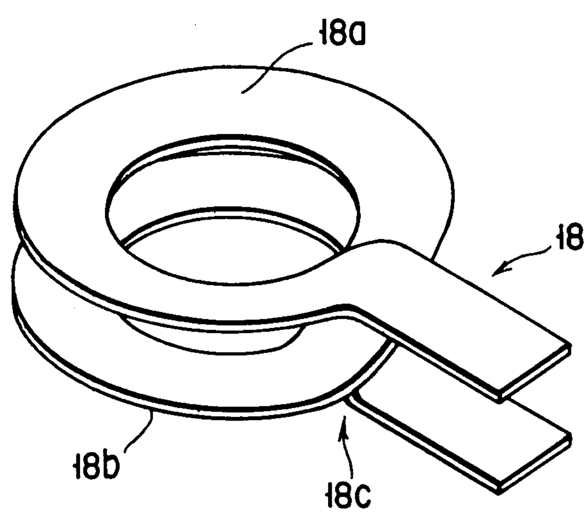
characterized in that said high-frequency excitation coil (18, 62, 64, 66, 68) consists of at least one coiling of a flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) having a width in a direction crossing an axial direction of said coil, around an axis of said bulb, and said flat ring plate (18a, 18b, 62a, 62b, 64a, 64b, 66a, 66b, 68a, 68b) satisfies relationships:

$$0.06 \leqq W/d_1 \leqq 0.5$$
$$10 \leqq f \leqq 100$$
$$10 \leqq d \leqq 50$$
$$250 \leqq d \cdot f \leqq 7.5P$$

where d (mm) represents an inner diameter of the bulb (12), d_1 represents an inner diameter of said ring plate, W (mm) represents a significant width of a passage for allowing current to flow in the circumferential direction, f (MHz) represents a frequency of a high-frequency power supplied to said excitation coil (18, 62, 64, 66, 68), and P (watt) represents a rated input to said excitation coil (18, 62, 64, 66, 68).


0
26
24
30
32
28
14
10a
34
22
d1
36
SWITCH
42
W
18a
f
44a
L
MATCHING BOX
44b
18b
20
S
18
38
12
HIGH-FREQUENCY OSCILLATOR
16
40
13.56MHZ
0

F I G. 1


18a
18
18b
18c

F I G. 2

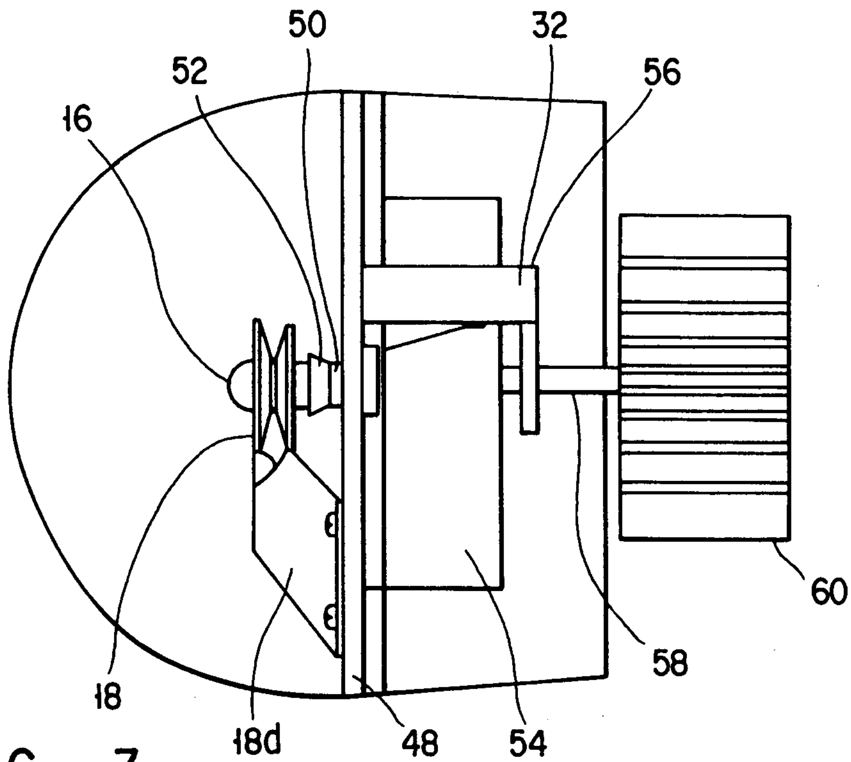

50
32
52
56
16
60
58
18
18d
48
54

FIG. 3

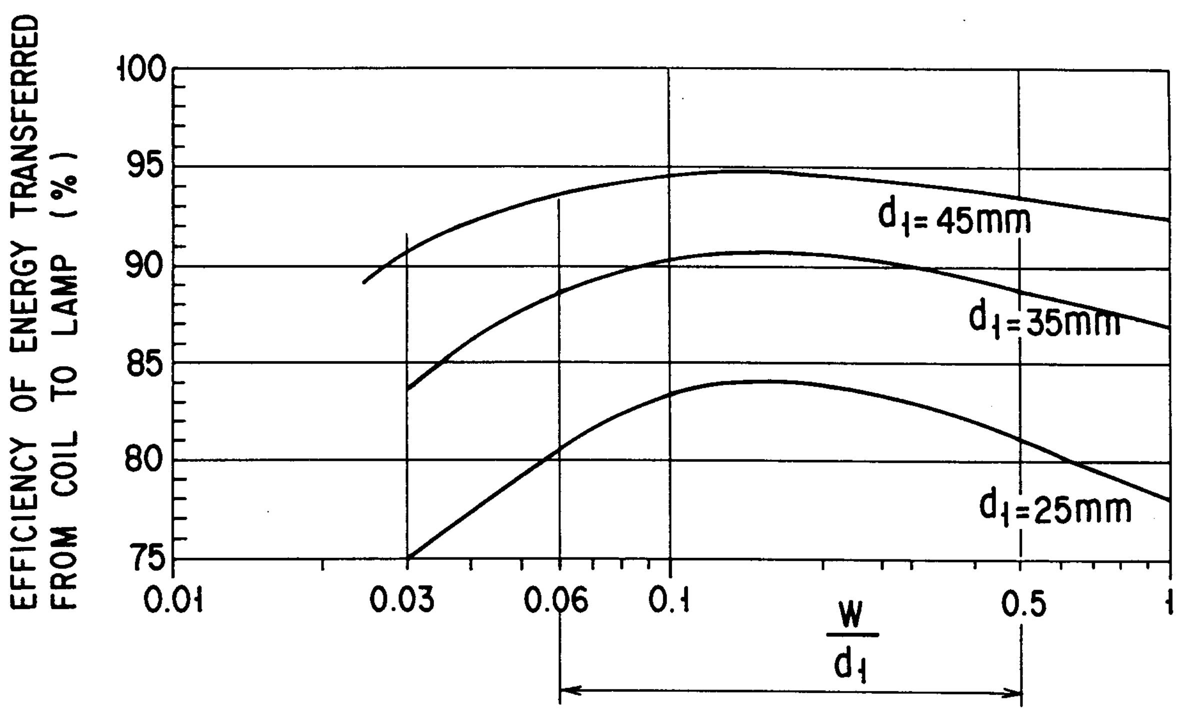

EFFICIENCY OF ENERGY TRANSFERRED FROM COIL TO LAMP (%)
100
95
90
85
80
75
0.01
0.03
0.06
0.1
0.5
1
d_1= 45mm
d_1=35mm
d_1=25mm
$\frac{W}{d_1}$

FIG. 4

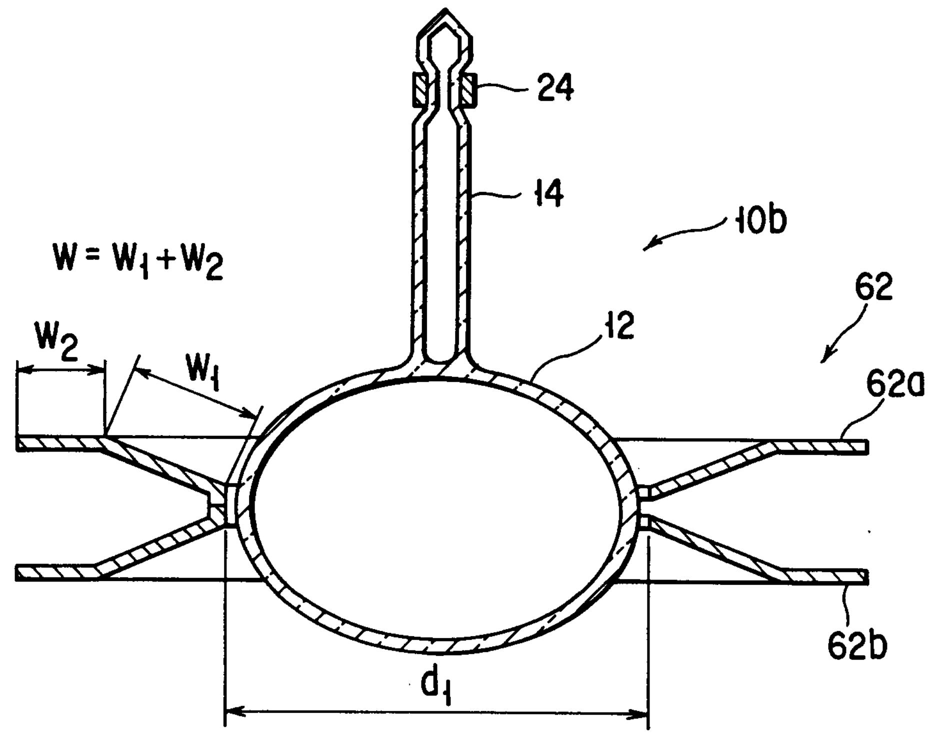

24
14
10b
W = W1+W2
62
W2
W1
12
62a
62b
d1

FIG. 5

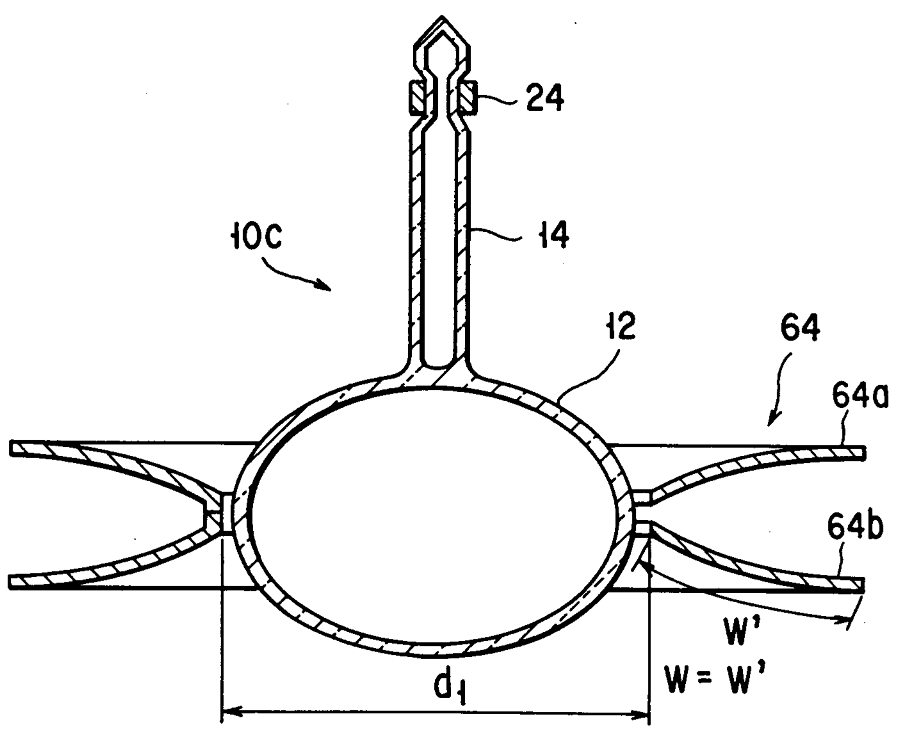
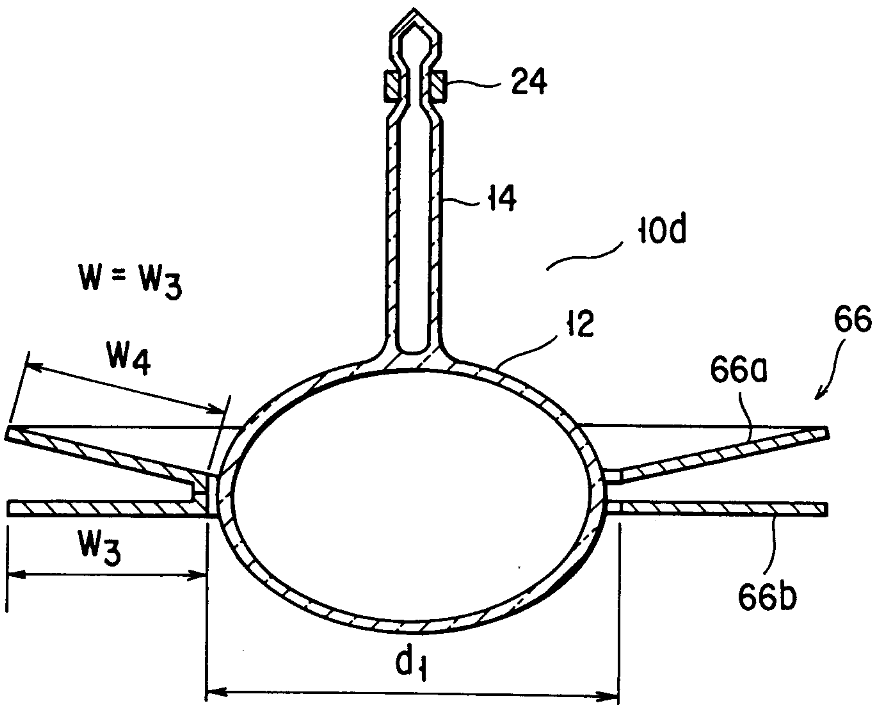
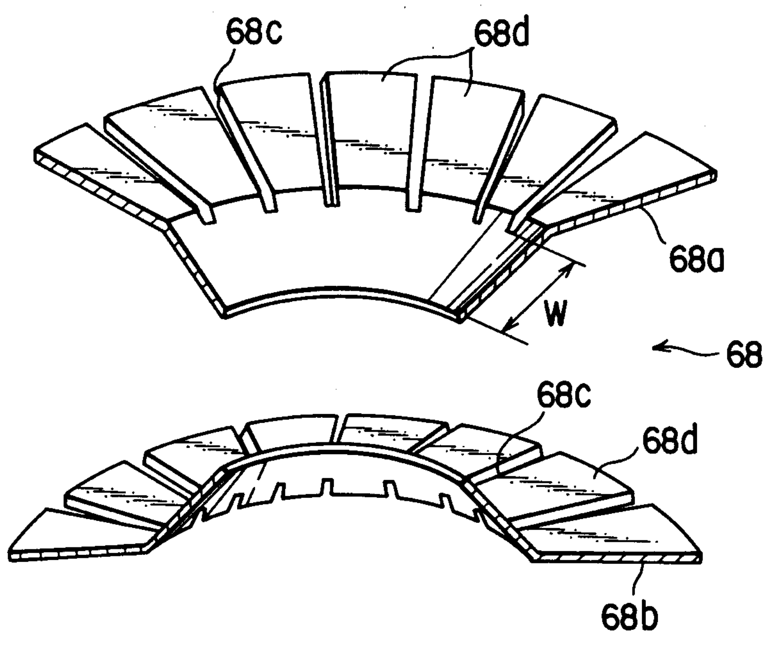

24
10c
14
12
64
64a
64b
W'
W = W'
d1

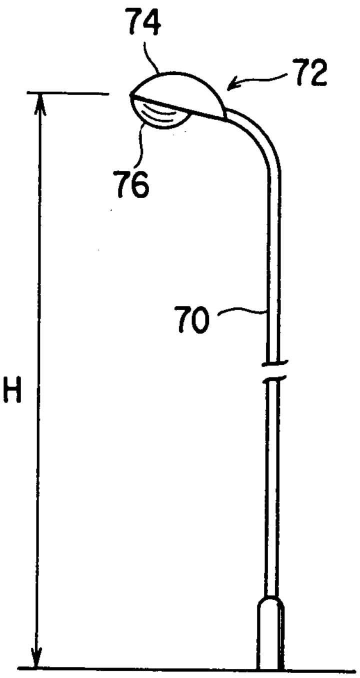
FIG. 6



F I G. 7



F I G. 8



F I G. 9

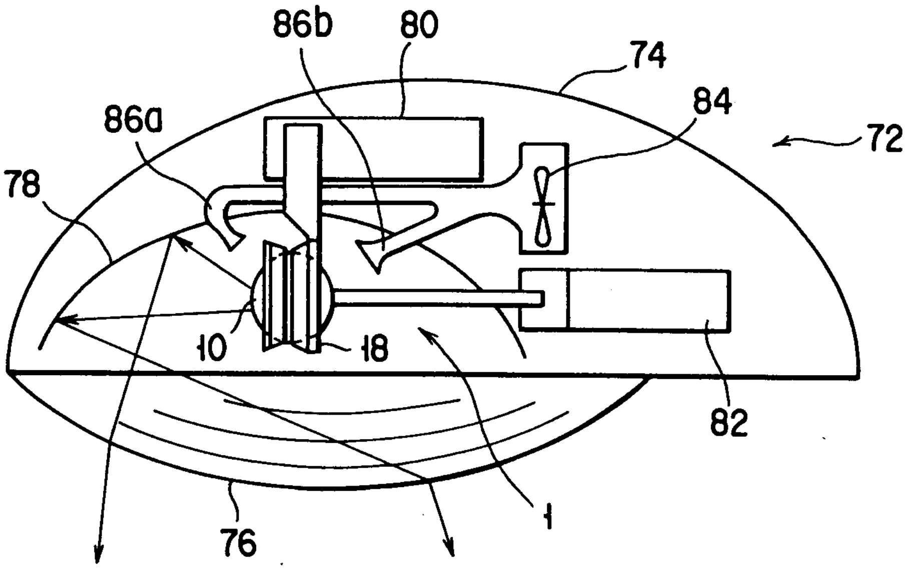


FIG. 10

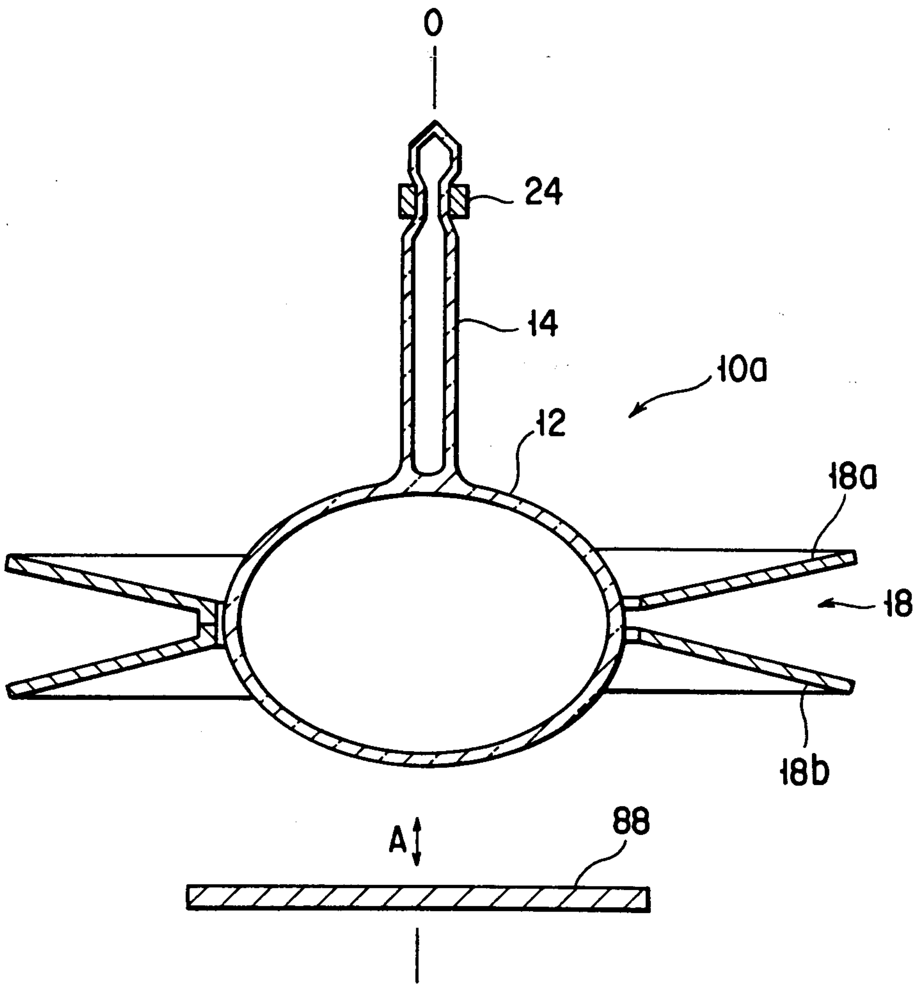


FIG. 11

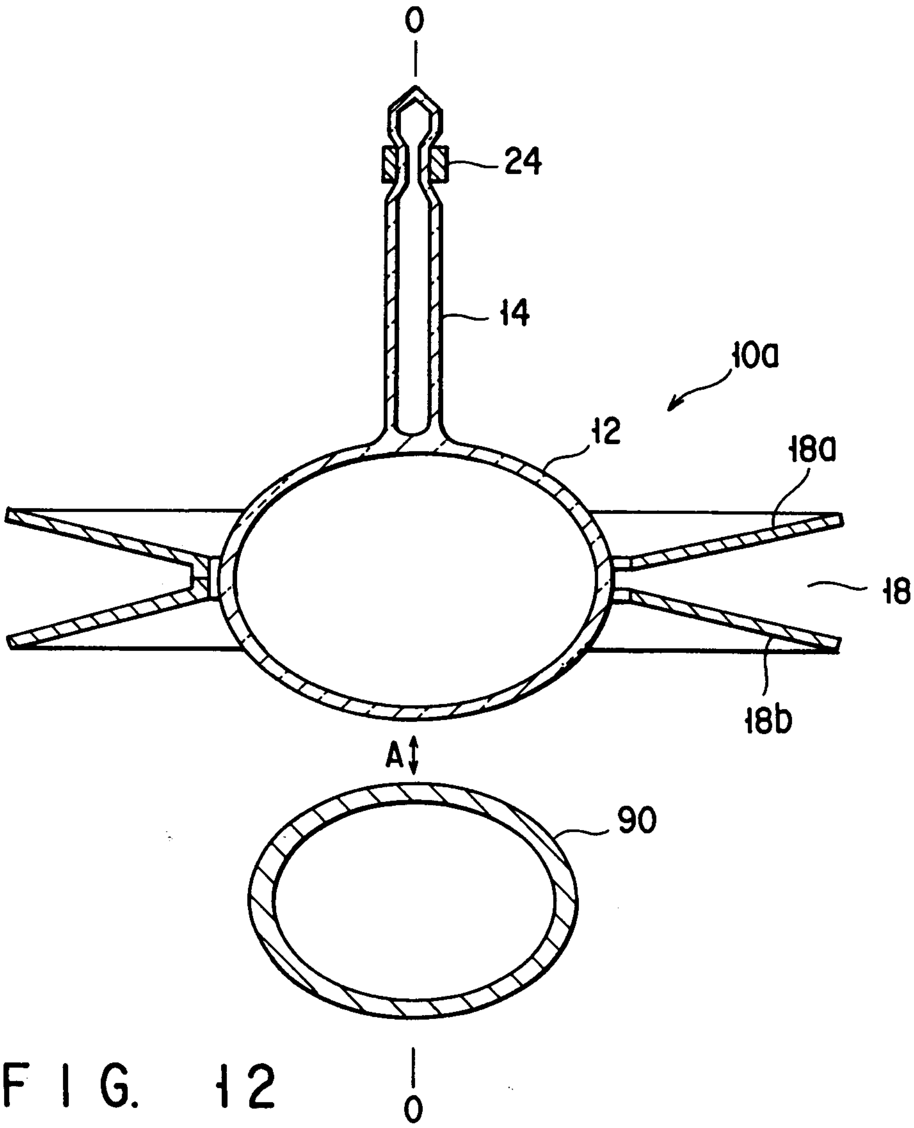


FIG. 12

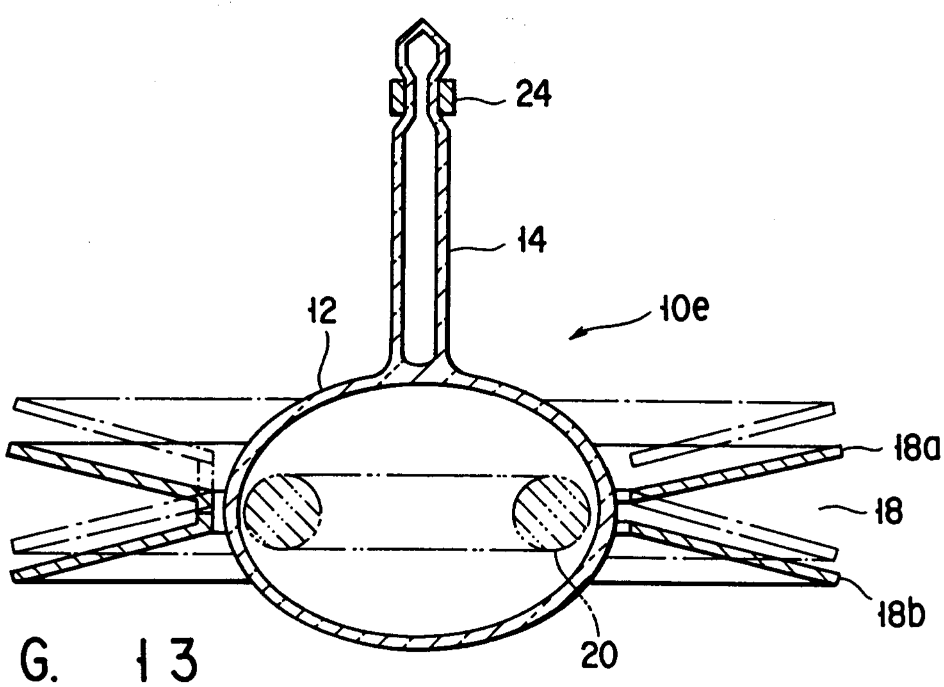


FIG. 13

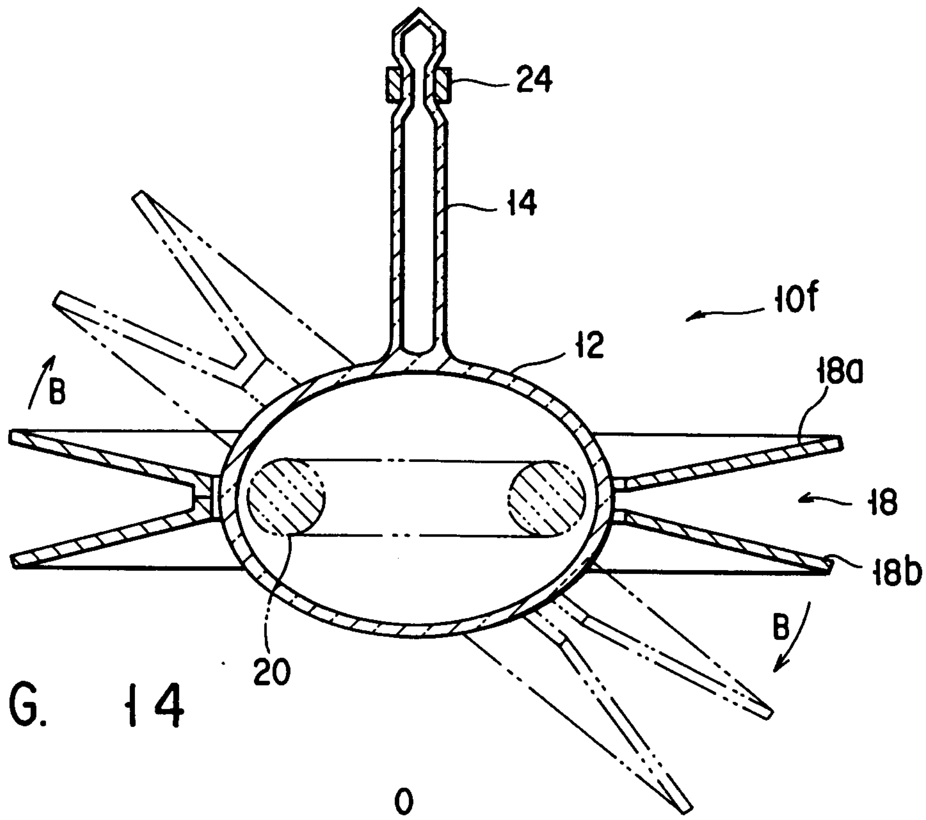


FIG. 14

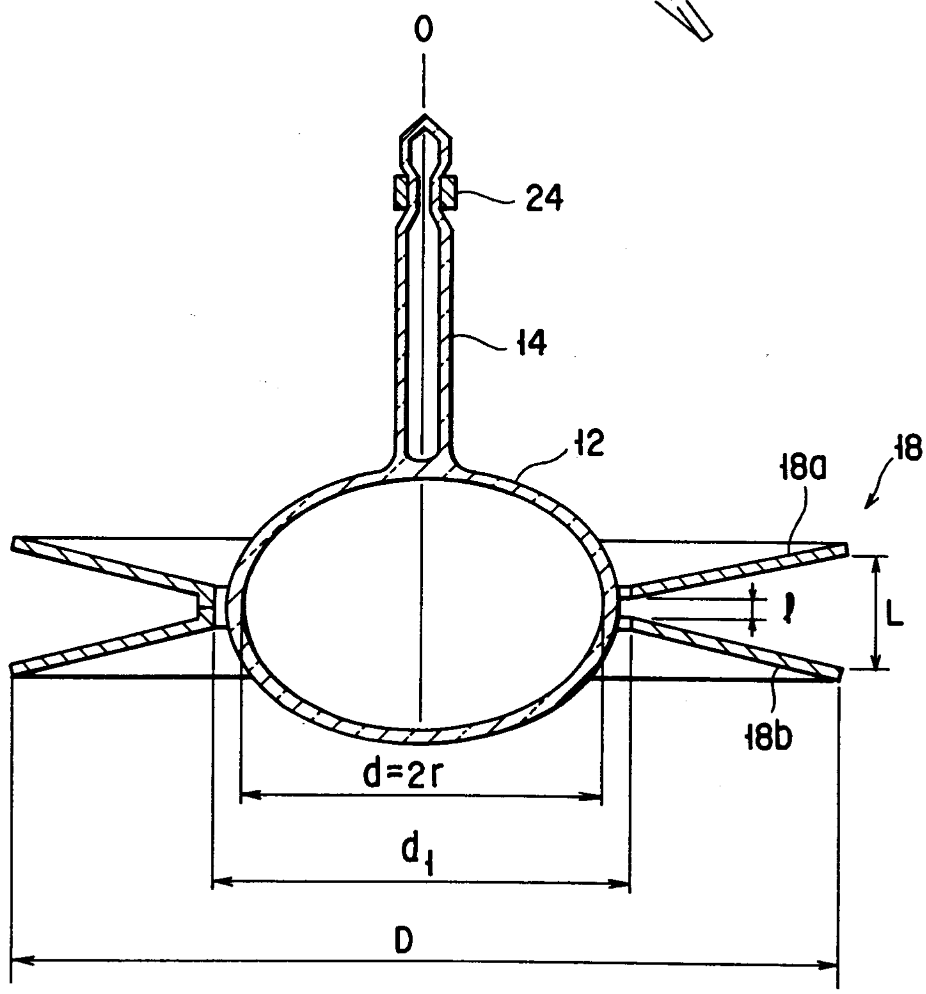


FIG. 15

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 10 9845

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
D,X	PATENT ABSTRACTS OF JAPAN vol. 17, no. 424 (E-1410) 6 August 1993 & JP-A-05 089 853 (TOSHIBA LIGHTING & TECHNOLOGY CORPORATION) 9 April 1993	1-8	H01J65/04
Y	* abstract *	1,5, 9-12, 14-20	
Y	PATENT ABSTRACTS OF JAPAN vol. 5, no. 34 (E-48) (706) 4 March 1981 & JP-A-55 161 362 (TOKYO SHIBAURA DENKI K.K.) 15 December 1980 * abstract *	5,9-12	
Y	EP-A-0 542 467 (GENERAL ELECTRIC COMPANY) * abstract * * page 3, line 6 * * page 3, line 56 - line 57 * * page 4, line 5 *	1,15-20	
Y	US-A-4 910 439 (EL-HAMAMSY ET AL.)	5,14,15, 19,20	
A	* abstract; figure 1 * * column 4, line 63 - line 66 * * column 5, line 11 - line 14 * * column 5, line 22 - line 25 * * column 8, line 32 - line 33 *	13	
E	EP-A-0 612 099 (N.V. PHILIPS' GLOEILAMPENFABRIEKEN) * page 2, line 20 - line 21; figures 1,2 * * page 3, line 56 * * page 4, line 7 *	1,2	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

H01J

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	31 October 1994	Martín Vicente, M

CATEGORY OF CITED DOCUMENTS

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